Effects of Fertilizer Management Practices on Urban Runoff Water Quality

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<u>Executive Summary</u>

Stormwater nutrient runoff loadings within the Chesapeake Bay watershed are being increasingly regulated, particularly through implementation of watershed level TMDL programs and associated runoff and development restrictions. One potential alternative for significantly reducing nutrient runoff loadings is to vigorously reduce or eliminate applications of nitrogen (N) and phosphorus (P) fertilizers and/or to implement a wide range of intensive fertilizer/ soil/plant management practices. To focus and frame this study, we considered the potential impacts of the following intensive N and P fertilization management practices on potential N and P losses to stormwater:

A. *<u>Prohibition of all N and P applications except for new seedings;</u>*
B. *<u>Ban on P except for new seedings or critical areas; slow-release N formulations only;</u>*
C. *<u>Soil-test only for P application rates; strict annual and one-time N limitations;</u>*
D. *<u>Ban on sidewalk/driveway applications of fertilizers and clippings;</u>*
E. *<u>Use of organics such as composts;</u>*
F. *<u>Fertilizers applied only by certified applicators</u>*

It is clear that implementation of a wide range of fertilizer management practices and/or policies could significantly reduce total stormwater runoff of both N and P. The scientific literature indicates that by carefully restricting application rates (e.g. no more than 1 1b/1000 ft^2 of soluble N at least 30 days apart for cool season grasses), that N runoff losses from well-managed turfgrass will be minimal. Similarly, use of slow-release N fertilizers or labeled organic-N sources would also significantly reduce the risk of N runoff losses. Restricting P-fertilizer applications to urban soils to correspond to actual plant needs (via soil testing) is the most effective way to reduce P-runoff losses over time. However, limiting long-term P release from soils that have received repeated and excessive fertilizer applications will be challenging. The single most important factor or practice for reducing short-term nutrient runoff would be to limit or prevent application and losses of fertilizers and clippings from impervious surfaces. We do not support an across-the-board ban on all N and P fertilizer applications for the simple reason that we cannot establish and maintain healthy vegetation to control soil erosion and filter sediment out of overland flow/runoff without adequate plant-available N and P.

Overall, we believe that a combination of **Options B, D and F** would be the most effective for both short- and long-term reductions in N and P loadings to stormwater runoff from individual home lawns and landscaped areas. Alternatively, where fertilizers are applied by commercial entities or certified individuals, the prescriptions laid out in **Option C** should be rigorously followed. Implemented together, these practices would (1) limit P applications in all settings to those prescribed by a current and valid soil test and (2) strictly limit total annual and one-time N application rates. Concurrently, (3) local policies should be established to ensure that fertilizers and clippings are not allowed to be applied and/or retained on impervious surfaces. Finally, where required and necessary, (4) fertilizers should be prescribed and managed by certified applicators. There are very few studies currently available that directly measure the effects of reduced or limited N and P fertilization practices on runoff nutrient loadings. Several studies indicate a potential 25 to 50% reduction in total-P loading to stormwater within several years. The literature also indicates that significant reductions (10 to 20%) in total N loadings to stormwater could be achieved through intensive fertilizer management practices. Local monitoring/validation of these reductions is recommended.

Introduction

Stormwater nutrient runoff loadings within the Chesapeake Bay watershed are being increasingly regulated by Chesapeake Bay Program initiatives, particularly through implementation of watershed level TMDL programs and associated runoff and development restrictions. In regions such as the urban/suburban areas of the Chesapeake Bay watershed, many have voiced concerns that compliance with TMDL based nutrient runoff standards may seriously hamper new development or may in fact be unattainable with current landuse/soil/plant management practices. One potential alternative for significantly reducing nutrient runoff loadings is to vigorously reduce or eliminate applications of nitrogen (N) and phosphorus (P) fertilizers and/or to implement a wide range of intensive fertilizer/soil/plant management practices. For example, one current study from Michigan (Lehman et al., 2009) reports a 28% reduction in total-P loadings to stormwater one year after implementation of a local regulation that banned or greatly restricted fertilizer P applications. Another EPA supported study (Lake Access, 2010) reports over 50% reduction in total P runoff in 2001/2002 between two adjacent watersheds due to P fertilizer restrictions. In contrast, Minnesota enacted statewide limitations on fertilizer P applications in 2002 and 2004 which greatly reduced total-P applications (as controlled by site-specific soil testing), but significant decreases in P in receiving streams had not been validated or quantified by 2007 due to high variability in their water quality data sets (Minn. Dept. Ag., 2007). Meanwhile, a directly related study in Wisconsin (Garn, 2002) found that stormwater runoff P events from home lawns were more frequent than expected and significantly enriched in P which was directly related to soil-test P levels. That same study reported very little total-N runoff from the same densely developed lakeshore lawns. Other nutrient runoff studies (as discussed later) report very different behavior for N vs. P in both agricultural and urbanized areas.

Thus, while the studies cited above (and other related reports) clearly indicate a potential for reduced stormwater nutrient loadings through enhanced fertilizer management or restrictions, a number of inter-related factors including soil-site properties, plant nutrient uptake patterns and efficiencies, and local surface hydrologic conditions must also be factored into our discussion. Furthermore, active construction and other site/soil disturbances can generate pulses of sediment-bound nutrient loadings that are quite different from stormwater runoff contributions from established lawns and landscapes. Similarly, direct runoff of mis-applied fertilizers, animal droppings and lawn clippings and leaves from sidewalks and other impervious surfaces must also be considered and managed appropriately to reduce net stormwater N and P levels.

The overall goal of this paper is to discuss and describe the probable effects of a wide range of fertilizer nitrogen (N) and phosphorus (P) application and management practices on potential nutrient runoff loadings in developed and urbanizing environment. Specifically, we will discuss how direct N and P application restrictions and intensive soil/plant management alternatives might reduce nutrient runoff loadings versus current conventional practices. To accomplish this we will review current scientific knowledge on the behavior of nitrogen (N) and phosphorus (P) in soil/plant systems with a particular focus on intensively managed urban home lawns and landscapes. The known relationships between soil/plant N and P dynamics and their potential contributions to runoff loadings will be discussed in detail.

It is important to point out that due to the dearth of published scientific studies on this particular topic, our conclusions are necessarily based on the best literature and knowledge from the fields of agricultural and urban soil nutrient management coupled with those directly applicable to urban runoff as influenced by fertilization practices.

Fertilizer application reduction strategies

To properly frame this paper and our evaluation, we assume that any of the following potential limitations or management restrictions could be likely candidates for use alone or in various combinations in urban/suburban areas of the Chesapeake Bay Watershed:

A. *Prohibition of all N and P applications except for new seedings*. This would be the most drastic proposed restriction. Fertilizers would only be allowed on "new ground" seedings, active construction sites, etc., with very restricted rates (based on soil test for P) and only with associated sediment/runoff control BMPs in place.

B. *Ban on P except for new seedings and critical areas; slow-release N formulations only*. This option *assumes* that most well-established home lawns and landscapes will not be soil P limited, but exceptions would be needed for "new ground" seedings, active construction sites, or critical renovation areas in home lawns where soil test validates an actual P deficiency. At least 25% of total-N applied must be from a slow-release source with strict one-time and annual application rate limitations as described on page 18.

C. *Soil-test only for P application rates; strict annual and one-time N limitations*. Fertilizer P applications would only be allowed when indicated as necessary by soil test (M^- or lower). Total N would be limited to no more than 3.5 lbs of water soluble N/1000 ft^2 per year with no more than 1 lb/1000 ft^2 per application at least 30 days apart for cool season grasses. For warm-season grasses, the annual N level can be as high as 4.0 lbs N/1000 ft^2. This would in fact reflect current "best turf management practice" in the region and would be similar to Virginia DCR Nutrient Management Plan restrictions for managed turfgrass areas. For this option (and B above) to be viable, fertilizer sales would need to restricted in some fashion and/or certified applicators would need to apply all materials.

D. *Ban on sidewalk/driveway applications.* Should be a mandatory BMP and applies to both fertilizers and lawn clippings/leaves/trimmings.

E. *Use of organics*. Organic fertilizer sources (e.g. composts and manures) can offer significant secondary soil building benefits (e.g. aggregation, water holding and micronutrients) along with slow release N and P behavior. However, these products are highly variable and over-application can lead to runoff nutrient losses as well.

F. *Fertilizers applied only by certified applicators*. Both Virginia and Maryland have relatively new regulations that require all private sector (e.g. lawn care firms) non-agricultural fertilizer applications to be directed by a state-certified individual. More rigorous application of this policy to all urban lawns and landscapes should be considered. This approach would necessarily need to be coupled with site-specific soil testing and appropriate N and P application restrictions.

Other alternatives or combinations of restrictions and management practices are likely to evolve over time. Our goal in this paper is to provide the reader with the appropriate understanding and background to predict their potential impacts on runoff N and P losses.

Current EPA model assumption on N and P loadings vs. urban land use cover types.

While it was beyond the scope and intent of this document to review and critique the current assumptions that USEPA and its cooperators are using to simulate runoff nutrient loadings of N and P in its current version of the "Bay Model", we do provide the following summary as a frame of reference for our findings. According the EPA's on-line guidance documentation (USEPA, 2008a):

> *A standard practice for estimating nutrient loads from developed land is the simple method, in which the annual nutrient load is determined by the annual runoff multiplied by the median event mean concentration (EMC) (Schueler, 1987; Pitt et al., 2004). The annual runoff is typically estimated from rainfall, detention storage, and the runoff coefficient, or in the case of the Phase 5 simulation, is directly simulated and the runoff estimates are taken directly from model output. We estimate the annual discharge of total surface and groundwater, from the Phase 5 model to represent the runoff, which is consistent with the Phase 1 observed data we use. Simply multiplying the annual discharge by the concentration gives an estimate of loading.*

Accordingly, the two critically important factors used to derive the annual runoff loadings as presented in Table 1 are (a) the median assumed nutrient concentrations in stormwater and (b) the % impervious surface. Furthermore, the EPA asserts that the literature and data sets available for their review varied little in relative runoff concentrations and therefore they established median concentrations of 2.0 mg/l total N and 0.27 mg/l total P for *all initial inputs* and then the model varies the proportional loadings given in Table1 based on the relative water balance assumptions in the runoff model employed (e.g. Schueler's "simple method"). The EPA's assessment of literature related to N and P losses from active construction also revealed a wide range of reported losses and their estimated loadings from that land use type as shown in Table 1. The loading values shown there assume no sediment control BMPs are in place.

The importance of direct runoff from impervious surfaces has long been recognized in the turfgrass nutrient management area and by landuse planners. For example over 10 years ago, Arnold and Gibbons (1996) defined four basic qualities of "imperviousness" that make it an important indicator of environmental quality: (1) while an impervious surface does not directly generate pollution, there is a clear link between an impervious surface and the degradation of water quality; (2) urbanization logically increases the area of impervious surfaces; (3) an impervious surface prevents natural pollutant processing in the soil by preventing percolation; and (4) impervious surfaces convey pollutants into the waterways, typically through the direct piping of stormwater.

Table 1. Runoff loadings for land uses as presented in USEPA (2008a) Chesapeake Bay Model support documents. A range of land use loading values are presented here for reference. Loadings from "urban lands" are based upon combined contributions of the "pervious developed" and "impervious developed" values shown below. Bare Construction values assume no sediment control BMPs.

Land Use	**Median Total-N Load (lb/ac-yr)**	**Median Total-P Load (lb/ac-yr)**
conventional crop receiving manure	23	2.0
conventional crop without manures	23	2.5
conservation crop receiving manures	XX	1.4
alfalfa	5.5	0.7
hay fertilized	6.0	0.8
hay unfertilized	4.0	0.4
pasture	4.5	0.7
pervious developed	8.7	1.1
impervious developed	11.8	2.1
nurseries	240	85
bare-construction	25	7.0
extractive	21.5	3.5

For reasons discussed later in this paper, we question the use of one median runoff concentration value for N and P in the Bay Model simulations. However, we also acknowledge the fact that the literature is scant with specific catchment-specific measured values which could be used to better specify this critical modeling parameter. Similarly, the active construction runoff loadings appear high, particularly for P where subsoils are the major sediment contributor. However, we can only assume that the EPA chooses to be conservative here.

Review of Related Regional Reports and Data Sets on Urban Runoff

Large, continuous flow and water quality records of urban catchments are not common. The Occoquan watershed has been monitoring gages upstream from Occoquan dam (a public water supply intake) from 1982-present (Dougherty et al., 2006). Upstream of the monitoring gages, the contributing catchments' sizes are on the order of 200 mi^2 with heterogeneous land use. Thus, this data is not at the scale needed for this analysis.

The Long Term Ecological Research (LTER) site in Baltimore consists of an 80 acre forested catchment and 6 urban catchments ranging in size from 19 to 40,200 acres in size, with impervious proportions from 1 to 41% (Groffman et al., 2004). Continuous storm flows are not collected. The focus of the research in this area is N retention, and the authors report that N retention was high in suburban catchments, with sources attributed to atmospheric deposition and lawn fertilizer. In a later study with surveys and soil testing aimed at estimating the fertilizer N application rate, Law et al. (2004) found a wide range in application rate, with a mean of 87.1 lb N/ac/yr (97.6 kg N/ha/yr) and a variance of 78.8 lb N/ac/yr (88.3 kg N/ha/yr). The authors attributed the main differences in application rate to a variety of physical factors such as soil bulk density and N, and social factors including property valuation and structural age.

The LTER Plum Island research site has collected 2 years of data from a range of catchments 148 to 1037 acres in size across a range of urban development, with impervious surfaces ranging from 1.3-28.6%. These catchments are heterogeneous in land use, but contain between 6.6-89% of residential land use (Wollheim et al., 2005). The authors found that impervious surfaces from urban development result in increased water runoff, increased N loading and N exports, and decreased N retention through a variety of mechanisms, not all of which are measureable or understood. Some of the best measurements of urban runoff quality for small catchments were taken as part of the National Urban Runoff Program (NURP). Metropolitan Washington Council of Government (MWCOG) conducted a study of detention ponds for various land uses (MWCOG 1983). The influent watersheds for Burke Pond (51UR03, Virginia) and Westleigh (51UR15, Maryland) were 18.3 and 28.4 acres, with impervious ratios of 32.7% and 21.2%, respectively. Continuous storm measurements were collected for a period slightly more than a year. These catchments were considered stable during the time period of the study. Figure 1 illustrates runoff depth for Burke and Westleigh. Burke, while smaller, maintains a much greater median runoff depth than Westleigh due to its higher impervious surface. Normalized Event Mean Concentration (EMCs) for Sediment and COD are provided in Figure 2. These values can be converted to load in kg/ha/year by multiplying by the annual runoff volume through the simple method. Sediment values are essentially the same for each. Phosphorus values and P-forms are illustrated in Figure 3; the same for N forms as shown in Figure 4. The values for total P are roughly equivalent for the two watersheds, the higher variance shown in the Westleigh catchment may in part be due to the larger extents of pervious lawns. Little difference is shown in Nitrogen exports from the same watersheds (Figure 4).

Evaluating the effects of development upon urban runoff quality necessitates observing small, homogenous catchments over a long period of record. For residential development, a longer record period can enable evaluation of the different phases of development. Line and White (2007) monitored a 10 acre developing catchment paired with an 8.2 acre undeveloped catchment in the central Piedmont region of North Carolina for a period of 5.5 years. Phases of development included clearing, followed by two phases of building. The first phase consisted mainly of house construction and landscape development. The second and final phase consisted mainly of construction of roads and storm sewers. Table 2 summarizes the relative loading rates for each phase of development.

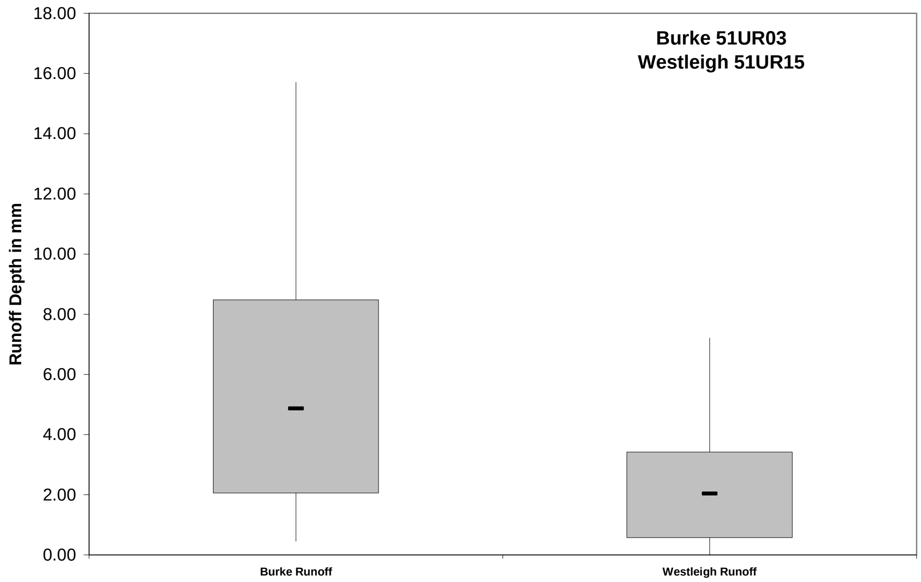

Figure 1. Distribution of Runoff volumes for Burke and Westleigh urban Catchments, Metropolitan Washington. *Note: 25.4 mm = 1.0 inch.*

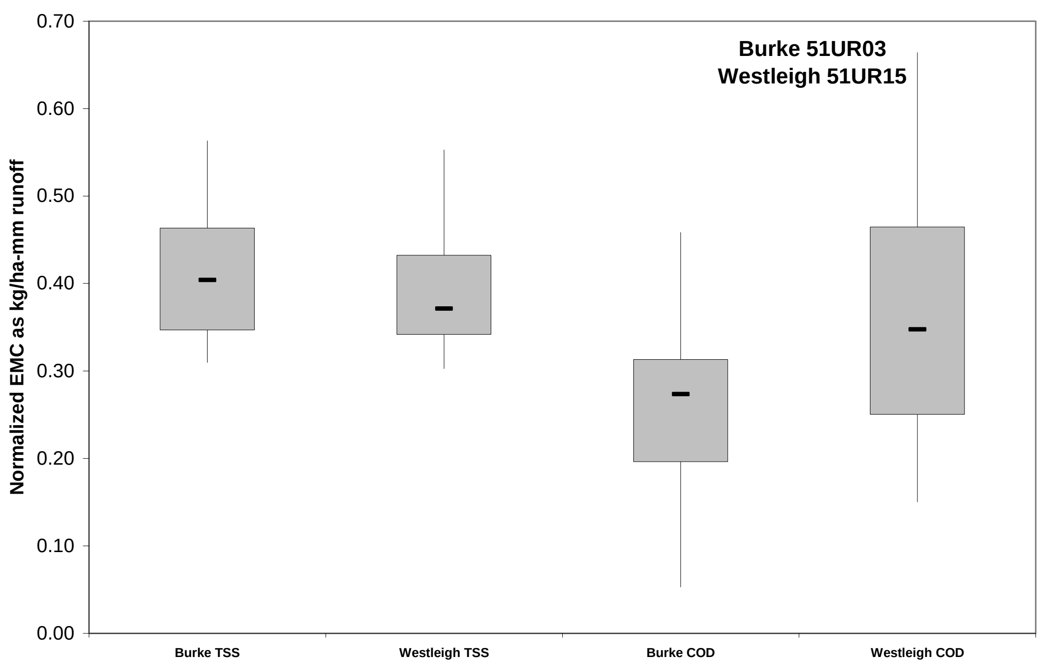

Figure 2. Distribution of TSS and COD loading for Burke and Westleigh urban catchments, Metropolitan Washington. *Note: 1.0 lb/acre = 1.12 kg/ha.*

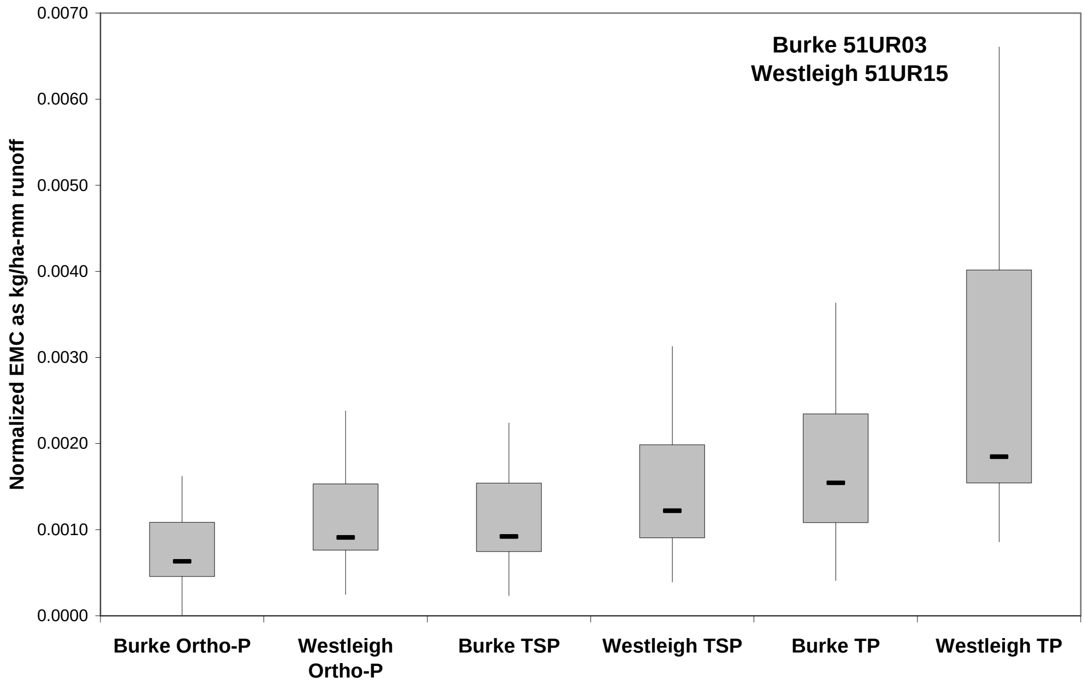

Figure 3. Distribution of P Loadings (and speciation) for Burke and Westleigh urban catchments, Metropolitan Washington. *Note: 1.0 lb/acre = 1.12 kg/ha.*

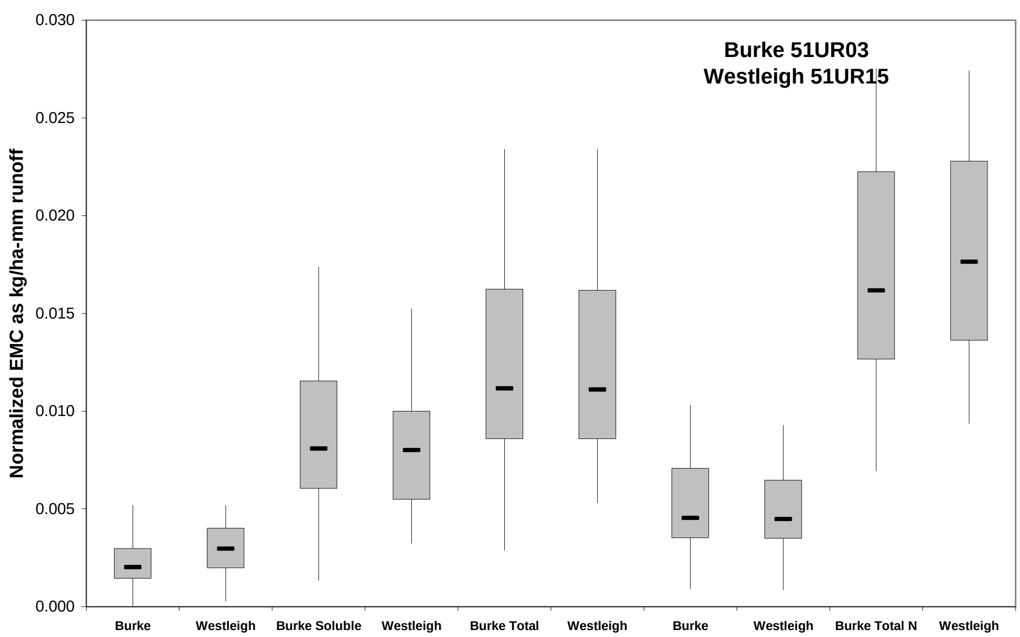

Figure 4. Distribution of N Loadings (and speciation) for Burke and Westleigh urban catchments, Metropolitan Washington. *Note: 1.0 lb/acre = 1.12 kg/ha.*

Table 2: Pollutant export rates during urban development from a small catchment

Type	Phase	Period Length (years)	Avg Ratio of Runoff to Rainfall	TSS	TP	Nitrate+ Nitrite-N	TKN	NH_4-N	TN
				Loading in kg/ha-yr					
Developing Catchment	Clearing	0.7	0.5	29250	2.8	2	8.4	0.7	10.4
	Building-1st phase	1.4	0.6	6170	1.3	5.9	25.6	3.3	31.5
	Building-2nd phase	3.5	0.55	1958	1.7	1.8	16.2	1.7	18
Undeveloped Catchment	N/A	5.6	0.21	349	0.5	1	5.3	0.2	6.3

Source: Line and White (2007). *Note: 1.0 lb/acre = 1.12 kg/ha.*

Construction sites are a special case, and difficult to predict because of their spatially disperse and sporadic nature. Monitored sites would also be highly variable, and likely unrepresentative. EPA is presently revising the General NPDES Stormwater Permit for Construction Activities. The USEPA conducted an analysis in support of its effluent guidelines (USEPA 2008b). From this source, the estimated sediment loss from typical construction sites in Washington, DC was estimated; these data are found in Table 3. Based upon average construction activities and modeled conditions, the estimated sediment load from Virginia from construction sites, based upon multiple control scenarios is found in Table 4. These are "edge of field" numbers, to become "edge of stream"; EPA typically reduces them by 85% to reflect attenuation and settling. For comparison, the total Virginia sediment load from all sources was 2,204,161 tons/year. The USEPA Chesapeake Bay program currently uses 40 tons/acre/year for uncontrolled construction site sediment loading. EPA proposes to apply option 3 in the proposed permit, which would be an 87% reduction from no control.

Nutrient and sediment loading from the Occoquan watershed were computed for the period from 2003-2008 for comparison (Grizzard, 2010) in one particularly relevant, but unpublished study. The Occoquan watershed has two main tributaries, Occoquan Creek (less urbanized, 369 mi^2), and Bull Run Creek (more urbanized, 201 mi^2). Occoquan Creek had a Total N, Total P, and TSS loading of 5.5 lb/ac/yr (6.2 kg/ha/yr), 6.2 lb/ac/yr (0.7 kg/ha/yr), and 370 lb/ac/yr (415 kg/ha/yr), respectively. Bull Run Creek had a Total N, Total P, and TSS load of 4.0, 0.7 and 558 lb/ac/yr (4.5, 0.8, and 625 kg/ha/year), respectively.

Due to the existence of complete vegetative cover, associated mitigation of raindrop impact and internal sediment detention, loss of sediment-bound N and P will be negligible from established and well-managed home lawns and landscapes (Soldat and Petrovic, 2008). The exception would be where clippings or other low density particulate organic matter was mobilized in overland flow. However, where site development and construction removes established vegetation and litter layers, the highest risk is clearly associated with previously P-enriched topsoil layers. This risk will be highest where the soil was previously managed for agricultural production or intensive turf. P runoff risk would be lowest where forest covers are removed. Regardless, all topsoil (A+E horizon) materials should be carefully segregated and protected on-site, seeded to a temporary vegetative cover, and surrounded by silt fences, compost berms or other appropriate sediment control BMPs. While exposed subsoil materials (typically Fe- and clay-rich Bt and C horizons) may pose a significant site-specific risk for sediment loss, their effect on nutrient levels in runoff would be negligible. In fact, these subsoil materials (particularly yellow/red, acidic clays) would actually be expected to adsorb soluble P forms from overland or channelized flow paths and may thereby actually limit P-losses to some extent. That being said, once sediment bound P forms are deposited into anaerobic zones in stormwater basins or wetlands, this Fe-bound P will be reduced and become bioavailable.

Table 3: Estimated Sediment Loss from Typical Construction Sites in Washington, DC

Estimated Sediment Loss, Wash DC, Tons/Acre, CASE:	Low	Average	High
Large, Medium, and Small Transportation Model Construction Projects	96.5	133.58	173.39
Large and Medium Residential Model Construction Projects	138.15	194.91	256.99
Large and Medium Nonresidential Model Construction Projects	156.46	222.21	294.57
Small Residential and Small Nonresidential Model Construction Projects	111.34	155.3	202.85

Source: US EPA 2008b

Table 4: Estimated Total Construction Site Sediment Loads for Virginia

Estimated Annual Construction Site Discharged Loads, Total for Virginia	**Low (Tons/year)**	**Avg (Tons/year)**	**High (Tons/year)**
No control	1,686,403	2,378,049	3,134,251
Option 1 (baseline, existing)[1]	722,808	1,019,253	1,343,368
Option 2[2]	306,259	430,958	567,018
Option 3[3]	87,599	122,142	159,486

[1]Option 1 would establish minimum sizing criteria for sediment basins used at construction sites with 10 or more disturbed acres draining to one location.
[2]Option 2 includes all Option 1 requirements, and numeric turbidity standards would be required to be met by all construction sites of 30 acres or greater.
[3]Option 3 contains the same requirements as Option 1, but also requires all sites with 10 or more acres of disturbed land to meet a numeric turbidity standard.

Source: US EPA 2008b

Soil N and P accumulation, mobility & management response

Forms of soil N and P and fertilizer recommendations

Native soils tend to be N and P deficient relative to plant requirements, with additions through fertilization necessary for optimum plant growth. This is particularly true in urban environments where nutrient deficient subsoils have often been brought to the surface through construction activities and soil disturbance. Most P in soils is in the inorganic form attached primarily to iron and aluminum, with only 30 to 50% in the organic form. Fertilization with commercial fertilizers mostly builds up the inorganic fraction and it is primarily this inorganic soil P that is measured by soil tests such as the Mehlich 1 extractant that is the basis for soil P recommendations in Virginia. Soil testing is the basis for good nutrient management. A soil test taken from a situation such as homeowner's yard and sent to a soil testing laboratory will enable the owner to know how much P and K is in the soil and therefore how much fertilizer P and K is needed for strong plant growth (Maguire and Heckendorn, 2009). About 97-99% of N in soils is in the organic form, and release of this N is hard to predict as it relies on soil microbes. As the plant available inorganic N tends to be very mobile in soils, fertilizer N recommendations are based on the plant to be grown and immediate growing season uptake needs rather than a soil extraction per se.

It is important to understand that as fertilizer P is held by soils, over-application can build up P above recommended levels and present a long term problem for P loss. However, as N is very mobile it does not build up in soils. Therefore, applications of P should be done according to a soil test and are not required each year, while N applications are generally required each year. Figure 5 below shows an agricultural soil that had P well above what was needed for crop growth. This soil had corn grown and removed with no P fertilization, and despite this annual P removal by the corn crop, it took 15 years for the soil P to drop to where more P fertilizer was required. In urban situations, such as turf where clippings are not removed, soil test P will remain fairly constant over a long time period with no fertilization. One recently published study from Minnesota (Bierman et al., 2010) reported that on sites testing high in soil P, P runoff from turfgrass over a five-year period was significantly reduced without affecting turf quality by not applying any P fertilizer. However, that same study also noted an increase in second-year total P runoff from unfertilized (0 N-P-K) plots due to poor grass growth and sediment/particulate P losses.

Accumulation of P and P-saturation

Most soils retain P very strongly, especially when they are relatively low in P. However, soils have a finite capacity to retain P, and they can therefore become saturated to such a point where they cannot retain more P (Maguire et al., 2005a). As soil P is built up through fertilizer P additions, the strength with which the soil retains P decreases. In practical terms, this means that as soil test P increases, the amount of soluble P (primarily as ortho-P anion) and sediment-bound P lost in runoff also increases (Sims et al., 2002).

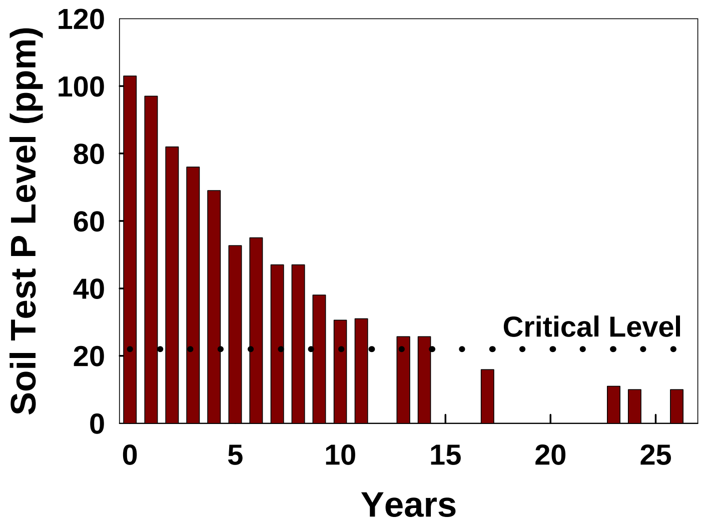

Figure 5. Soil test P with time, where corn was grown and removed for 26 years with no P fertilizer additions (McCollum, 1991). The "critical level" is the soil test value above which no fertilizer P would be recommended for optimum growth.

P-release to leaching and surface runoff vs. P-saturation

There are three main pathways for P losses: 1) leaching, 2) soluble P in runoff, and 3) sediment bound P in runoff (Virginia P Index, 2005). Of these, leaching is only a concern in artificially drained soils, where drains immediately under the topsoil conduct water to streams, and sandy soils. Loss of P in leachate is minimal where the soil test P level is maintained according to recommendations, but rises with overapplication of P fertilizer and saturation of soils with P above levels recommended for plant growth (Maguire and Sims, 2002a, b). For example, P in leachate was below the detection limit until 81 mg Mehlich 1 P/kg, but rose rapidly above this until the leachate concentration was 9.8 mg P/L at 600 mg Mehlich 1 P/kg (Maguire and Sims, 2002b). This compares to an optimum P concentration for turf growth of 55 mg Mehlich 1 P/kg. While P loss in leachate can be a concern in a few cases, soluble and sediment P losses associated with surface runoff are the major P loss pathways in the urban environment. Soil testing is a key component of estimating how much P will be lost through each of these pathways (Maguire et al., 2005a). Soil test levels well above the agronomic optimum raise serious concerns for environmentally damaging P losses, while maintaining soil test P within recommended ranges leads to healthy turf with little risk of environmentally damaging losses. DeLaune et al. (2004) found a linear relationship between soil test P and soluble P concentration in runoff from pastures. Below 36 mg Mehlich 3 P/kg, there was no significant soluble P in runoff, but it increased linearly above this until soluble P concentration was 2.61 mg P/L at 300 mg Mehlich 3 P/kg (relative to optimum for turf growth of 100 mg Mehlich 3 P/kg). Most data relate soil test P to concentrations of P in runoff, and many have related soil test P or soil saturation to P concentrations (Pote et al., 1999). However, loads of P per land area were summarized from data in North America, with total P losses for pasture range from 0.26 to 2.5 lb/ac/yr (0.3 to 2.8 kg P/ha/yr) with a median of 0.8 lb/ac/yr (0.9 kg P/ha/yr) (Young et al., 1996; Beaulac and Reckhow, 1982). As soil test values increase, soluble and sediment P losses in runoff increase, but losses of environmental concern mainly occur above soil test P recommendations (Fig. 6). Since soil test P remains high for many years once built up to excessive levels (Fig. 5), soils high in P will represent a great risk of excessive P losses in runoff for many years. Maintaining healthy turf is a good way to maintain soil cover that minimizes soil erosion and thus sediment bound P losses in runoff. Easton and Petrovic (2004) reported that nutrient losses in runoff were greatest during turf establishment, but that fertilization "ultimately results in less water contamination" as it speeds turf establishment and thus soil stabilization.

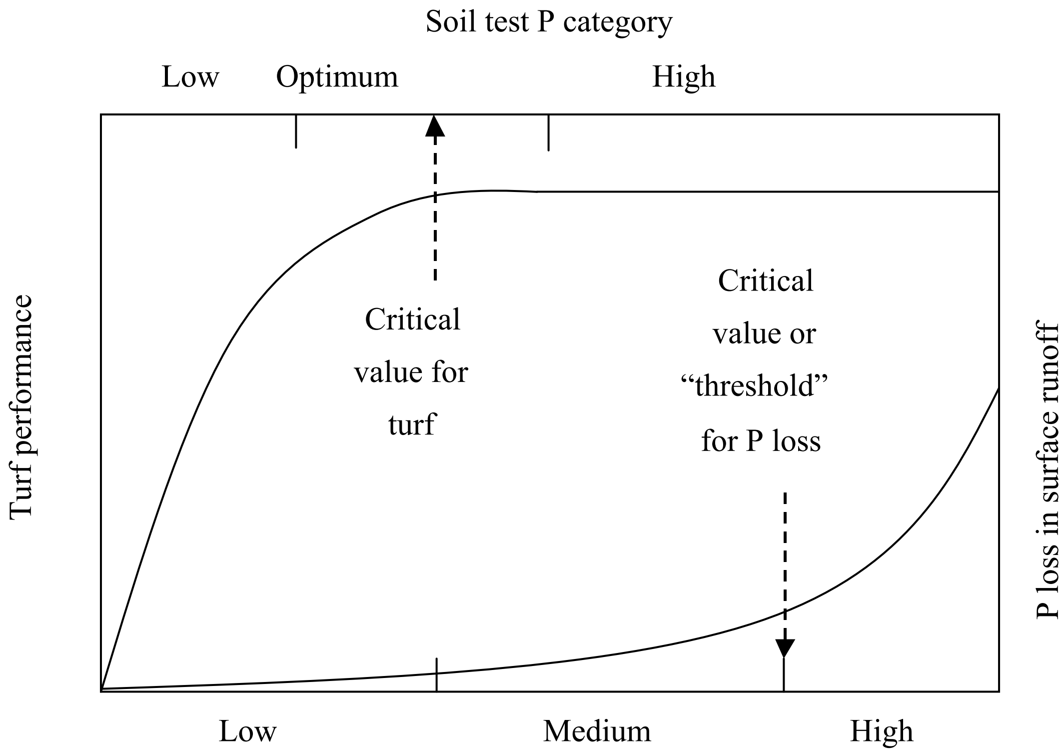

Figure 6. Influence of soil test P on turf performance and P losses in surface runoff (adapted from Sharpley et al., 2002).

Fertilization is important for plant establishment, but should not exceed soil test recommendations. For example, Soldat et al. (2009) found a linear relationship between soil test P and P losses in runoff in turf, with soil test P levels excessive to turf requirements leading to greater P losses in runoff. This is why nutrient management regulations in Virginia, where they are mandated, require that commercial fertilizer P additions are not permitted when a soil test shows that no P is required for optimal plant growth (DCR, 2005). Apart from soil test P levels, many other factors also play an important role in P losses (Maguire et al., 2005b). These include soil type, slope, proximity to streams and drainage and plant cover to avoid excessive soil erosion. The vulnerability of a site to P losses and the relative importance of each of these factors can be determined by a Phosphorus Index (Virginia P Index, 2005). Even under worst-case conditions where fertilizer was applied to turf but not watered-in and a major storm event or simulated event occurred within a few hours of application, the amount of fertilizer N and P lost to runoff was generally less than 10% of applied and, more often, only 2 to 4% of applied

(Walker and Branham, 1992). The levels of P reported during studies of nutrient runoff from turf were sometimes no greater than those reported in natural rainfall (East et al., 1998).

In research comparing the effectiveness of buffer strips of Kentucky bluegrass versus native forb and prairie grasses in handling surface runoff from impervious surfaces, the two systems performed comparably in terms of sediment capture and P loading, even though the Kentucky bluegrass turf was periodically fertilized with P (Steinke et al., 2007). During periods of runoff on non-frozen soils, the turf had lower P loading than the native vegetation, but there were no differences when soils were frozen, regardless of vegetation or size of the buffer. Another source of P that is often overlooked in identifying sources of water pollution is tree leaves. Dorney (1986) reported that up to 9.3% of the total P in the leaves was leachable within 2 hours. As discussed later, lawn clippings are also contain significant P and post a concern for runoff contributions as well.

Soil N in turfgrass management and runoff effects

Forms of soil N and relative availability

Nitrogen (N) is the most dynamic macro-nutrient in soils, rapidly changing between plant-available and unavailable forms. A brief discussion of the nitrogen cycle helps explain why N requires so much attention in turf and landscape fertilization programs. Although N gas makes up 78% of the atmosphere, this form of N is not available to common turf and landscape plants, although some common legume components of lawns (clovers and medics) can form symbiotic relationships with specific N-fixing bacteria that can be captured and ultimately released into the soil in an organic form. The intent of N fertilization in turf and landscape systems defined in the figure is assimilation**,** the uptake and incorporation of N into amino acids, nucleic acids, and proteins. For turfgrass systems, the regular mowing of leaf blades returns clippings (and their N) to the soil where it is decomposed by soil bacterium. This organic N that is found in the decaying plant tissues is converted by the bacteria to the ammonium (NH_4^+) cation during the process of mineralization (also called ammonification). Ammonium is plant available although it is not the primary form of N uptake. It is also important to note that since NH_4^+ is a cation, it resists leaching and can be held and exchanged for other cations in soils with significant net negative charges due to large percentages of clay and/or organic matter. Mineralization is an important ‘recycling’ step in soils.

Ammonium can be oxidized by specific soil bacteria to the primary form of plant available N, the nitrate (NO_3^-) anion in a process called nitrification. This process requires very specific soil-borne bacteria that oxidize NH_4^+ first to nitrite (NO_2^-, a very short-lived compound) and finally the plant-available NO_3^-. Nitrate can also be lost back to the atmosphere by the process of denitrification**,** another series of reactions involving soil-borne bacterium that convert the N back to N_2 gas. Both NH_4^+ and NO_3^- can also be assimilated by some of the same soil-borne bacteria involved in mineralization by what is called immobilization**.** The frequency and speed at which these N conversions occur is a primary reason why soil tests are rarely conducted for N. As indicated in this discussion, there are only two plant-available forms of N, NH_4^+ and NO_3^-.

Nitrogen Sources

Nitrogen sources are frequently categorized according to their water solubility that will be detailed below as readily and slowly-available N. A fertilizer label must state the percentage of total N as well as the varying percentages of water soluble and slowly available N (SAN); SAN can also be identified as water insoluble N (WIN) or controlled release N (CRN) depending on the N source. If there is no detail of SAN, WIN or CRN, then it is assumed that all of the N is water soluble. Since turf and landscape plant materials are most often not being grown for yield (the exception being sod and container/field landscape production systems) and are confined to relatively small land areas as compared to row crop production systems, slowly-available N sources often provide sensible management, cost, and environmental advantages to readily-available N sources. It is important to understand that all N sources will gradually lower soil pH. However, readily available N sources will drop pH much more quickly that slowly-available N sources, a management point that needs to be addressed by soil testing. Each source has different strengths and weaknesses.

Readily-available nitrogen and application rates

Readily-available sources are also referred to as water soluble, quick-release, or fast-acting to designate how quickly they become available following application. The rapid conversion of the fertilizer to the plant-available forms of ammonium (NH_4^+) and nitrate (NO_3^-) is why they provide such a quick growth and color response. As described previously regarding the N cycle, these forms also are readily transformed by chemical and microbial processes into plant-unavailable forms as well. Readily-available sources are less expensive than slowly-available sources of N and can be applied as either liquid or dry formulations. Light and frequent applications of 0.25 to 0.5 lb N/1000 sq ft are desirable, but up to 1 lb N/1000 sq ft in a single application is suitable as long as applications are spaced at least 30 days apart. The level and frequency of the application typically depends on the grass being grown, its intended use, the soil, and the climate. In order to optimize nutrient utilization by the turf, reduce potential injury due to their high salt concentrations, and lessen potential environmental impact from nutrient leaching (especially the highly leachable NO_3^-), an increased frequency of application at lower levels is often desirable. Excessive salt accumulations in the soil can damage roots and/or reduce their function; however, since most areas of the mid-Atlantic receive periodic rainfall, concerns from salt accumulations in the soil from quickly-available fertilizers are limited. The primary concern with turf damage from quickly-available, high salt content fertilizers is the potential for "foliar burn" caused by tissue desiccation. In this scenario, the water soluble, typically high salt content fertilizer that remains on the turfgrass leaves actually attracts water from the cells of the plant; this causes cell and leaf tissue desiccation in localized areas, resulting in the visual foliar burn.

Some of the most common forms of inorganic, readily available N sources used in turf and landscape management are ammonium nitrate, ammonium sulfate, potassium nitrate, calcium nitrate, diammonium phosphate and monoammonium phosphate. The sources with the highest water solubilities (ammonium nitrate, urea, and ammonium sulfate) are often dissolved in water and are foliar applied. The water solubilities and salt indices for these sources are provided in Table 5 below.

Table 5. The grade, salt index, and water solubility of the most common readily-available nitrogen sources used in turf and landscape management fertility programs (after Turgeon, 1985).			
Fertilizer	Grade*	Salt index[z]	Water solubility[y]
	$N\text{-}P_20_5\text{-}K_20$ (%)		Grams/liter (pounds/gallon)
Ammonium nitrate	34-0-0	3.2	1810 (15)
Ammonium sulfate	21-0-0	3.3	710 (5.9)
Potassium nitrate	13-0-44	5.3	130 (1.1)
Monoammonium phosphate	11-48-0	2.7	230 (1.9)
Diammonium phosphate	20-50-0	1.7	430 (3.6)
Urea	45-0-0	1.7	780 (6.5)
[z]The salt index scale is <1 = low, 1 to 2.5 = moderate, and >2.5 = high.			
[y]Water solubility expressed in grams per liter (pounds per gallon in parentheses).			

**Fertilizer grade* refers to % total N, soluble phosphate (as P_2O_5) and soluble potash (as K_20). Thus, a 50 lb bag of "10-10-10" would contain 5 lbs each of total-N, soluble phosphate and soluble potash. However, since P_2O_5 is only 44% P by weight, the bag would actually contain 2.2 lbs of actual P. This convention is used to allow uniform labeling because fertilizer forms (particularly P) vary widely. Oxide forms of P and K do not actually appear in commercial fertilizers. Modern soil test levels, fertilizer recommendations and literature runoff values for P are always expressed as "P" and not as P_20_5.

Slowly-available nitrogen

A unique aspect of N fertilization programs in turf and ornamental management is the use of a vast array of slowly-available N sources that provide very controlled growth and color responses, along with inherent environmental advantages due to the slow-release characteristics. Their use in turf and ornamental systems is typically more economically viable than in production agriculture systems since "yield" is generally not a consideration (except in sod or nursery production systems) and quality, appearance, and playability (in the case of turf), are the driving factors in management programs. The incremental release characteristics of these materials is particularly valuable in turfgrass systems with completely modified, sand-based soils (i.e. sand-based golf greens, tees, and athletic fields) that possess inherently low cation exchange capacities and high N leaching potential.

Slowly-available (SAN) sources of N are also referred to as water-insoluble (WIN), controlled release (CRN), slow-release, and slow-acting to designate their ability to meter out N over a certain length of time, similar to timed-release cold capsules. Using Virginia Department of Conservation and Recreation's Nutrient Management Training and Certification Regulations 4 VAC 5-15 criteria, SAN is defined as "N sources that have delayed plant availability involving compounds which dissolve slowly, materials that must be microbially decomposed, or soluble compounds coated with substances highly impermeable to water such as polymer coated products, methylene urea, isobutylidene diurea (IBDU), urea formaldehyde based (UF), sulfur coated urea, and natural organics". Slowly available N sources provide a sustained growth and color response that lasts for weeks to months rather than providing a quick surge in growth and greening response. Slowly-available N sources also have a very low salt index; hence they do not contribute to a build-up of soluble salts in the soil that might affect root system development. These sources also have minimal foliar burn potential. Because of the added steps involved in their production, they are typically more expensive than quick-release fertilizers. The primary SAN sources used in turf management systems are listed in Table 6 and the products are further described below.

Combinations of quickly and slowly available N

Many manufacturers combine quick and slow release sources of N to take advantage of both strengths. The quick release source provides quick green up but is at a sufficiently low rate to prevent salt injury or reduce the potential for leaching. The slow release source is available to provide a greening response for a longer duration.

Practical considerations in interpreting and applying slowly available N (SAN) sources.

The SAN sources offer advantages from both an environmental perspective as well as reductions in application frequency and controlled plant response. The following application criteria were developed for SAN sources (all categories and combinations of WIN, CRN, etc. apply) in order to optimize plant nutrient use efficiency and environmental responses:

- If the fertilizer is ≥ 50 percent SAN then up to 1.5 lb N/1000 sq ft is acceptable in a single application during optimal growing periods.
- If the fertilizer is 25 to 49 percent SAN then up to 1.25 lbs N/1000 sq ft is acceptable in a single application during optimal growing periods.
- If the fertilizer is ≤ 25% SAN then no more than 1 lb N/1000 sq ft should be applied in a single application during optimal growing periods.

Organic N sources

Organic N sources will likely have SAN percentages as high as 75 to 85%, thus these materials can be applied up 1.5 lb N/1000 sq ft. However, even at these N levels anticipate a very controlled plant response since the N is slowly made available by microbial activity. Depending on the source, composts might contain 1 to 2% N (and likely P) by weight. Again, the majority of the N will be SAN. However, these materials are not normally applied as fertilizers but instead as organic amendments to improve the physical properties (structure, water and nutrient holding capacity etc.) of the soils.

Optimizing N use efficiency

While appropriate N application rates are obviously important in optimizing turfgrass performance, it is also critical to consider the timing of the applications depending on whether the grasses are cool- or warm-season. The most important cool-season grasses used in the United States are Kentucky bluegrass (*Poa pratensis*), hybrid bluegrass (*Poa pratensis* x *P.*

Table 6. A list of slowly available nitrogen[z] (SAN) sources, their typical chemical analyses, and general comments regarding the source.

N source	Typical Grade	General comments about the fertilizer
Natural organics	6-2-0[y]	Derived from waste byproducts; very low N analyses, usually contain some phosphate and other micronutrients; very controlled release that is dependent on microbial activity
Sulfur coated urea (SCU)	32-0-0[x]	Urea granules coated with molten S; analyses and release rate varies depending on amount of coating; N release due to osmosis, so moisture and temperature govern release rate; Relatively inexpensive compared to other SAN sources; will reduce soil pH; handling is important because scratching the coat removes the controlled release characteristic
Polymer coated urea (PCU)	32-0-0[x]	Synthetic polymer is also sometimes combined with S; N analyses variable depending on coating thickness; noted for very predictable release characteristics and handling is not as much of a concern as for SCU in terms of coating integrity
Isobutylidene diurea (IBDU)	31-0-0	Synthetic organic with more than 90% SAN; release is not dependent on microbial activity; quicker release obtained with smaller sized particles, moist soils, and warm temperatures;
Methylene urea	30-0-0[w]	Synthetic organic that can have varying levels of SAN that are defined by their solubility in hot or cold water; N release rates are depending on the chain length of the carbon polymers (higher percentage of short chains increases water solubility); N availability based on microbial activity.
Ureaformaldehyde (UF)	38-0-0	Synthetic organic with predominantly long chain carbon polymers and very controlled N release; N availability based on microbial activity; very limited response in cold temperatures.

[z]Slowly available nitrogen (SAN) is used as a comprehensive term for N availability and includes sources also identified as water insoluble N (WIN) and controlled release N (CRN). In general, SAN is 2x - 5x as expensive than soluble-N forms like urea.

[y]N analyses variable depending on the source.

[x]N analyses variable depending on the coating thickness.

[w]The percentage of SAN varies depending on the source.

arachnifera), tall fescue (*Festuca arundinacea*), perennial ryegrass (*Lolium perenne*), the fine-leaf fescues of creeping red (*Festuca rubra)*, chewings (*F. rubra* ssp. *Fallax*), and hard fescue (*F. brevipila*), creeping bentgrass (*Agrostis stolonifera* var. *palustris*), annual ryegrass (*Lolium multiflorum*). Even though they all have different potential uses, they each are best adapted to temperatures of 65 to 80^{o} F.

The seasonal pattern of roots, shoots, and carbohydrate storage (i.e. food) for cool-season grasses is shown in Figure 7. As a rule of thumb, the optimal time to fertilize any grass is during periods when roots are developing. There are two 'windows of opportunity' for optimal N fertilization: a primary window during the fall and a secondary window in mid-spring. Approximately ¾ of the seasonal N should be applied in the fall; warm soil temperatures and cooling air temperatures are an ideal combination that promotes desirable increases in roots, shoots, and carbohydrates. While spring presents the greatest increase in root development, aggressive N fertilization can promote shoot growth at the expense of roots and carbohydrates. A small amount of N (typically up to 1 lb N/1000 sq ft for the season) is beneficial. Unfortunately, spring is the period when human nature and savvy marketing sells the most fertilizer and it is common that homeowners regularly over apply N fertilizer. The applications result in an aesthetically pleasing, lush green turf, but because of the emphasis on the shoot system over the roots and carbohydrate storage, the turf often struggles during periods of temperature and moisture extremes in the summer.

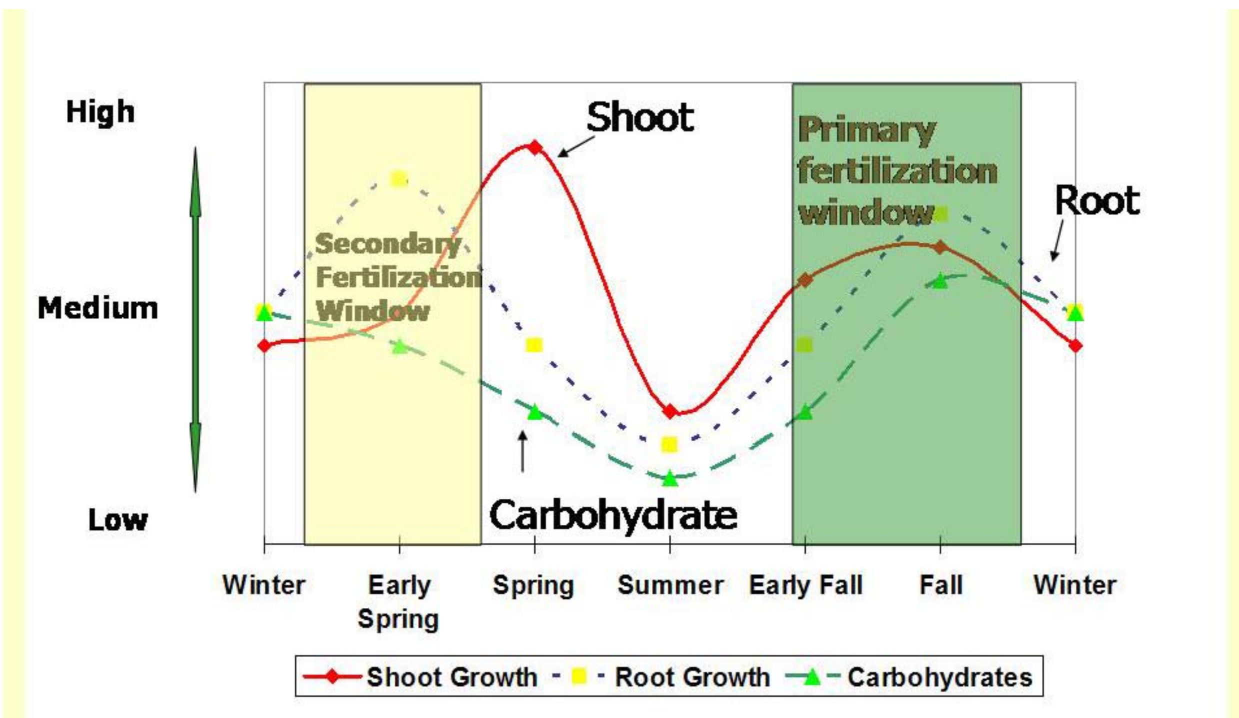

Figure 7. The seasonal growth and response patterns of shoots, roots, and carbohydrates of cool-season grasses.

Also, it is important to realize that even though the grasses respond to the temperatures similarly, different species have varying N needs. For instance, Kentucky bluegrass has a very high annual N requirement (up to 3.5 lbs per 1000 sq ft), while fine leaf fescues' seasonal N requirement might be only 1 to 2 lbs N per 1000 sq ft. Table 7 provides typical seasonal N levels and strategies to optimize the application response for cool-season grasses.

Table 7. General seasonal nitrogen fertilization strategies for cool-season turfgrasses.

Time of Year	Relative N Rate/Application	Comments
Early Spring	None to low (0.25 lb N/1000 sq ft/growing month)	-Never apply to frozen ground -if following aggressive fall fertilization, probably not necessary
Mid-late spring	Low to Medium (0.25 to 0.5 lb N/1000 sq ft/ growing month)	-have been shown to benefit root growth with responsible applications -exceeding these levels promotes shoots at expense of roots
Summer	None to low (0.25 lb N/1000 sq ft/growing month)	-in general, refrain from N fertility, but small amounts can aid recovery from stress/pest pressures… avoid applications during high heat/drought pressures
Late summer thru early winter	Medium to high (0.5 to 1 lb N/1000 sq ft/growing month)	-Promotes recovery from summer stress with early fall applications -Continue program (while grass is still green without much shoot growth) to promote roots, color, turf density and carbohydrate levels.

The primary warm-season grasses are bermudagrass (*Cynodon* spp.), zoysiagrass (*Zoysia* spp.), centipedegrass (*Eremochloa ophiuroides*), and St. Augustinegrass (*Stenotaphrum secundatum*). These grasses are best adapted to temperatures of 80-95^{o} F. Seasonal growth and carbohydrate patterns are detailed in Figure 8. These grasses enter dormancy in late fall after repeated frosts and do not renew active growth until mid-spring. Similar to cool-season grasses, aggressive spring fertilization with N is risky as it promotes shoot growth at the expense of the roots and carbohydrate system. It is desirable to wait on spring N fertilization until after the last average frost date has passed. After spring greening is complete, regular fertilization with N is possible through the remainder of the summer and into early fall. As cooler temperatures arrive, N fertilization should be reduced as the grasses begin to prepare for winter dormancy. As for cool-season grasses, the seasonal N requirements vary between species. For example, bermudagrass might have a seasonal N requirement of up to 4.5 lbs N per 1000 sq ft on heavy use turfs, whereas zoysiagrass will likely only receive 1 to 2 lbs N per 1000 sq ft per season.

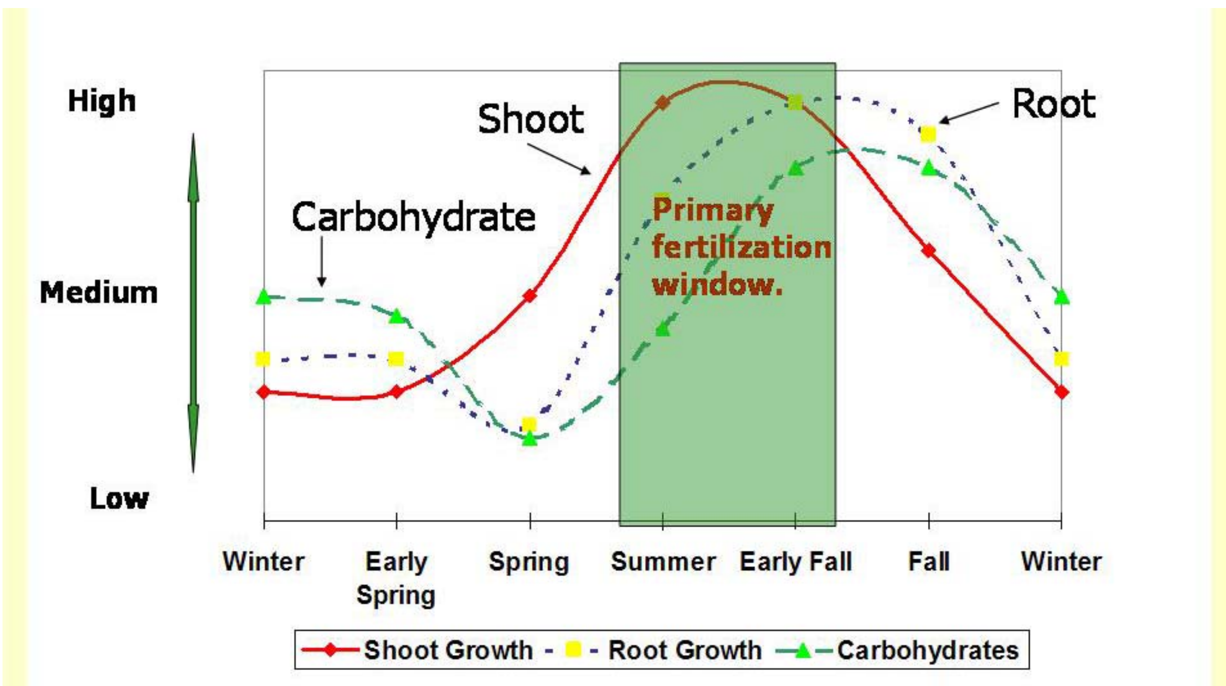

Figure 8. The seasonal growth and response patterns of shoots, roots, and carbohydrates of warm-season grasses.

Nitrogen application rates and strategies for warm-season grasses are presented in Table 8. As before, the seasonal levels will vary depending on the grass as bermudagrass can respond positively to up to 4.5 lbs N per 1000 sq ft on an annual basis, whereas zoysiagrass and centipedegrass likely only need 1 to 2 lbs N per 1000 sq ft.

Table 8. General seasonal nitrogen fertilization strategies for warm-season turfgrasses.

Time of Year	Relative N Rate/Application	Comments
Early Spring	None to low (0.25 lb N/1000 sq ft/every 30 days of optimal growing conditions)	-Never apply to frozen ground -Ideally wait until complete greening, but strategy doesn't fit standard weed and feed products designed for PRE crabgrass control
Mid-late spring	Low to Medium (0.25 to 0.5 lb N/1000 sq ft/ every 30 days of optimal growing conditions)	-excessive levels promote shoots at expense of roots -be aware of average "last frost" dates for the area
Summer	Medium to High (0.5 lb to 1 lb N/1000 sq ft/every 30 days of optimal growing conditions)	-primary season for fertilization, but still wise to avoid applications under severe environmental stress
Late summer to winter dormancy	Low (0.25 to 1 lb N/1000 sq ft/every 30 days of optimal growing conditions)	-maintaining active growth until dormancy promotes late season rooting and carbohydrate storage but N applications terminated prior to first frost date

Runoff losses from established turfgrass

A dense turf is a strong deterrent to runoff. Linde and Watschke (1997) reported no detectable sediment in approximately 83% of 237 runoff samples from creeping bentgrass and perennial ryegrass turf. Even under worst-case conditions where fertilizer was applied to turf but not watered-in and a major storm event or simulated event occurred within a few hours of application, the amount of fertilizer N and P lost to runoff was generally less than 10% of applied and, more often, only 2-4% of applied (Walker and Branham, 1992). Runoff N losses in cool-season turfgrasses has been reported as minimal (Gross et al., 1990; Morton et al., 1988). Similar results were reported for a St. Augustinegrass lawn on a 10% slope (Erickson et al., 2001). Responsibly managed turfgrasses have generally been observed to have little N leaching and/or runoff potential (Gross et al., 1990; Miltner et al., 1996). Henry et al. (2002) detail that if fertilizer is applied directly to turf, there is very little chance of unintended environmental consequences, but if it ends up on impervious surfaces it is potentially a major source of water pollution since it can enter stormwater drains.

In a comparison of a mixed-species landscape and a St. Augustinegrass turf on a medium-textured sand soil in FL, the turfgrass system had a 10x reduction in N leaching even though it received 2x greater seasonal N levels (Erickson et al., 2001). A muck-grown St. Augustinegrass sod had significantly less nitrate and phosphate leaching than a sand-based sod during establishment, with the potential reductions in leaching being increased by delaying the initial fertilization until 30 days after installation (Erickson et al., 2010). Bell and Koh (2009) reported that under normal rainfall conditions a bermudagrass golf course fairway in OK lost 0.5% N and 2% P in surface runoff, and under record rainfall conditions, the loss was 1.3% of applied N and 7.7% P. Bermudagrass buffers of various widths and clipping heights were highly effective in reducing nutrient and pesticide movement, with the primary effect being dilution of the chemical applied (Cole et al., 1997). Further research demonstrated that employing graduated buffers (maintaining strips of turf at increasing cutting heights as they approach water's edge) resulted in 17% less N, 11% less P, and 19% less runoff volume during 60 min of natural rainfall runoff (Moss et al., 2005). The graduated buffer resulted in 18% less N and 14% less P during 60 min of irrigation runoff, and reduced runoff volume by 16% for simulated bermudagrass golf fairways.

Lawn clippings management

In addition to direct runoff from fertilizer applied N and P, mis-management of lawn clipping can also have significant effects on nutrient runoff levels. Research in MN indicated that clipping management (recycled to the turf or collected) was not an important factor for P runoff, indicating that returning clippings to the turf canopy does not significantly increase P runoff (Bierman et al., 2009). However, clippings that are deposited on hardscapes (impervious surfaces) that are washed into stormwater drainage do pose significant risk. Shapiro and Pfannkuch (1973) concluded that street sweeping to remove organic debris would reduce P loading of urban lakes from stormwater, but that removal of P from lawn fertilizers would "not materially reduce concentrations of P in runoff ". Waschbusch et al. (1999) reported that lawns and streets were responsible for most of the P transported to the lakes in runoff and that home lawns were the largest single source of both total and dissolved P and at least 25% of the Total-P was associated with vegetative material. Oak leaves have also been reported (Dorney, 1986) to contribute significant P to urban runoff waters. Once in stormwater basins or other deposition zones, lawn clippings and other vegetation can release substantial amounts of their total N and P content to the water column (Strynchuk et al., 1999) within 30 days.

Importance of soil testing and balanced nutrition

Nitrogen and P solubility, availability and plant uptake are strongly controlled by soil pH. Similarly, the viability of the soil microbial biomass that is critical to N and P transformations over time is also highly pH dependent. Therefore, any effective nutrient management program needs to ensure that the soil pH is within the adequate range for the managed vegetation. For turf, this range is typically between pH 6.0 and 7.5, but it may be lower (e.g. 5.0 to 6.0) for certain acid-adapted grasses and native trees. It is therefore critically important that fertilizers only be applied to soils within the appropriate pH range to ensure adequate plant and soil microbial uptake to limit runoff and leaching loss potentials.

Summary and Synthesis

It is clear from our review of the scientific literature and our personal research experience that implementation of a wide range of fertilizer management practices and/or policies could significantly reduce total stormwater runoff of both N and P. However, there are very few published and publically available studies that actually measure the extent and timing of those reductions. The most optimistic estimate would be up to a 25% reduction within the first year with an expectation of continued reductions over time, particularly for total P. However, we also feel it is quite possible that even greater short- and long-term reductions in runoff N and P would be achievable if a combination of the practices described below were fully implemented.

The collective scientific literature on N-fertilizer application and management in intensively managed urban turfgrass systems clearly indicates that by carefully restricting application rates (e.g. no more than 1 1b/1000 ft^2 of soluble N at least 30 days apart for cool season grasses), that N runoff losses will be quite minimal. Certainly, intensive N fertilizer management as described herein will be superior to more infrequent and heavier applications (e.g. one time in the fall) which are common. However, this more intensive management approach will require two or more split applications per season for optimum turf management. Similarly, appropriate use of slow-release N fertilizers or carefully prescribed rates of labeled organic-N sources would also significantly reduce the risk of N runoff losses. However, slow release sources (e.g. polymer/sulfur coated urea) are two the three times as expensive per pound of N applied when compared with conventional soluble granular urea. Labeled organic sources of N can be 4 to 5 times as expensive per pound of N applied.

It is also clear that restricting P-fertilizer applications to urban soils to correspond to actual plant needs (via soil testing) is the most effective way to reduce P-runoff losses over time. However, limiting long-term P release from soils that have received repeated and excessive fertilizer applications will be challenging. For example, an urban soil that contains 100 ppm (mg/kg) of soil-test P contains 200 lbs per acre of P in relatively bioavailable forms in the upper six inches of soil. That P is readily available for plant uptake and deposition in clippings and a considerable portion will be available for desorption into runoff waters over time. Thus, it may take many years for runoff loadings from these high P soils to decline significantly.

Collectively, we believe that the single most important factor or practice for reducing short-term nutrient runoff would be to limit or prevent application of fertilizers directly onto sidewalks, driveways and other impervious surfaces. This can be readily accomplished by use of drop spreaders or liquid spray fertigation equipment rather than conventional spin/rotary spreaders. Unfortunately, this latter type (spin/rotary) is the most commonly employed by homeowners and readily broadcasts fertilizers several feet beyond the turf and onto adjacent impervious areas. However, this type of fertilizer can be moved back onto targeted areas and off the impervious surface by using leaf blowers. Similarly, lawn clipping and other vegetative wastes should be carefully controlled, removed from impervious surfaces, and not allowed to accumulate on turf edges or in low spots where they can readily be entrained into runoff following storm events.

In context, however, it is essential to point out that both N and P fertilization are required for establishment of new vegetation on construction sites and in newly prepared and landscaped areas. Similarly, adequate soil N and P must be available to sustain desired turf and landscape plantings over time and appropriate applications should be made to N- and P-deficient soils where those limitations are clearly apparent and documented.

Loss of sediment-bound N and P will be negligible from established and well-managed home lawns and landscapes. However, where site development and construction removes established vegetation and litter layers, the highest risk is clearly associated with previously P-enriched topsoil layers. These materials should be carefully segregated and protected on-site, seeded to a temporary vegetative cover, and surrounded by silt fences, compost berms or other appropriate sediment control BMPs. While exposed subsoil materials (typically Fe and clay-rich B and C horizons) may pose a significant short-term site specific risk for sediment loss, their effect on nutrient levels in runoff is negligible.

With respect to various management practices and regulatory control measures discussed earlier in this paper, we have the following conclusions and suggestions. First of all, we **do not** support an across-the-board ban on all N and P fertilizer applications (**Option A**) for the simple reason that we simply cannot establish and maintain healthy vegetation to control soil erosion and filter sediment out of overland flow/runoff without adequate plant-available N and P. Thus, adequate (but limited) applications of N and P must be allowed for new seedings on construction and redevelopment sites and for areas where the soil/vegetation system is clearly nutrient deficient. **Option B** (*Ban on P except for new seedings or critical areas; slow-release N formulations only*) would be the most readily applicable option for individual home lawns that are not serviced by commercial lawn care providers and/or certified applicators. This option assumes that previous P fertilization to established lawns has led to significant soil P enrichment, but would allow limited P applications to new seedings or turf renovation where supported by site-specific and current soil testing. The minimum SAN content (see page 18) of commercially available fertilizers would need to be specified in order for Option B to be implemented and the added cost per pound of N applied may affect homeowner acceptance. A slightly less restrictive policy (**Option C**) would require that all P-fertilizer applications be based on a current soil test to limit P applications to actual plant needs. This would also ensure that soil pH is adequate to maximize plant/ microbial P-uptake. When coupled with strict one-time and annual N loading limits, this option closely resembles current intensive turf management practices as specified by Virginia DCR for areas under Nutrient Management Plan restrictions.

Secondly, we strongly believe that policies that restrict or prevent the application of fertilizers onto impervious services and mandate the removal and safe disposal of grass clippings and other vegetative materials are warranted and could potentially have the greatest impact on short-term nutrient runoff levels for both N and P **(Option D).** Furthermore, as discussed above, we strongly believe that all P applications to urban lawns and landscapes should be based on soil test recommendations and that all N applications should be limited in both total annual and one-time application amounts as described above. Use of slow-release N fertilizers and properly analyzed and labeled organic nutrient sources should be encouraged and integrated into intensive soil/plant nutrient management systems where available and appropriate **(Options B and E).** However, both of these options would require the use of more expensive N and P fertilizers and greatly increased management inputs.

Widespread implementation of these recommendations would clearly be daunting for the general public, but readily accepted by lawn care professionals and the commercial landscaping industry. Where nutrients are being applied by commercial entities, newly enacted Virginia legislation (regulated by VDACS; 2008) will greatly assist in implementation (**Option F**) but these provisions currently do not apply to homeowners and other non-commercial nutrient applicators. In order to control and optimize nutrient management by individual citizens on their own property, a system whereby fertilizer sales are limited by soil testing documentation would be required along with some independent measure or homeowner certification of actual size of lawns or fertilized areas. Clearly, we would expect resistance by homeowners to these restrictions.

<u>Overall Conclusions</u>

Taking all potential options into account, we believe that a combination of **Options B, D and F** would be the most effective for both short- and long-term reductions in N and P loadings to stormwater runoff from individual home lawns and landscaped areas. Alternatively, where fertilizers are applied by commercial entities or certified individual applicators, the prescriptions laid out in **Option C** should be rigorously followed. Implemented together, these combined practices would (1) limit P applications in all settings to those prescribed by a current and valid soil test and (2) strictly limit total annual and one-time N application rates. Concurrently, (3) local policies should be established to ensure that fertilizers and clippings are not allowed to be applied and/or retained on impervious surfaces. Finally, where required and necessary, (4) fertilizers should be prescribed and managed by certified applicators.

There are very few studies currently available that directly measure the effects of reduced or limited N and P fertilization practices on runoff nutrient loadings. Several available studies indicate a potential 25 to 50% reduction in total-P loading to stormwater within several years following implementation of P-fertilizer bans or stringent soil-test based limitations. The scientific literature also indicates that intensive N management can minimize or largely eliminate direct runoff losses from turfgrass; thus, we would also expect significant reductions of 10 to 20% in total N loadings to stormwater. However, these predictions are based on a very small set of published (and largely non-refereed) studies. Catchment-specific runoff studies and monitoring would be required to validate and confirm the response of actual N and P runoff loadings to actual changes in application rates and management practices.

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