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Urban Water Quality and Fertilizer Ordinances: Avoiding Unintended Consequences: A Review of the Scientific Literature[1]

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Summary

Degraded inland urban and coastal water quality is a critical concern in Florida. Nutrients released from urban land-based human activities (disturbed soil, fertilizer, pet wastes, plant debris, atmospheric deposition, septic systems, and others) are present in water bodies, resulting in eutrophication and an increase in algal blooms that impair water quality. There are many scientific publications that document the nature and scope of the water pollution problem. There are differing approaches to addressing eutrophication, including adoption of current best management practices (BMPs) for nutrients, state regulation, or local ordinances. The local ordinance, sometimes including a summer fertilizer ban, has been the chosen approach by several Florida counties and municipalities to address local water quality issues. Many components of these ordinances follow published BMPs. There is agreement in the national literature on the effectiveness of BMPs and public education programs to reduce local water quality problems. However, there has been disagreement among stakeholders over the inclusion of a summer fertilizer ban in an ordinance. Other states do not use summer fertilizer bans, rather they use BMPs to reduce the risks for nutrient losses from landscapes. There are numerous research reports that provide information about proper management of nutrients and irrigation throughout the year, especially in the summer, to optimize the benefits of turf in the landscape while protecting the environment. This paper provides a literature review of the critical eutrophication problem and the pertinent literature regarding managing urban landscapes to improve water quality with particular attention to N and P fertilization during the active plant growth period corresponding to summer fertilizer bans.

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Reasons for this publication

This publication was developed to serve the need for educational information on the urban landscape nutrient and water management issues, especially pertaining to protecting urban and coastal water quality. Eutrophication of water bodies is a major problem faced by the state, counties, and municipalities; their officials are asking for more information to assist them in making decisions about legislation for protecting water quality. Educators, county extension agents, representatives of non-governmental organizations, and leaders of the fertilizer, turf, nursery, and landscape maintenance industries also are asking IFAS for information about how to best protect the environment. This document is a review of the scientific literature addressing the major questions being asked about fertilization practices for turfgrass.

This document consists of three major sections. The first section reviews the science about the eutrophication problem for urban and coastal water bodies, and the sources of nutrients that lead to water pollution. The second section of the document presents the current state of the scientific knowledge about fertilizer and irrigation management in urban landscapes with emphasis on turfgrass health and water quality. The final section summarizes some of the approaches that are being used in the United States to deal with the nutrient problem. There are regulatory and incentive-based programs that include BMPs, educational programs, and rules that restrict fertilization. Our goal is to take the reader through the process: learning about the pollution issue, the sources of pollutants, management of nutrients in the urban landscape, and the most effective approaches being undertaken to reduce the nutrient loading problem.

Section 1. Introduction to the Issue of Urban Nutrient Pollution

Eutrophication or nutrient enrichment of fresh and coastal waters is a serious and growing concern (Diaz and Rosenberg, 2008; Heisler et al., 2008). Eutrophication is largely the result of human activities in managing land, energy, plants, nutrients, and wastes (Selman and Greenhalgh, 2009). Human impact on the land is increasing. For example, in the United States, during the decade of 1982–1992, there were 1.4 million acres converted to urban development, and there were 2.2 million acres converted during the 5-year period of 1992–1997 (USDA, NRCS, 2005). It is well documented that urbanization changes land cover and hydrology and leads to "unintended consequences" on urban ecosystems that include altered nutrient flows (Roach et al., 2008).

Human influences lead to point and non-point source nutrient pollution of water bodies causing degradation or impairment of the water bodies for their intended uses, such as recreation, fishing, drinking water, irrigation, etc. Nitrogen (N) and phosphate (P) are often involved in eutrophication because these are two limiting nutrients for algal growth in most natural water bodies. Earlier research reports therefore focused on N or P, but Paerl (2009) pointed out that today N and P must be managed together to control eutrophication in the freshwater-marine water system.

Cleanup of impaired water bodies is required under the total maximum daily load (TMDL) program (US, EPA, 2010; FDEP 2009a), which places severe economic burdens on local governments (Baker, 2007). In addition to the costs to local governments, harmful algal blooms were determined to result in significant revenue losses for local businesses on the panhandle of Florida, even more than other environmental events such as tropical storms and rains (Larkin and Adams, 2007). Nutrient enrichment of Florida waters is a serious and costly issue and must be addressed in an informed and comprehensive process. Before a comprehensive nutrient management process can be determined, however, we must understand the various sources of nutrients causing the problems in urban water bodies.

Urban land-based nutrient sources and impacts

Research has pointed to many sources of nutrients contributing to increased nutrient loads and eutrophication of surface waters throughout the world (Alcock, 2007; Baker, 2007; Gilbert et al., 2005; Heisler et al., 2008). Impairment of urban water bodies in Florida includes increases in algal growth, including those algae that produce toxins that can potentially harm aquatic wildlife and humans (Anderson, 2002; Paerl et al., 2010). The following information summarizes the many and varied sources of nutrients that should be of concern in any approach addressing the overall urban water quality problem.

Sewage-based nutrients. Water bodies can receive nutrients from several sewage sources including water treatment plant discharges and on-site septic systems. Land-based sewage sources were implicated in algal blooms off the southeast coast of Florida (Lapointe et al., 2005). Paerl et al. (2010) found that cyanobacteria (one of the bacteria associated with red tide) responds to iron, N and P from sewage outfalls, urban wastewater, urban development runoff, and nutrients from groundwater. Lapointe et al. (2006), determined that large algal blooms of *Microcystis aeruginosa* in the Caloosahatchee estuary in 2005 were likely related to sewage effluent as were red tide blooms off Sanibel Island in 2004. There are examples where the removal of sewage-based nutrient sources was related to a subsequent reduction in algal blooms (Anderson et al., 2002).

Land-based N and P discharges. Nutrients from a mixture of sources can enter the water stream moving off of land toward a water body. N discharges from Lake Okeechobee and the Caloosahatchee River following hurricanes of 2004/2005 were implicated in algal blooms in southwest Florida. Nutrient flux from bays, harbors, and rivers along the west coast of Florida can provide significant amounts of nutrients to support high-biomass blooms of red tide, *Karenia brevis* (Vargo et al., 2008). Land-based N and P sources vary from location to location, and this variability leads to a gradient of P- and N-limited phytoplankton communities (Heil et al., 2007). Although the ultimate source of nutrient enrichment may be land-based, there can be considerable cycling, transport, and mineralization of N and P from phytoplankton, and these cycled quantities can be greater than external loadings (Wang et al., 1999). These authors suggested that, while nutrient load reductions are needed at the source, time will be required before observing impacts of those reductions because cycling of already imported nutrients plays a role in algal blooms. Further, some algal species can fix nitrogen from the atmosphere, adding another level of complexity to the nutrient source picture (Havens, 2004). Finally, the impacts of eutrophication differ depending on the algal species (Anderson et al., 2002).

Distant sources. While nearby land-based sources are important, studies have also implicated long-distance transported nutrients in Florida red tides. For example, depositions of Saharan dust, containing iron, could relieve iron deficiency of certain aquatic organisms (Walsh and Steidinger, 2001). Stumpf et al., (2008) used thermal and ocean color satellite data to suggest the possible importance of nutrients from the Mississippi River that travel in a plume to the west Florida shelf, 30 to 50 miles from the coast. The connectivity of the water bodies makes it difficult to clearly distinguish among the many and varied sources of nutrients at any single locale.

Industrial emissions (e.g., smoke) and fossil fuel combustion (e.g., automobiles) adds N oxides to the air, which can be later deposited onto land or water bodies during rainfalls. For example, the Tampa Bay Estuary Program predicted in 1996 that as much as 33% of nutrients in Tampa Bay by 2010 would result from atmospheric deposition (Zarbock et al., 1996). An updated report (Janicki et al., 2001), using the methods of Zarbock et al. (1996) predicted that for 2010 conditions, atmospheric deposition would be 20% and non-point contributions of N to Tampa Bay would be 49%. The total annual N load predicted for 2010 in the latter report was 2950 tons, down from the predicted value of 3670 tons in the Zarbock et al. (1996) report. Predicted total quantities of non-point N losses in both estimates were similar. The percent loads due to non-point sources increased because material losses and atmospheric deposition were predicted to be lower in the later model. A planning and management document from the Tampa Bay Estuary Program concluded that the two largest contributors of nutrients to Tampa Bay were atmospheric deposition and storm water runoff (Tampa Bay Estuary Program, 2006).

Fertilizers. Fertilizer has been a common input for managing healthy urban turfgrass and landscape

plants and gardens. Amounts of fertilizers sold and used in non-farm areas in Florida (nurseries, golf courses, athletic fields, roadsides, airfields, cemeteries, parks, and retail establishments) have declined over recent years (FDACS, 2009). For example, N use increased from 2000 to 2004, but it declined from 2004 to 2008. In 2005, the non-farm use of N fertilizer was 69,522 tons, but it declined to 36,074 tons in 2008, a 48% reduction in urban fertilizer use. The non-farm use of P fertilizer declined from 14,168 tons in 2005 to 8,034 tons in 2008--
http://www.flaes.org/complimonitoring/past_fertilizer_reports.html. Although the recent negative economy may have influenced this trend toward the latter part of the period, this overall reduction in fertilizer use is significant in light of fertilizer limitations imposed by passage of the Urban Turf Fertilizer Rule in Florida and the potential positive environmental implications from adoption and training about BMPs.

Fertilizers are used in urban landscapes to increase the ability of plants to provide aesthetic, recreational, and functional benefits for residential homes, businesses, and common areas. Research has been conducted in most states to determine the most appropriate amounts, sources, and time-of-application of fertilizers for many landscape plants, especially turf. For example, fertilizer BMPs for Florida can be found at http://edis.ifas.ufl.edu, and the UF/IFAS Florida-Friendly Landscaping™ Program (http://fyn.ifas.ufl.edu/). Selected examples of Florida Extension publications dealing with turf and landscape plants include Sartain (2007) and Knox et al. (2002). Best management practices have been developed in many states including Florida (FDEP, 2008; FDEP, 2009a) to help homeowners minimize the chances that nutrients will be lost from the urban landscape at times when the root system is not actively growing.

Research shows that fertilizer-derived nutrients can be lost from the urban landscape under certain circumstances. Losses are most likely when fertilizer is applied just before or during heavy rainfall (Soldat and Petrovic, 2008), when fertilizer is applied before the turf root system is established (Erickson et al., 2010; Trenholm et al., 2011), or when fertilizer is applied in excess of research-based recommendations (Trenholm et al., 2011). Studies in Florida using isotopes have documented the presence of fertilizer-derived nutrients in water bodies (Jones et al., 1996; Pinellas County DEP, 2004; TBEP, 2008a; 2008b). While these studies show fertilizer is being found in urban water bodies, they do not conclude whether the nutrients were lost predominantly from landscapes fertilized properly according to BMPs or from improperly fertilized landscapes.

Animal wastes. The U.S. Environmental Protection Agency (2009) has stated that "Decaying pet waste consumes oxygen and sometimes releases ammonia. Low oxygen levels and ammonia can damage the health of fish and other aquatic life. Pet waste carries bacteria, viruses, and parasites that can threaten the health of humans and wildlife. Pet waste also contains nutrients that promote weed and algae growth (eutrophication)." A 45-pound dog can excrete approximately 9 pounds of N and 2 pounds of P per year, while a human produces 13 pounds of N and 1.5 pounds of P (Baker, 2007). Most of the pet N would be in urine and the P in the solids so that "pooper scooper" ordinances can be effective in P control but less so for N (Wood et al., 2004). Groffman and colleagues (2004) suggested that approximately 15 lb/acre/year of N could be added to the Glyndon (Baltimore, Maryland) watershed from pet waste.

Plant litter and debris. In urban communities, nutrients can come from the native and introduced landscape plants, such as tree leaf fall and grass clippings (Cowen et al., 1973; Dorney, 1986; Strynchuk et al., 2004). From a time-series analysis of decomposition of leaf and grass clippings in Brevard County, Florida, Strymchuck et al. (2004) determined that quick removal of street organic debris is needed to avoid the rapid impacts of pollutants from the debris on water quality. Leaf litter in Milwaukee, Wisconsin, was determined to be a major source of P and the amount of leachable P per whole leaf varied by tree species, but not by tree diameter (Dorney, 1986). Up to 9% of the total leaf-P could be leached from leaves in 2 hours. In an early paper on leaf-P, Cowen et al. (1973) calculated concentrations of P in oak and poplar leaves in Madison, Wisconsin. Leaves that were in the literal zone of Lake Mendota had less P than leaves collected from the ground surface near the shore. In heavily canopied communities, leaves can be greater sources of P than lawns (Baker, 2007).

These studies on the subject of nutrients from plant debris point to two conclusions: First, there is considerable potential nutrient load from plant debris in the urban environment that can add significant amounts of nutrients to the storm water. Second, plant debris should be removed from impervious surfaces (street sweeping, blowing) or mulched and put back into the lawn with mulching mowers as soon as possible because water (rain) can easily and rapidly extract nutrients from the leaf debris.

Urban watersheds. In a Baltimore, Maryland study, Groffman et al. (2004) measured increased nitrate losses from urban and suburban watersheds (approx. 2 to 7 lb per acre per year of N) compared with a forested watershed (less than 1 lb per acre per year of N). These researchers also noted high retention (75%) of N inputs in the urban watersheds mostly consisting of fertilizer and atmospheric deposition. In other studies of urban turf and forested landscapes in Baltimore, researchers noted that grasslands exported more N than forests, but the urban grasslands (turf) had significant ability to retain N (Groffman et al., 2009). The authors found that, in some instances, unfertilized urban turfgrass lands had more leaching losses than fertilized grasslands. The authors emphasized that changing from agricultural land to urban grasslands would have N-load benefit for reducing N losses to the Chesapeake Bay watershed. In a study of urbanization impacts on water quality in small coastal watersheds, Tuffurd et al. (2003) found that dissolved organic nitrogen (DON) and P-containing particulates were the dominant sources of these nutrients and there was variation in location and season. For instance, in the summer, DON from forested wetland creeks and P from urban ponds dominated. These authors concluded that broad land-use or land cover classes should not be used to predict nutrient concentrations in streams of small watersheds. Baker et al. (2001) calculated an N balance for the central Arizona-Phoenix ecosystem. They determined that humans controlled as much as 88% of the N inputs; half of the total N was imported by humans as food and fertilizer. Another third of the N came in as combustion products. 20% of the N accumulated in the watershed and the main avenue for N loss was atmospheric with only 3% of the N leaving in the surface water. The Arizona study identified several topics in need of research including dry deposition processes, soil N dynamics, and denitrification losses.

Take-home message for nutrient sources and impacts

The brief literature review above clearly documents the complexity of eutrophication of inland and coastal water bodies. Land-based nutrient (N and P) sources are important in the nutrient loads to the water bodies, and there are many distinct nutrient sources. These sources undergo changes and interact with the environment in route to a water body. Once in the water body nutrients play a role in complex nutrient cycling that maintains nutrients in forms suitable for algal growth. Controlling nutrients at the source is a sound approach to reducing nutrient loading to water bodies, but nutrient sources and fates are complex processes (Alcock, 2007). Due to the myriad of sources and their complex interactions, source reduction requires a comprehensive and careful approach.

Section 2. Relationship of lawn fertilization to leaching and runoff from landscapes

In this section we examine several important issues relative to fertilization, leaching, rainfall, irrigation, soil, and runoff. We present the information from national research studies on several questions:

- What role does healthy turfgrass play in the urban environment? Will unhealthy turfgrass lead to increased nutrient losses and when?

- How might various urban soil types and qualities impact the effectiveness of landscape fertilizer management?

- How might rainfall patterns and amounts affect fertilizer nutrient leaching and runoff before, during, or after the summer growth period?

- What role does irrigation management play in the leaching and runoff of nutrients?
- What role does reclaimed water play in nutrient runoff and leaching before, during, and after the summer growth period?

Issue #1. What role does healthy turfgrass play in the urban environment? Will unhealthy turfgrass lead to increased nutrient losses and when?

Published books (Beard and Green, 1994; Beard and Kenna, 2008; Nett et al., 2008) have summarized the research literature on turfgrass systems and their care with attention to environmental impacts. Turfgrass benefits (Beard and Green, 1994) can be grouped into *functional* (e.g., preventing erosion, preventing weeds), *recreational* (sports fields), and *aesthetic* (beauty and value-added homes and properties). Healthy turfgrass systems absorb the majority of nutrients when applied at recommended rates, thus minimizing leaching and runoff from landscape surfaces (Brown et al., 1977; Easton and Petrovic, 2004; Frank 2008; Hull and Liu, 2005; Shuman, 2001). Eighty to 90% of N was assimilated in the transition fall and spring months for Bermuda turfgrass in North Carolina (Wherley et al., 2009). The following description of healthy turfgrass that meets its many roles in the landscape is summarized from these citations above. *Healthy turfgrass* means turfgrass that maintains a complete and dense cover over the soil to reduce erosion and weed growth. Healthy turfgrass has an expansive root system that fills the soil and absorbs nutrients and water. Healthy turfgrass is reflected in the medium-green color that is desired for aesthetic purposes and to add value to the home and community. Healthy turfgrass consists of strong plants that stand up to the wear and tear of athletic use.

Scientific data shows that healthy turfgrass has a positive impact on the environment by reducing leaching and runoff. Petrovic and Easton (2005), reviewed the literature on the relationship of healthy turfgrass and urban water quality. Numerous, research studies show that turfgrass has a lower impact on groundwater N levels than other land uses. Raciti et al. (2008) outlined N flows in an urban environment where lawns, under low to moderate management, can be nutrient sinks rather than sources. These authors found high retention of atmospheric N in the soil organic matter pools of urban lawns.

Beard and Green (1994) have described the functional and nonfunctional benefits of properly maintained lawns and landscapes to be:

- excellent soil erosion control and dust stabilization,
- improved recharge and quality protection of groundwater,
- enhanced entrapment and biodegradation of synthetic and organic compounds,
- soil quality improvement that includes CO_2 conversion,
- accelerated restoration of disturbed soils,
- substantial heat reduction,
- reduced noise, glare, and visual pollution problems,
- decreased noxious weed pests and allergy-related pollens,
- safety in vehicle operation on roadsides and engine longevity on airfields,
- lowered fire hazard via open, green-grassed firebreaks,
- improved security of sensitive installations provided by high-visibility zones.
- low-cost surface for outdoor sport and leisure activities,
- enhanced physical health for participants, and a low-cost cushion against personal injuries.
- enhanced beauty and attractiveness;
- a complementary relationship to the total landscape ecosystem of flowers, shrubs and trees;

- improved mental health with a positive therapeutic impact, social harmony and stability;
- improved work productivity;
- and an overall better quality of life, especially in densely populated urban areas.

Studies demonstrating the importance of healthy turfgrass for controlling nutrient losses from lawns

The literature on the fate and transport of P in turfgrass systems was reviewed by Soldat and Petrovic (2008). They found that soil properties had great impacts on P runoff, sometimes more than plant growth. Greatest P runoff and leaching occurred when P was applied close to heavy rainfall. P inputs slightly exceeded the P uptake in grass clippings. Rate, timing, and source for P fertilization were critical factors for P losses. In an early review of the fate of N in turfgrass systems, Petrovic (1990) analyzed the literature on N uptake, leaching, runoff, atmospheric losses (volatilization and denitrification), and immobilization. The research showed that proper fertilizer management was important for minimizing impacts to the environment. These strategies would include proper irrigation management, using slow-release fertilizers (at least 15% slow-release fertilizer), and modifying sandy soils for better nutrient and water-holding capacities.

Several of the environmental benefits have been addressed in research from various sites around the country and in Florida. In a study in Minnesota with Kentucky bluegrass, zero, low, and high P (and a zero control) fertilization programs were imposed during the year (Bierman et al., 2010). The researchers measured runoff volume and P loads moving off the research site plots. Where N and K were supplied (better growth), P in the runoff increased as the P rate increased. P runoff from the unfertilized plots (no N and K and lower growth) was greater than from fertilized turf. The researchers attributed the increased P runoff to poorer growth of the turfgrass in the unfertilized plots. P runoff was greater when P was applied in the fall, when plant growth slows and plants enter dormancy. These researchers concluded that P should not be applied in the fall or when soils already are high in P content, and that P runoff was reduced in healthy, fertilized (N and K) turf. Authors of the Minnesota study noted their results were consistent with other studies showing runoff was reduced by dense turf (Easton and Petrovic, 2002; Gross et al., 1990; 1991).

The same result has been found for Florida. Properly maintained lawns include attention to proper fertilization. For example, there are times when fertilization should not be practiced. Phosphorus fertilization is not needed when the soil already is high in P content as determined by a soil test (Sartain, 2007).

In a 6-year study in Wisconsin, Kussow (2008) evaluated management practices that affect N and P losses from upper Midwest lawns. Annual nitrate-N leachate concentrations were typically between 2 and 4 ppm and the quantity of N leached was about 3 pounds per acre, which is intermediate between losses from agricultural and natural areas in the upper Midwest. The most important factor for increasing runoff loss of N and P was runoff depth. Next in importance was failure to fertilize.

Leaching and runoff will increase as fertilizer rates are increased above the rates recommended by UF/IFAS and established in the Florida Department of Agriculture and Consumer Services (FDACS) Fertilizer Rule (Trenholm et al., 2011). However, even though leaching of N increased with fertilizer rates above those recommended, the total mass leached was minimal in studies with healthy St. Augustinegrass. Fertilization practices must maintain strong photosynthetic activity and movement of metabolites from the leaves to roots, thus maintaining an actively growing root system for maximum nutrient absorption.

The most active growth period for warm-season grasses is during the long, warm days of late spring and summer (Figure 1). This is the time of greatest growth and nutrient requirements for these grasses. Bermuda grass captured more N during the active growing season (Wherley et al., 2009) and large amounts of N also were captured in a summer Kentucky bluegrass system (Frank, 2008).

Leached N averaged 0.23% of the total N applied over two years for Kentucky bluegrass (Miltner et al., 1996). Total recovery of N was 64 and 81% for Spring and Fall, pointing to potential gaseous losses of N. Research shows that the active growth period is the time when the grasses have the greatest ability to take up nutrients, due to larger, denser, and more actively growing root and shoot systems. Following recommended fertilization practices helps maintain healthy turfgrass with a strong, expansive root system to absorb nutrients, especially during periods of active growth in the summer. Recommended fertilization rates lead to dense turf growth that prevents erosion and slows overland transport of water and nutrients (Easton and Petrovic, 2004). Nitrate leaching was three times greater from turfgrass that had been killed than when Kentucky bluegrass turfgrass was living (Jiang et al., 2000). The latter authors stressed the importance of living turf roots in stabilizing nitrate-N in the turf-soil ecosystem.

Root biomass of warm-season grasses declines in the fall (Figure 2). Bushoven and Hull (2001) showed that the nitrate assimilative capacity of roots correlates with greater dry matter allocation to root mass by the whole plant. This greater nitrate assimilative capacity was correlated with increased N uptake efficiency in one of the two grass species studied. Bermudagrass roots were more competitive than the soil microbial population for assimilating nutrients (Wherley et al., 2009). Grass (annual bluegrass and bentgrass) with greater above-ground biomass also had greater root biomass that, in turn, led to more N uptake (Pare et al., 2006). Bowman et al. (1998) showed that deep-rooted turf resulted in less nitrate-N leaching losses than a shallow-rooted turf. Nitrogen uptake efficiency was greater with increased amounts of finer, fibrous roots, while amounts of thick roots had little impact on N uptake rate (Sullivan et al., 2000). Increased rhizome length had a negative relationship with N uptake efficiency. These studies showed that management practices that lead to better root development, especially deeper root expansion and more fibrous roots can be important in controlling fertilizer N leaching.

Management of turf clippings is important for N management in the turfgrass system. Turfgrass clippings are a large repository of assimilated N and P. Turf scientists recommend returning grass clippings to the lawn so the nutrients can be recycled. Fertilizer N was rapidly converted to non-mineral forms within 3 weeks of application and the loss of N was mostly due to volatilization and denitrification (Starr and DeRoo, 1981). Fertilizer N, accounted for by direct measurement, was 76% where clippings were returned and 64% where clippings were not returned. Clippings management affected N fertilization, turf growth, and quality in a study in Connecticut by Kopp and Guillard (2002). These scientists found that returning grass clippings did not decrease turf quality, but did result in an increase in N uptake and recovery. These research reports show that returning clippings to the lawn is an important aspect of good N and P management in the turfgrass system.

Fertilizers can be supplied in soluble (fast) or slow- or controlled-release forms. Controlled-release fertilizers have been shown to be effective for producing healthy turfgrass (Sartain, 1981; 2008; Petrovic, 1990) and reducing the potential for nutrient losses (Saha et al., 2007; Snyder et al., 1984) from lawn grasses. Similarly, research also shows that properly managed soluble N sources can result in low leaching losses. This result was observed by Sartain (2008) and Quiroga-Garza et al. (2001). The latter authors found that highly insoluble N sources reduced N leaching losses but had negative impacts on turf growth and health. These authors, however, pointed out that a trade-off between turf color and N leaching may be important, i. e., lighter green turf color is associated with reduced N leaching losses, which may be an important consideration in the turfgrass system. They determined that proper N fertilization and irrigation practices, even with soluble N sources, can avoid risks of N leaching losses. These latter two conclusions suggest the importance of a rigorous homeowner education program about fertilizer sources and application in the overall management of fertilizer in the urban environment.

UF/IFAS research showed that leaching was negligible during the summer months from St. Augustinegrass grown with a commercial fertilizer containing 62% soluble/38% controlled-release N at a 1.0 lb N/1000 sq. ft. rate (Erickson et al., 2001). The current (2011) N recommendations for turf limit a single application to 1.0 lb per 1000 sq ft. of N under the FDACS' Fertilizer Rule (FDACS, 2007). Therefore, under a summer fertilizer ban the turfgrass manager will be limited to this 1.0 lb application for the entire 4-month summer growing period. Studies are underway to determine if there are fertilizer materials that will maintain healthy turf for this 4-month period when applied at the recommended rate at the beginning of the period.

shows that leaching was dependent on fertilizer rates and turfgrass type (Trenholm et al., 2011). Leaching was greater from zoysiagrass than from St. Augustinegrass (Trenholm et al., 2011). Similar results for these two species were found in a North Carolina study by Bowman et al. (2002), and leaching was greater just after planting than after the establishment phase. In well-established and maintained St. Augustinegrass turf, inorganic N leaching was lower with concentrations of NH_4-N and NO_3-N in drainage generally less than that reported for rain water in southern Florida. This experiment was conducted over a three-year period encompassing wet and dry season cycles that bracket proposed black-out periods when the turf was fertilized at 1 lb N/1000 sq. ft. bimonthly with a 62%/38% soluble/controlled-release commercially available fertilizer (Erickson et al., 2008).

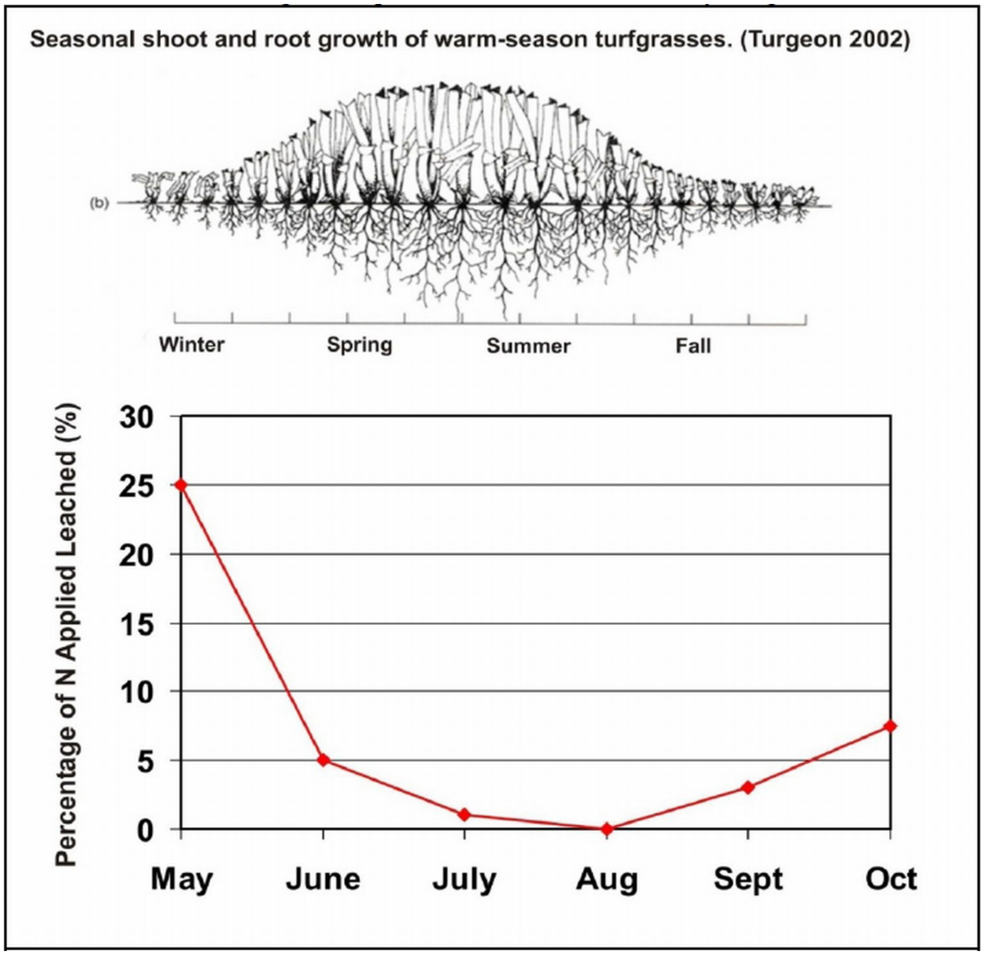

Figure 1. Diagrammatic (textbook) presentation of growth of warm-season turfgrass (top drawing) and actual N leaching during season (bottom figure-after Sartain, 2010).

The UF/IFAS Extension fertilizer recommendations for turfgrass, summarized by Sartain (2007), emphasize applications of slow-release (controlled-release) N in the summer. The use of controlled-release fertilizer in the summer helps minimize the losses of N because only very small amounts of N are released from the fertilizer at any one time (typically based on temperature and moisture). These release schedules are in relationship with the plant growth rate. Recent research in Florida

New research at UF/IFAS (accepted for scientific peer-reviewed publication) has shown that leaching from turfgrass is greater in the spring and fall than in the summer. In a Florida DEP-funded project, Trenholm et al. (2011) found that more fertilizer is lost from fertilizer applications made during the time of year when the turfgrass is not actively growing and that the lowest leaching levels were during the period of active growth (summer) . The following are some results from the multi-year study:

1. As St. Augustinegrass matured after the first establishment year, NO_3-N leaching in the summer was minimal, even at very excessive application rates. No significant correlation with N rate and NO_3-N leaching was found.

2. Zoysiagrass was more prone to leaching at high N rates. Less N was needed for zoysiagrass health and quality than for St. Augustinegrass.

3. Greater disease pressure leads to less healthy turf and more NO_3-N leaching.

4. There was greater NO_3-N leaching in spring and fall.

5. All cultural practices, including fertilization and irrigation, are important to reduce nutrient losses from turfgrass.

6. Even at high application rates imposed in this study, NO_3-N leaching did not exceed 1.3% of the applied N in St. Augustinegrass.

7. Turfgrass quality and health were adequate with the current UF/IFAS fertilizer recommendations.

Effectiveness of healthy turfgrass in preventing soil and nutrient losses by erosion

Erosion in urban landscapes can be a serious problem resulting in loss of topsoil and the associated nutrients. Reducing the velocity of runoff water with dense, healthy turfgrass will increase infiltration and result in groundwater recharge (Blanco-Canqui et al., 2004; 2006; Easton and Petrovic, 2004). Healthy turfgrass captured runoff that contained nutrients and displaced soil from a 10% slope. Capturing the runoff allowed time for nutrient uptake by the turfgrass, reducing the N concentration in the runoff to the concentration in the rain water (Erickson et al., 2001). Bare-soil areas are most prone to soil erosion that carries nutrients with the displaced soil.

Buffer strips consisting of healthy turf grass are used to capture, filter, and reduce nutrient runoff (Cole et al., 1997; Steinke et al., 2007). Buffer strips as small as 2 feet wide have reduced runoff, compared with no buffer strips. Dense turf vegetation reduces runoff by creating "tortuous pathways" that reduce runoff rate thus enhancing infiltration. Water can be filtered of its sediment and nutrient load by turf shoots and roots. For example, doubling the number of turfgrass shoots in a lawn reduced the amount of runoff by 67% (Easton and Petrovic, 2004). Weedy, unhealthy lawns had three times more N runoff than a healthy, dense turf (Easton, 2004; Easton, 2006).

Research summarized above shows that healthy turfgrass plays a major role in absorbing nutrients, especially in the periods of active growth. Further, research shows that nutrient-deficient turfgrass is less effective than healthy turfgrass at reducing runoff volume and nutrient losses. The research shows that the mass of a healthy turfgrass root system plays a large role in removing nutrients from the soil, and that a healthy plant is required to produce a healthy root system.

Iron and N are two essential nutrients for plants (Barber, 1984; Epstein and Bloom, 2005). Deficiency of either nutrient shows up as yellowing of the turfgrass. Fe is involved in the synthesis of chlorophyll and N is part of the chlorophyll molecule, which gives plants their green color (Marschner, 1995). Iron can be rendered unavailable to turfgrass in high-pH (>7.2) soil at certain times in the year (Carrow et al., 2001; Turgeon, 2008). Reduced availability of Fe occurs in spring when the high-pH soils are cool and the root system is not very active in absorbing Fe, as it is recovering from winter dormancy (Carrow et al., 2001). Iron yellowing ("iron chlorosis") also can occur in the summer when turfgrass is growing rapidly (possibly just after a nitrogen application). In this situation not enough iron is available from the soil to meet the rapid

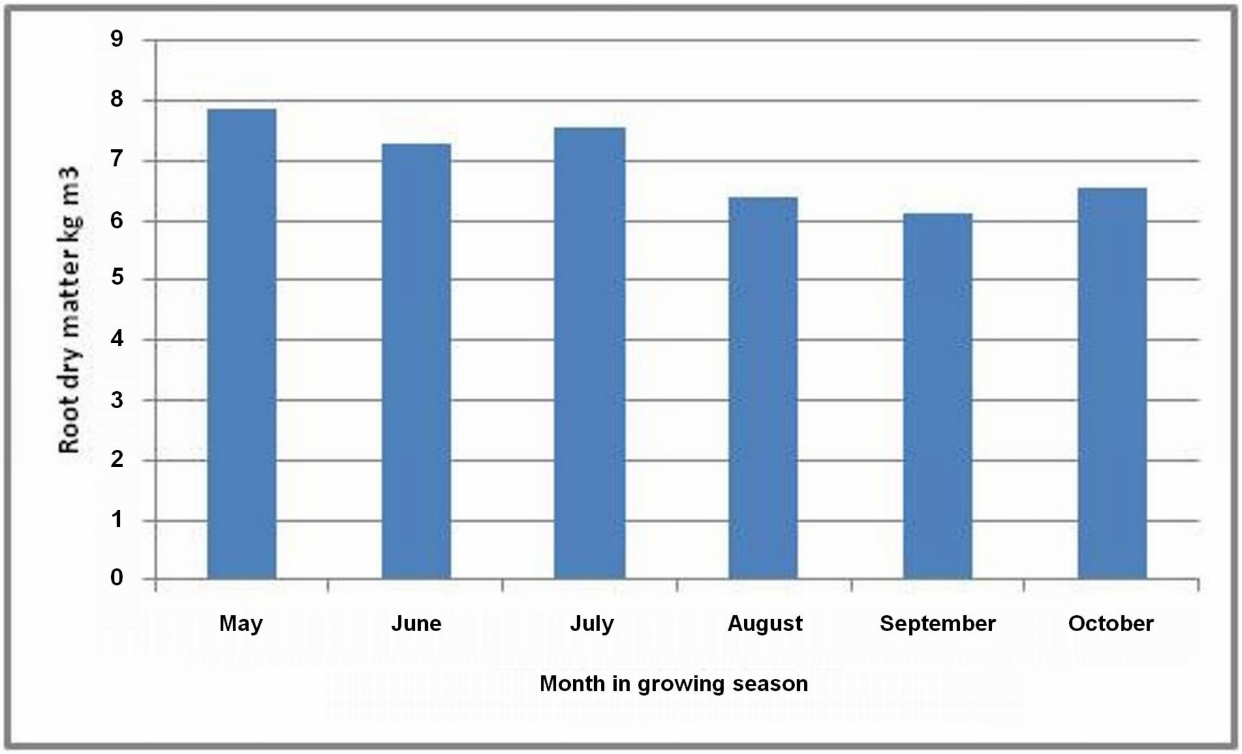

Figure 2. Root mass of warm-season turfgrass (bermudagrass) across the growing season in Florida (after Sartain, 2002). There was a significant difference between the mean of dry matter for May-July and that for August-October.

growth and micronutrient demand. In the summer, frequent irrigations with high-pH (aquifer or reclaimed) water causes the soil pH to rise, rendering Fe unavailable. Other conditions leading to Fe deficiencies include saturated soils and compacted soils (Carrow et al., 2001), which restrict root growth. Foliar iron will help green-up the yellow areas in the lawn caused by iron deficiency (Carrow et al., 2001). The greening results from correcting the underlying iron deficiency so that the turfgrass can synthesize more chlorophyll leading to better greener color (Barker and Pilbeam, 2007; Marschner, 1995).

Yellowing of turfgrass also can result from N deficiency. N deficiency is typically more general in scope in the lawn while Fe deficiency is in spots or patches. N deficiency results in significantly reduced clipping yields while Fe deficiency typically does not (Carrow et al., 2001). Wording in the Florida Yards and Neighborhoods Handbook (UF IFAS, 2009): "*Apply an iron source instead of a nitrogen fertilizer. To green the lawn without increasing growth in the summer, use chelated iron or iron sulfate"* may lead to misinterpretation. While both Fe and N deficiencies result in yellowing, they are distinctly different deficiencies. Applying iron will not cure yellowing of turfgrass due to an N deficiency, and iron fertilizer is not a substitute for N fertilizer.

Issue #2. How might various urban soil types and qualities impact the effectiveness of landscape fertilizer management?

Probably no other factor is more important to nutrient management and water quality in urban environments than the soil in the landscape. There may be no definition for a "typical" urban soil (Pouyat et al., 2010) since there are so many soil types, many types of urban fill-soils, and many ways to impact soils during construction and landscape installation. Soils can have *direct* effects on ecosystems, such as soil disturbance, and they can have an *indirect* impact, such as pollution resulting from soil management practices. Pouyat et al. (2010) showed how these direct and indirect effects can contribute to a "mosaic" of soil conditions in their study in Baltimore, Maryland. They found that urban soils, even though disturbed, can have a high capacity to deliver positive effects on the ecosystems relative to the native soils they replaced. McKinney (2008) also noted a particularly high degree of plant species diversity or richness in urban areas. These studies suggest that urban soils offer potential for using the diversity for the development of sustainable management practices for improving the capacity of the urban landscape to deliver environmental benefits.

Urban soils can be highly disturbed due to the excavation, grading, soil moving, and construction processes, and fill-soils can take many forms (USDA-NRCS, 2005). Urban soils can be highly compacted during the construction period and the water infiltration rate is reduced in these compacted soils (Gregory et al., 2006). These authors found that construction activity reduced infiltration rates 70 to 99% and infiltration rates were typically lower than design storm infiltration rate (10 inches per hour) used in northern Florida. Understanding these soil formation and transformation processes is important for developing (after construction) and maintaining landscapes that achieve the desired aesthetic properties yet also do not result in degradation of nearby water bodies. Paving and compacted soils can be facilitators of urban runoff and pollution. In a meta-analysis of research studies on the relationship between impervious surface and stream water quality, Schueler et al. (2009), found the *impervious cover model* was supported; stream water quality can be predicted from impervious cover percentage. Relative proportion of open urban turf and landscape areas and impervious areas should be considered to minimize runoff impacts on stream water quality (USDA-NRCS, 2005). However, municipalities considering regulations regarding limits to impervious cover should first conduct a comprehensive evaluation of receiving water bodies and environmental assessments such as sources and mitigation because limits may lead to increased environmental problems (Jones et al., 2005).

Plant growth and health are related to soil properties (USDA-NRCS, 2005). For example, soils that are high in organic matter (>3%) may require less N than soils with low organic matter (1% or less) because significant amounts of N can be made available from the organic matter in these soils. Urban soils that test high in P content would be unlikely to require additional P fertilization for at least several years, and then a well-calibrated soil test could predict when P fertilization could resume. The majority of soils in a North Carolina study did not need P fertilizer (Osmond and Hardy, 2004).

Urban soil systems can be responsible for significant N losses due to denitrification (Groffman and Crawford, 2003). Their studies in an urban riparian zone in Baltimore, Maryland, showed strong positive relationships between soil moisture and organic matter and denitrification. These authors suggested taking advantage of these soil properties in storm water treatment in urban environments.

The potential for nutrient retention can be great for urban soils, especially for lawns. This is because lawns are typically managed with irrigation and fertilizer to encourage plant growth and development (Pouyat et al., 2010). Plant biomass is converted to soil organic matter, especially in lawns, and this organic matter retains nutrients and water. Unfertilized lawns would reduce their productivity and reduce their nutrient retention capacity. The key will be to balance the amount of nutrient inputs during the summer with the need to maintain nutrient-assimilation capacity and organic matter building capacity with reductions in nutrient losses to water bodies.

In summary, research shows that urban soils can be highly disturbed yet maintain a high degree of capacity to benefit the environment. Urban soils are highly variable in nutrient-supplying and retention capacities. Urban landscape management, especially for soil disturbance, fertilization, and irrigation, is a critical factor determining whether a soil/landscape system will be a nutrient sink or a nutrient source and the degree to which it will either retain or release nutrients. Research shows the most effective approach to reducing nutrient losses will not be a one-size-fits-all approach, such as a fertilizer ban across all landscapes. Proper fertilization is needed to maintain healthy turfgrass that retains nutrients and water.

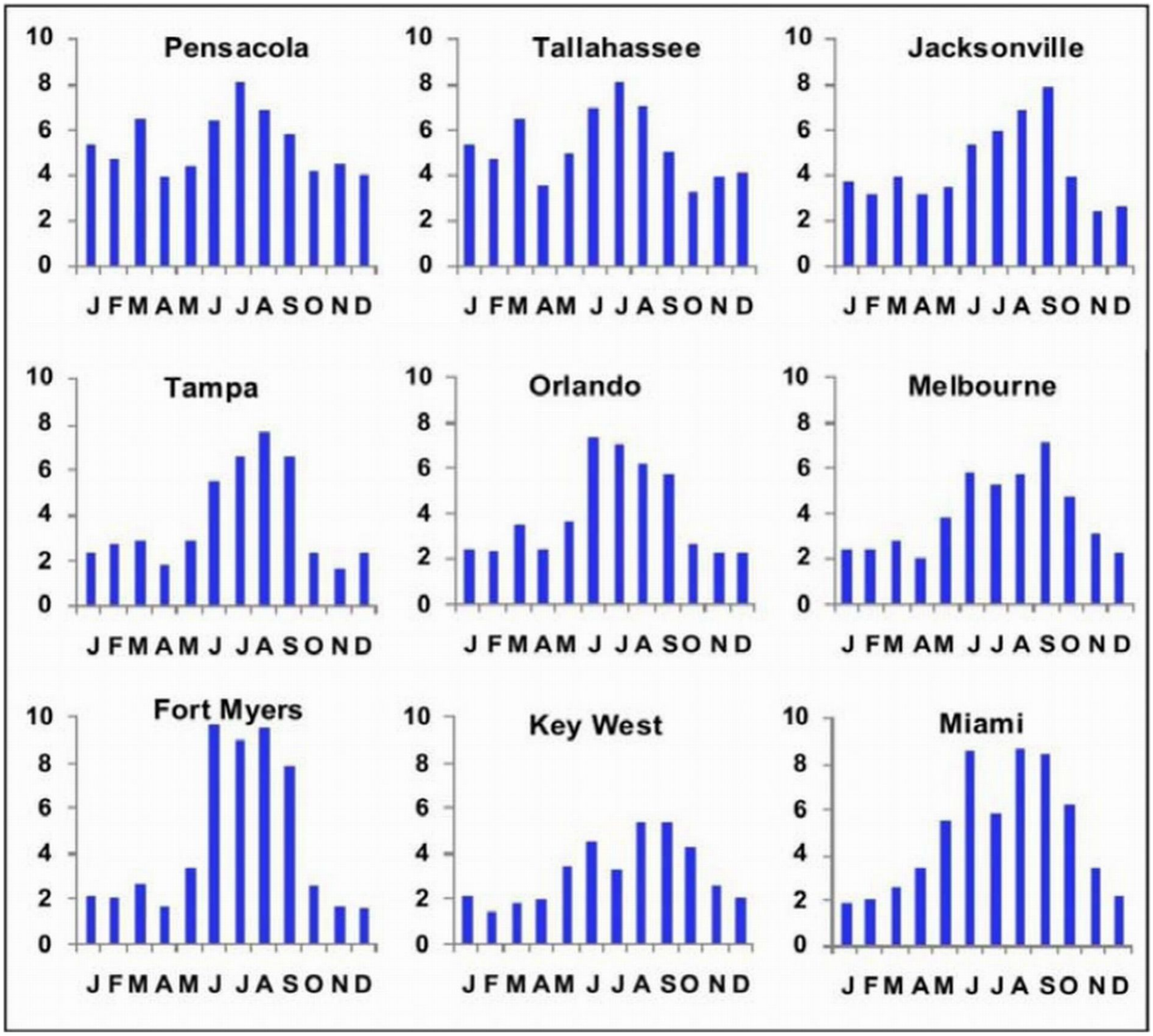

Figure 3. Mean monthly rainfall totals (inches) at select stations across Florida from 1971–2000 (CLIM20, 2004).

Issue #3. How might rainfall patterns and amounts affect fertilizer nutrient leaching and runoff before, during, or after the summer growth period?

Florida receives more rain than nearly all other states, but the rain sometimes falls in large amounts over short periods (Purdum, 2007). Erosion may occur where soils are on slopes and where groundcover is poor. Florida may receive significant rainfall at any time of the year but particularly in the summer months from thunderstorms or tropical systems (Figure 3). There are times in the year when heavy rainfall occurs before and after the summer period (Figure 3). As recommended in the UF/IFAS Florida-Friendly Landscaping™ Program, fertilizer applications during the summer result in less leaching than applications at other times of the year (Trenholm et al., 2011).

Potential for fertilizer leaching and runoff increase when the soil becomes saturated following a heavy rain or several successive heavy rains. The World Meteorological Society and National Weather Service have established a two-inch rainfall as a "heavy rain"— when soil saturation is most likely to occur for most soils in Florida. However, there are several factors that affect how fast the soil will become saturated leading to leaching or runoff (Brady and Weil, 2002; Zotarelli et al., 2010). These factors include the soil texture, natural soil bulk density, compaction, and how much of the

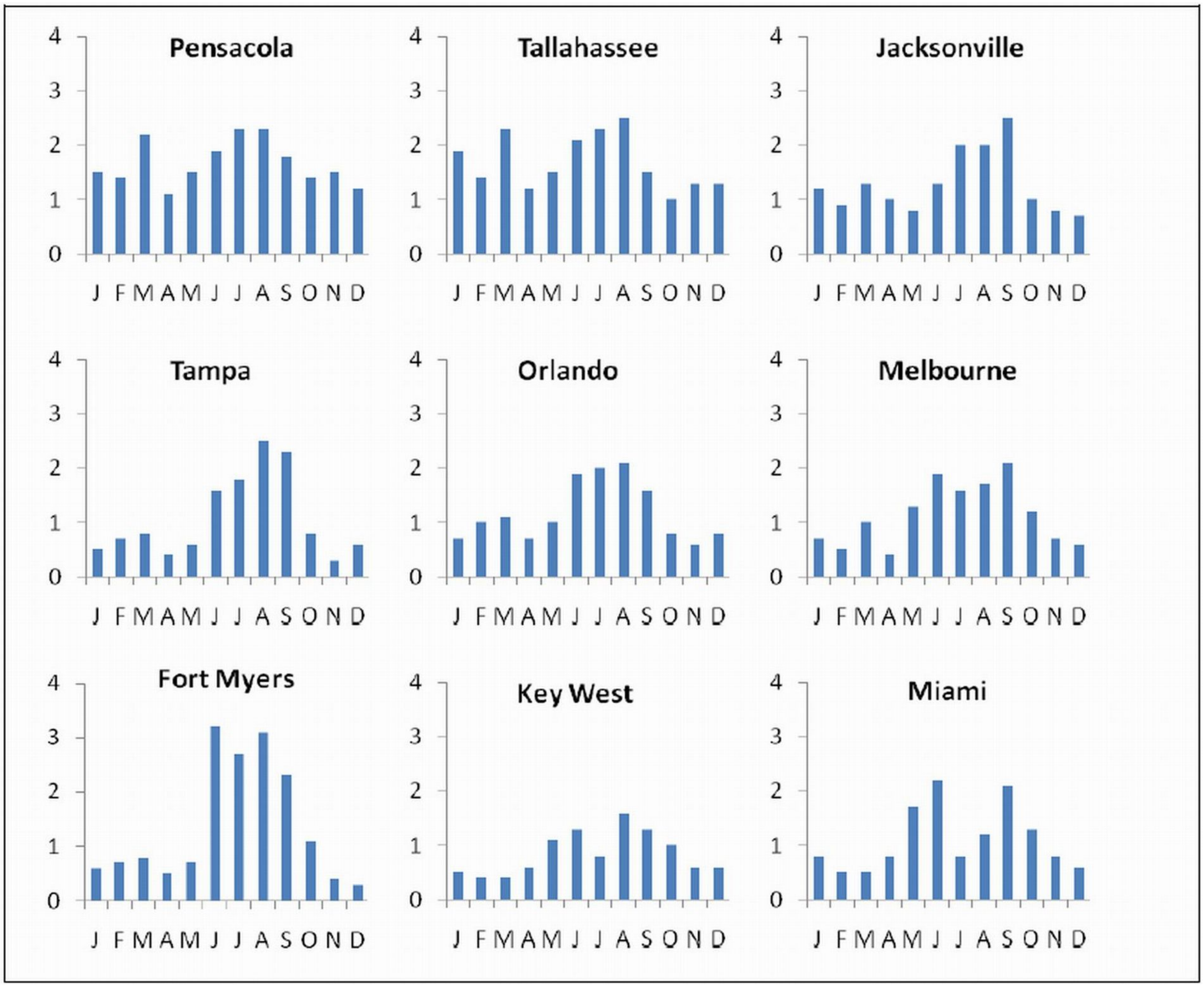

Figure 4. Mean number of rainfall events greater than 1 inch (CLIM20, 2004).

water-holding capacity is already filled by prior rain or irrigation. Sandy soils that are present in most urban areas in Florida only hold from 0.7 to 1.0 inches of water per foot of soil. Up to 25% of P fertilizer was lost in runoff and leaching when applied to saturated soils (Linde and Watschke, 1997). This illustrates the importance of careful irrigating so as not to keep the soil saturated. Following irrigation BMPs throughout the year helps minimize the negative impacts of these natural leaching rain events.

During the year there are rarely more than 2 or 3 rainfall events of more than 1 inch, considered to be a significant rainfall in any month at any location (Figure 4). Only about 10–15% of rainfall events in Florida are 1 inch or more (i.e., those most likely to result in nutrient leaching or runoff) (Figure 5). Additionally, leaching or runoff occurs not simply because of "heavy" rainfall but because the rainfall is in excess of the soil's water-holding capacity. Homeowners should be educated more about not fertilizing immediately before a heavy rainfall event. Education should also focus on not irrigating when the soil already is at its water-holding capacity.

Issue #4 What role does irrigation management play in the leaching and runoff of nutrients?

Irrigation accounts for nearly one-third of residential water use in the United States and this amount is greater in warmer climates (Mayer et al., 1999). Romero and Dukes (2010) studied irrigation water use in southwest Florida. While the average irrigation closely matched the calculated irrigation need, they found over-irrigation was commonplace in some cities. On average 53% of the irrigating households accounted for nearly all of the

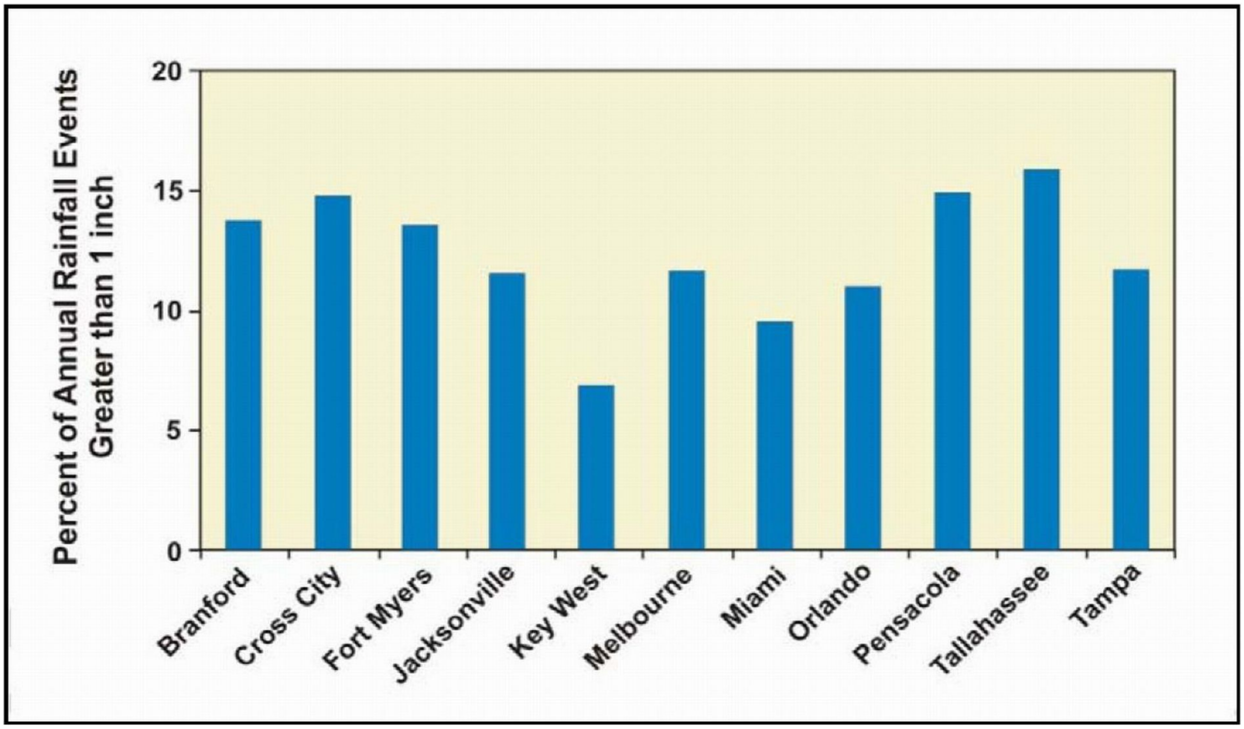

Figure 5. Percentage of annual rainfall events greater than 1 inch at selected locations in Florida. Rain events separated by less than 6 hours are considered to be a single event. Period of record used: 1942–2005. The data sets analyzed contained between 28 and 64 complete years of data (Harper and Baker, 2007).

over-irrigation showing that some homeowners greatly exceeded irrigation requirements.

Any attempt to minimize N and P pollution from the urban landscape will be for naught if irrigation management practices are not included in fertilizer guidelines. Barton and Colmer (2004) reviewed the literature regarding irrigation and N management. These authors concluded that N losses are low (<5% of applied N) from any established turfgrass when irrigation is not excessive, and with moderate (not excessive) rates of N fertilizers. Irrigation scheduling that does not result in water moving below the root zone helps keep N in the root zone minimizing N losses. Sometimes this approach even resulted in improved turfgrass growth and quality.

In an early benchmark study in Florida by Snyder et al. (1984) on irrigation management and N leaching, scheduling irrigation was done by a moisture sensor device that canceled irrigation when the soil contained adequate moisture. Controlled irrigation led to more efficient irrigation and to negligible loss of the soluble N applied (ammonium nitrate) (Snyder et al., 1984). Irrigation at 125% of evapotranspiration (ET) + rainfall resulted in loss of 50% of the applied soluble N (Snyder et al., 1984). Proper irrigation management is critical to preventing nutrient losses.

New technology is available in the irrigation arena known as "Smart Irrigation." New controllers typically monitor soil moisture status and void or permit irrigation based on soil moisture levels. These irrigation controllers use inputs of information (sensors) from the irrigated area to determine or regulate irrigation. Research in Florida on soil moisture sensor controllers has shown that irrigation savings can exceed 70% of automatic, clock-scheduled irrigations with a variety of controllers under normal rainfall conditions (Cardenas-Lailhacar et al., 2008; McCready et al., 2009). Savings during dry periods were less dramatic but were as much as 30 to 40% (McCready et al., 2009). Finally, evapo-transpiration controllers have also been shown to result in savings of 43% during dry conditions (Davis et al., 2009). It should be noted that scheduling irrigation with soil sensors may not be consistent with current rules on irrigation of Florida landscapes. The reader is referred to the local water management authorities for pertinent rules on irrigation water availability.

In a study in North Carolina, Osmond and Hardy (2004) found that residents with movable sprinklers used about one-half the water as residents with fixed systems. Automatic systems that irrigate during rainfall or when the soil is saturated, or that simply over-irrigate all intensify leaching and runoff potential (Hull and Liu, 2005). Irrigation and fertilization practices go hand-in-hand. Properly fertilized and irrigated turf results in minimal nutrient losses to the environment (Beard and Green, 1994).

Morton et al. (1988) studied N losses from Kentucky bluegrass in Rhode Island. N mass losses due to leaching were 2 lb/acre with the managed-irrigation treatment (tensiometer) and 30 lb/acre with the over-watered treatment. The N loss with the managed irrigation treatment was the same as the N loss with the non-irrigated control treatment. Leaching, not runoff, was the main avenue of loss of N. Runoff occurred only on two occasions, once when rain fell on frozen ground and once when rain fell on an already saturated soil.

Runoff volume from bermudagrass was related to simulated rainfall amounts and soil moisture level prior to rain (Shuman, 2002). Runoff was 24 to 44% of an applied 50 mm rain and 3 to 27% for the 25 mm rainfall. The greatest mass loss of P was from the first 4 hours after the first rainfall. The P loss decreased after 24 hours and for later rain events. Loss of N increased with rate of N. The author suggested that runoff losses of N and P could be minimized with small applications of irrigation after fertilizer application and by not applying fertilizer before heavy rainfall or when the soil is saturated.

Current trends in Florida point to greater mandated water restrictions, even during non-drought periods, to help conserve potable water supplies. Homeowners should be educated about refraining from excessive irrigation on "your day," which could result in saturated soils, nutrient leaching, and runoff. For irrigation recommendations to have maximum benefit, other recommended practices must be followed. For example, the irrigation system should be properly designed and installed to achieve a high degree of uniformity of water application (Baum et al., 2005).

Nutrient and water management go together for maintaining healthy turfgrass (Dukes, 2008; Dukes et al., 2009). Proper irrigation management is needed for healthy turf and to prevent nutrient losses. An urban irrigation scheduler tool is available on the Florida Automated Weather Network (FAWN) at http://fawn.ifas.ufl.edu/tools/urban_irrigation/. This tool allows a user to determine irrigation controller runtime estimates with three clicks of the computer mouse. Research has shown that using guidelines such as this tool can reduce irrigation by as much as 30% (Haley et al., 2007). Careful attention to irrigation helps keep the water and nutrients in the root zone where nutrients will be used to grow healthy turfgrass and not be lost to the environment.

In summary, proper irrigation management is critical for achieving minimal nutrient losses for the urban landscape, irrespective of time of year. The research shows that timing of fertilizer in relation to rain or irrigation is important for minimizing leaching of nutrients. There are websites containing assistance in scheduling irrigation and there are "smart irrigation" systems that help take the guesswork out of irrigation management.

Issue #5 What role does reclaimed water play in nutrient runoff and leaching before, during, and after the summer growth period?

Reclaimed water contains nutrients such as N and P. Where reclaimed water is used for irrigation, these nutrients could be leached if nutrient levels are high and if irrigation is excessive. The information below is presented to make several points about managing reclaimed water and cautions for relying on reclaimed water as a total substitute for fertilizers during a restricted period. A history of reclaimed water use in Florida, by Toor and Rainey (2009), can be found at http://edis.ifas.ufl.edu/ss520. Information on Florida's reclaimed water program was summarized by Martinez and Clark (2009a).

Reclaimed water can be a valuable resource for urban landscapes (Martinez and Clark, 2009b; Parsons, 2009). Many new residential developments have made reclaimed water available for irrigating lawns and landscapes as a means to reserve potable water for direct human use (drinking and food preparation, etc.). In addition to the water for irrigation, reclaimed water is sometimes viewed as a source of nutrients (Martinez et al., 2010) and these nutrients may be beneficial for plants. Florida is a leading state for the use of reclaimed water (Assoc. Calif. Water Agencies, 2009; FDEP, 2009c). There is a new concern that the proposed EPA numeric nutrient criteria may lead to unintended consequences that constrain the beneficial use of reclaimed water in Florida, for example as irrigation for landscapes (Arrington and Melton, 2010).

There are challenges to using reclaimed water in the landscape, especially if reclaimed water is seen as a way to replace fertilizers during a restricted period. The data presented in Tables 1 and 2 are for illustration purposes only and are not meant to be used for estimating reductions in fertilizer, for reasons discussed below.

Thomas et al. (2006) used reclaimed water from San Antonio, Texas, to irrigate bermudagrass and zoysiagrass. The reclaimed water contained 12.6 ppm nitrate-N. Irrigation was managed to only replace evapotranspiration. Concentrations of nitrate-N in leachate exceeded 10 ppm on only 6 out of 27 sampling dates and most of those events were when the turf growth was inactive.

FDEP provides regulation of reclaimed water utilities in Florida. Reclaimed water from advanced wastewater treatment (AWT) facilities is limited to no more than 3.0 ppm N and to 1.0 ppm total P. Using these maximum limits, the mass balance indicates that excessive amounts of water (more than 100 inches) would be required to deliver even the lowest recommended amounts of N for most lawn grasses. This is due to the low concentration of N in AWT reclaimed water (Table 1). Reclaimed water users should know the concentrations of nutrients in their water before determining an irrigation schedule. Concentrations of total N can be greater from facilities with only secondary waste water treatment (the 20 and 30 ppm rows of data in Table 1). These are the calculated amounts of total N that may be in the reclaimed water, but the quantity of specific species of N in the reclaimed water that is immediately available will depend on the wastewater treatment methods used. Research has not been completed to address the unknowns about N losses from reclaimed water during transport; therefore, it is not clear that there is a 1:1 substitution of reclaimed water N for fertilizer N.

Reclaimed water is a nutrient solution (water plus nutrients) and should be managed to keep the solution in the root zone. Proper irrigation management with reclaimed water is required to prevent N leaching from over-application of reclaimed water. Rates of reclaimed water used in irrigation should be based primarily on the water needs of the turfgrass. Excessive irrigation with reclaimed water may result in leaching of the N contained in the reclaimed water as well as fertilizer-N previously applied to the turfgrass. Irrigation with reclaimed water should be practiced with careful attention to avoid overirrigation, as described above in the section on irrigation.

Proper irrigation management with reclaimed water can also reduce the overapplication of P. For example in Table 2, using 30 inches of reclaimed water with 0.5 ppm P would result in the application of 0.179 lbs of P_2O_5 per 1,000 ft^2 for the year. The amount of P from the reclaimed water can influence the amount of fertilizer-P needed as indicated by appropriate soil testing. Many of the combinations of reclaimed water P concentrations and irrigation amounts in Table 2 would exceed the FDACS "Urban Turf Fertilizer Rule" (FDACS, 2007), especially where the soil tests show high levels of P already in the soil. This rule, which currently pertains only to bagged fertilizer and not reclaimed water, places a limit of 0.25 lb P_2O_5 per 1,000 ft^2 per application and no more than 0.50 lb P_2O_5 per 1,000 ft^2 per year.

Accumulation of salts contained in the reclaimed water might become a problem for certain turfgrasses during periods of drought and could result in an unhealthy turfgrass with a reduced root system. This may lead to an increase in leaching of applied fertilizer nutrients later on due to the damaged root system's inability to take up the nutrients (more information on salinity in reclaimed water can be found at Martinez and Clark, 2009b; http://edis.ifas.ufl.edu/ae449). Evanylo et al. (2010)

found that problems with certain ions in reclaimed water can result even in the humid eastern U. S., especially with newly established sod. Turfgrass, however, was able to remove the N from reclaimed water precluding groundwater impairment even under a wide variety of irrigation practices.

Application of reclaimed irrigation water to impervious surfaces such as driveways, sidewalks, or roads will result in losses of nutrients to the storm water system and in potential pollution. Irrigation systems should be designed to ensure on-target application of all reclaimed water used for irrigation.

Irrigation systems set to automatically irrigate with reclaimed water year-round would contribute N, P, and other nutrients during the slow-growing or dormant period of turfgrass and landscape plants when these nutrients are not needed by the plants. For example, in most areas of the state, fertilization of turfgrass is not recommended in the winter (Sartain, 2007).

The specific N and P concentrations in reclaimed water are not always optimal for turfgrass requirements. For example, a homeowner may have a soil that tests high in P and therefore does not require the P from the reclaimed water. In this case, it might not be wise to use reclaimed water if there is a nearby water body that would be harmed by increased P concentrations. The actual availability to the turfgrass of the added P in reclaimed water is governed by the soil chemical properties, which may render the P unavailable to the turfgrass. This may occur if the soil pH is too high or the soil contains high levels of iron and/or aluminum.

Issue #6 Does the scientific literature say anything about homeowners' willingness to adopt best management practices?

There are only a few reports in the scientific literature on the relationship between human behavior and urban water quality. However history does indicate that homeowners may be willing to change practices. For example we are recycling one-third of municipal waste today, an increase from 7% in the 1970s (USEPA, 2005; 2007). Zhou et al. (2009) studied lifestyle as a predictor of lawn care expenditures. While the relationship between socio-economic status and lawn greenness was statistically significant, the correlation was weak. Law et al. (2004) surveyed homeowner lawn fertilization practices in two watersheds in Baltimore County, Maryland. Fertilizer amount in the Glyndon watershed averaged 110 lb/acre/year N, but the standard deviation was 100 lb/acre N, meaning that the application rates were extremely variable in the watershed. The rate varied from 2 to 4 lb/1000 square feet per year. Rates used were more related to the soil type than to socio-economic variables. More fertilizer was applied to turf on nutritionally poorer soils. These findings pointed to more "hot-spots" for nutrient losses and suggested the need for more soil-based testing to predict fertilizer needs. The authors above and others (Grove et al., 2006), point to the importance of comprehensive and detailed environmental testing and education programs, rather than "one-size-fits-all" approaches. Baker (2007) studied literature on the question of whether fertilizer laws would work and concluded that programs most likely to result in behavioral change include a mix of components including education, incentives (subsidies), disincentives, and marketing. Further, programs may need to be spatially and socially targeted.

Section 3. Some approaches to controlling nutrient losses in the urban environment

Local Ordinances as an Approach to Reduce Fertilizer Losses to the Environment

The research presented above points to potential losses of nutrients from various lands and land use practices. The research points to potential differences in nutrient losses among various landscapes and various nutrient management practices, which leads to the question, "*How can we best address water quality issues, nutrient sources, and losses to the environment?*" State and federal rules and guidelines and research-based University recommendations have been developed to encourage improved nutrient management practices in the urban environment that have source reduction as their goals. However, some counties and municipalities have instituted rules more stringent than the IFAS and FDEP BMPs. In some cases, some states and counties have chosen the local ordinance approach as a means to locally control urban fertilizer application (Florida Department of Agriculture and Consumer Services, 2007; Hartman et al., 2008). In particular, the severe Florida red tide blooms in 2005 and 2006 precipitated local governmental action in Florida (Hartman et al., 2008).

Examples of other states with fertilizer ordinances

Minnesota enacted in 2002 the first state regulation on P in urban fertilizers. This regulation prohibited P application to soils already high in P content. The Minnesota Department of Agriculture reported to the Minnesota Legislature on the effectiveness of the Minnesota Phosphorus Lawn Fertilizer Law over the first years (Minnesota Dept. Agriculture, 2007). The findings included: P-free fertilizer had become widely available in Minnesota; amount of P applied was reduced 48%; and the law created a "teachable" moment for fertilizer management. Also, the report pointed out that additional research was needed to ensure avoidance of "un-intended" negative consequences of P-free fertilizers on turf health and water quality.

Ann Arbor, Michigan, enacted a fertilizer ordinance controlling P fertilization (Ann Arbor, 2011). The ordinance was in conjunction with a statewide EPA Total Maximum Daily Load (TMDL)-driven P fertilizer reduction effort. The ordinance went into effect in 2007. Manufactured fertilizers cannot be applied prior to April 1 or after November 15, coinciding to the colder part of the year when the turf is not growing. P fertilizer cannot be used except where establishing new turfgrass or where a soil test indicates a deficiency in soil-P.

Researchers established water quality sampling stations in the Huron River watershed in southeastern Michigan (Lehman et al., 2009). Sampling was conducted under the jurisdiction of the Ann Arbor, Michigan, fertilizer ordinance and upstream in a geographic area not under the city ordinance. P concentrations in the water were compared for 2008 data against older data collected before the ordinance was enacted. P concentrations in the river water were lower in 2008 compared to the period prior to the ordinance and lower for the Ann Arbor sampling sites compared to upstream sites. The ordinance not only controlled P fertilization but also included strong education programs about proper fertilizer management. The study showed a positive relationship between P reduction in the water with the implementation of the ordinance BMPs, but the authors acknowledged that it was impossible to determine if the controls on fertilizer solely led to the reductions in P. Other components of the overall program, such as fertilizer-management education, may have also played a role.

The Ann Arbor ordinance and the Minnesota law are similar to the Florida Green Industries Best Management Practices (BMPs) (FDEP, 2008) and the Florida-Friendly Landscaping™ Program (FFL) approaches (FDEP, 2009b). These best-management approaches control fertilizer applications through research-based turfgrass management decisions. These ordinances do not have across-the-board blackouts of fertilizer use during the active growing period. Wisconsin is seeking to manage P fertilizer in a similar manner to Minnesota. It is interesting to note that Dane County (Madison) is the only county allowed to pass fertilizer ordinances (http://www.wisconsinlakes.org/press1-12-09.html). While other counties cannot use the ordinance approach, the municipalities can do this. Madison, Wisconsin, has a P ordinance addressing P loads to Lake Mendota. Apparently Wisconsin counties and municipalities are interested in a statewide fertilizer rule.

These programs in Minnesota, Wisconsin, and Michigan demonstrate the potential improvements in water quality by following the BMPs in the ordinance and implementing a strong public education program.

Other municipalities in the country have enacted ordinances controlling fertilizer, most often P fertilizer. A brief summary is presented below:

- Municipalities in New Jersey--http://www.lakehopatcong.org/ordinances.htm --ban P fertilizer in the winter when the ground is frozen and have set-backs from water bodies. They do not prevent P fertilization of newly established turf.

- Several municipalities in Michigan use an ordinance to control P applications--http://www.michigan.gov/documents/mda/mda_Michigan_Local_Fertilizer_Ordinance_List_297174_7.pdf. Most of these ordinances contain the following parts:

  P application is not allowed in the winter. P fertilizers should contain 0 P except when fertilizing newly planted sod or when a soil test indicates a need for P. Some ordinances include set-backs and reference to keeping fertilizer from impervious surfaces.

- New York has similar rules for not allowing P application in the winter, controlling P-content of fertilizers, involving a soil test in the decision to apply P, and limiting the per-application amount of N.

- Annapolis, Maryland, has an ordinance similar to those above, banning P fertilizer in the winter and allowing P use of soils testing low in P or for newly planted turfgrass--http://www.ci.annapolis.md.us/Government/Headlines/Arhives/OctDec2008.aspx.

While probably not exhaustive, the survey above found no laws or ordinances that banned fertilizer in the summer period of active turfgrass growth. The rules in these states typically control fertilizer application based on BMPs, including the use of a soil test to predict P needs, the use of set-backs from water bodies, advice on keeping fertilizer off impermeable surfaces, controls on total amounts of fertilizer per application and for the season, bans on fertilization in the winter when the ground is frozen or when the turfgrass is not actively growing, and allowing fertilization of newly planted turf seeds or sod. The ordinances in other states are much like Florida DEP's Green Industries Best Management Practices, DEP's state model ordinance, the state's Urban Fertilizer Turf Rule, and the UF/IFAS Florida-Friendly Landscaping™ Educational program for homeowners, commercial fertilizer applicators, and builders and developers.

The Florida situation with fertilizer ordinances

Many counties and municipalities in Florida, like other states and municipalities, have chosen the ordinance as a means to control fertilizer use, however, some have included a fertilizer ban in the summer active growing season. Most Florida ordinances contain guidelines that are supported by research and are consistent with the University of Florida, IFAS, and FDEP nutrient BMPs. These practices include following recommended fertilizer application methods and keeping grass clippings and fertilizer from impervious surfaces. These materials can be moved into water bodies via the storm water. Fertilizer management is important because studies (North Carolina) have shown only one-half of residents remove fertilizer from impervious surfaces (Osmond and Hardy, 2004). This result shows that lack of knowledge about how to avoid misapplication of fertilizer may be a contributing factor to nutrient losses, and a more serious one than properly fertilized lawns where lawn maintenance activities are consistent with BMPs.

Certain ordinances in Florida contain a ban on fertilizer sale and application during the summer months of June 1 through September 30. The rationale is that heavy rainfall events are common in the summer months and the likelihood of leaching and runoff of fertilizer is therefore greater during the summer. However, the summer months also are the months when landscape plants such as turfgrass grow the most actively and require nutrients for healthy development. National research shows that this is the time of the year when turfgrass is most active in taking up nutrients and nutrient loss is negligible. The ban was part of a recommendation of a workgroup for a model ordinance from the Tampa Bay Estuary Program (TBEP, 2008a; TBEP, 2008b). This workgroup was composed of members from most of the important stakeholders (public, private, turf and fertilizer industry, and non-governmental organizations) in the urban water quality issue for the Tampa Bay area. The ban or restricted period, or "blackout" part of the model ordinance was not supported by all stakeholders but was included in the final model ordinance (TBEP, 2008). The model ordinance including the summer ban was proposed as a model for counties and municipalities in Florida, especially around Tampa Bay to follow in their own ordinances.

In 2007 the FDACS created the Urban Turf Fertilizer Rule (FDACS, 2007) to help protect water quality in Florida by restricting the application of N and P fertilizers for urban turf and lawns. The rule requires that all fertilizers less than 50 lbs. sold for urban turf use are labeled with only the amount of N and P needed to sustain healthy turf. The rule requires the directions on any turf fertilizer label to limit the amount of N and P that can be applied in a single application and per year. This rule was designed to help guide Florida's citizens to apply fertilizers in the urban environment at rates that sustain healthy turfgrass and minimize potential nonpoint source pollution from nutrient movement. After reviewing urban landscape leaching and runoff literature reports, the Urban Fertilizer Task Force, established by the Florida Legislature in 2008, decided not include a restricted period (ban) in their report to the Florida Legislature (FDACS, 2008). Evans et al. (no date) from the Conservation Clinic of the University of Florida, College of Law, summarized the arguments for and against BMPs or fertilizer bans. These authors suggested that bans should be considered after mandated or voluntary BMPs have been tried and found ineffective.

Center for Landscape Conservation and Ecology/Florida-Friendly Landscaping™ Program

Education programs and timely communication of new research results to the stakeholders is extremely important in addressing urban water quality issues (Heisler et al., 2008). The Florida-Friendly Landscaping™ (FFL) Program is a UF/IFAS Cooperative Extension program that educates Florida's citizens about protecting the state's water resources and environment through sustainable landscaping practices. In conjunction with the Florida Department of Environmental Protection (FDEP), the FFL Program operates out of Extension offices in all 67 counties. The three-part educational program is composed of the GI-BMP program, which trains commercial horticulture professionals in BMPs; the FYN Homeowner program, which targets the education of homeowners; and the FYN Builder & Developer program, which does outreach to Florida's many builders and developers. The FFL Program educates each of these groups with print and online materials, in-person workshops and trainings, Florida-Friendly Yard Recognitions, and continuous outreach.

The FFL Program has come increasingly into the spotlight since the July 2009 passage of SB494, which determined that all commercial fertilizer applicators in Florida must be certified in the Florida Green Industries Best Management Practices for Protection of Water Resources in Florida by January 1, 2014; and of SB2080, which prevents homeowner associations from interfering with residents' implementation of Florida-Friendly Landscaping™ practices. The FFL Program is the UF/IFAS vehicle for delivering sound scientific information to the public for educational purposes, including scientifically based fertilization practices. More information on the FFL Program can be found at: http://fyn.ifas.ufl.edu.

Take-home lesson: Will fertilizer restricted periods result in an improvement of urban water quality?

The literature reviewed in sections 2 and 3 regarding urban nutrient management and water quality, and the experiences of other states shows that:

- Nutrient losses are negligible during the active growth period for healthy turf being fertilized according to BMPs.
- Increased runoff and increased nutrient loss may result when turfgrass is over-fertilized or when fertilizer is applied to unhealthy turfgrass.
- Properly fertilized turfgrass helps prevent soil erosion which moves soil and nutrients off-site.
- There are no scientific reports relating summer fertilizer bans with improved water quality, but fertilizer control by science-based BMPs has been shown to be effective in reducing water pollution.

- The literature documents the importance of using BMPs and education programs together to maximize the improvement of nutrient management and its impact on water quality.
- Some other states and municipalities in the country are using local ordinances based on BMPs as a means to control fertilizer use in residential areas, but none could be found that included a blackout of fertilizer application in the summer growing period.

Continued research needed:

Considerable research has been completed on nutrient and water management in urban landscapes addressing water quality. There is an increasing amount of research-based information for nutrient management in urban environments, but there are still areas in need of further work as identified in the national research reports. Some of these areas are described below.

There is an inadequate level of understanding about the nutrient sources and fates in the urban environment. Some of these sources have been described in this paper. While the Tampa Bay Estuary Program (2006) attributed a large portion of storm water runoff to residential sources, no information was presented on the portion due to fertilizer use. Before specific control measures can be determined, more information is needed about the particular nutrient sources, their relative amounts, and how they potentially could contribute to a problem in water quality. This nutrient mass balance is needed for N and P.

Fertilizer recommendations should be continually evaluated for turfgrass health and for impacts on water quality from leaching or runoff. These studies should include the relationship of healthy or unhealthy turfgrass and landscape plants with nutrient losses from the landscape.

Human behavior plays a large role in the success of programs, voluntary or regulatory. For example, misinterpretation or lack of good understanding of fertilizer, fertilizer ordinances, and landscape maintenance practices may result in misapplied fertilizer before and after the restricted period and throughout the year. More research is needed in the social sciences to determine what individuals understand about water quality and the relationship their landscape management activities may have on water quality.

Research also is needed on appropriate and most effective educational programs. The University of Florida provides the Florida-Friendly Landscaping™ program (FFL, 2009) through the Green Industries Best Management Practices for the Protection of Water Resources (GI-BMPs) professional training program and the Florida Yards & Neighborhoods (FYN, 2009) homeowner program. The Florida-Friendly Landscaping™ program (FFL, 2009; Hansen et al., 2009) has been developed to educate the public about conserving water and protecting water quality through sustainable landscaping practices.

More research is needed on the interaction of irrigation and nitrogen fertilization to determine the optimum fertilizer and irrigation combinations for various turfgrasses and landscape plants.

More information is needed on the specific nutrient and water requirements of common and new landscape plants. This research should include native and non-native plants.

Research is needed on optimum construction site management for best soil preparation for landscape installation, with attention to minimizing negative environmental impacts.

Research is needed on reclaimed water use in urban environments for supplying water and nutrients. Questions include, "Is there a fertilizer offset when using reclaimed water?"

Overall Summary/Concluding Comments

From this literature review and analysis, the following conclusions can be made:

- Coastal and urban eutrophication is an increasing problem and is, at least in part, related to urban land-based activities. Sources of nutrients involved with eutrophication are numerous and the interactions with harmful algal blooms are complex.

- Based on an analysis of national research, unfertilized turf will lead to increased runoff and nutrient losses as turfgrass health and density declines over time due to insufficient nutrient supply.
- BMPs, whether voluntary or embodied in a fertilizer ordinance, have been shown to be effective in reducing pollution of water bodies.
- Developing nutrient BMPs involves an iterative process based on science and must be sustained to develop continually advancing knowledge.
- The BMP solution avoids the "one-size-fits-all" approach because BMPs, by definition, provide for adjustments in the practices depending on local conditions and science-based recommendations.
- All published scientific research should be part of a comprehensive and complete discussion of approaches to reduce urban nutrient losses. All stakeholders should actively engage in this process.
- Research publications point to the importance of a continued education effort to inform homeowners about how their landscape practices impact water quality. UF/IFAS conducts public education for the consumer and the landscape management professional. Continuing the effort to educate the public about the BMPs, as determined by scientific research, is of the utmost importance.

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Table 1. Amounts of total N applied depend on the concentration of N in the reclaimed water and the amount of reclaimed water applied during irrigation. Highlighted columns represent the approximate average annual irrigation needs for turf in Florida.

N conc. in reclaimed water (ppm total N)	1.0 inch irrig. water	5.0 inches irrig. water	10 inches irrig. water	20 inches irrig. water	30 inches irrig. water	50 inches irrig. water	100 inches irrig. water	150 inches irrig. water
	Resulting lbs N per 1,000 ft^2							
1.0	0.005	0.026	0.052	0.104	0.155	0.259	0.518	0.777
2.0	0.010	0.052	0.104	0.207	0.311	0.518	1.036	1.554
3.0	0.016	0.078	0.155	0.311	0.466	0.777	1.554	2.331
5.0	0.026	0.130	0.259	0.518	0.777	1.295	2.590	3.885
10.0	0.052	0.259	0.518	1.036	1.554	2.590	5.180	7.770
20.0	0.104	0.520	1.041	2.081	3.121	5.202	10.41	15.61
30.0	0.156	0.780	1.561	3.121	4.682	7.804	15.61	23.41

Table 2. Amount of P_2O_5 applied as a function of the concentration of P (as P) in reclaimed water and the quantity of reclaimed water applied. Highlighted columns represent the approximate average annual irrigation needs for turf in Florida

P conc. in reclaimed water (ppm)	1.0 inches irrig. water	5.0 inches irrig. water	10 inches irrig. water	20 inches irrig. water	30 inches irrig. water	50 inches irrig. water	100 inches irrig. water	150 inches irrig. water
	Resulting lbs P_2O_5 per 1,000 ft^2							
0.1	0.001	0.006	0.012	0.024	0.036	0.060	0.119	0.179
0.25	0.003	0.015	0.030	0.060	0.089	0.149	0.298	0.447
0.5	0.006	0.030	0.060	0.119	0.179	0.298	0.596	0.894
0.75	0.009	0.045	0.089	0.179	0.268	0.447	0.894	1.340
1.0	0.012	0.060	0.119	0.238	0.357	0.596	1.191	1.787
2.0	0.024	0.119	0.238	0.477	0.715	1.192	2.383	3.575
5.0	0.060	0.298	0.596	1.192	1.787	2.979	5.957	8.936