Management of Fertilizers and Water for Ornamental Plants in Urban Landscapes: Current Practices and Impacts on Water Resources

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Introduction

Studies have shown that water and chemical use in urbanizing areas is significantly influenced by the desire for beautiful landscapes (Haley et al., 2007a; Hipp et al., 1993). Improper irrigation and fertilization of ornamentals in urban landscapes may have a negative impact on water quality. Various best management practices (BMPs) have been developed and implemented in an effort to reduce environmental pollution and water consumption associated with urban landscapes. Recommended BMPs include fertilization practices, irrigation strategies, alternative landscape materials (e.g., native ornamentals instead of turfgrass), and structural features (e.g., swales, green roofs, rain gardens). However, the impacts of these BMPs have not been fully evaluated in urban landscapes. Consequently, our objectives in this paper are to (i) describe the current fertilizer and water use practices that are used by homeowners and landscape professionals, (ii) summarize the research related to nutrient and water use by landscape plants, and (iii) provide an overview of the critical issues that should be considered as we evaluate the need for improved management of water and nutrients in urban landscapes.

Nutrient and Water Management Practices for Landscape Ornamentals

The nutrient and water management practices of homeowners and commercial landscape professionals are difficult to quantify. Most of the available information about water and nutrient use on landscape ornamentals plants has been gathered using surveys. It is important to understand that results from surveys conducted outside of Florida may not be representative of fertilizer and water use by Florida homeowners and landscape professionals.

Homeowners. A survey of Florida residents from 23 counties (who had not received information or training related to landscape management practices from Florida Cooperative Extension) was conducted in 1995 to determine the landscape management practices of Florida consumers. Results of the survey found 20% of residents were not fertilizing ornamental landscape plants. Among residents who did fertilizer landscape plants, 60% of respondents were applying fertilizers 2-4 times per year (Knox et al., 1995). Similarly, a survey of the landscape management practices followed by Georgia homeowners indicated that 76% of respondents maintained and applied fertilizers to their own landscapes. Among the respondents, 66% indicated that they fertilized shrubs and trees and 75% indicated that they fertilized flowers (Varlamoff et al., 2001). In contrast, a survey of residents of the Neuse River Basin, NC indicated that most homeowners did not fertilizer ornamental landscape plants, and as a result, this question was removed from later surveys (Deanna Osmond, personal communication).

With respect to water management in Florida landscapes (ornamentals + turf), a survey conducted in Central Florida found that, on average, 64% of the total household water was used for irrigation purposes (Haley et al., 2007a). This equated to 2-3 times the amount of irrigation required by the plants (Haley et al., 2007a). Research suggests that the over-irrigation of landscapes may be directly influenced by the type of irrigation system being used by homeowners. For example, Florida homeowners who utilize automatic timers for irrigation currently apply 47% more water for landscape irrigation than homeowners without automatic irrigation systems (Mayer et al., 1999). Similarly, the volume of water used by residents of Cary, NC who utilized fixed irrigation systems was approximately twice as much water than residents who used moveable sprinklers (420 vs. 230 thousand L mo^{-1}; Osmond and Hardy, 2004). The 1995 survey of Florida residents indicated that 41% of respondents had fixed irrigation systems installed in their landscapes (Knox et al., 1995). The number of landscapes irrigated with fixed irrigation systems has likely increased since 1995 since the majority of new homes are built with in-ground irrigation systems (Tampa Bay Water, 2005; Whitcomb, 2005). As a result, it is probable that overwatering has also increased since that time and it is probably not uncommon throughout Florida. Additionally, the survey of Florida residents conducted by Knox et al. (1995) indicated that only 15% of respondents used low-volume irrigation, but that 80% were watering landscapes during the recommended early morning or evening hours.

Results of homeowner surveys in Florida and Georgia suggested that approximately 25% of homeowners employ a maintenance professional to manage the ornamental plants and turf in their home landscapes (Israel and Knox, 2001; Varlamoff et al., 2001). However, it is likely that homeowners retain control over irrigation of landscapes.

Commercial Landscape Professionals. Commercial landscape professionals are responsible for the installation and maintenance of landscapes and/or irrigation systems at residential, public and commercial properties. A survey of Florida commercial landscape professionals indicated that 46% of respondents applied fertilizer to ornamental landscape plants at a frequency of 3 or more times per year. Most of the professionals surveyed also indicated that they were fertilizing mature trees and shrubs (Israel et al., 1995). A more recent survey of landscape maintenance and lawn care professionals in the Atlanta, GA area indicated that 68% of respondents fertilized ornamental beds. Landscape professionals indicated that complete fertilizers were most commonly used on ornamentals. The use of visual appearance and soil testing were reported as methods used to determine fertilizer application, however, these results were misleading since 88% of respondents indicated that they applied fertilizer according to a predetermined schedule. Spring application of N fertilizer was the most common practice reported, possibly due to the establishment of new ornamental beds during this period (Beverly et al., 1997). When surveyed about irrigation, Florida professionals indicated that they dealt primarily with fixed irrigation systems (88% of respondents) and that watering was scheduled for early morning or evening hours (Israel et al., 1995).

Educational Opportunities for Homeowners and Commercial Landscape Professionals

Homeowners. Over the years, a variety of educational programs related to proper landscape management have been offered to homeowners, gardeners and landscape professionals through the Florida Cooperative Extension Service. Surveys indicate that these educational programs have led to the adoption of UF-IFAS recommended fertilizer and irrigation practices among program participants (Israel et al., 1999; Israel et al., 1995; Knox et al., 1995). Adoption of recommended fertilizer and irrigation practices has been best when the behavior change had low costs or limited additional effort (Israel et al., 1995). For homeowners, Florida Cooperative Extension currently provides education and outreach programming related to landscape management practices that are designed to help residents reduce pollution and conserve water through the Florida Yards and Landscapes (FYN) and Master Gardener programs. To date, information to determine the adoption rate of FYN practices among Florida homeowners or the effect of these practices on water use in and nutrient losses from residential landscapes is limited.

Commercial Landscape Professionals. Certification programs for commercial landscape professionals are becoming more common throughout Florida. The Florida Green Industries BMP program offered by UF-IFAS provides training for landscape professionals related to irrigation system design and fertilizer use (turf and ornamentals). Certification programs are also offered to landscape professionals through the Florida Nursery Growers and Landscape Association (FNGLA) and the International Society of Arboriculture (ISA). The Landscape Maintenance Association (LMA) is currently developing a certification program. Regardless of the availability of these programs, the reality is that most landscape professionals have not received formal training on fertilizer use or irrigation management.

Available Information Related to Fertilizers and Water for Ornamental Landscape Plants

Nutrient sources. There is very little information about utilization of specific fertilizer sources for ornamentals by homeowners and landscape professionals. Also, the availability of specific fertilizers sources will vary with location throughout the state. Browsing through the inventory of ornamental fertilizers at a national box store chain in the Tampa Bay Region, we found that granular, liquid, polymer coated and fertilizer spike products were widely available to area consumers. Most of the fertilizers available to homeowners for use on ornamentals in the landscape are complete fertilizer (containing N, P, and K) blends that are formulated primarily using inorganic materials, in soluble and slow- or controlled-release formulations; some contain additional micronutrients. Consumers also have access to specialty fertilizers for palms (8-2-12-4 Mg) that have been formulated based on University of Florida – IFAS research, which suggests this formulation can prevent K, Mg and other potentially fatal nutrient deficiencies in palms (Broschat, 2001). A wider variety of fertilizer products are available to commercial landscape professionals because they have access to single nutrient fertilizers and can blend them accordingly.

Fertilization Rates. Few studies have investigated optimum fertilization of ornamental plants growing in the landscape; most of which have focused on the nutrient requirements of selected woody shrubs and tree species. Information about the fertilizer requirements of annuals and perennials in the *landscape* is lacking. In addition, research on fertilizer needs of ornamentals tends to focus heavily on N needs of the plants because most of the available research showed no plant response to applications of P or K. For example, Gilman and Yeager (1990) reported no response to applications of P and K to established Live Oaks. Gilman et al. (2000) also reported no growth response to P and K applications during establishment or maintenance of Live Oak (*Quercus virginiana*) or Southern Magnolia (*Magnolia grandiflora*). It has also been suggested that that research has also been focused on N because excessive applications may result in water quality degradation or plant problems (e.g., pests, diseases, winter injury, etc.; Perry and Hickman, 1998).

Researchers have evaluated the response of several woody species to N fertilizers. For example, Gilman and Giaque (1982a; 1982b) evaluated response of Hibiscus (*Hibiscus rosa-sinensis*) to N applied as urea and as slow release fertilizers to sandy, alkaline soils. They found that 5 lbs N·1000 $ft^{-2}·yr^{-1}$ (in five equal applications) produced acceptable leaf color and plants receiving 15 lbs N ·1000 $ft^{-2}·yr^{-1}$ (in five equal applications) held leaf color until just prior to the next fertilizer application (approximately 7 to 8 weeks). Leaf color, twig length and flowers per plant all increased with increasing N rate from 0.5 to 3.0 lb N·1000 ft^{-2} per application (Gilman and Giaque, 1982a). Fertilizer rates of 0.5 to 3 lbs N·1000 $ft^{-2}·yr^{-1}$ were reported as suitable for Japanese Holly (*Ilex crenata*), Forsythia (*Forsythia* sp.), and Crepe Myrtle (*Lagerstroemia* sp.) (Rose and Joyner, 2003).

Research also suggests that response of trees and shrubs to fertilization will be influenced by environmental factors. For example, fertilizer studies conducted by the TruGreen Company L.L.C. on trees and shrubs ranging from 1 to 10 years of age growing in the landscape showed little to no fertilizer response to N application when plants were grown in fertile topsoil. Similar findings are reported by Broshcat et al. (2008) for Pentas (*Pentas lanceolata*), Dwarf Allamanda (*Allamanda cathartica*), and Nandina (*Nandina domestica*). Gilman and Yeager (1990) and Gilman et al. (2000) also reported similar growth of Laurel Oak (*Quercus laurifolia*), Ligustrum (*Ligustrum japonicum*), Southern Magnolia (*Magnolia grandiflora*), and Live Oak (*Quercus* virginiana) in fertile soils both with and without fertilization. In contrast, trees and shrubs showed a significant response to N fertilizers when plants were grown in recreated soils (using subsoil material of low-fertility) that would be typical of those encountered in urban landscapes by inverting the soil profile (Rose and Joyner, 2003).

Nitrogen fertilization standards for woody ornamental plant maintenance have been developed by the National Arborist Association (ANSI, 1998). The recommended rates are from 1 to 6 lbs N·1000 $ft^{-2}·yr^{-1}$ (ANSI, 1998). According to Rose (1999), these recommendations were based on research to determine the maximum fertilizer response that was conducted from the 1950's to the 1970's. Rose (1999) also reports that these recommendations are higher than those for agronomic crops and provide less guidance for selecting a rate within the range.

Both the Florida Green Industries BMP manual and the current FYN handbook provide N fertilizer rate recommendations for established ornamental plants (excluding palms) in the landscape (Table 1) that are in line with the ANSI recommendations; neither publications references applications of P or K for ornamental landscape plants. The recommended N rates have been categorized based on a level of desired maintenance; however, definitions for basic, moderate, and high maintenance are not provided in either document (Florida Department of Environmental Protection, 2002; Florida Yards and Neighborhoods Program, 2006). In contrast, the University of Florida-IFAS Extension Soil Testing Lab (ESTL) recommends application rates of 2.3 lb N·1000 $ft^{-2}·yr^{-1}$ (Kidder et al., 1998) for most woody ornamentals in the landscape. The only exceptions are Azaleas (*Rhododendron* sp.), Camellias (*Camellia* sp.), Gardenias (*Gardenia* sp.), Hibiscus (*Hibiscus rosa-sinensis*) and Ixora (*Ixora coccinea*), which have an N recommendation of 1.1 lb N·1000 ft^{-1} $year^{-1}$. This information is provided as part of the Landscape and Vegetable Garden soil test report. In addition, fertilizer P and K rate recommendations are based on Mehlich 1 soil test results (Tables 2-3). TruGreen (a professional landscape company) reports application rates of 1.5 lb N1000 ft^{-2} per application (two applications per year) to ornamental plants (Rose and Joyner, 2003).

Fertilization Timing. As was the case with fertilizer rates, information on the timing of fertilizer application for non-woody components of the landscape is notably missing. For woody ornamental plants during maintenance, the ANSI fertilization standards state that "fertilizer should be applied so that nutrients are available when roots are actively growing" (ANSI, 1998). This provides little guidance about actual timing of fertilizer applications, because it is difficult to determine when root growth is occurring. The majority of U.S. states recommend that fertilizers be applied in early spring (before bud break) or late fall (after leaf drop) or that the fertilizer applications be split between the two seasons (Rose, 1999). This is similar to the calendar based applications made by TruGreen (Rose and Joyner, 2003). These recommended seasonal fertilizer applications contradicts fruit crop research, which has indicated that little nutrient uptake occurs before bud break or after leaf drop. Similarly, the N use efficiency of shade trees is low in early spring and high in the summer, with plant N uptake increasing between periods of shoot growth. During this time, leaves become a carbohydrate source, rather than a carbohydrate sink, which stimulates root growth and N uptake (Struve, 2002). Struve (2002) also reports that spring-applied N is utilized by the plant during that season, but that it only contributes 25% of the total N in the foliage. The other 75% was N absorbed in the previous season.

The Florida Green Industries BMP manual and the current FYN handbook do not provide information about the timing of fertilizer applications (Florida Department of Environmental Protection, 2002; Florida Yards and Neighborhoods Program, 2006). However, the University of Florida-IFAS ESTL recommends that P application be broadcast in one or two yearly applications, while N and K should be applied every 12 weeks, adding 33% of the recommended amount at each application. In contrast, TruGreen makes two applications per year (spring and fall) to ornamental plants (Rose and Joyner, 2003). There is little or no information about fertilizer rates, application methods or timing used by other landscape companies. It can only be assumed that it varies widely and that applications tend to be based on a timed schedule (Beverly et al., 1997).

Fertilization with N at the time of planting or during the establishment period has been reported to have little or no benefit in trees. A study of fertilization of Southern Magnolia (*Magnolia grandiflora*) and Live Oak (*Quercus virginiana*) by Gilman et al. (2000) reported that "addition of fertilizer was not necessary for survival or growth…in the first 3 to 4 years after transplanting." Ferrini and Baietto (2006) also report that tree N fertilization was most effective in the third year after planting. However, the effect of N fertilization soon after planting may be species dependant. For example, research showed no response of Live Oak (*Quercus virginiana*) (Gilman et al., 2000) and Sugar Maple (*Acer saccharum*) (van de Werken, 1981) to N application during establishment, while Southern Magnolia (*Magnolia grandiflora*) showed faster growth following N applications (Gilman et al., 2000).

Fertilization practices in nursery production appear to have an effect on the rate of establishment and growth of woody ornamentals after planting in the landscape. Cabrera and Devereaux (1999) found that increased N fertilization during nursery production had a positive effect on post-transplant growth of Crape Myrtle (*Lagerstroemia* sp.). However, flowering was delayed in those plants grown under higher N conditions. Lloyd et al. (2006) also investigated the effects of "nutrient loading" in the nursery on post-transplant performance. They found that growth of Crabapple (*Malus* sp.) was enhanced when the plants were produced under high N conditions. However, their findings suggest that "nutrient loading" reduced post-transplant plant resistance to certain insects and decreased drought tolerance. The effect of N fertilization in nursery production did not manifest itself beyond the year of transplant.

Fertilizer Application Methods. Fertilizer application method may also influence plant response. Research conducted by TruGreen suggested that injection and drench applications of urea provided better plant response than dry surface applications (Rose and Joyner, 2003). However, in a review of shade tree N fertilization research, Struve (2002) states that surface application of N fertilizer is as effective as soil injection or soil drilling techniques. The Florida Green Industries BMP manual and the current FYN handbook suggest that fertilizers for ornamentals be broadcast uniformly over the desired landscape area (Florida Department of Environmental Protection, 2002; Florida Yards and Neighborhoods Program, 2006).

Fertilizer Type. Gilman and Giaque (1982b) evaluated the response of Hibiscus (*Hibiscus rosa-sinensis*) to applications of urea or slow-release N at 0, 1, or 2 lb N 1000 ft^{-2} per application (four applications per year). This study indicated that slow release fertilizers produced more growth than soluble fertilizer applications. In contrast, another study showed no significant difference in growth of Japanese Holly (*Ilex* crenata) receiving 50% slow release or soluble urea during the first two years after planting (Rose and Joyner, 2003).

Available Information Related to Water for Ornamental Landscape Plants

Irrigation sources. In Florida, the main water source for irrigation of ornamental landscape plants is potable water from the public supply or from a private well. On the Central Florida Ridge, potable water used for landscape irrigation has been found to be as high as 74%, with an average of 64% of total household consumption (Haley et al., 2007b), even when irrigation is restricted to two days a week (St. Johns River Water Management District, 2006). Over the last several years, there has been an expansion of infrastructure to allow for the use of reclaimed water for irrigation of urban landscapes. As of 2006, there were 216,248 home landscapes in FL that could be irrigated using reclaimed water (Florida Department of Environmental Protection, 2007).

Irrigation application rates, timing, and methods. Depending on location in Florida, the irrigation of commercial and residential landscapes with potable water may be restricted due to widespread drought conditions (Figure 1). Currently, the Northwest Florida Water Management Districts (WMD) does not impose watering restrictions for lawn and landscape irrigation. However, the district has issued water shortage notification and has asked for voluntary use reductions. The Suwannee River, South Florida and St. Johns WMDs allow irrigation two days per week between the hours of 4 pm and 10 am. The Southwest Florida WMD has the most stringent watering restrictions, allowing irrigation one day per week (based on address) between 6 pm and 8 am. All restrictions allow hand watering, micro-irrigation of non-turf areas and provide exceptions for newly installed landscape plant material. There are fewer restrictions on the use of reclaimed water for landscape irrigation. In fact, only the South Florida WMD restricts the use of reclaimed water for irrigation of landscape. Irrigation with reclaimed water is allowed between 4 pm and 10 am daily, with the exception of Fridays, when no watering is allowed.

Irrigation scheduling. Many Florida homeowners are under watering restrictions, which limits the frequency and time of day that irrigation can be scheduled (see irrigation rates, timing, and methods). Most of the ornamental plants that receive irrigation are on a timed schedule and it is likely that the majority of Florida homeowners with in-ground irrigation systems use the "set it and forget it" approach to irrigation scheduling. Research has shown that setting irrigation time clocks monthly based on UF-IFAS recommendations (Dukes and Haman, 2002) can reduce irrigation water applied to residential landscapes by up to 30% (Haley et al., 2007). In general, research in Florida has indicated that irrigation is often applied in excess of plant water needs, thus achieving control of irrigation application will likely lead to more immediate water conservation benefits.

Irrigation scheduling based on soil moisture status or evapotranspiration (ET) also has the potential to reduce water use in residential landscapes. A Central Florida study demonstrated that irrigation controlled by soil moisture sensors had the potential to save up to 90% of the irrigation water that would be used if irrigation was applied on a time-based schedule (Cardenas-Laihacar et al., 2008). When soil moisture sensor technology was implemented on established home landscapes, irrigation water use was reduced by as much as a 51% (Haley and Dukes, 2007). A study demonstrated that irrigation scheduling using ET controllers was able to reduce the volume of water used on mixed landscape when compared with time-based irrigation methods, with no negative impacts on ornamental plant growth or quality (Dukes et al., 2008). Rain sensor shut off devices are another irrigation technology designed to reduce outdoor water use and are mandated on all new irrigation systems in Florida. They have not been extensively studied for their water conservation potential, but Cardenas-Laihacar and Dukes (2008) demonstrated that rain sensors could reduce irrigation by 17-44%.

Irrigation Strategies. More efficient use of in-ground irrigation systems can also reduce outdoor water use by homeowners. Irrigation strategies that improve the efficiency of fixed irrigation systems include: 1) conducting period checks of the irrigation system to ensure proper coverage and system function; 2) watering in the early morning (4-7 a.m.); 3) utilizing micro-irrigation systems for ornamental beds; 4) watering less in cooler months or when there is adequate rainfall; and 5) selection and proper hydro-zoning of plants. Research indicates that replacing sprinkler irrigated areas with micro-irrigated ornamental areas (from 100% to 35% sprinkler irrigated area) further increased irrigation savings to 50%. Selection of drought tolerant plants may reduce water use in the long-term, however, landscapes consisting of entirely mixed ornamentals (no turf) have been shown to have higher water requirements during establishment relative to properly maintained turfgrass (Park et al., 2005).

Water requirements of ornamental plants in the landscape. There is a wide body of research related to the water needs of ornamental landscape plants during production. In contrast, information about the water requirements/use for establishment and maintenance of ornamental plants grown in the landscape is limited. Often landscape plants are assigned to water use categories based on anecdotal evidence of water plant performance under various water stress conditions. For example, California uses the Landscape Coefficient Method (LCM) to estimate irrigation needs of landscape plants. As part of this method landscape plants were placed into categories of water needs, based on the scientific judgment of selected committee members rather than actual measurements of water use/requirements in the field (Costello and Jones, 1998).

Most of the research evaluating the water use or drought tolerance of ornamental plants has involved plants growing in pots and/or growing in the arid Western U.S. states (Garcia-Navarro et al., 2004; Levitt et al., 1995; Zollinger et al., 2006). Levitt et al. (1995) evaluated the water use of Live Oak (*Quercus virginiana*) and Mesquite (*Prosopis alba* 'Colorado') in containers and found that under nonstress conditions, Mesquites (xeric trees), required more water than the Live Oaks (mesic trees). In a study conducted in Utah, Zollinger et al. (2006) evaluated the drought tolerance of six herbaceous perennials during establishment and maintenance phases in a 3.8 L pot-in-pot system. Results indicated that response to water stress conditions varied, with some species exhibiting dieback when water was insufficient. The researchers were able to rank the six species based on tolerance to mild, moderate or severe drought conditions, however, the impact of drought conditions on plants grown in pots may differ significantly from conditions when plants are grown in the landscape. García-Navarro (2004) showed that the relative water use by four woody landscape species in 3.8-L pots was significantly correlated to water use by the same species grown in the landscape, suggesting that water use at the end of production could be useful to predict water needs during landscape establishment.

A recent study by Scheiber et al. (2007) evaluated the effect of 2-, 4-, or 7-day irrigation frequencies on growth, aesthetic quality and establishment of three shrub species (*Ilex cornuda, Pittosporum tobira,* and *Viburnum odorotissimum*) in central Florida. Plants received 3-L of water per irrigation event, which was delivered through a micro-irrigation system. Results of this study suggested that plant growth and quality were similar for all irrigation treatments; however, plants watered every 2- or 4-days established approximately 1-2 months earlier than shrubs watered once a week. Results of this study also suggest that the 60-d or less of daily irrigation allowed for establishment of new plant material during periods of water restriction is not sufficient to ensure establishment of woody ornamental materials. The shrub establishment research is being repeated at three locations (Balm, Citra, and Ft. Lauderdale) throughout Florida. Preliminary results suggest that watering every 4-d was sufficient for establishment of the shrubs in Citra and Balm. However, results from Ft. Lauderdale suggest that plants will establish within 20-28 weeks after transplant when watered every 2-d (Gilman et al., 2008). These watering frequencies are currently being evaluated on 12 additional shrub species at each site. In addition, the study also evaluates time of planting (season) on water requirements of these shrubs during establishment.

Factors that Affect Water and Nutrient Use Efficiency in the Landscape

Site Design and Preparation. When designing and preparing for new landscapes, most resources are allocated to the planting materials and above-ground installations, with the little attention placed on the soil quality (Jim, 1998). Soil compaction is required for site stabilization of the home site during construction. The small lot sizes for new Florida homes often means that the entire lot, not just the home site, is compacted by heavy equipment and constant traffic during construction (Gregory et al., 2006). Soil compaction in the landscaped areas can result in: 1) limited root development, which is needed for healthy plant establishment and 2) a reduction in infiltration rates, which leads to runoff and nutrient loss (Jim, 1998; Rivenshield and Bassuk, 2007; Whalley et al., 1995). In addition, soil compaction, which is quantified by high bulk density, affects the transport, adsorption, and transformation of nutrients. This can impact the plant availability of nutrients and water (Lipiec and Stepniewski, 1995). Homeowners and landscape professionals may mistakenly apply additional water and fertilizers to landscape plants that exhibit nutrient and water stresses in compacted landscapes.

Construction activities that occur as a result of urbanization have also been shown to impact water quality. Gregory et al. (2006) showed that compaction of the soil during construction had the ability to significantly decrease infiltration and increase the amount of runoff from developed areas in North Central Florida. Similarly, Law et al. (2004) suggested that soil compaction may reduce N leachate potential to the surficial aquifer but increase runoff potential. In the UK, soils in areas of home construction were found to have high (vertical and horizontal) spatial soil nitrate variability as a result of topsoil stripping and soil compaction during construction (Wakida and Lerner, 2006). Concentrations of nitrate-N in these UK soil profiles ranged from an average 6 kg ha^{-1} in the vegetated control sites to 28 to 138 kg ha^{-1} in the construction sites, suggesting that construction practices can increase the risk for N leaching (Wakida and Lerner, 2006). Runoff monitoring from small (< 7 ha) drainage areas of relatively homogeneous land uses (residential, golf course, industrial, pasture, construction site) in the Neuse River Basin (NC) indicated that total N export was greatest for the construction site during the house-building phase (36.3 kg N ha^{-1}), followed closely by the residential and golf course land uses. Total P export was greatest for the golf course site (5.3 kg P ha^{-1}), followed by the pasture and residential land uses (Line et al., 2002). These studies suggest that nutrient loss in runoff and/or leachate from urban landscapes is a legitimate concern.

Plant Selection and Zoning. Selection of resource efficient landscape plant materials has the potential to reduce fertilizer and irrigation use in the landscape. Information about plant water requirements and "drought tolerant" plants is available in numerous sources like the Florida-Friendly Plant List (Florida Yards and Neighborhoods Program, 2006) and the Waterwise plant list (SFWMD, 2003). However, the information in these sources is anecdotal and does not provide actual water requirement. Instead, they place species into broad categories (i.e. low, medium, and high), similar to the California model described previously. This information can be used to attempt to group plants according to irrigation requirements, but it does not offer insight into the actual amount of water plants in the "medium" category require. This make the translation of plant water use category into an actual irrigation system run time and frequency extremely difficult. Zoning plants according to their irrigation requirement is widely recommended and is one of the principles in Waterwise Landscaping (SFWMD, 2003), Xeriscaping™ (Colorado Water Wise Council, 2008), and Florida-Friendly Landscaping (Florida Yards and Neighborhoods Program, 2006). There is little information about how effective this strategy is at saving water or how frequently this principle is implemented.

Additionally, there are numerous reports of significant variation within a species for water requirement [e.g., *Acer* – (St. Hilaire and Graves, 2001; Zwack et al., 1999; Zwack and Graves, 1998); *Eucalyptus* – (Li, 1998; Li et al., 2000; Tuomela, 1997); *Pinus* – (Cregg, 1994) *Fraxinus* – (Abrams et al., 1990); *Cercis* – (Griffin et al., 2004); *Taxodium* – (Denny et al., 2007)] and nutrient use efficiency [e.g., (*Cercis* – (Zahreddine et al., 2007); *Carya* – (Wood et al., 1998); *Hibiscus* – (Valdez-Aguilar and Reed, 2006); *Prunus* – (Shi and Byrne, 1995); and *Taxodium* -

(Denny et al., 2006)]. These reports suggest that there is the potential to select or breed ornamental plant material for resource efficiency. One advantage to selecting for resource efficiency within a species that is already utilized in landscape is that it may be more readily adopted and used compared to material that is new or unknown to landscape designers and consumers.

<u>*Fertilizer and irrigation management practices.*</u> It has been suggested that the landscape management practices of homeowners and green industries professionals can have a negative impact on water quality. A USEPA report estimates that 12% of the non-point pollutant load in the U.S. originates in urban runoff (USEPA, 1995). This figure may be higher for Florida, due to the state's high population density; Florida ranked 8th in the nation with a population density of 296.8 people·mi^{-2} in 2000 (U.S. Census Bureau, 2004). Nutrient losses from urban landscapes may be exacerbated in Florida as a result of high rainfall, high irrigation use and sandy soils, which tend to promote rapid nutrient leaching.

Relatively few studies have documented the impact of fertilizer or irrigation practices for ornamentals in urban landscapes on water quality. Hipp et al. (1993) evaluated nutrient losses and water use under four mixed landscape (ornamentals and turf) management systems in Texas: 1) Xeriscape™ – native ornamentals + no irrigation or chemicals; 2) low maintenance – native ornamentals + 73 kg N ha^{-1} yr^{-1} [2 applications] + irrigation at 15% pan evaporation; 3) medium maintenance – non-native grasses and shrubs + 146 kg N ha^{-1} yr^{-1} [3 applications] + irrigation at 40% pan evaporation; and 4) high maintenance – non-native grasses and shrubs + 293 kg N ha^{-1} yr^{-1} [6 applications] + 21 kg P ha^{-1} yr^{-1} + 36 kg K ha^{-1} yr^{-1} + irrigation at 60% pan evaporation. Results showed little or no runoff from Xeriscape™ and low maintenance treatments. The highest N losses were documented from the high maintenance landscape (1.3 kg ha^{-1}). The highest nitrate losses occurred in first 0.32 cm runoff immediately after fertilizer application from high maintenance landscape (15.7 mg kg^{-1} first collection vs. 7.9 mg kg^{-1} fourth collection). In addition, P losses were significantly higher from landscapes where P was applied.

Studies conducted in Ft. Lauderdale, FL indicated that N, P, and K losses from field plots planted with turfgrass monoculture were lower than from field plots planted with mixed ornamental species (Erickson et al., 2005; Erickson et al., 2001). However, the fine root weight density (upper 15 cm) was much greater with the turf monoculture (467 g m^{-2}) than with the mixed landscape (235 g m^{-2}). As a result, mixed ornamental landscape leached more N, P and K than St. Augustine grass during the first year after planting (48.3 vs. 4.1 kg N ha^{-1}, respectively). The researchers reported significantly greater leachate volumes and higher ET from mixed landscapes right after planting than at the end of year 1, suggesting that the amount of N in leachate from mixed landscapes appears to decrease as plants become more established.

As discussed previously, there is limited information about the fertilizer needs or response of many types of ornamentals (e.g., annuals, perennials, ground covers) in the landscape. These plants often have different and greater N fertilization requirements than trees. Therefore, fertilization based on recommendations for woody ornamentals may result in poor plant quality and appearance of landscape plants. As a result, consumers and professionals may apply higher rates of fertilizer to the entire landscape. Over fertilization is a direct threat to water quality because in increases the potential for nutrients to be lost in leachate or runoff. Fertilization also effects the water requirements of a plant. Inappropriate fertilization practices can decrease how efficiently a plant uses its water. This increases the amount of irrigation that needs to be applied to the landscape, negatively effecting water conservation efforts. Additionally, increased landscape irrigation further increases the danger of water pollution by increasing the volume of leaching and runoff. Obtaining additional information about the nutrient requirements of landscape plants will allow for more targeted, efficient fertilizer application. The development of more accurate N recommendations will also allow landscape plants to be zoned based on their fertilizer requirements. This zoning approach is already promoted by FYN (right plant/right place) and accepted by landscape professionals for landscape plant water requirements. Zoning for fertilizer needs will result in a more targeted and efficient approach to fertilizer application. Unlike than the current practice of broadcast fertilizer application, zoned fertilization strategies may help reduce nitrate leaching from urban landscapes to springs by reducing the overall amount of fertilizer applied to the landscape.

Future Research Needs

Rapid population growth and urbanization is expected to continue in Florida. As a result, statewide programs that advocate the protection of Florida's natural resources (e.g., FYN, Green Industries BMPs) will become increasingly important. These types of programs often promote the implementation of BMPs to protect water resources; however, many of these BMPs have not been validated in residential landscapes. The success of programs like FYN will partially depend upon sound scientific data supporting the recommended practices.

In 2006, the Florida legislature created The Center for Landscape Conservation and Ecology in response to the Green Industry's concern for the long-term sustainability of current landscape management practices. The mission of the Center for Landscape Conservation and Ecology is to protect and preserve Florida's natural resources. University of Florida, IFAS faculty members that are affiliated with the center have been conducting research related to water and nutrient use in Florida's urban landscapes. Current areas of research for ornamental landscape plants include: fertilizer and water requirements during establishment and maintenance, nutrient and water management for ornamentals in the landscape, and validation of BMPs (including FYN; Table 4).

According to state and county faculty, there is a definite need for additional research and the resulting educational programs to help homeowners and commercial landscape professionals to better manage water and nutrients in urban landscapes (Tables 5-6). Approaches to improve water quality and reduce water use will help to preserve Florida's resources for future generations. It would seem that advocating actions such as fertilizing and watering ornamentals appropriately or using slow- or controlled-release fertilizers would be easy, but much of the fundamental research needed to make the appropriate recommendations has not yet been completed. Also, researchers studying landscape ornamentals often struggle to obtain funding when compared to other horticultural crops such as turf grass and row crops.

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Table 1. Recommended N fertilizer rates for established landscape plants.

Level of Maintenance	**Recommended N Rates**
	lb N 1000 ft^{-2} yr^{-1}
Basic	0-2
Moderate	2-4
High	4-8

Table 2. Mehlich-1 soil test interpretations used for environmental horticulture crops in Florida.

Element	**Very Low**	**Low**	**Medium**	**High**	**Very High**
			mg kg^{-1}		
P	<10	10-15	16-30	31-60	>60
K	<20	20-35	36-60	61-125	>125
Mg		<15	15-30	>30	

Table 3. Target pH and recommended N, P_2O_5, and K_2O fertilizer rates for ornamentals in the landscape. Phosphorus and K rates are based on interpretation of a Mehlich-1 soil test.

Crop Description	Target pH	N	P_2O_5					K_2O				
			VL	LO	MED	HI	VH	VL	LO	MED	HI	VH
			lb·1000 ft^{-2}·yr^{-1}									
Woody ornamentals and trees in the landscape	6.0	2.3	0.7	0.7	0.4	0	0	1.4	1.4	0.7	0	0
Azaleas, Camellias, Gardenias, Hibiscus, or Ixora in the landscape	5.5	1.1	0.3	0.3	0.2	0	0	0.7	0.7	0.3	0	0

Table 4. Summary of current BMP research areas for landscape plants, level of knowledge, gaps.

BMP research area	Level of knowledge	Knowledge Gaps
Fertilizer requirements of ornamental landscape plants	Spotty	No information on non-woody species (except palms); need research during establishment and maintenance phases
Water needs of ornamental landscape plants	Spotty	Need state-wide information for other species; need to look at additional factors (planting season, plant size, soil type/nutritional status)
Nutrient losses from ornamental plants in the landscape	Spotty	Limited research showed landscapes with all ornamentals leached more N, P, and K; need research for systems with established root systems; need information about mixed landscapes; need information on realistic lot size plots
Management of soil in urban landscapes	Spotty	Information available for soil compaction effects on tree and woody species only; need more information about impacts of soil compaction on nutrient losses from landscapes.
Validation of BMPs (including FYN)	Spotty	Need solid data to indicate the impact of FYN and other BMPs on water quality and water use.

Table 5. Questions to and summary of vision statements by key UF/IFAS state and county faculty with active programs in BMPs for landscape ornamentals (non-turf).

Question	Needs of Issues	Comments
1. What is your opinion/vision for the next 5 years on what homeowners or commercial landscape professionals need to do to improve irrigation management for ornamental plants?	• Install drip irrigation for trees and shrubs. • Conduct periodic checks of irrigation systems for leaks or broken/misaligned heads. • Move toward irrigation based on soil moisture or plant wilt symptoms, not time-based systems. • Management irrigation system time clocks properly. • Hydrozoning of plants. • Understand the effect of irrigation practices on the watershed and water supply. • More stringent certification programs for industry. • Homeowners hire certified professionals. • More enforcement of watering restrictions.	• Most problems with irrigation systems go unnoticed because watering restrictions require irrigation during non-daylight hours. • Effective irrigation controllers that take the responsibility out of the hands of the homeowner.
2. What is your opinion/vision for the next 5 years on what homeowners or commercial landscape professionals need to do to improve their fertilizer management for ornamental plants?	• More people need to learn to read a fertilizer label correctly. • More appreciation of water quality issues related to fertilizer. • Understand that more fertilizer isn't always better (established trees and shrubs may need no fertilizer). • Shift from water soluble fertilizers to "slow- or controlled-release" products. • Develop products designed for soils and climatic conditions in Florida, not the northeast. • Install/maintain buffer zones. • Shift from timed applications of fertilizers to fertilization when needed. • Choose a fertilizer based on analysis and cost. • Calibrate fertilizer application equipment. • More stringent certification programs for industry. • Homeowners hire certified professionals.	

Table 5 (continued).

Question	Needs or Issues	Comments
3. What educational programs are needed? (need to be separated for agents, landscape professionals, and homeowners)	All groups: • There is a lot of information available, but a better method to disseminate that information is needed. • Spanish materials. • Education about actual plant P requirements. • Information about reclaimed water, including nutrient levels, effects on plants, salt content. • Online materials/tutorials, etc. • Information about fertilizer sources and properties. • Hands-on training for fertilizer application (including calibration). • Irrigation system training (operation and trouble shooting). Agents: • Need to know what the most current research says and how to use it. • Public policy/administrative guidance for county faculty working with local governments and state agencies. • Training on how to conduct a water audit. Landscape Professionals: • Need to know what the most current research says and how to use it. • Training on UF fertilizer recommendations. Homeowners: • Information about how, when and where to apply fertilizer • Information about fertilizer products. • More demonstrations for FYN in neighborhoods, parks, etc. • Training on conversion from overhead to microirrigation. Local officials: • Need to be educated about what the science says with a consistent, unbiased message from UF.	• Many times BMPs and local government officials are connected, so it is critical that UF Administration, Specialists, and County faculty have a consistent message. This is especially important when dealing with issues that involve emotions, such as water quality. • When local governments break away from researched science for guidance and direction, county faculty are sometimes forced to teach both "local" science and "real" science BMPs. Therefore, further discussion is needed to decide how UF should engage public policy as well as teach alongside "pseudo"-science based landscape ordinances. In the end, it is possible that this guidance will address water and fertilization policy issues, thus providing a closer relationship with local government; hopefully based on sound agronomic/horticulture principles.

Table 5 (continued).

Question	Needs or Issues	Comments
4. What are the critical issues on the horizon (5 to 10 years) that may affect the landscape industry (or homeowners)?	• Irrigation restrictions. • Water availability. • Regulations affecting fertilizer and other landscape practices. • Nutrient runoff prevention. • Fertilizer ordinances. • HOA and COA covenants that required landscape materials/practices that are not FL-friendly. • Public perceptions of a beautiful landscape. • Salinity of alternative irrigation water sources. • Fertilizer cost. • Can we document the impacts of FYN on nutrient pollution and water use?	• Homeowners are desperate for a reasonable alternative to turf.
5. Other	• New insect/disease pests	

Table 6. Strategic areas of future research involving landscape ornamentals (non-turf) for improving the quality of Florida waters, their respective approaches and estimated chances of success.

Approach used to improve water quality	Possible areas of research	Chance of success	Why?
Reduce P applications to only situations where it is required	Determine the P fertilizer requirements for various landscape plants and correlate with soil test levels.	Good	High P soils may dominant the landscape requiring research in pots or other controlled situations.
Use "slow- or controlled-release" fertilizers	Determine the actual release times of specific materials.	Good	Manufacture release times may not be accurate for Florida conditions.
Buffer (no application) zones	Runoff volume and nutrient loads reductions with and without buffer areas	Fair	Need long-term homeowner buy-in and participation. Need to change homeowner perception of "water-front".
Optimize fertilizer use efficiency for ornamentals	Determine the fertilizer response of ornamentals	Excellent	Research trials are straightforward with proven methods.
Alternative groundcovers for urban landscapes	Evaluation of alternative landscape ground covers including performance and nutrient leaching/runoff related to maintenance	Good	Plant evaluation trials are straightforward; more difficult to quantify effect on nutrient losses.
Fertilize and water ornamentals appropriately	Determine the effect of many factors (e.g., planting season, location in FL, plant type, plant size, soil type, etc.) on the fertilizer and irrigation needs of ornamentals.	Good	Impossible to evaluate every landscape plant species. Many factors need to be evaluated individually.

Table 6 (continued).

Approach used to improve water quality	**Possible areas of research**	**Chance of success**	**Why?**
Protect soil quality during construction of new landscapes	Determine methods to mitigate soil compaction; evaluate the effects of organic soil amendments.	Good	May require expensive infrastructure or cooperation of developers/landscape designers.
Provide accurate fertilizer recommendations for ornamentals	Fertilizer requirements/response of ornamental plants (including trees, woody shrubs, vines, annuals, and perennials) during establishment and maintenance phases	Good	Impossible to evaluate every landscape plant species. Can evaluate common species and use them to screen other plants for N requirements. Research trials are straightforward with proven methods for P and K requirements.
Follow BMPs (including FYN)	Development and validation of new (and existing) BMPs at a residential lot scale	Good	May require high cost infrastructure to begin. Difficult to measure success in "real-world" because landowners may not follow protocol correctly.
Use of reclaimed water	Effects of reclaimed water on ornamentals; chemical constituent levels and variability in reclaimed water	Good	Supply issues and wasted supply may make it impractical to provide access to all landowners.