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

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SUMMARY. Rapid population growth and urbanization in Florida have increased the number of urban landscapes that receive fertilization and irrigation. Consequently, maintenance of these landscapes may contribute to water shortages and water quality degradation. This article 1) describes the current fertilizer and water use practices that are used by homeowners and landscape professionals; 2) summarizes the research related to nutrient and water use by landscape plants; and 3) provides 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.

Water and chemical use in urbanized areas is significantly influenced by the desire for beautiful landscapes (Haley et al., 2007; Hipp et al., 1993). Improper irrigation and fertilization of ornamentals in urban landscapes may result in water quality degradation (e.g., eutrophication). 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 plant species (e.g., native ornamentals instead of turfgrass, plants requiring low water input), and structural features (e.g., swales, green roofs, rain gardens). However, the impacts of these BMPs on water consumption in and nutrient losses from urban landscapes have not been fully evaluated. Consequently, our objectives in this article are to 1) describe the current fertilizer and water use practices that are used by homeowners and landscape

professionals; 2) summarize the research related to nutrient and water use by landscape plants; and 3) 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 represent 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 the Florida Cooperative Extension Service) 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 fertilize landscape plants, 60% of respondents were applying fertilizers two to four 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 fertilize ornamental landscape plants (D.L. 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, which equated to two to three times the amount of irrigation required by the plants (Haley et al., 2007). Research suggests that the overirrigation of landscapes may be directly influenced by the type of irrigation system being used by homeowners. For example, Florida homeowners who use 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 used fixed irrigation systems was about double that of

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
0.3048	ft	m	3.2808
0.0929	ft ²	m ²	10.7639
3.7854	gal	L	0.2642
2.54	inch(es)	cm	0.3937
48.8243	lb/1000 ft ²	kg·ha ⁻¹	0.0205
1.1209	lb/acre	kg·ha ⁻¹	0.8922
2.5900	mile ²	km ²	0.3861
305.1517	oz/ft ³	g·m ⁻²	0.0033
1	ppm	mg·kg ⁻¹	1

the volume used by residents with moveable sprinklers (420,000 versus 230,000 L per month) (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 because 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 that overwatering is presumably common 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 80% were watering landscapes during the recommended early morning or evening hours.

Results of homeowner surveys in Florida and Georgia suggested that $\approx 25\%$ 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 the application of irrigation to 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 three 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 area indicated that 68% of respondents fertilized ornamental beds. Landscape professionals indicated that complete fertilizers [those containing sources of nitrogen (N), phosphorus (P), and potassium (K)] were most commonly used on ornamentals. Visual appearance and soil testing were reported as methods used to determine fertilizer application; however, these results were misleading

because 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 as a result of the planting 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 has 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 University of Florida–Institute of Food and Agricultural Sciences (UF-IFAS) -recommended fertilizer and irrigation practices among program participants (Israel et al., 1995, 1999; Knox et al., 1995). Adoption of recommended fertilizer and irrigation practices has been best when the behavior change had low costs or required limited additional effort. For homeowners, the Florida Cooperative Extension Service currently provides education and outreach programming on landscape management practices designed to reduce the risk for pollution and conserve water through the Florida Yards and Neighborhoods (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 BMPs 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 and the International Society of Arboriculture. The Landscape Maintenance Association 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 for ornamental landscape plants

FERTILIZER PRODUCTS. There is very little information about the use of specific fertilizer sources for ornamentals by homeowners and landscape professionals. Also, the availability of specific fertilizer sources varies with location throughout the state. Browsing through the inventory of ornamental fertilizers at a national “big-box” store chain in the Tampa Bay region, we found that granular, liquid, polymer-coated, and fertilizer spike products are widely available to area consumers. Most of the fertilizers available to homeowners for use on ornamentals in the landscape are complete fertilizer blends (containing N, P, and K) that are formulated primarily using inorganic materials in both soluble and slow- or controlled-release formulations; some also contain micronutrients. Consumers also have access to specialty fertilizers for palms (Arecaceae) (8N–0.9P–10K–4Mg) that have been formulated based on UF-IFAS research (Broschat, 2001). A wide 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 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 growth or color 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 oak trees (*Quercus virginiana*). Gilman et al. (2000) also reported no growth response to P and K applications during establishment or maintenance of live oak or southern magnolia (*Magnolia grandiflora*). Establishment is a broad term that is frequently used by many authors in various ways. It is used most frequently to refer to the general stage of plant growth that occurs between transplanting and the resumption of “normal growth” after the root system has redeveloped. That is the general definition used for the term in regard to this review. It has also been suggested that research has been focused on N because excessive applications may result in water quality degradation or plant problems (e.g., pests, diseases, winter injury, and so on) (Perry and Hickman, 1998).

Researchers have evaluated the response of several woody species to N fertilizers. For example, growth and color response of hibiscus (*Hibiscus rosa-sinensis*) to surface applications of liquid urea or slow-release N (applied to a 64-ft² area around the plant) were evaluated in sandy, alkaline soils (E.F. Gilman and P. Giaque, unpublished data). Researchers found that N applied at 5 lb/1000 ft² per year (in five equal applications) produced acceptable leaf color for a period of 3 to 4 weeks and plants receiving N at a rate of 15 lb/1000 ft² per year (in five equal applications) maintained leaf color until just before the next fertilizer application ($\approx$ 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/1000 ft² per application (E. F. Gilman and P. Giaque, unpublished data). Nitrogen fertilizer rates of 0.5 to 3 lb/1000 ft² per year were reported as suitable for Japanese holly (*Ilex crenata*), forsythia (*Forsythia* spp.), and crape myrtle (*Lagerstroemia* spp.) when applied using liquid soil injection or liquid surface drench (Rose and Joyner, 2003).

Research also indicates that response of trees and shrubs to fertilization is influenced by environmental factors. For example, fertilizer studies conducted by a professional landscape company (TruGreen, Memphis, TN) 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 field soils (Rose and Joyner, 2003). Similar findings are reported by Broschat 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*), Japanese ligustrum (*Ligustrum japonicum*), southern magnolia, and live oak 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 (American National Standards Institute, 2004). The recommended N rates are from 1 to 6 lb/1000 ft² per year (American National Standards Institute, 2004). According to Rose (1999), these recommendations were based on research to determine the maximum fertilizer response that was conducted from the 1950s to the 1970s. 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. TruGreen reports N application rates of 1.5 lb/1000 ft² per application (two applications per year) for ornamental plants (Rose and Joyner, 2003).

Both the Florida Green Industries BMPs manual (Florida Department of Environmental Protection, 2002) and the current FYN handbook (FYN, 2006) provide N fertilizer rate recommendations for established ornamental plants (excluding palms) in the landscape (Table 1) that generally agree with the American National Standards Institute recommendations; however, neither publication 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; FYN, 2006). In contrast, the

Table 1. Recommended annual nitrogen (N) fertilizer rates for established landscape plants in Florida (Florida Department of Environmental Protection, 2002; Florida Yards and Neighborhoods, 2006).

Level of maintenance ^a	Recommended N rates (lb/1000 ft ²) ^b
Basic	0–2
Moderate	2–4
High	4–8

^aDefinitions for basic, moderate, and high level of maintenance are not provided in the referenced documents.

^b1 lb/1000 ft² = 48.8243 kg·ha⁻¹.

UF-IFAS Extension Soil Testing Laboratory recommends N application rates of 2.3 lb/1000 ft² per year (Kidder et al., 1998) for most woody ornamentals in the landscape. The only exceptions are azalea (*Rhododendron* spp.), camellia (*Camellia* spp.), gardenia (*Gardenia* spp.), hibiscus, and ixora (*Ixora coccinea*), which have an N recommendation of 1.1 lb/1000 ft² per year. 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 (Mylavarapu and Kennelley, 2002) (Tables 2 and 3). The basis for these low P and K fertilizer recommendations for ixora is not known. Broschat (2000) determined that P and K deficiencies are a widespread and serious problem for ixora grown in Florida landscapes.

FERTILIZATION TIMING. As is the case with fertilizer rates, information on the timing of fertilizer application for nonwoody components of the landscape is notably missing. For woody ornamental plants during maintenance, the American National Standards Institute fertilization standards state that “fertilizer should be applied so that nutrients are available when roots are actively growing” (American National Standards Institute, 2004). 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 budbreak) or late fall (after leaf drop) or that the fertilizer applications be split between the two seasons (Rose, 1999). This

recommendation is similar to the calendar-based applications made by TruGreen (Rose and Joyner, 2003). According to Rose and Joyner (2003), these recommended seasonal fertilizer applications contradict 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 (grown in temperate regions) 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 used 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. There has been limited research on timing of fertilizer applications for woody plants in tropical or subtropical climates where growth can be year-round or linked to wet-dry seasonal cycles.

The Florida Green Industries BMPs manual and the current FYN handbook do not provide information about the timing of fertilizer applications (Florida Department of Environmental Protection, 2002; FYN, 2006). However, the UF-IFAS Extension Soil Testing Laboratory recommends that

P fertilizer be broadcast in one or two yearly applications, whereas N and K should be applied every 12 weeks (three times per growing season), adding 33% of the recommended amount at each application (Kidder et al., 1998). 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 for trees. A study of fertilization of southern magnolia and live oak 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-dependent. For example, research showed no response of live oak (Gilman et al., 2000) and sugar maple (*Acer saccharum*) (van de Werken, 1981) to N application during establishment, whereas southern magnolia showed faster growth after

N applications during the first year after transplant (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 posttransplant growth of crape myrtle. However, flowering was delayed in those plants grown under higher N conditions. Gilman et al. (1996) also report greater posttransplant shoot growth in burford holly (*Ilex cornuta* 'Burfordii nana') that received more N fertilizer during production. However, they also report slower posttransplant root growth for plants produced under higher N conditions. Lloyd et al. (2006) also investigated the effects of "nutrient loading" in the nursery on posttransplant performance. They found that growth of crabapple (*Malus* spp.) was enhanced when the plants were produced under high N conditions. However, their findings suggest that "nutrient loading" reduced posttransplant 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. Broschat et al. (2008) concluded that container-grown plants established slowly in the landscape as a result of N deficiency in the pine bark-based container substrate within the root ball.

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

Table 2. Mehlich-1 soil test interpretations used for environmental horticulture crops in Florida (Kidder et al., 1998).

Element	Soil test level				
	Very low (mg·kg ⁻¹) ^a	Low (mg·kg ⁻¹)	Medium (mg·kg ⁻¹)	High (mg·kg ⁻¹)	Very high (mg·kg ⁻¹)
Phosphorus	<10	10–15	16–30	31–60	>60
Potassium	<20	20–35	36–60	61–125	>125
Magnesium		<15	15–30	>30	

^a1 mg·kg⁻¹ = 1 ppm.

Table 3. Target pH and recommended annual fertilizer rates for ornamentals in Florida landscapes.^a

Crop description	Target pH	Nitrogen (lb/1000 ft ²) ^b	P ₂ O ₅ (lb/1000 ft ²)					K ₂ O (lb/1000 ft ²)				
			Very low	Low	Medium	High	Very high	Very low	Low	Medium	High	Very high
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
Azalea, camellia, gardenia, 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

^aPhosphorus and potassium rates (expressed in the oxide forms P₂O₅ and K₂O, respectively) are based on interpretation of a Mehlich-1 soil test (Kidder et al., 1998).

^b1 lb/1000 ft² = 48.8243 kg·ha⁻¹.

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 BMPs 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; FYN, 2006).

FERTILIZER TYPE. Researchers evaluated the response of hibiscus to applications of urea or slow-release N at 0, 1, or 2 lb/1000 ft² per application (four applications per year) and found that slow-release fertilizers produced more growth than soluble fertilizer applications (E.F. Gilman and P. Giaque, unpublished data). In contrast, another study showed no significant difference in growth of Japanese holly receiving 50% slow-release or soluble urea during the first 2 years after planting (Rose and Joyner, 2003). Broschat et al. (2008) found that cannas (*Canna ×generalis*) and areca palms (*Dypsis lutescens*) had higher quality (less severe nutrient deficiency symptoms) when fertilized with an 8N-0.9P-10K-4Mg slow-release fertilizer than with a mostly water soluble 24N-0.9P-9.1K product. However, there were no differences in size or quality among dwarf allamandas or pentas that were similarly fertilized.

Palms in the landscape present special problems because they are subject to a number of debilitating and even fatal nutrient deficiencies (Broschat, 2005). Broschat (2001) developed a fertilizer with an analysis of 8N-0.9P-10K-4Mg for palms growing in Florida landscapes. Palms have extensive root systems and will absorb nutrients from fertilizers applied to turfgrasses some distance away, often with detrimental results. Thus, Knox et al. (2002) and Trenholm et al. (2002) each indicate that landscape areas that are to be fertilized within 30 ft of a palm should be fertilized with the 8N-0.9P-10K-4Mg formulation.

Available information related to water use and requirements of 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% of total household consumption with an average of 64% (Haley et al., 2007), even when irrigation was restricted to 2 d per week (St. Johns River Water Management District, 2006). During the last several years, there has been an expansion of infrastructure to allow for the use of reclaimed water (treated domestic wastewater) for irrigation of urban landscapes. As of 2006, there were 216,248 home landscapes in Florida that could be irrigated using reclaimed water (Florida Department of Environmental Protection, 2007). There are some concerns related to the use of reclaimed water for irrigation of landscape ornamentals. In particular, reclaimed water may contain higher levels of salt than potable water, which may impact the health of some ornamentals. Also, reclaimed water may contain plant-available nutrients such as nitrate and phosphate. When irrigating with reclaimed water, these soluble nutrients should be considered before applying additional fertilizers (Dukes et al., 2008).

IRRIGATION TIMING. Depending on location in Florida, the irrigation of commercial and residential landscapes with potable water may be restricted as a result of widespread drought conditions. Currently, the Northwest Florida Water Management District 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 South Florida Water Management District and St. Johns River Water Management District allow irrigation 2 d per week between 1600 and 1000 HR (South Florida Water Management District, 2008; St. Johns River Water Management District, 2008). The Southwest Florida Water Management District has the most stringent watering restrictions, allowing irrigation 1 d per week (based on address) between 1800 and 0800 HR (Southwest Florida Water Management District, 2008). All restrictions allow hand watering, microirrigation of nonturf areas, and provide exceptions for newly installed landscape plant material. Fewer restrictions exist on the use of reclaimed water for landscape irrigation. In fact, only the

South Florida Water Management District restricts the use of reclaimed water; allowing irrigation between 1600 and 1000 HR daily, with the exception of Fridays when no watering is allowed (South Florida Water Management District, 2008).

IRRIGATION SCHEDULING. Many Florida homeowners are subject to watering restrictions, which limit the frequency and time of day that irrigation can be scheduled. 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-Laihar 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). Another study demonstrated that irrigation scheduling using ET controllers was able to reduce the volume of water used on mixed landscapes compared with time-based irrigation methods without negative impacts on ornamental plant growth or quality (A.L. Shober, unpublished data; M.D. Dukes, unpublished data). Rain sensor shutoff 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-Laihar et al.

(2008) demonstrated that rain sensors could reduce irrigation by 17% to 44%.

IRRIGATION STRATEGIES. More efficient use of in-ground irrigation systems could also reduce outdoor water use by homeowners. Irrigation strategies that improve the efficiency of fixed irrigation systems include: 1) conducting periodic checks of the irrigation system to ensure proper coverage and system function; 2) watering in the early morning (0400 to 0700 HR); 3) using microirrigation systems for ornamental plant beds; 4) watering less in cooler months or when there is adequate rainfall; and 5) selection and proper hydrozoning of plants. Research indicates that replacing sprinkler-irrigated areas with microirrigated ornamental areas (from 100% to 35% sprinkler-irrigated area) further increased irrigation savings to 50% (Haley et al., 2007). 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 plant performance under various water stress conditions. For example, California uses the landscape coefficient method 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 and mesquite (*Prosopis alba* 'Colorado') in containers and found that under nonstress conditions, mesquite (xeric tree) required more water than the live oak (mesic tree). 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. 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. Garcia-Navarro et al. (2004) showed that the relative water use by four woody landscape species in 3.8-L containers 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-d irrigation frequencies on growth, aesthetic quality, and establishment of three shrub species, burford holly (*Ilex cornuta*), japanese pittosporum (*Pittosporum tobira*), and sweet viburnum (*Viburnum odorotissimum*), in central Florida. Plants received 3 L of water per irrigation event, which was delivered through a microirrigation system. Results of this study suggested that plant growth and quality were similar for all irrigation treatments; however, plants watered every 2 or 4 d established $\approx$ 1 to 2 months earlier than shrubs watered once per week. Results of this study also suggest that the 60 d or less of daily irrigation allowed for establishment of new plantings during periods of water restriction is not sufficient to ensure establishment of woody ornamentals. This conclusion is supported by study results for live oak (Gilman, 2001). The shrub establishment research has been repeated at three locations throughout Florida (northern, central, and southern). Results suggest that watering every 8 d was sufficient for establishment of the shrubs in northern and central Florida. However, results

from southern Florida suggest that plants will establish within 20 to 28 weeks after transplant when watered every 4 d (Moore et al., 2009; Shober et al., 2009; Wiese et al., 2009).

Irrigation frequency seems to affect tree root growth. Frequent irrigation for 24 weeks resulted in increased root number, root cross-sectional area, and uniformity of root distribution for red maple (*Acer rubrum*) (Gilman et al., 2003). "Frequent" irrigation was defined as 38 L of water daily during Weeks 2 through 9 and then every other day during Weeks 9 through 24 in this study. Vertical distribution of roots of red maple and burford holly were affected by irrigation frequency. In both cases, root systems were shallower in plants receiving more frequent irrigation (Gilman et al., 1996, 2003). Survival of live oak also increased with irrigation frequency and duration (Gilman, 2001; Gilman et al., 1998). Irrigation for only 6 weeks after transplanting resulted in 58% survival compared with 100% survival for trees that received irrigation two times per week for several months after planting (Gilman, 2001). Irrigation frequency seems to be more critical for the survival of container-grown trees when compared with field-grown plants (Gilman, 2001; Marshall and Gilman, 1997).

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 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; Riveshield 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. Compaction 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 United Kingdom, 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 U.K. 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 (less than 7 ha) drainage areas of relatively homogeneous land uses (residential, golf course, industrial, pasture, construction site) in the Neuse River Basin (North Carolina) indicated that total N export was greatest for the construction site during the house-building phase (N at 36.3 kg-ha⁻¹) followed closely by the residential and golf course land uses. Total P export was greatest for the golf course site (P at 5.3 kg-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 (Wichman et al., 2006) and the WaterWise plant list (South Florida Water Management District, 2003). However, the information in these sources is anecdotal and does not provide actual water requirements. 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. Thus, the translation of plant water use category into an actual irrigation system run time and frequency is extremely difficult. Zoning plants according to their irrigation requirement is widely recommended and is one of the principles in Waterwise Landscaping (South Florida Water Management District, 2003), XeriscapingTM (Colorado Water Wise Council, 2008), and Florida-Friendly Landscaping (FYN, 2006). There is little information about how effective this strategy is at saving water or how frequently this principle is implemented.

A study investigating the post-establishment landscape performance of Florida native and exotic shrubs under both irrigated and nonirrigated conditions found that the plant’s indigenous status did not affect any of the parameters measured (e.g., growth, aesthetic quality) (Scheiber et al., 2008). There are numerous reports of significant variation within taxa for water requirement [e.g., maple (*Acer* spp.) (St. Hilaire and Graves, 2001; Zwack et al., 1999; Zwack and Graves, 1998), eucalyptus (*Eucalyptus* spp.) (Li, 1998; Li et al., 2000; Tuomela, 1997), pine (*Pinus* spp.) (Cregg, 1994), ash (*Fraxinus* spp.) (Abrams et al., 1990), redbud (*Cercis canadensis*) (Griffin et al., 2004), and baldcypress (*Taxodium*

Table 4. Summary of current best management practice (BMP) research areas for landscape plants, level of knowledge, and knowledge gaps in Florida.

BMP research area	Level of knowledge	Knowledge gaps
Fertilizer requirements of ornamental landscape plants in the landscape	Incomplete	No information on nonwoody species (except palms); need research during establishment and maintenance phases
Water needs of ornamental landscape plants in the landscape	Incomplete	Need statewide 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	Incomplete	Limited research showed landscapes with all ornamentals leached more nitrogen, phosphorus, and potassium; 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	Incomplete	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	Incomplete	Need solid data to indicate the impact of the Florida Yards and Neighborhoods program and other BMPs on water quality and water use

Table 5. Questions to and summary of vision statements by University of Florida–Institute of Food and Agricultural Sciences (UF-IFAS) state and county faculty with active programs in best management practices (BMPs) for landscape ornamentals (nonturf).

Question	Need or issue	Comments
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 Manage irrigation system time clocks properly Group plants according to water needs Understand the effect of irrigation practices on the watershed and water supply Provide more stringent certification programs for industry Hire certified professionals (homeowners) Enforce watering restrictions more consistently	Most problems with irrigation systems go unnoticed because watering restrictions require irrigation during nondaylight hours Effective irrigation controllers are needed to take the responsibility out of the hands of the homeowner
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?	Educate more people about how to read a fertilizer label correctly Instill more appreciation of water quality issues related to fertilizer Understand that more fertilizer is not 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 northeastern United States 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 Provide more stringent certification programs for industry Hire certified professionals (homeowners)	
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 Develop Spanish materials Educate clientele about actual plant phosphorus requirements Provide information about reclaimed water, including nutrient levels, effects on plants, salt content Develop online materials/tutorials, and so on Provide information about fertilizer sources and properties Conduct hands-on training for fertilizer application (including calibration)	Many times BMPs and local government officials are connected, so it is critical that UF-IFAS administration, specialists, and county faculty have a consistent message; this is especially important when dealing with issues that involve emotions such as water quality

(Continued on next page)

Table 5. (*Continued*) Questions to and summary of vision statements by University of Florida–Institute of Food and Agricultural Sciences (UF-IFAS) state and county faculty with active programs in best management practices (BMPs) for landscape ornamentals (nonturf).

Question	Need or issue	Comments
	Provide irrigation system training (operation and troubleshooting) Agents: Know what the most current research says and how to use it Provide public policy/administrative guidance for county faculty working with local governments and state agencies Provide training on how to conduct a water audit Landscape professionals: Know what the most current research says and how to use it Offer training on UF-IFAS fertilizer recommendations Homeowners: Provide information about how, when, and where to apply fertilizer Supply information about fertilizer products Create more demonstrations for the Florida Yards and Neighborhoods (FYN) program in neighborhoods, parks, and so on Offer training on conversion from overhead to microirrigation Local officials: Educate officials about what the science says with a consistent, unbiased message from UF	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 the University of Florida 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 based on sound agronomic/ horticulture principles
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 Homeowners association and condominium owners association covenants that require landscape materials/practices that are not “Florida-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
Other	New insect/disease pests	

distichum) (Denny et al., 2007)] and nutrient use efficiency [e.g., redbud (Zahreddine et al., 2007), pecan (*Carya illinonensis*) (Wood et al., 1998), hibiscus (Valdez-Aguilar and Reed, 2006), peach (*Prunus persica*) (Shi and Byrne, 1995), and baldcypress (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 used in the landscape is that it may be more readily adopted

and used compared with plants that are new or unknown to landscape designers and consumers.

FERTILIZER AND IRRIGATION MANAGEMENT PRACTICES. It has been suggested that the landscape management practices of homeowners and

Table 6. Strategic areas of future research involving landscape ornamentals (nonturf) 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 nitrogen (N) and phosphorus (P) applications to only situations where it is required	Determine the N and P fertilizer requirements for various landscape plants and correlate with soil test levels	Good	High P soils may dominate 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 “waterfront”
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 groundcovers, 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 Florida, plant type, plant size, soil type, and so on) on the fertilizer and irrigation needs of ornamentals	Good	Impossible to evaluate every landscape plant species; many factors need to be evaluated individually
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 potassium (K) requirements
Follow best management practices (BMPs) (including the Florida Yards and Neighborhoods program)	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

green industries professionals can have a negative impact on water quality. A U.S. Environmental Protection Agency report estimates that 12% of the nonpoint pollutant load in the United States originates in urban runoff (U.S. Environmental Protection Agency, 1995). This figure may be higher for Florida as a result of the state’s high population density; Florida

ranked eighth in the nation with a population density of 296.8 people per square mile in 2000 (U.S. Census Bureau, 2004). Nutrient losses from urban landscapes may be exacerbated in Florida as a result of rainfall, 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 + N at a rate of 73 kg·ha⁻¹ per year (two

applications) + irrigation at 15% pan evaporation; 3) medium maintenance—nonnative grasses and shrubs + N at a rate of 146 kg·ha⁻¹ per year (three applications) + irrigation at 40% pan evaporation; and 4) high maintenance—nonnative grasses and shrubs + N at a rate of 293 kg·ha⁻¹ per year (six applications) + P at a rate of 21 kg·ha⁻¹ per year + K at a rate of 36 kg·ha⁻¹ per year + irrigation at 60% pan evaporation. Results showed little or no runoff from XeriscapeTM 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 the first 0.32 cm runoff immediately after fertilizer application from high-maintenance landscapes. 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., 2001, 2005). 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. augustinegrass (*Stenotaphrum secundatum*) during the first year after planting (N at 48.3 versus 4.1 kg·ha⁻¹, respectively). The researchers reported significantly greater leachate volumes from mixed landscapes right after planting than at the end of Year 1, suggesting that the amount of N leached from mixed landscapes may decrease as plants become more established.

Future research needs

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 (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 and 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 compared with those studying other horticultural crops such as turfgrass and row crops.

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