Determining Nutrient Leaching From Ornamental Landscapes for the Development of Landscape Fertilizer BMPs

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Introduction

Non-point source pollution of surface and groundwater in urban areas continues to be a major concern as cities expand to accommodate an increasing global population (Fisher et al., 2006; Hauxwell et al., 2001; USEPA, 1999). Excessive or poorly-timed fertilization of residential landscapes can result in water quality degradation as nutrients, particularly nitrogen (N) and phosphorus (P), are lost in leachate or runoff. Line et al. (2002) reported that average total N and P export from a residential setting was 256% greater than from wooded sites.

Excess nutrient loading to water bodies can accelerate eutrophication, which results in excessive algae growth, death of fish and other aquatic species, and degradation of overall water quality (Howarth, 1988). Burkholder et al. (1992) reported surface-water quality degradation was seen with N levels as low as 0.05 to 0.1 mg nitrate per liter. Although fertilizer is not the sole contributor to N exports from residential landscapes it is the most direct and deliberate addition of these nutrients to the urban ecosystem. As such, fertilizer management practices (e.g., application rates, timing of application, and method of application) must be monitored closely to ensure that fertilizer application does not exceed the specific N requirements of growing plants.

Federal, state, and local lawmakers have begun addressing environmental concerns surrounding fertilization with a range to season- and formulation- specific bans around the country in areas with impaired water bodies that are linked to elevated nutrient levels (e.g. Chesapeake Bay, Gulf of Mexico delta-Mississippi River basin, Florida Everglades). In 2007, the Florida Legislature appointed the Florida Department of Agriculture and Consumer Services to create the Florida Consumer Fertilizer Task Force, which helped develop recommendations for statewide policies and programs regarding consumer fertilizer use (Hartman et al., 2008). As state agencies worked to implement plans for the statewide protection of surface and groundwater, many local governments began to implement their own preventive measures via county and city-wide fertilizer ordinances. Several counties in the Tampa Bay region and other areas of Florida have adopted a summer fertilization blackout period with the goal of decreasing nutrient losses during the rainy season, which coincides with the period of active plant growth in Florida. The full impact of these fertilizer blackout periods on the environment has yet to be seen as few scientific studies have been conducted.

Beyond directly limiting fertilization, many industry and government organizations have created standards or best management practices (BMPs) that help guide landscape maintenance efforts. For example, the American National Standard Institute's (ANSI) A300 Tree Care Standard for Fertilization (ANSI, 2011) and the Florida-friendly Landscaping™ Green Industries BMP manual (Florida Department of Environmental Protection, 2010) provide standard recommended fertilizer application rates and other guidelines for maintaining woody ornamentals. Industry consensus and a limited body of research serve as the basis for these published application rates.

Recently, Shober et al. (2013) found N application rates of 98 to 195 kg ha^{-1} (2 to 4 lbs N per $1000ft^2$) were sufficient to maintain acceptable plant growth (i.e., volume or size index, chlorophyll content, and dry weight) and visual quality for woody ornamental landscape plants grown in Florida. Similarly, Werner and Jull (2013) reported N application rates of 49 to 146 kg ha^{-1} (1 to 3 lbs N per $1000ft^2$) were able to support the healthy growth of young and mature Hackberry (*Celtis* occidentails) trees. Both of these study reported optimal fertilizer application rates within the ANSI's standard recommendation rate range of 49 to 195 kg ha^{-1} (1 to 4 lbs N per $1000ft^2$) annually for woody ornamentals (ANSI, 2011).

With the exception of the recent work by Werner and Jull (2013), the majority of the research guiding woody ornamental fertilization recommendations has focused almost exclusively on optimizing plant aesthetics. Far fewer studies have looked at the environmental impacts when using these recommended rates. This research investigates the effects of application rate, method, and timing on N use efficiency of woody ornamentals and N leaching from urban residential planting beds. Using large-volume lysimeters, N use efficiency and leaching were tracked from initial shrub installation to establishment in the landscape, offering a unique insight into the changing nutrient demand and capture potential of woody ornamentals over time. Overall, data from this study will be used for validating or adjusting current fertilizers standards and BMPs for woody ornamentals by supplying recommended fertilizer rates that not only take in to account the aesthetics of the ornamentals but also the possible impacts on the surrounding environment.

MATERIALS AND METHODS

Location and Lysimeter Construction

The experiment was conducted from 9 May 2012 to May, 2015 at the University of Florida Institute of Food and Agricultural Sciences (UF-IFAS) Gulf Coast Research and Education Center in Wimauma, FL (USDA hardiness zone 9a). Thirty-nine 1135-L (300-gallon) stock tanks (Rubbermaid Commercial Products LLC, Winchester, VA) were uniformly elevated on cinder blocks and fitted with drainage and leachate collection systems to serve as lysimeters (Fig. 1). These lysimeters, were filled with St. Johns fine sand [sandy, siliceous, hyperthermic Typic Alaquods) (U.S. Department of Agriculture, 2004)] subsoil collected from a local borrow pit. This fill is representative of material commonly used as ‘topsoil fill’ in new residential landscape construction areas in west-central Florida (Shurberg et al., 2012). Lysimeters were filled in order to achieve a bulk density of 1.5 g cm^{-3}. Each plant was irrigated at the rate of 4.35 L (1.15 gal.)

of water applied twice per week starting 16 May 2012. Precipitation data was collected using local weather station reported data (UF, 2013).

Fig.1. Sweet viburnum (Viburnum odoratissimum) planted in elevated lysimeters. Leachate from each lysimeter was pumped into an adjacent collection tank for sampling. In the absence of rain, supplemental irrigation was supplied by a spray stake (01SSBK-B, Netafim USA, Fresno, CA) irrigation system.

Two sweet viburnum (*Viburnum odoratissimum*) shrubs (Liner Source INC, Eusits, FL) grown in 3.78-L (1-gallon) containers were planted into each lysimeter on 10 May 2012. An automated spray irrigation system with irrigation controller (Hunter SVC, San Marcos CA) and flow meter (c700; Elster AMCO Water Inc., Ocala, FL) was installed to maintain soil moisture in the absence of rain.

Fertilizer Rate, Timing, and Application Method

Shrubs were fertilized every twelve weeks with a polymer coated urea fertilizer (Polyon, 42-0-0; Harrell's, Lakeland, FL) containing 33.6% slow release N. Fertilizer was applied per plant (i.e., the calculated rate for the planting bed/lysimeter was divided between the two plants and applied underneath each plant's respective canopy/dripline) or broadcast across the entire surface of the planting bed/lysimeter to evaluate the effect of application method on nutrient leaching. Shrubs receiving a broadcast application were fertilized to maintain annual N rates of 98, 196, and 293 kg N ha^{-1} (0, 2, 4, and 6 lb N per 1000 ft^2). Shrubs reciving a per plant application were fertilized with 78.4, 156.8 and 234.4 kg N ha^{-1} (80% of the broadcast rate). The fertilizer application rates were selected based on past research that evaluated woody ornamental growth response and visual quality (e.g., SI, quality, SPAD) in response to N fertilizer at various application rates (Shober et al. 2013). Scheduling of fertilization was assessed with and without a locally-enforced summer blackout period (Manatee County, FL). Regular fertilization treatments (no blackout period during rainy season) occurred every 12 weeks based on manufacturer release curve information beginning on 6 Aug. 2012 for a total of 4 applications annually. The blackout fertilization treatments (no fertilizer applied from 1 June-30 Sept 2012 based on local ordinances) occurred every 12 weeks beginning on 1 Oct. 2012 for a total of three annual applications.

Leachate Collection and Analysis

Leachate was collected and measured daily as needed starting 6 Aug. 2012. Any daily leachate collected was sampled and stored frozen for until analysis. Weekly flow-weighted composite leachate samples (weighted by daily volume) were analyzed colorimetrically for nitrate + nitrite-N (NO_3+ NO_2-N) and ammonium-N (NH_4-N) using a discrete automated analyzer (AQ2; Seal Analytical, Burgess Hill, UK). Composite samples were also analyzed for total Kjeldahl nitrogen (TKN) using a micro-segmented flow analyzer (Astoria 2 Analyzer, Astoria Pacific International, Clackamus, OR).

Plant Growth and Quality Measurements

Plant size measurements (height, widest width, and width perpendicular to widest width) were taken at planting and every six weeks until experiment completion. The product of these three measures served as a size index (SI) to quantify plant growth over time. Dry shoot weight will be measured at the end of the study period.

Quality ratings were recorded every six weeks. Quality ratings considered plant size, canopy density, chlorosis, and dieback for each individual plant on the following scale: 0 indicated a dead plant; 1 indicated a poor quality plant (low canopy density, small plant and chlorosis); 2 indicated a below average quality plant (significant dieback, lower canopy density and chlorosis); 3 indicated an average quality plant (moderate dieback, acceptable canopy density and chlorosis); 4 indicated an above average quality plant (minimal dieback or chlorosis, above average canopy density); and a quality rating of 5 indicated an outstanding plant (dense leaf canopy and no nutrient deficiencies or dieback). Additionally, chlorophyll content (SPAD) was estimated every six weeks using a portable chlorophyll meter (SPAD-502, Minolta Corp., Ramsey, NJ). Three readings were taken per plant and averaged.

Experimental Design and Analysis

The study was arranged as factorial design with three levels of fertilization (i.e., 2, 4, and 6 lb N per 1000 ft^2), two levels of application method (i.e., per plant and broadcast), and two levels scheduling (i.e., regular and blackout). Each treatment combination was replicated three times (total n = 36). Additionally, three planted plots/lysimeters received no fertilizer to serve as an untreated references (i.e., 0 lb N per 1000 ft^2). These reference plots provided baseline measures for the leachate responses. Prior to analysis, measurement averages for the three controls were subtracted from the response measures (i.e., NH_4-N, NO_3+NO_2-N, TKN) allowing us to gauge the additive effect of each treatment combination and the relative differences among them. Data for this project was assessed separately for two distinct development stages: initial plant establishment (through 52 weeks after planting) and long-term plant maintenance. In this report, data for the second half of the establishment period is included up to week 52.

Cumulative nutrient loads (i.e., NH_4-N, NO_3+NO_2-N, TKN) for the 52-week establishment period and subsequent long-term maintenance period were derived from the leachate analysis. These responses were analyzed via multivariate analysis of variance (MANOVA) followed by a series of univariate analyses of variance (ANOVAs) in R [version 3.0.0 (R Core Team, 2013)]. Plant SI and SPAD measurements were analyzed as repeated measures ANOVAs using the nlme (Pinheiro et al., 2013) package in R. Plant quality was analyzed using the Friedman test – a nonparametric equivalent to repeated measures ANOVA (de Mendiburu, 2013). To meet the requirements of this test, the 12 unique factorial combinations were coded as 12 different treatments. All underlying assumptions were checked for methods listed above prior to reporting. All inferences for these analyses above are based on an α=0.05 level of type I error.

Results and Discussion

Establishment Period (First 28 Weeks)

NUTRIENT LEACHING. Neither NH_4-N nor TKN loads varied much with regard to the main effects or their interactions. For ammonium, fertilization method of delivery [i.e., per plant or broadcast (P = 0.0578)], as well as the interaction between rate and delivery method (P = 0.0532), were marginally significant – though not sufficiently so, given our rejection criteria, to warrant further means separation. Similarly, only fertilization method (P = 0.0205) significantly affected TKN loads in leachate, with the per plant application generating greater leachate TKN loads than broadcast application.

These results come as little surprise. The high temperatures (median average daily temperature of 77.8°C) experienced during the 28-week study period likely accelerated the ammonification and nitrification processed, quickly converting urea N in the fertilizer to ammonium, which was then converted to nitrate if not bound to the soil. None of the plants were mulched after planting. Without this addition of plant material to the nutrient-poor fill soil, TKN (a measure of ammonium and organic nitrogen) loading was similarly limited.

More significant was the impact of fertilization regime on NO_3+NO_2-N loading in leachate (Table 1). Nitrate loads varied by rate (P<0.0001), method of application (P<0.0001), schedule [i.e., regular or blackout (P<0.0001)], the interaction between rate and method (P=0.0017), the interaction between rate and schedule (P<0.0001), the interaction between method and schedule (P<0.0001), and the three-way interaction between all main effects (P=0.0055).

Table 1. Cumulative nitrate (NO_3+NO_2-N*) loads (mg ± SE) for fertilized planting beds over 28 wks (i.e. Establishment Period). Beds were planted 10 May 2013 with (Viburnum odoratissimum) shrubs. Slow release fertilizers were applied to maintain an annual rate of 2, 4, or 6lbs N per 1000 ft*^{2}*. Shrubs under a blackout schedule received no fertilization from 1 June to 30 September. Broadcast fertilization was applied across the entire planting surface. Per plant fertilization was applied directly beneath the shrub canopy.*

Fertilizer Annual N Rate and Application Method	**Leachate NO_3+NO_2-N Load**	
	Regular	**Blackout**
	mg	
2 lb/1000 ft^2		
Per Plant	225 ± 32.9	30.5 ± 12.7
Broadcast	405 ± 39.9	47.5 ± 24.6
4 lb/1000 ft^2		
Per Plant	449 ± 51.0	23.2 ± 28.1
Broadcast	1200 ± 27.7	109 ± 123
6 lb/1000 ft^2		
Per Plant	1201 ± 20.5	63.7 ± 8.90
Broadcast	1682 ± 48.0	45.6 ± 34.9

In looking at the averages for each treatment combination (Table 1), the nitrate loading responses are distinct for each of the main effects. Loading increases as fertilization rate increases, when using a broadcast fertilization method, and when adhering to the traditional (no blackout) fertilization schedule. The significance of the interactions reflects the differing magnitudes in which loading increases or decreases when comparing treatment combinations. For example, a blackout period has less of an impact on nitrate loads when applying fertilizer at the 2 lb/1000 ft^2 annual N rate (as compared to the other rates), especially when using the per plant method. However, a blackout period greatly limits nitrate loading at the highest rate, especially when using a traditional broadcast application method.

While these preliminary findings are promising, their use comes with one notable *caveat* – the cumulative leachate results in their current form do not include data from heavy rain events. The initial lysimeter design included a 114 L (30 gallon) leachate collection reservoir. This reservoir was sufficient to collect leachate for most rain events under 5 cm (2 in.), depending on the time elapsing since the last rain event. However, during the measurement period several storms had precipitation levels above this 5 cm capacity and, while concentrations of ammonium, nitrate, and TKN were recorded, we were not able to measure leachate volume given overflow. These volume measurements are needed to calculate the final load. Larger, 208-L (55-gallon) containers were added for the second season (currently underway), offering a total capacity of 322 L (85 gallons).

Given this initial limitation, the results above only include cumulative loads for small-to-moderate rainfall events. Actual nitrate loading for the 28-week study period and differences among the treatment combinations are likely greater than currently reported. Once more data is collected using the larger-capacity leachate reservoirs, we will be able to model the missing leachate volumes and use regression imputation to complete the data set. This refined analysis will be provided in the final project report and published journal article.

PLANT GROWTH AND QUALITY. Plant SI did vary by week ($P < 0.0001$), but did not vary significantly by fertilizer rate ($P = 0.6240$), method ($P = 0.9454$), or schedule ($P = 0.3710$). Similarly, SPAD measurements varied by week ($P = 0.0160$), but not by fertilizer rate ($P = 0.8354$), method ($P = 0.5492$), or schedule (P = 0.1032). Plant quality, a visual ranking which factors in both size and appearance (including greenness), did not vary by treatment ($P = 0.1493$)

These results reflect the short duration of this initial test period. Until the initial stress of planting is overcome, shrub roots will be largely confined to their original growing mix from the container. This mix is largely composed of organic material and may contain some residual fertilizer from production. Overtime as plants recover from transplanting and grow into the surrounding fill sand, we expect to see measurable differences in plant size and quality. Pairing this response with the leachate data will help determine the optimal rate and application method for balancing aesthetic and environmental demands.

End of Establishment Period (29 Weeks and Beyond)

NUTRIENT LEACHING. As seen during the beginning of the establishment period, neither the NH_4-N nor the TKN loads varied much with regard to the main effects (i.e., rate, method of delivery, or schedule) or their interactions during Wks 29-52 (lowest *P*-value for all factors and interactions = 0.1470). Similarly, this non-significance contrasted with what was observed with the NO_3+NO_2-N loading response. Cumulative nitrate loads differed significantly by rate (P = 0.0355), though method of delivery (*P* = 0.1575) and schedule (P = 0.6366) were not found to be significant. Additionally, neither the three-way nor any of the two-way interactions between the three main effects was found significant (lowest *P* = 0.2347).

As anticipated, NO_3+NO_2-N loading was greatest in the lysimeters where fertilization was applied at the 6 lb rate and least in the lysimeters where fertilization was applied at the 2 lb rate (Table 2). The nitrate loading associated with the 4 lb rate was not significantly different than either of the other two rates.

Table 2. Cumulative nitrate (NO_3+NO_2-N*) loads (mg ± SE) for fertilized planting beds after establishment and continuing through the first year of the study (i.e., wks 29-52). Beds were planted 10 May 2013 with (Viburnum odoratissimum) shrubs. Slow release fertilizer was applied to maintain an annual rate of 2, 4, or 6lbs N per 1000* ft^2*. Shrubs under a blackout schedule received no fertilization from 1 June to 30 September. Broadcast fertilization was applied across the entire planting surface. Per plant fertilization was applied directly beneath the shrub canopy.*

Fertilization Rate		
2 lb/1000 ft2	**4 lb/1000 ft2**	**6 lb/1000 ft2**
106.0 ± 36.44 b[z]	242.7 ± 60.04 ab	321.1 ± 60.04 a

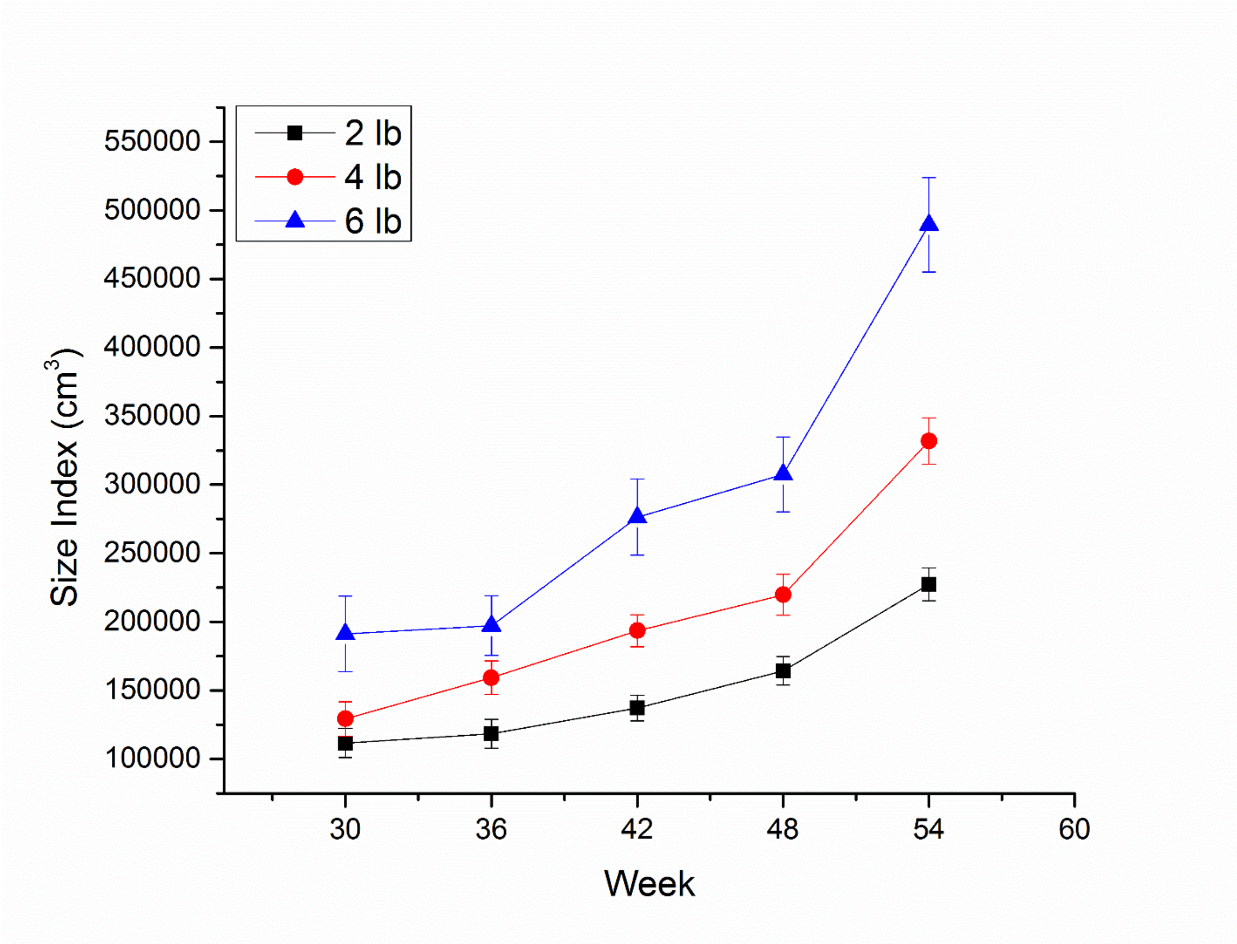
[z]Nonsignificant differences are denoted with the same letter. Mean separation conducted using a Tukey's Honestly Significant Difference (HSD) test with an α=0.05

Overall, loading was reduced for all of the rate factor levels during the dry season months as compared to the initial loading seen in Wks 0-28 (Tables 1 and 2). As this response measure is linked to both volume of leachate and concentration of nitrogen in the leachate, the results are intuitive.

Given the timing of the initial planting in Year 1, fertilization for the blackout treated plants did not occur until after the summer blackout period. It will be interesting to see if the initial loading differences seen in Wks 0-28 (Table 1) are replicated this summer after several months of slow-release fertilization. The loadings as summarized in Table 2 suggest this trend will continue, even if at a reduced rate.

PLANT GROWTH AND QUALITY. Plant size index varied significantly by fertilizer rate (P = 0.0012), fertilization schedule [i.e., blackout or regular (P = 0.0039)], and week (P < 0.0001). In addition, there were significant interactions between fertilization rate and method (P = 0.0474) and between fertilization rate and week (P < 0.0001)

Fig. 2 Interaction between fertilization rate and week with regard to the plant size index (crown volume) response.

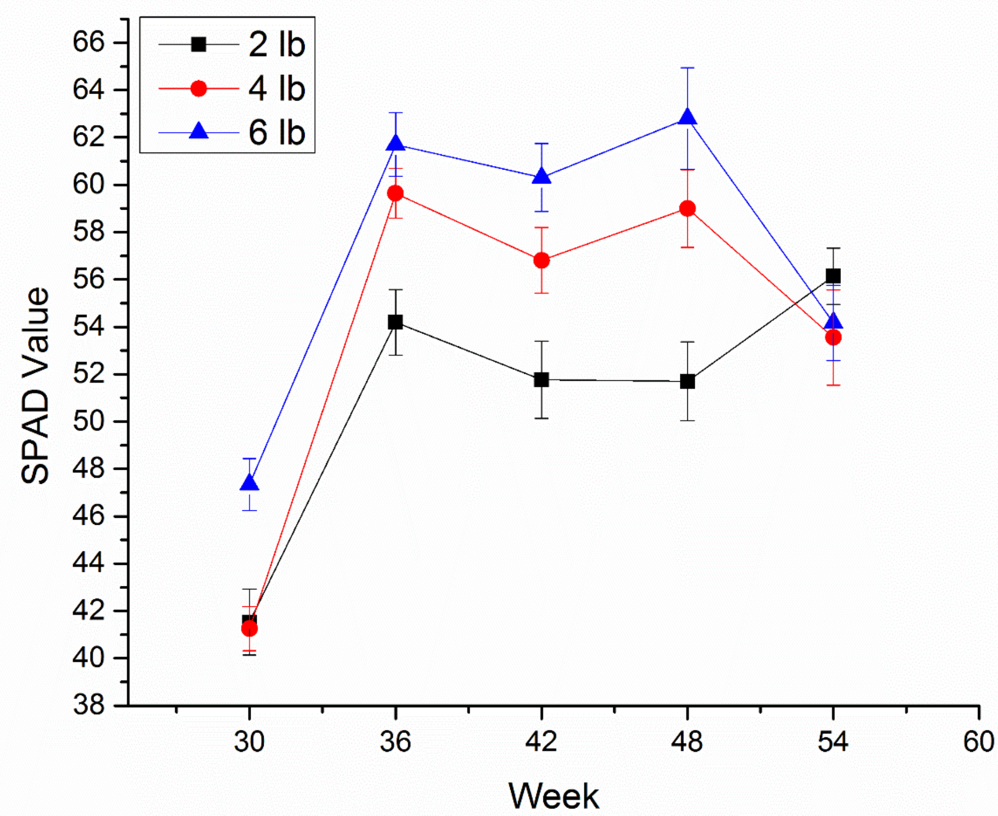


The interaction between rate and week ($P < 0.0001$) appears to be largely driven by an increasing divergence in SI over time between the three fertilization dosages (Fig. 2). While all are increasing volume over time, the rate of increase is greater for the 4 and 6 lb N per 1000 ft^2 rates.

SI varied significantly by fertilization schedule ($P = 0.0039$). Though not detectable in the first measurement period (see results for establishment period above), the initial fertilization applied to the regular schedule plants (as opposed to blackout plants) offered a significant growth benefit which persisted throughout the rest of the year (i.e. Wks 29-52).

SPAD measurements varied significantly by fertilizer rate ($P = 0.002$), method of application ($P = 0.0300$), and measurement week ($P < 0.0001$). Additionally, there were significant interactions between week and fertilizer rate ($P = 0.0009$) and schedule (i.e. blackout or regular) and week ($P = 0.0145$).

Fig. 3. Interaction between fertilization rate and week with regard to SPAD value (plant greenness/relative chlorophyll content) response.



SPAD values generally increased with fertilization rate. For Wks 36, 25, and 48, this response appeared relatively stable (Fig. 3); however, there was some crossing with the 2 lb rate averaging higher SPAD values than the 4 lb treated shrubs in Wk 30 and both the 4 and 6 lb treated shrubs in Wk 54 (though preliminary visual assessment indicates the treatments noted above did not differ significantly for these two weeks). We will continue to monitor this for the duration of the experiment. Maintenance records (i.e. the fertilization schedule) offer little insight into the patterns noted above (Fig. 3).

As mentioned above, SPAD measurements also differed by method of application (*P* = 0.0300). The mean SPAD values for the per plant-fertilized shrubs were higher than the broadcast-fertilized shrubs in all but the final measurement week, indicating that per-plant fertilization may offer a more precise, concentrated fertilization dose to recently-established woody ornamentals.

Finally, visual plant quality differed significantly ($P < 0.0001$) by the combined treatment (which included rate, method, and schedule). This quality rating includes both aspects of foliar color and plant size. The results displayed in Table 3 are similar to what was noted earlier in the SI and SPAD results. However, these differences are more biologically significant as they represent visual differences which could potentially influence the value of the plant in the landscape.

Table 3. Median, Quartile 1, and Quartile 3 plant quality ratings from weeks 29-52.

Fertilizer Rate	**Fertilizer Method**	**Fertilizer Schedule**	**Median Rating**	**Q1**	**Q3**	**Statistical Grouping**[z]
6 lb	Per Plant	Regular	4	4.0	4.5	a
6 lb	Per Plant	Blackout	4	3.75	4.25	ab
6 lb	Broadcast	Blackout	4	3.5	4.25	bc
4 lb	Per Plant	Regular	3.5	3.25	4.0	c
6 lb	Broadcast	Regular	3.5	3.0	4.0	cd
4 lb	Per Plant	Blackout	3.5	3.0	3.5	de
4 lb	Broadcast	Blackout	3	3.0	3.5	de
4 lb	Broadcast	Regular	3	2.75	3.5	ef
2 lb	Per Plant	Blackout	3	2.75	3.0	fg
2 lb	Per Plant	Regular	3	2.5	3.0	fg
2 lb	Broadcast	Regular	2.5	2.5	3.0	g
2 lb	Broadcast	Blackout	2.5	2.5	3.0	g

[z]Nonsignificant differences are denoted with the same letter. Mean separation conducted at an α=0.05

The findings for this latest section highlight some of the longer-term impacts of our fertilizer rate and application method treatment combinations. As the shrubs continue to grow, it will be interesting to see if these initial trends and differences in the early maintenance period remain stable, increase, or subside.

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