

**Growth, nitrogen content, and leaching from container-grown *Cornus* and
Ilex amended with combinations of moisture and fertilizer**

by

Thomas Lee Schultz

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Graduate College
Iowa State University

This is to certify that the Master's thesis of
Thomas Lee Schultz
Has met the requirements of Iowa State University

Signatures have been redacted for privacy

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ABSTRACT

Nitrate (NO_3^-) is a major pollutant in much of the surface water in the nation. High concentrations of NO_3^- are common in runoff from container-production nurseries. Our objective was to investigate effects of four fertigation treatments (Miracle Gro Excel™ 21N–2.2P–16.6K \times 65 or 75% media moisture, respectively) combined with three rates of controlled-release fertilizer (CRF) (Osmocote® 18N–2.6P–9.9K, 8-9 month release) on nitrate (NO_3^-) runoff, N uptake, and growth of winterberry (*Ilex verticillata* L.'Stoplight') and red-osier dogwood (*Cornus sericea* L.). In 1999, 12 treatments were arranged in a randomized block design with eight replications. Treatment combinations of fertigation and CRF [(WSF $\text{mg}\cdot\text{L}^{-1}$ applied at 65 or 75% media moisture)/ CRF (g) $\text{N}\cdot\text{pot}^{-1}$] were a 4×3 factorial for each species: [(1.84, 3.62, 4.98, or 6.08) \times (0, 0.57, or 1.15)] for *I. verticillata* and [(3.45, 4.09, 7.73, 8.48) \times (0, 0.57, 1.15)] for *C. sericea*. Shoot dry weight (SDW) and shoot nitrogen content were higher in *I. verticillata* with increased rates of fertigation. Root dry weight (RDW) decreased as CRF rates increased. Root-to-shoot ratio (R:S ratio) and N efficiency decreased as fertigation and CRF increased. In *C. sericea* SDW, RDW, and R:S ratio were not affected by fertigation or CRF treatments. Shoot N increased as CRF rate increased and root N increased as fertigation rate increased. As CRF rate increased, NO_3^- leaching increased for both *I. verticillata* and *C. sericea*. These data suggest that fertigation and CRF management are important to increase growth of *I. verticillata* while in this experiment *C. sericea* did not respond to increasing N input. Applying higher rates of CRF in addition to fertigation resulted in higher NO_3^- -N leaching for both species.

CHAPTER 1. GENERAL INTRODUCTION

INTRODUCTION

Nitrate nitrogen creates problems as it diffuses into the ecosystem in high concentrations. Iowa is currently the second highest user of supplemental nitrogen in the United States and has problems dealing with nitrate (NO_3^-) in ground, surface, and drinking water. Lowering NO_3^- concentrations in drinking water is a priority because, according to EPA drinking water regulations, NO_3^- concentrations above 10 ppm are harmful to people and animals. Nationally, the horticulture and agriculture industries are shown to contribute to point and non-point source pollution (Brand et. al, 1993). The drinking water issue, along with substantial fines that can be imposed on nurseries releasing runoff with high concentrations of nitrate from their production areas, has become the major catalyst spurring research on reducing fertilizer and water use in the nursery industry.

Producers of container-grown plants depend on fertilizer and irrigation to grow high quality plants in as short a time period as possible. Unfortunately, mineral elements not utilized by the plant can leach out of the growing medium. The leachate produced from container nursery operations can pollute ground and surface water making this water unsuitable for use as drinking water (Yeager et al., 1992). Leachate containing high NO_3^- concentrations currently is managed by either allowing runoff to leave the nursery premises and percolate into the ground or collecting for recycling. Many growers have become interested in reducing the amount of fertilizer and water used in the nursery. In the long run, this will reduce water pollution and expenses involved with fertilizer and water loss.

Various fertilizer and irrigation application techniques that supply essential mineral elements and reduce leachate recently have been the subject of study (Kabashima, 1993; Ruter, 1992). In the past, growers have relied on liquid fertilization (LF) programs to provide nutrients to container-grown plants. Presently, growers use more controlled-release fertilizers (CRF's) because of the advantages, such as lowered NO_3^- leaching, they offer over liquid fertilization (Cabrera, 1997).

Because fertilizer often is applied in irrigation water, fertilization and irrigation practices can equally effect plant growth and NO_3^- in runoff in container nursery production. The main irrigation strategies employed by nursery growers are overhead irrigation, drip irrigation, and hand watering. Overhead irrigation often is the least costly to install, but requires over-application because much of the water is lost around containers. Drip irrigation systems are versatile, they apply water directly to the media surface, and can be set up in a wide variety of patterns. Hand watering is still used in some nurseries as the main method of irrigation.

Most irrigation systems are set up using a timer system versus watering plants based on their evaporative demand. Timed systems do not allow for system shutoff when container capacity has been reached and subsequently leads to over-irrigation. Often, this over-irrigation produces a high leaching fraction and carries NO_3^- out of the container media. Tensiometers can be used to manage irrigation cycles by measuring moisture content within containers, initiating irrigation only when the media has dried, thereby reducing leaching while supplying plants with adequate moisture. Using a tensiometer-based irrigation and fertigation system, our research objective was to determine how different combinations of

irrigation, controlled-release fertilizer, and water-soluble fertilizer affect plant growth, N uptake and NO_3^- leachate of two woody ornamental shrubs growing in containers.

THESIS ORGANIZATION

The first chapter is devoted to a review of the literature. Included in the review are reviews on container nursery production, irrigation strategies, and fertilization practices. The second chapter consists of one manuscript that has been prepared for HortScience. The final chapter contains the general conclusions.

LITERATURE REVIEW

Plant-Growth Management.

Plant-growth management is a concept used to produce crops. Methods of crop production are continually evaluated and fine-tuned so plant growth is maximized and negative effects (such as nitrate accumulation in groundwater) are minimized. Point and non-point source pollution with NO_3^- has become an issue in agriculture and horticulture areas. The time between irrigation events, fertilizer application rate, and type of fertilizer used will affect both plant growth and nutrient leaching from containers (Alexander, 1993). The question is, how can water and fertilizer be managed to efficiently produce high quality plants, while minimizing leaching of nitrate?

Container nurseries rely on irrigation for most of their water needs. Using irrigation as a primary water source is costly because of irrigation system setup, maintenance, and cost of water. Improperly managed irrigation can contribute considerably to runoff from nurseries.

Fertilization is essential for container-grown plants because most media used for container production is soil-less and has limited nutrient levels. Most nutrients in nurseries are supplied in the form of synthetic fertilizers which come from a variety of sources and in a variety of formulations (Broschat, 1995; Gouin and Link, 1973; Niemiera and Leda, 1993; Rathier and Frink, 1989; Ruter, 1992; Sartain and Ingram, 1984; Yeager and Ingram, 1985).

Irrigation and fertilizer effects on runoff from nurseries

Irrigation.

Different types of irrigation systems are used in container-production nurseries. Hand watering is used for single high-investment plants and small groups of plants, but is labor intensive. Overhead irrigation is common in many nurseries, but can lead to excessive runoff because water falls around pots as well as into them. Drip irrigation uses small capillary tubes to deliver water directly into pots eliminating water loss in between containers and reducing runoff (Kabashima, 1993). Drip irrigation systems usually require more maintenance than overhead systems. Subirrigation allows growers to irrigate to container capacity by capillary action without runoff. These systems frequently are used in greenhouses, but rarely are used outdoors because of their initial cost and permanence.

Growers are more interested in watering regimes that reduce or eliminate runoff in response to drinking water contamination by nitrate. For container crops, many nursery growers use timer-controlled drip irrigation to deliver a predetermined amount of water to plants at hourly or daily intervals. Using drip irrigation instead of overhead irrigation can improve efficiency of the system by up to 75% (Beeson and Haydu, 1995). Drip systems

also give the grower the ability to micromanage nursery areas for less leaching and nitrate-nitrogen loss by being able to irrigate in small, specific areas at different times.

Cyclic irrigation can be programmed on any base irrigation system, overhead or drip, but instead of providing a certain amount of water to saturate the media at predetermined schedules, it provides split applications of the same amount of water several times throughout the day. Cyclic irrigation of sub-volumes of water is more efficient than providing one single volume because water absorption of media becomes limiting when high volumes of water are applied (Beeson and Haydu, 1995). They also determined cyclic irrigation is not beneficial unless the moisture provided by one irrigation becomes limiting in a day. A study by Fare et al. (1994) showed that leachate volume was reduced by 13% when 'Compacta' Japanese holly (*Ilex crenata* Thunb.) plants were irrigated with three applications of 6 mm (2 mm 3 times a day) with a 10 minute duration instead of one continuous application of 6 mm for 30 minutes. Another study stresses the importance of knowing pre-irrigation substrate moisture content. Karam and Niemiera (1994) found that water application efficiency can be improved by using a cyclic irrigation method and relating that to the pre-irrigation substrate moisture content. Detecting the pre-irrigation moisture content of media and using that information to determine watering need is the main idea behind environmentally activated irrigation.

Environmentally activated irrigation also can be set up for any type of irrigation system. The difference is the irrigation controller. Instead of a timer that delivers water at specified times throughout the day, a tensiometer is installed in a representative container and is connected to the control valve of the irrigation system. The tensiometer measures water potential of the media and the irrigation system is turned on when the tensiometer senses that

media moisture potential falls below the programmed critical level (Lieth and Burger, 1989; Andersen and Hansen, 2000). Other sensors employed in environmentally controlled irrigation systems are: rain sensors that shut off irrigation if a certain amount of moisture has been supplied by precipitation, wind sensors that detect if irrigation should be turned on under current conditions, temperature sensors, and flow sensors that stop irrigation in case pipes break.

Fertilizer.

Main factors converging to affect nutrient leaching are plant material (if the plant is a high or low nitrogen user), amount of water applied, amount and type of fertilizer applied, and placement of fertilizer. When fertilizers are applied in conjunction with an irrigation system, nutrients are taken up by the plant, immobilized in the media or leached out of the container. NO_3^- is the primary nutrient that leaches and it is causing concern for drinking water safety.

Release rates of most coated fertilizers are temperature dependent and release nutrients faster at higher temperatures. This is dependent on the coating being used to control release rate, but ultimately depends on how temperature affects the vapor pressure of water. The release mechanism of many controlled-release fertilizer (CRF) capsules operate on the pressure of water vapor entering the capsule, condensing, and subsequently dissolving the fertilizer salt. The saturated salt solution within the capsule then has a lower vapor pressure than that of pure water, which creates an uptake gradient of water into the capsule. The solution inside gradually increases in volume until the capsule expands, dilating pinholes in the coating which allows fertilizer solution to flow out (Ahmed et al., 1963). Many CRF's

have a specified release rate at a certain temperature. For example, Osmocote 18N–6P–12K, 8 to 9 month fertilizer is supposed to release 100% of its nutrients at 70° F over the stated period. If the temperature increases by 16° F, the functional life of the fertilizer is cut in half (Harbaugh and Wilfret, 1982). Moisture content of media near field capacity has little effect on the vapor pressure of water (Kochba et al., 1990). This suggests that moisture is less important than temperature in release of fertilizer from fertilizers encapsulated with polymer-coated fertilizers.

Synthetic fertilizers that are applied to container crops usually have a constituent of nitrogen in the NO_3^- , urea, or ammonium form. Ideally, applied fertilizer should release nutrients corresponding to the growth needs of a particular crop. Brand et al. (1993) found that crop requirement of nitrogen can significantly affect leachate NO_3^- characteristics. The study compared nitrate levels in the soil profile under a fast growing versus a slow growing container crop, [silky dogwood (*Cornus amomum* Mill.) versus Cary's Red rhododendron (*Rhododendron* 'Cary's Red'), respectively] topdressed equally with 60 g Osmocote 18N–2.6P–10K. They found consistently higher levels of N under the slow growing crop, suggesting that rate of growth has an impact on nitrogen leaching dynamics. Rose and Biernacka (1999) studied the influence of fertilizer rate on growth patterns and nutrient accumulation in Freeman maple (*Acer x freemanii* E. Murr. 'Jeffersred'). The study compared three fertilizer rates (50, 100, and 200 $\text{mg}\cdot\text{L}^{-1}$) from soluble fertilizer 20N–8.7P–16.6K and 24N–3.5P–13.3K for experiment one and two, respectively. They found that as plants increased in size, they increased their N uptake. The highest N uptake corresponded with the time period when the plant's major emphasis was leaf growth.

NO_3^- leaching is related to the amount and number of fertilizer applications. Rathier and Frink (1989) found that using two split applications of CRF instead of a single application at the same rate, can reduce nitrogen release and consequently, the amount of NO_3^- in leachate. Yeager et al. (1992) states that using split CRF applications slows NO_3^- leaching. Fertilizer release dynamics of CRF also affect the fate of NO_3^- in the environment. Hershey and Paul (1982) found that when CRF was applied to chrysanthemums, most nitrogen leaching occurred within the first half of the crop cycle. It was found that when applied to *Ilex cornuta* Lindl. & Paxt. 'Burfordii', CRF's do not maintain uniform nutrient release rates throughout the growing season (Ruter, 1992). Broschat (1995) reiterated this finding but added that reducing fertilizer application in the first part of the growing cycle could reduce NO_3^- leaching without reducing plant growth. Not all studies agree that split application of fertilizer reduce nitrogen in leachate. Reapplication of CRF to containers (after an initial application earlier in the season) can increase the amount of nitrogen leached from holly by up to 42% (Shiflett et al., 1994).

In-pot placement of fertilizer also can affect NO_3^- leaching. The two main placement strategies for CRF are incorporation (mixing into the media before potting) or topdressing (applying fertilizer to the top of media in each container after planting). Topdressing usually results in lower leaching of nitrogen than incorporation (Cabrera, 1997). This probably is due to the distance nitrogen must travel through the pot for topdressed versus incorporated fertilizers.

The benefit of CRF is a continuous release of fertilizer over a period of time. The amount of irrigation supplied will influence nitrogen leaching dynamics through a container. Fare et al., (1994) found that regardless of fertilizer rate applied, NO_3^- leaching depends on

irrigation volume and amount of leachate produced. Even in woody ornamentals produced in the field, the amount of nitrogen leached below the root zone of the plant is more closely related to the amount of water supplied by irrigation than the rate of fertilizer supplied (Jarrell et al., 1983). It was no surprise that Shiflett et al. (1994) found that by reducing the leaching fraction of water, the amount of nitrogen leached also is reduced.

Different nitrogen sources and their release rates can affect NO_3^- concentration in leachate. Warren et al. (1995) found that compared to composted turkey litter, CRF lost 12% more nitrate in leachate. They also found that the quantity of daily nitrogen loss varied with different nitrogen sources.

Irrigation and fertilizer effects on plant growth

Traditional irrigation protocols in nurseries included a high leaching fraction to reduce salt buildup and improve yield (Jarrell et al., 1983). Using a high leaching fraction has changed dramatically since NO_3^- in groundwater became a health concern. Overhead irrigation was the system of choice in most nurseries before water prices became a concern to growers. Now, overhead irrigation is used primarily for containers of less than 20 liters (Beeson and Knox, 1991).

Along with changes in irrigation setup, some nurseries are experimenting with irrigation delivery scheduling. Fare et al. (1994) determined that cyclic irrigation produced better shoot growth in 'Compacta' Japanese holly than single-dose waterings. Root growth in the same study was not affected by cyclic irrigation. Cyclic irrigation also produced higher root and shoot nitrogen concentrations as well as better nitrogen utilization in marigold (*Tagetes*

erecta L. ‘Apollo’) which could lead to lower irrigation levels and less fertilizer application (Karam et al., 1994).

Along with irrigation practices, fertilizer rate applied and release-rate of nutrients affect plant growth. Rate of fertilizer applied is the most relevant factor responsible for producing faster growth, larger plant sizes, and higher dry weights (Jarrell et al., 1983; Rauch and Murakami, 1994). In a study by Ruter (1992), shoot dry weight of *Ilex cornuta* Lindl. & Paxt. ‘Burfordii’ and *Ilex* × ‘Nellie R. Stevens’ increased as fertilizer rate increased. The root rating, which estimated percentage of roots, was not affected by the fertilizer increase. In another study by Hicklenton and Cairns (1992) *Cotoneaster dammeri* C.K. Schneid ‘Coral Beauty’ grew more consistently and had higher tissue concentrations of nitrogen, phosphorus, and potassium when fertilizer rates were increased. They found that *C. dammeri* ‘Coral Beauty’ was affected more by total nutrient amount available during the growing season than nutrient availability at certain times. The fertilizer formulation did not affect plant growth and nutrient content. Hicklenton and Cairns also found fast-growing species (*Cotoneaster dammeri* ‘Coral Beauty’) to uptake available nutrients more readily than slow-growing species (*Juniperus horizontalis* ‘Plumosa Compacta’). In a study by Ruter (1992), shoot growth in holly was not affected by fertilizer source (Osmocote 17N-3P-9.9K, Sierrablen 17N-3P-8.3K, and High-N 24N-1.7P-5.8K). Warren et al. (1995) also found no increase in weight for roots of *Rhododendron* sp. ‘Sunglow’ provided with different sources (resin-coated NH₄ NO₃ and P, urea and sulfur coated P, and composted turkey litter) of fertilizers.

Research has not addressed the combined use of WSF, CRF, and tensiometer-controlled irrigation systems in a container nursery setting. The objectives of this experiment were: to

determine how WSF, CRF, and tensiometer-controlled irrigation in combination affect growth of *I. verticillata* and *C. sericea*, to determine nitrogen uptake for *I. verticillata* and *C. sericea* under specific treatment combinations, and to examine NO_3^- leaching from combined fertilizer and irrigation treatments.

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**CHAPTER 2. GROWTH, NITROGEN CONTENT, AND LEACHING FROM
CONTAINER-GROWN *CORNUS* AND *ILEX* AMENDED WITH COMBINATIONS
OF MOISTURE AND FERTILIZER**

A paper to be submitted to HortScience

Thomas L. Schultz and Ursula K. Schuch

ABSTRACT

Nitrate (NO_3^-) is a major pollutant in much of the surface water in the nation. High concentrations of NO_3^- are common in runoff from container-production nurseries. Our objective was to investigate effects of four fertigation treatments (Miracle Gro Excel™ 21N–2.2P–16.6K \times 65 or 75% media moisture, respectively) combined with three rates of controlled-release fertilizer (CRF) (Osmocote® 18N–2.6P–9.9K, 8-9 month release) on nitrate (NO_3^-) runoff, N uptake, and growth of winterberry (*Ilex verticillata* L.'Stoplight') and red-osier dogwood (*Cornus sericea* L.). In 1999, 12 treatments were arranged in a randomized block design with eight replications. Treatment combinations of fertigation and CRF [(WSF $\text{mg}\cdot\text{L}^{-1}$ applied at 65 or 75% media moisture)/ CRF (g) $\text{N}\cdot\text{pot}^{-1}$] were a 4 \times 3 factorial for each species: [(1.84, 3.62, 4.98, or 6.08) \times (0, 0.57, or 1.15)] for *I. verticillata* and [(3.45, 4.09, 7.73, 8.48) \times (0, 0.57, 1.15)] for *C. sericea*. Shoot dry weight (SDW) and shoot nitrogen content were higher in *I. verticillata* with increased rates of fertigation. Root dry weight (RDW) decreased as CRF rates increased. Root-to-shoot ratio (R:S ratio) and N efficiency decreased as fertigation and CRF increased. In *C. sericea* SDW, RDW, and R:S ratio were not affected by fertigation or CRF treatments. Shoot N increased as CRF rate

increased and root N increased as fertigation rate increased. As CRF rate increased, NO_3^- leaching increased for both *I. verticillata* and *C. sericea*. These data suggest that fertigation and CRF management are important to increase growth of *I. verticillata* while in this experiment *C. sericea* did not respond to increasing N input. Applying higher rates of CRF in addition to fertigation resulted in higher $\text{NO}_3\text{-N}$ leaching for both species.

INTRODUCTION

Reducing nitrate concentrations in drinking water is a priority because nitrate concentrations above 10 ppm are harmful to people (EPA, 1998). Nationally, the horticulture and agriculture industries are shown to contribute to point and non-point source pollution (Brand et al., 1993). Drinking water pollution, along with substantial fines that can be imposed on nurseries releasing runoff with high concentrations of nitrate from their production areas, has become the major catalyst spurring research concerned with reduction of fertilizer and water use in the nursery industry.

The container-production nursery industry is based on the premise of using fertilizer and irrigation to efficiently grow high quality plant material (Groves et al., 1998). The leachate produced from nursery operations can pollute ground and surface water, rendering this water unsuitable for use as drinking water (Yeager et al., 1992). Leachate containing high NO_3^- concentrations currently is allowed either to run off the nursery premises, or is collected for recycling. By reducing the amount of fertilizer and water used in the nursery, growers can reduce water pollution and lower expenses for fertilizer and water.

Fertilizer and irrigation practices affect plant growth, nitrogen uptake, and leaching in container nursery production. Various fertilizer and irrigation application techniques that

reduce fertilizer and leachate loss recently have been the subject of study (Andersen and Hansen, 2000; Haver and Schuch, 1996; Fare et al., 1994; Groves et al., 1998; Huett, 1997; Kabashima, 1993; Rose and Biernacka, 1999; Ruter, 1992). In the past, many growers have relied exclusively on water-soluble fertilizer (WSF) because of ease of application to container plants. However, WSF can be inefficient due to loss of nutrients through leaching (Hershey and Paul, 1982). Now, nursery growers are using more controlled-release fertilizers (CRF's) because CRF's can reduce nutrient loss from leaching and increase nutrient recovery in plants (Cabrera, 1997). By using CRF's, plants do not require fertigation, and if rain reduces the need for irrigation, there is sufficient fertilizer in the medium (Jarrell et al., 1983).

Many nurseries still use overhead sprinklers as a primary method of irrigating small (< 20 L) containers. Studies have shown that using trickle as opposed to overhead irrigation can reduce NO_3^- loss through runoff (Rathier and Frink, 1989). Most irrigation systems are operated with a timer versus watering plants based on their evaporative demand (Lieth and Burger, 1989). Timed systems provide irrigation water regardless of plant demand and can waste much water by over-irrigating. Tensiometers measure media moisture content and can reduce leaching and minimize runoff while supplying plants with adequate moisture. New Guinea Impatiens grown in a glasshouse using a tensiometer-controlled irrigation system and CRF with no runoff grew to saleable quality with little loss in size (Haver and Schuch, 1996). Growing plants without runoff alleviates NO_3^- leaching problems from the growing site. Using a tensiometer-based irrigation system, our research objective was to determine how different combinations of irrigation, controlled-release fertilizer, and water-soluble fertilizer

affect plant growth, N uptake, and NO₃-N leaching from container-grown red-osier dogwood and winterberry.

MATERIALS AND METHODS

Plant material

One-year-old *Ilex verticillata* 'Stoplight' and *Cornus sericea* transplants (Bailey Nursery, St. Paul, MN and Lawyer Nursery, Plains, Montana, respectively) were root-pruned and potted (one per pot) 4 to 24 Mar. 1999 in 3.8 L pots (15.2 cm bottom diameter × 17.7 cm top diameter × 12.7 cm height). Pots contained Fafard[®] Heavyweight Growing Mix No. 51 (Conrad Fafard Inc., Agawam, MA) amended with 0.89 kg·m⁻³ Micromax[™] micronutrients (Sierra Chemical Company, Milpitas, Calif.). Plants grew for ten weeks in a glasshouse in Ames, Iowa (42N latitude), under natural photoperiod and temperatures ranging from 31.1C to 18C (day/night) in the glasshouse. Mean photosynthetic photon flux was 673 μmol·m⁻²·s⁻¹ at canopy level under cloudless conditions at 11:00 AM. Plants were irrigated once every week to container capacity until leaves emerged and then were irrigated to container capacity every 3 d with tap water. Starting 7 May 1999, plants were fertilized twice a month during a scheduled irrigation, with 0.23 g·L⁻¹ N Miracle-Gro[®] Excel[™] 21N-2.2P-16.6K WSF (Scotts, Marietta, Ga.). On 28 May 1999, the potted plants were placed outdoors under 30% shade at the Iowa State University Horticulture Research Station near Ames, Iowa. Six plants of each species were destructively sampled at the beginning of the experiment and dry weight of root and shoot portions were measured. *Cornus* shoots were 8.3 g and roots were 11.4 g with a standard deviation of 2.7 and 5.8, respectively, while *Ilex* shoots were 26.6 g and roots were 93.5 g with a standard deviation of 8.8 and 30.0, respectively, at the

beginning of the experiment. Shade cloth was removed after 2 weeks when plants had acclimatized.

The fertigation system was a tensiometer-controlled drip system that continuously delivered N to pots at 90 or 180 mg·L⁻¹ from the WSF (Miracle-Gro® Excel™ 21N-2.2P-16.6K) at 65 or 75% media moisture. Each tensiometer controlled WSF solution distribution over 3 CRF treatments. Distribution uniformity of the system was 93% at the beginning of the experiment. Tensiometers were located in treatments [(g N·pot⁻¹ at 65 or 75% moisture) / CRF (assumed release) g·pot⁻¹)] 1.84/0.57, 3.62/1.15, 4.98/0, and 6.08/1.15 for *I. verticillata*, and 3.45/0.57, 4.09/1.15, 7.73/0, and 8.48/1.15 for *C. sericea*. N input levels between species differed because tensiometers applied different amounts of WSF solution based on when media content reached 65% or 75%.

Osmocote 18N-2.6P-9.9K (9-month release Scotts-Sierra Horticultural Company, Marysville, Ohio) at 0, 1.53, or 3.06 g N·pot⁻¹ was incorporated into the top 5 cm of medium at the beginning of the experiment (28 May 1999). N applied was calculated by adding N from CRF application and N from WSF application. Actual N released from CRF was assumed to be 3/8 of total g N in CRF that was incorporated. The experiment being approximately 3 months of the 8-9 month total release time stated for Osmocote. WSF solution application was dependent on media moisture. Percent N efficiency was calculated as the ratio of total plant N content at harvest and the total N applied (Struve, 1995).

Leachate sampling

Plants were placed on raised benches (30 cm) to facilitate use of the irrigation leachate-collection system. Leachate-collection plates beneath each pot collected and funneled runoff into 2 L bottles placed under the benches. A 18.9 L bucket collected irrigation for each treatment to determine water volume, NO_3^- concentration, and total N applied for each treatment. Leachate volume was measured, and samples of up to 250 ml were removed weekly from each bottle. NO_3^- concentration in the leachate was determined using an Orion[®] ion-specific electrode (Analytical Technology Inc., Boston, Mass.). Leachate samples were taken for 12 weeks; from 2 June 1999 to 18 August 1999. It rained 38 cm over the experimental period. Average leaching fraction for *C. sericea* was 0.29 and 0.27 at 1.84, 3.62 and 4.98, 6.08 g N fertigation, respectively. Average leaching fraction for *I. verticillata* was 0.41 and 0.35 at 3.45, 4.09 and 7.73, 8.48 g N fertigation, respectively.

End of season analysis

Root and shoot dry weight were determined 14 weeks after treatments were begun (3 September 1999). Shoot portions were separated, placed in paper bags, and dried in a forced-air oven at 67C for \approx 96 h. Roots were kept in pots in a walk-in cooler at 38F until they were washed and processed as described for shoots. Shoots and roots were weighed and plant samples were ground through a 40 mesh screen in a Wiley Mill. Total N was determined using a modified micro-Kjeldahl digestion procedure (Jones, 1991; Nelson and Sommers, 1980).

The two species were kept separate. Data were analyzed by using the Statistical Analysis System (SAS Institute, Cary, N.C.). Analysis of variance was performed by using

the General Linear Model (GLM) procedure and orthogonal contrasts to compare specific sets of treatment combinations.

Experimental design

Experimental units (one potted plant) were arranged in a randomized complete block design in a four by three factorial arrangement with 8 replications. Treatment combinations of fertigation and CRF [(WSF mg N·L⁻¹ applied at 65 or 75% media moisture) / (CRF g N per pot)] were: [(1.84, 3.62, 4.98, or 6.08) / (0, 0.57 or 1.15)] for *I. verticillata*, and [(3.45, 4.09, 7.73 or 8.48) / (0, 0.57 or 1.15)] for *C. sericea*. Fertigation treatments were based on tensiometers set at 29 and 9 cb of tension for 65% and 75% gravimetric media water content, respectively, as determined by a moisture release curve (Figure 1).

RESULTS AND DISCUSSION

Plant Growth

Ilex verticillata receiving the 6.08 g N fertigation treatment produced 23% more stem dry weight (SDW) than plants receiving at the 1.84 g N fertigation treatment (Table 1). *I. verticillata* SDW generally increased when fertigation was supplemented with CRF, except for the 4.98 g N fertigation treatment. Root dry-weight (RDW) of *I. verticillata* decreased linearly as CRF rates increased, but was not affected by fertigation treatments.

An increase in SDW of *Ilex crenata* ‘Helleri’ similar to our study was found by Niemiera and Wright (1982). Similarly, increased shoot weight of *Rhododendron*, ‘Pink Supreme’ azalea (Keever and Cobb, 1987) and total plant weight of *Juniperus horizontalis* (Hicklenton and Cairns, 1992) were reported in response to increasing fertilizer rates. Ruter

(1992) studied *Ilex cornuta* ‘Nellie R. Stevens’ and found SDW increases as CRF-N increases from $0.9 \text{ kg N}\cdot\text{m}^{-3}$ to $1.5 \text{ kg N}\cdot\text{m}^{-3}$. It is apparent that for slower-growing species, increasing the rate of fertilizer increases total plant growth. In our study, *I. verticillata* generally improved shoot growth as N input increased suggesting that higher rates of growth may be obtained with total N rates higher than 7.23 g per pot.

In a study by Niemiera and Wright (1982), results of RDW in *Ilex crenata* ‘Helleri’ were similar to our findings in *I. verticillata*. They found that the highest RDW occurred at $14 \text{ mg}\cdot\text{L}^{-1}$ N in irrigation solution and as N increased from $14 \text{ mg}\cdot\text{L}^{-1}$ to $24 \text{ mg}\cdot\text{L}^{-1}$, RDW decreased. Like Niemiera and Wright, we found RDW to decrease as CRF N rates increased.

At inception of the experiment, *I. verticillata* root to shoot ratio (R:S ratio) was 3.52. Over the course of the experiment, R:S ratio decreased by 21% and 28% in response to increasing fertigation rates and increasing CRF rates, respectively (Table 1). This decrease in R:S ratio as fertilizer rates increase shows that plants increase shoot growth relative to root growth in response to increasing N, either from fertigation or CRF. A similar study of 16 container-grown woody ornamentals found as the rate of Osmocote 18N–4.8P–8.3K or Nutricote 16N–4.4P–8.3K increased, R:S ratio decreased (Worrall et al., 1987). A grower who increases fertigation and CRF rate can obtain more shoot growth, relative to root growth, in *I. verticillata*. This improves plant size and may move borderline plants up to the next sale size.

Growth of *C. sericea* was not increased or decreased due to any treatment (Table 2). The R:S ratio for *C. sericea* at the beginning of the experiment was 1.37. Over the course of the experiment, R:S ratio for *C. sericea* decreased to 0.92 showing *C. sericea* to increase shoot growth relative to root growth over all fertilizer rates (Table 2).

In this experiment, *C. sericea*'s growth was not affected by increasing fertigation or CRF rates. Contrary, studies of Freeman maple (*Acer x freemanii* E. Murr. 'Jeffersred') and Andorra juniper (*Juniperus horizontalis* Moench. 'Plumosa compacta') found increased dry weights to be related to increasing fertilizer rates (Rose and Biernacka, 1999; Hicklenton and Cairns, 1992). The fact that increasing fertilizer rates between 3.45 and 9.63 g N did not affect biomass production suggests that *C. sericea* was already beginning luxury consumption of N at the lowest rate supplied in this experiment.

The best treatment combination for growing the highest SDW for *I. verticillata* was 6.08/0.57 (fertigation WSF total N applied / g N CRF per pot) providing a total of 6.65 g N over 12 weeks. *C. sericea* produced between 62 g and 103 g total biomass with treatments ranging from 3.45 g to 9.63 g N application over 12 weeks without significantly affecting biomass.

Plant N Content

Shoot N content of *I. verticillata* was 34% higher for plants receiving the 6.08 g N fertigation treatment than those receiving 1.84 g N (Table 1). Increasing CRF from 0 to 1.15 g increased shoot N content by 30%. Root N content was not affected by fertigation or CRF treatments.

N efficiency of *I. verticillata* was affected by an interaction between fertigation and CRF (Table 1). At low fertigation rates, the addition of CRF lowered N efficiency more than 50%. As N fertigation rates increased from 1.84 g to 6.08 g, N efficiency decreased from 54 to 16, and the addition of CRF at the highest fertigation rate did not further decrease N efficiency.

Our findings are different from those of Jarrell et al., (1983) who studied N uptake of *Ligustrum texanum*. They found higher leaching fraction (0.4) to be consistent with lower plant nitrogen contents than lower leaching fraction (0.1). This was attributed to more fertilizer staying in media as less water was applied. Our study shows *I. verticillata* had more shoot nitrogen as the fertigation rate increased. The higher fertigation rates also supplied the most water as fertigation rate was dependent on tensiometers sensing media moisture. *I. verticillata* used N more efficiently at the lower rather than higher moisture level.

Increasing CRF from 0 g to 1.15 g raised *C. sericea* shoot N content 44% (Table 2). *C. sericea* root N was 15% higher in plants receiving 8.48 g fertigation rather than 3.45 g fertigation. Increasing fertigation from 3.45 g to 8.48 g decreased N efficiency 51% when averaged over all CRF treatments.

C. sericea had more shoot nitrogen but did not produce more SDW or RDW with 1.15 g N CRF than with 0 g CRF suggesting the plants were beginning luxury consumption. They used N less efficiently as fertigation rates increased. *C. sericea* was less efficient at N uptake than *I. verticillata*. This may have been due to the larger plant size of *I. verticillata* at the beginning of the experiment.

Leachate N Content

NO₃⁻ leaching increased progressively for *I. verticillata* as CRF rates went from 0 g N to 1.15 g N (Table 1). Treatments receiving 1.15 g N CRF had 51% higher NO₃⁻ leaching compared to those amended with 0 g N CRF. These results corroborate the study by Hershey and Paul (1982), who reported increased NO₃⁻ leaching as fertilizer application increased.

NO₃⁻ leaching over time (Figure 2) shows a trend of high NO₃⁻ that dropped during the first five weeks. This trend may correspond to active growth of plant material or N release pattern of CRF. A study on nutrient uptake patterns in *Acer x freemanii* E. Murr. ‘Jeffersred’ found recently-potted plants required less fertilizer and were less efficient in nutrient uptake. As Freeman maples matured, they required more fertilizer and were more efficient at nutrient uptake (Rose and Biernacka, 1999). Another study focused on release patterns of CRF’s and found certain 8 to 9 month CRF’s to be temperature responsive and have higher release rates earlier in the season (Cabrera, 1997).

NO₃⁻ leaching increased 48% for *C. sericea* as CRF rates went from 0 g N to 1.15 g (Table 2). The pattern of NO₃⁻ leaching over time was similar to *I. verticillata* leaching over time (Figure 2).

These findings correspond well to nitrogen use efficiency discussed earlier. *C. sericea* and *I. verticillata* plants used nitrogen less efficiently as rates of N application increased. This finding is supported with leachate data showing 48% and 51% more nitrate leaching from 1.15 g N CRF treatments than from 0 g N CRF treatments, respectively.

With N input ranging from 1.84 g to 7.2 g for *I. verticillata*, SDW increased and RDW decreased, while N inputs from 3.4 to 9.6 g caused no significant differences in SDW or RDW in *C. sericea* over the course of the experiment. This shows that these two species differ dramatically in their fertilizer and moisture requirements. The same cultural practices for these two species will lead to different plant growth, N efficiency, and nitrate in leachate.

Growers should be aware of CRF release patterns and how plants take up nitrogen to alleviate any NO₃⁻ leaching problems. In this study, increasing fertigation from 90 to 180 mg·L⁻¹ N, coupled with providing moisture on plant demand at either 9 or 29 cbar, did not

affect NO₃⁻ leaching but increasing CRF rates did. Although once applied, CRF reduces time spent fertilizing, our results suggest that when they are used in combination with fertigation, they may be more problematic because of increased nitrate in leachate.

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Table 1. N input, shoot and root dry weight, root to shoot ratio, Kjeldahl N recovered in plant tissue, percent N use efficiency, and NO₃⁻ recovered in leachate, of *Ilex verticillata* treated with different fertigation and CRF regimes from 6 June to 18 August, 1999.

Treatments									
Fertigation N input (g) ^z	CRF N input (g) ^y	Total N input (g) ^x	SDW (g) ^w	RDW (g) ^v	R:S ratio ^u	Shoot N (g) ^t	Root N (g) ^s	N Efficiency (%) ^r	NO ₃ ⁻ in leachate (g) ^q
1.84	0	1.84	38.6	110.1	2.9	0.33	0.67	54.5	0.73
1.84	0.57	2.41	42.4	95.9	2.3	0.43	0.59	42.3	1.00
1.84	1.15	2.99	46.3	87.8	1.9	0.53	0.62	38.1	1.61
3.62	0	3.62	41.4	104.6	2.4	0.36	0.63	27.8	0.72
3.62	0.57	4.19	48.2	89.0	2.2	0.48	0.44	21.8	1.08
3.62	1.15	4.77	48.3	78.7	1.7	0.52	0.44	20.1	1.61
4.98	0	4.98	47.0	136.3	3.1	0.38	0.64	20.1	0.71
4.98	0.57	5.55	29.7	71.3	2.6	0.38	0.50	15.5	1.15
4.98	1.15	6.13	34.8	82.7	2.3	0.45	0.46	14.8	1.54
6.08	0	6.08	50.5	103.0	2.1	0.46	0.56	16.4	0.88
6.08	0.57	6.65	58.1	120.6	2.1	0.59	0.65	18.7	1.16
6.08	1.15	7.23	57.5	99.1	1.7	0.64	0.64	17.8	1.49

Table 1. Continued...

ANOVA							
Fertigation (3 df)	0.0001	NS ^P	0.0486	0.0002	NS	0.0001	NS
Fertigation linear (1 df)	0.0084	NS	NS	NS	NS	0.0001	NS
CRF (2 df)	NS	0.0349	0.0122	0.0001	NS	0.0005	0.0001
CRF linear (1 df)	NS	0.0112	0.0031	0.0001	NS	0.0002	0.0001
Fertigation * CRF	0.0199	NS	NS	NS	NS	0.0177	NS

²Fertigation = amount of N applied with WSF at 65% or 75% gravimetric moisture content of media

^YCRF = assumed that 3/8 of N applied was released over a 3-month from controlled-release fertilizer (Osmocote 18N—2.6P—9.9K, 8-9 month release)

^xTotal N input= The average N input from CRF and fertigation

^wSDW = Shoot dry weight

^yRDW = Root dry weight

^uR:S Ratio = RDW/SDW

^tShoot N = Kjeldahl nitrogen found in the plant shoot at harvest

^sRoot N = Kjeldahl nitrogen found in the plant roots at harvest

^rN Efficiency (%)= Plant N at harvest / total N applied (averaged from single pots within one treatment)

^qNO₃⁻ in leachate= nitrate totals (g) found in leachate over 12 weeks

^pNS = non-significant at P ≥ 0.05

Table 2. N input, shoot and root dry weight, root to shoot ratio, Kjeldahl N recovered in plant tissue, percent N use efficiency, and NO₃⁻ recovered in leachate, of *Cornus sericea* treated with different fertigation and CRF regimes from 6 June to 18 August, 1999.

Treatments		Total N input (g) ^x	SDW (g) ^w	RDW (g) ^v	R:S ratio ^u	Shoot N (g) ^t	Root N (g) ^s	N efficiency (%) ^r	NO ₃ ⁻ in leachate (g) ^q
Fertigation N input (g) ^z	CRF N input (g) ^y								
3.45	0	3.45	47.8	55.4	0.80	0.21	0.17	11.6	0.73
3.45	0.57	4.02	48.9	48.6	0.87	0.32	0.22	13.6	0.99
3.45	1.15	4.60	47.7	43.5	1.17	0.43	0.29	15.1	1.32
4.09	0	4.09	33.7	28.2	0.87	0.24	0.26	12.1	0.68
4.09	0.57	4.66	40.9	36.6	0.75	0.35	0.53	19.0	0.91
4.09	1.15	5.24	42.7	41.2	0.96	0.44	0.67	21.2	1.23
7.73	0	7.73	42.1	46.2	0.96	0.19	0.22	5.2	0.65
7.73	0.57	8.30	38.8	34.2	0.87	0.34	0.20	6.5	1.02
7.73	1.15	8.88	45.9	54.7	1.09	0.31	0.19	5.6	1.46
8.48	0	8.48	47.4	55.4	0.84	0.25	0.31	6.6	0.65
8.48	0.57	9.05	37.3	33.2	0.89	0.34	0.23	6.5	0.92
8.48	1.15	9.63	45.8	43.2	1.06	0.38	0.27	6.7	1.28

Table 2. (continued)

ANOVA							
Fertigation (3 df)	NS ^p	NS	NS	NS	0.0083	0.0001	NS
Fertigation linear (1 df)	NS	NS	NS	NS	0.0070	NS	NS
CRF (2 df)	NS	NS	NS	0.0001	NS	NS	0.0001
CRF linear (1 df)	NS	NS	NS	0.0001	NS	NS	0.0001
Fertigation * CRF	NS	NS	NS	NS	NS	NS	NS

²Fertigation = amount of N applied with WSF at 65% or 75% gravimetric moisture content of media

^yCRF = assumed that 3/8 of N applied was released over a 3-month from controlled-release fertilizer (Osmocote 18N—2.6P—9.9K, 8-9 month release)

^xTotal N input= The average N input from CRF and fertigation

^wSDW = Shoot dry weight

^vRDW = Root dry weight

^uR:S Ratio = RDW/SDW

^tShoot N = Kjeldahl nitrogen found in the plant shoot at harvest

^sRoot N = Kjeldahl nitrogen found in the plant roots at harvest

^rN Efficiency (%) = Plant N at harvest / total N applied (averaged from single pots within one treatment)

^qNO₃⁻ in leachate= nitrate totals (g) found in leachate over 12 weeks

^pNS = non-significant at P ≥ 0.05

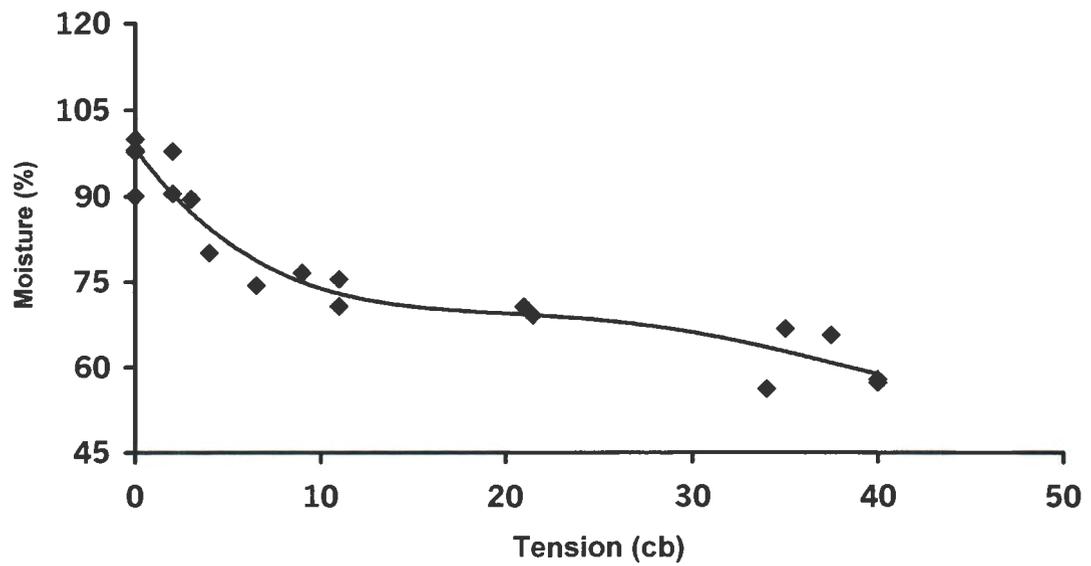


Figure 1. Moisture release curve of growing medium used in experiments. Irrigation treatments of 65% and 75% gravimetric moisture content correspond to 9 cb and 29 cb, respectively.

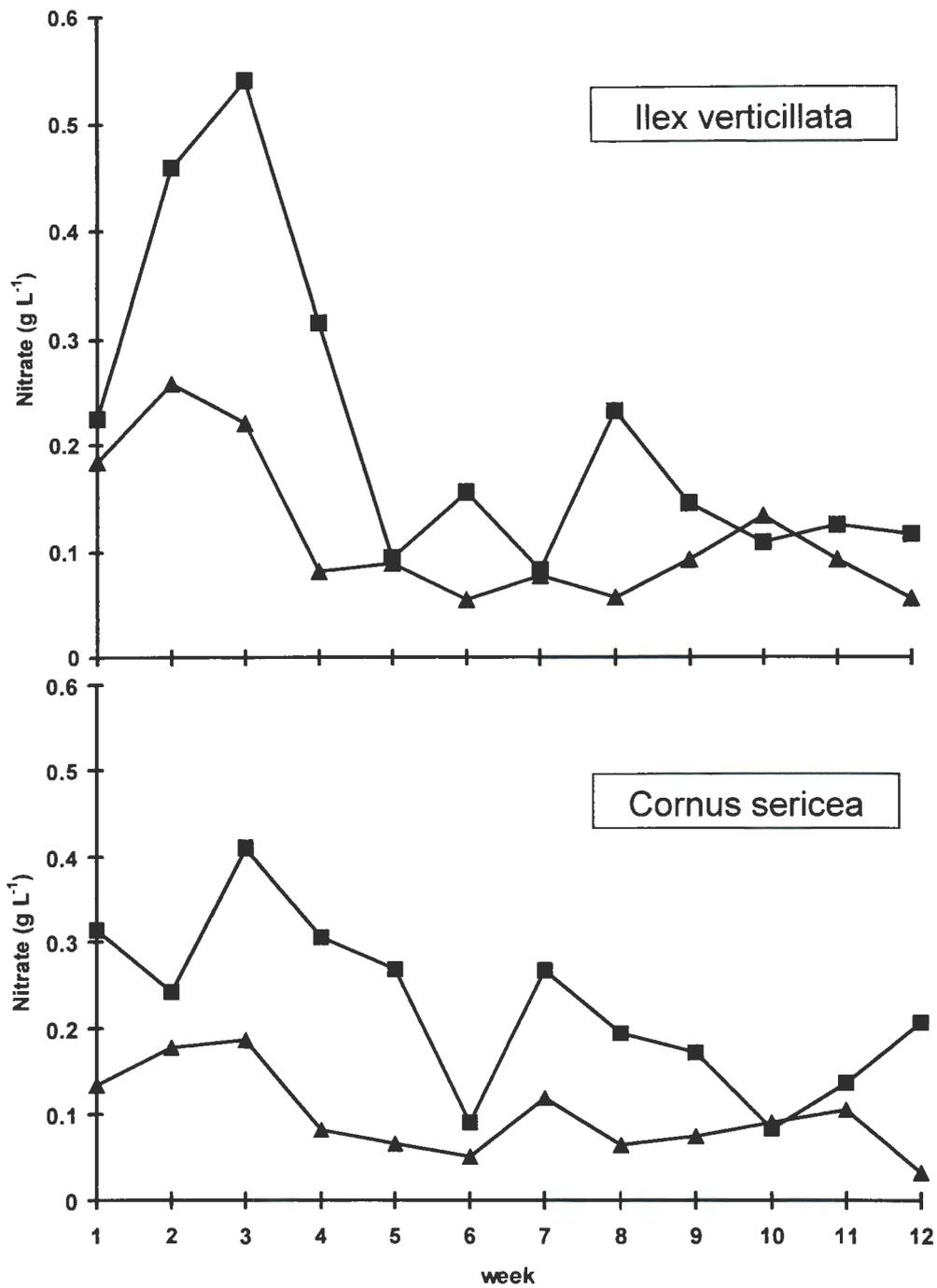


Figure 2. Average total nitrate leaching over twelve weeks from 2 June 1999 to 18 August 1999. Lines represent treatments with the minimum and maximum water and fertilizer input. Treatments are: 0 g controlled-release fertilizer (CRF), and 1.84 g N fertigation (▲), and 1.15 g CRF, and 6.08 g N fertigation (■).

CHAPTER 3. GENERAL CONCLUSIONS

GENERAL DISCUSSION

For growers, the two main items of concern are growth of plants (specifically stems; their length, number of canes, and size are often used to determine prices) and runoff. This study found combining fertigation with controlled-release fertilizer is useful to maintain high rates of stem and root growth along with increased rates of N in tissue for *I. verticillata*. Fertigation and CRF treatments increased growth of *C. sericea*, but no significant differences in SDW or RDW were found at the end of the experiment. SDW of *I. verticillata* was affected by a significant interaction between fertigation and CRF. SDW generally increased when fertigation was supplemented with CRF, except for the 4.98 g N fertigation treatments. RDW decreased linearly as CRF rate increased, but was not affected by fertigation treatments. While supplementing fertigation with CRF in most cases modestly increases biomass, the increased N input leads to higher NO_3^- leaching and lowers N efficiency. For *I. verticillata*, the treatment that most effectively increases SDW and RDW while keeping NO_3^- leaching as low as possible is 4.98/0 (fertigation g N/ CRF g N), respectively

Interestingly, all of the treatments resulted in plants with similar SDW and RDW for *C. sericea*. It was surprising that *C. sericea* produced between 62g and 103g total biomass with N input ranging from 3.45g to 9.63g N over 12 weeks. However, nitrate leachate increased in response to higher CRF rates similar to *I. verticillata*. Greatest N efficiency was found for plants fertigated with 4.09 g N, but N efficiency dropped below 7% for all treatments that received higher fertigation levels. This leads us to examine more closely the relationship between N input, growth, and nitrate lost to leaching. The lack of response of *C.*

sericea to increasing N input suggests that plants were supplied with luxury levels of N even at 3.45 g N, the lowest fertilizer input.

Nitrate in runoff in this experiment was a result of increasing rates of controlled-release fertilizer in addition to fertigation. This experiment suggests that *Ilex* and *Cornus* require different amounts of N input for maximum biomass production. Growers have to determine schemes of fertigation and CRF management to obtain optimum growth with lowest N leaching losses. This research also suggests, contrary to previous findings, that using CRF in addition to fertigation will not decrease nitrate losses through leaching.

APPENDIX A. FIRST-YEAR STUDY

MATERIALS AND METHODS

Plant material

Procedures in 1998 were similar to those in 1999 (Schultz and Schuch, to be submitted to HortScience) except for the following differences. One-year-old *Ilex verticillata* ‘Stoplight’ (L.) Gray were obtained from Simpson Nursery Company, Vincennes, Ind. *Ilex* were not root pruned and were potted (one per pot) 16 to 20 Mar. 1998. Plants grew for twelve weeks in a glasshouse in Ames, Iowa (42N latitude), under natural photoperiod. Starting 7 May 1998, *Cornus* and *Ilex* plants were fertilized twice a month during a scheduled irrigation, with 0.23 g·L⁻¹ N from Miracle-Gro[®] Excel[™] 21N–2.2P–16.6K WSF (Scotts, Marietta, Ga.). On 16 June 1998, the potted plants were placed outdoors under 30% shade at the Iowa State University Horticulture Research Station near Ames, Iowa. The irrigation system was set up on a timer and delivered N to pots at 90 or 180 mg·L⁻¹ from the WSF (Miracle-Gro[®] Excel[™]) by injection. CRF 18N–2.6P–9.9K Osmocote (9-month release Scotts-Sierra Horticultural Company, Marysville, Ohio) at 0, 1.53, or 3.06 g N·pot⁻¹ was incorporated into the top 5 cm of medium at the beginning of the experiment (16 June 1999).

Leachate sampling

NO₃⁻ concentration in the leachate was determined by using an Orion[®] ion-specific electrode (Analytical Technology Inc., Boston, Mass.). Data were taken in Mv and then fitted to a logarithmic curve to determine nitrate N concentration of the leachate solution. This caused NO₃⁻ readings to be extremely high in some cases.

our study found RDW was not different as rates of applied N increased. Ruter reiterated these findings with *Ilex cornuta* ‘Nellie R. Stevens’ (1992).

Cornus sericea produced 2% more SDW as WSF levels were increased from 90 mg·L⁻¹ to 180 mg·L⁻¹ over all CRF levels. SDW was 4.5% higher for plants receiving 0 g CRF and 90 mg·L⁻¹ WSF than those receiving 3.06 g CRF and 180 mg·L⁻¹ WSF. RDW and R:S ratio was not affected by differing fertilizer rates.

In this experiment, *C. sericea*'s fertilizer needs to produce SDW were met and exceeded. While *C. sericea* produced more SDW at the 180 mg·L⁻¹ WSF level than at the 90 mg·L⁻¹ WSF level over all CRF treatments, plants produced less SDW as the total fertilizer rate went up from 0 g CRF and 90 mg·L⁻¹ WSF to 3.06 g CRF and 180 mg·L⁻¹ WSF. Keever and Cobb (1987) also found that top growth of azalea decreased in a response to increasing fertilizer and pot size. However, they also stated that fast growing species benefit most from large media volumes and high fertility rates. This experiment clearly showed that this is not always the case. In this experiment, *C. sericea* fertilizer needs were met and exceeded.

Plant N Content

I. verticillata stem nitrogen increased 23% from plants receiving 0 g CRF and 90 mg·L⁻¹ WSF to those receiving 0 g CRF and 180 mg·L⁻¹ WSF (appendix table 1). Root N was increased 18% as fertilizer application rate went up from 0 g CRF and 90 mg·L⁻¹ WSF to 0 g CRF and 180 mg·L⁻¹ WSF. Root N also increased 11% as total fertilizer rate increased from 0 g CRF and 90 mg·L⁻¹ WSF to 3.06 g CRF and 180 mg·L⁻¹ WSF. *I. verticillata* had a 28% higher N efficiency (the percentage of N applied that ends up in plant material) at the 0 g CRF and 90 mg·L⁻¹ WSF fertilizer application rate than at the 0 g CRF and 180 mg·L⁻¹

WSF fertilizer application rate. Plants increased N efficiency 36% as fertilizer application rate increased from 0 g CRF and 90 mg·L⁻¹ WSF to 3.06 g CRF and 180 mg·L⁻¹ WSF.

C. sericea had less stem nitrogen at 90 mg·L⁻¹ WSF than at 180 mg·L⁻¹ WSF suggesting the sufficiency rate was not passed. This is similar to the findings of Brand, McAvoy, and Corbett (1993) who found that rapid growing plants such as *Cornus* may be more efficient than slower growing plants such as *Rhododendron* when it comes to nitrogen uptake.

Leachate N Content

Leachate NO₃⁻ content from 1998 will not be discussed as faulty probe calibration lead to extremely high NO₃⁻ readings.

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Appendix Table 1. Average N applied, NO₃⁻ recovered in leachate, Kjeldahl N recovered in plant tissue, N use efficiency, and shoot and root biomass of *Ilex verticillata* treated with different fertilizer regimes from 21 June to 5 October, 1998.

Treatments		Total N Input (g) ^w	NO ₃ ⁻ in Leachate (g) ^w	Shoot N (g) ^y	Root N (g) ^u	N efficiency ^t	SDW (g) ^s	RDW (g) ^r	R:S Ratio ^q
CRF N (g) ^z	WSF N (mg•L ⁻¹) ^y								
0	90	8.37	18.13	0.56	0.55	8.19	36.13	45.66	1.01
1.53	90	9.87	15.79	0.59	0.57	9.19	35.19	43.18	0.98
3.06	90	11.37	14.72	0.63	0.65	11.64	37.77	49.10	1.09
0	180	14.47	16.06	0.69	0.65	10.50	42.97	51.76	0.97
1.53	180	15.97	13.65	0.67	0.54	9.90	41.31	52.56	0.83
3.06	180	17.47	13.23	0.67	0.61	11.12	42.20	53.29	0.97
0 vs 3 CRF				NS	NS	NS	NS	NS	NS
0 90 vs 0 180				*	***	***	NS	NS	NS
0 90 vs 3 180				NS	**	***	NS	NS	NS
0 90 vs 3 180				NS	NS	NS	NS	NS	NS

^zCRF N= Grams N input from controlled-release fertilizer (Osmocote 18N—2.6P—9.9K, 8-9 month release)

^yWSF N= (Peter's Excel 21N—2.2P—16.6K)

^xTotal N input= The average grams of the treatment's N input from CRF N and WSF N over 12 weeks

^wNO₃⁻ in Leachate= The average of nitrate totals (g) found in leachate over 12 weeks

^yShoot N = The average amount of Kjeldahl nitrogen (g) found in the plant shoot at harvest

^uRoot N = The average amount of Kjeldahl nitrogen (g) found in the plant roots at harvest

^tN Efficiency = Ratio of total plant N at harvest to total N applied

^sSDW = Stem dry weight (g)

^rRDW = Root dry weight (g)

^qR:S Ratio = Root to shoot ratio

NS = non-significant at P ≥ 0.05

Appendix Table 2. Average N applied, N recovered in leachate and plant tissue, N use efficiency, and shoot and root biomass of *Cornus sericea* treated with different fertilizer regimes from 21 June to 18 September, 1998.

Treatments										
CRF N (g) ^z	WSF N (mg·L ⁻¹) ^y	Total N Input (g) ^w	NO ₃ ⁻ in Leachate (g) ^w	Shoot N (g) ^v	Root N (g) ^u	N efficiency ^t	SDW (g) ^s	RDW (g) ^r	R:S Ratio ^q	
0	90	14.36	10.38	0.18	0.30	5.92	33.41	43.59	1.98	
1.53	90	15.86	9.95	0.24	0.26	5.09	38.32	48.85	0.76	
3.06	90	17.36	9.34	0.15	0.39	4.99	32.39	49.08	1.69	
0	180	50.27	9.86	0.33	0.63	2.77	35.40	42.69	2.85	
1.53	180	51.77	9.38	0.25	0.56	2.50	38.69	46.37	1.60	
3.06	180	53.27	9.51	0.24	0.58	2.22	31.92	35.59	1.43	
0 vs 3 CRF				NS	NS	NS	NS	NS	NS	
0 90 vs 0 180					*	***	NS	***	NS	NS
0 90 vs 3 180					NS	**	NS	***	NS	NS
0 90 vs 3 180					NS	NS	NS	NS	NS	NS

^zCRF N= Grams N input from controlled-release fertilizer (Osmocote 18N—2.6P—9.9K, 8-9 month release)

^yWSF N= (Peter's Excel 21N—2.2P—16.6K)

^xTotal N input= The average grams of the treatment's N input from CRF N and WSF N over 12 weeks

^wNO₃⁻ in Leachate= The average of nitrate totals (g) found in leachate over 12 weeks

^vShoot N = The average amount of Kjeldahl nitrogen (g) found in the plant stem at harvest

^uRoot N = The average amount of Kjeldahl nitrogen (g) found in the plant roots at harvest

^tN Efficiency = Ratio of total plant N at harvest to total N applied

^sSDW = Shoot dry weight (g)

^rRDW = Root dry weight (g)

^qR:S Ratio = Root to shoot ratio

NS = non-significant at P ≥ 0.05

Appendix Table 3. Percent N found in shoot, root, and media from *Ilex verticillata* treated with different fertigation and CRF regimes from 6 June to 18 August, 1999.

Fertigation N input (g) ^z	CRF N input (g) ^y	Shoot N (%) ^x	Root N (%) ^w	Media N (%) ^v
1.84	0	0.83	0.67	0.50
1.84	0.57	0.85	0.50	0.54
1.84	1.15	0.93	0.55	0.65
3.62	0	0.99	0.51	1.02
3.62	0.57	1.02	0.57	1.05
3.62	1.15	1.13	0.59	1.23
4.98	0	1.24	0.63	0.90
4.98	0.57	1.15	0.74	1.04
4.98	1.15	1.24	0.77	1.08
6.08	0	0.98	0.58	0.76
6.08	0.57	0.81	0.59	0.55
6.08	1.15	1.12	0.66	0.91
Anova				
Fertigation (3 df)		0.0093	NS	NS
CRF (2 df)		0.0001	NS	0.0001
Fertigation * CRF		0.0001	NS	0.0001

^zFertigation N = amount of N applied with WSF at 65% or 75% gravimetric moisture content of media

^yCRF N Input= assumed that 3/8 of N applied was released over a 3-month from controlled-release fertilizer (Osmocote 18N—2.6P—9.9K, 8-9 month release)

^xShoot N = percent of shoot that is N

^wRoot N = percent of root that is N

^vMedia N = percent of media that is N

Appendix Table 4. Percent N found in shoot, root, and media from *Cornus sericea* treated with different fertigation and CRF regimes from 6 June to 18 August, 1999.

Fertigation N input (g) ^z	CRF N input (g) ^y	Shoot N (%) ^x	Root N (%) ^w	Media N (%) ^v
3.45	0	0.89	0.75	0.85
3.45	0.57	0.69	0.71	0.68
3.45	1.15	0.83	0.80	0.90
4.09	0	0.91	0.65	1.26
4.09	0.57	0.68	0.75	0.64
4.09	1.15	0.95	0.75	0.88
7.73	0	0.52	0.60	0.78
7.73	0.57	0.73	0.78	1.33
7.73	1.15	0.80	0.92	0.68
8.48	0	0.72	0.64	0.79
8.48	0.57	0.89	0.70	0.96
8.48	1.15	0.56	0.58	0.66
Anova				
Fertigation (3 df)		0.0105	NS	NS
CRF (2 df)		0.0001	NS	0.0001
Fertigation * CRF		NS	NS	NS

^zFertigation N = amount of N applied with WSF at 65% or 75% gravimetric moisture content of media

^yCRF N Input= assumed that 3/8 of N applied was released over a 3-month from controlled-release fertilizer (Osmocote 18N—2.6P—9.9K, 8-9 month release)

^xShoot N = percent of shoot that is N

^wRoot N = percent of root that is N

^vMedia N = percent of media that is N

APPENDIX B. FIGURES



Figure 1. Experiment setup at the Iowa State University Horticulture Research Station near Ames, Iowa showing *C. sericea* on picture left and *I. verticillata* on picture right. Dositrons were used to inject water-soluble fertilizer, and 5 gallon buckets were used to collect irrigation amounts to determine total water-soluble nitrogen applied to treatment.

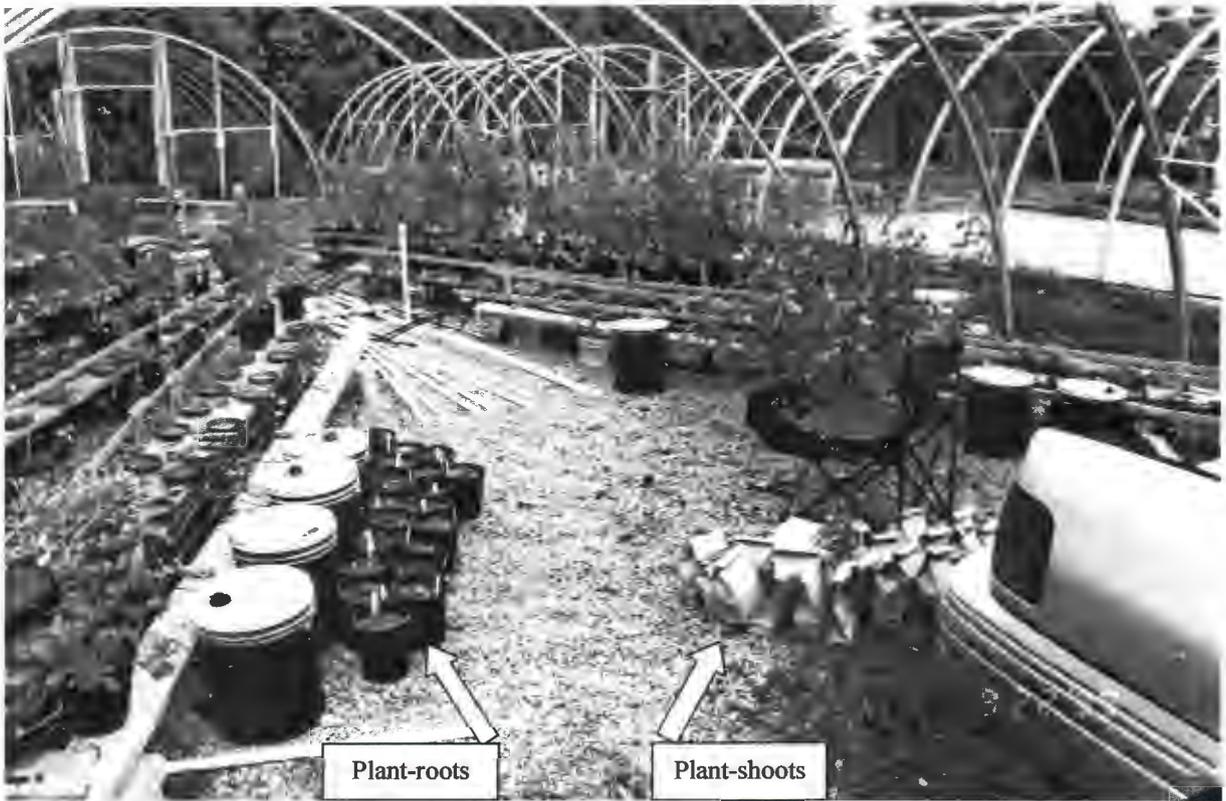


Figure 2. Harvest at at the Iowa State University Horticulture Research Station near Ames, Iowa. Plants were sectioned into shoot portions (in paper bags) and root portions which remained in pots in a walk-in cooler at 38F until washing and drying.

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