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Evaluation of fertilizer and irrigation production systems for large nursery containers

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EVALUATION OF FERTILIZER AND IRRIGATION PRODUCTION SYSTEMS FOR LARGE NURSERY CONTAINERS

A Thesis

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by
Anthony Lynn Witcher
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ABSTRACT

Container-grown woody ornamentals require high volumes of water and sufficient nutrients to develop into healthy, high quality plants. The increased awareness of possible contamination of ground and surface water resources from nursery runoff has forced growers to implement higher water use efficiency techniques to maximize fertilizer efficiency and reduce nutrient and irrigation runoff. Components of a large container production system that could affect irrigation volume, substrate nutrition levels and runoff include fertilizer placement, irrigation frequency and irrigation method.

Irrigation and fertilization components were evaluated in two experiments to determine which would maximize growth, minimize effluent and reduce the amount of nutrient loss from container substrate. Treatments tested included fertilizer placement (incorporated and topdressed), irrigation frequency [once daily (1x) and three times daily (3x)] and irrigation method (drip rings and spray stakes). In the first experiment, *Ulmus parvifolia* Jacq. (Chinese elm) trees were grown for a year and new trees were planted the second year. In the second experiment, *Lagerstroemia indica* x *fauriei* 'Acoma' ('Acoma' crape myrtle) trees were grown for two consecutive years.

Incorporated fertilizer produced higher growth indices and maintained higher substrate nutrient content (N, P and K) in Chinese elms compared to topdressed fertilizer. Similar results where found in crape myrtle with the exception of P substrate content, where no significant differences occurred. In the Chinese elm experiment, the 3x irrigation treatments resulted in higher growth indices and less effluent compared to 1x irrigation. Conversely, 3x irrigation resulted in higher growth indices but no differences in effluent in the crape myrtle experiment. Spray stake treatments resulted in less effluent in the elm study. Drip ring treatments produced larger growth indices in the crape myrtle study. These results suggest a grower could maximize growth and greatly reduce runoff by incorporating fertilizer, practicing cyclic irrigation methods and using drip rings in a large container production system. These results could be used to improve the nursery best management practices in a container nursery production setting.

CHAPTER 1

INTRODUCTION

Literature Review

Container-grown woody ornamental production is a major component (29%) of the nursery industry in the United States. Growers must design a production system tailored to the crop species, container size and amount of money they intend to invest. Several components traditionally considered when designing a container production system include: (1) irrigation method (overhead, drip, etc.), (2) irrigation schedule (once daily, cyclic, time of day, etc.), (3) container substrate (pine bark, sand, sphagnum peat moss, etc.) and (4) fertilizer placement (incorporating or topdressing). Design components affect plant growth and water usage, along with nutrient loss and runoff, the unused water draining from the production area (Fain et al., 1997). High quality container-grown ornamentals require sufficient nutrients and water in the substrate. High volumes of irrigation need to be used which results in wasted water and nutrient loss (Fare et al., 1994).

Container Size and Media

Traditionally, woody ornamentals are grown in containers ranging in size from 1 to 5 gal (3.8 to 19 L). Over the past several years, demand for larger landscape trees and shrubs has significantly increased, which encouraged some nurseries to expand into the large container production market (Gilliam et al., 1984). Container sizes 15 gal (57 L) and larger have become commonplace in recent years, especially in the southeastern United States where long growing seasons are prominent (Gray et al., 1998).

Over the years, many types of substrate have been utilized in container production of woody ornamentals including topsoil, manure and peat moss. Milled pine bark is the main ingredient in container substrate for the production of nursery stock in the southeastern United States. Pine bark is popular for several reasons including widespread availability, light weight, acid pH, ideal bulk density and low cost compared to other materials, yet it retains a low percentage of applied water and nutrients (Fare et al., 1994; Gilliam et al,. 1984). Pine bark is a very coarse material requiring high volumes of water to reach saturation, so sufficient water is a crucial component for container-produced woody ornamentals utilizing pine bark substrate.

Irrigation Management

Decreasing irrigation volume and runoff are primary concerns of the nursery industry. Overhead irrigation is the most practical and commonly used method for watering container-grown woody ornamentals (Beeson et al., 1991). Standard practice in the nursery industry is to irrigate container-grown plants with overhead irrigation once daily. Depending on the irrigation management program, application rates can vary from 0.24 to 0.9 in (0.6 to 2.3 cm) /hr. At this rate, up to 40,000 gal (151,400 L) of water can be applied per acre daily, 40% to 90% of which could be lost due to runoff and evaporation during application (Karam et al., 1992; Fain et al., 1997). Overhead irrigation systems apply high volumes of water with only a small portion reaching the container substrate. This could result in contamination of water sources if high amounts of fertilizer and pesticide residue are present in the runoff (Tyler et al., 1996a).

As a result, more emphasis has been placed on reducing the amount of water used by nurseries, so growers must consider irrigation techniques that will improve irrigation application efficiency. Irrigation application efficiency is calculated from the following equation: [(water volume applied - water volume lost) / water volume applied] (Fain et al., 1998). Irrigation application efficiency refers to the process of reducing effluent volume, unused water that leaches from each container, by increasing irrigation frequency and decreasing irrigation volume to a point that maintains a plant's optimum growth (Groves et al., 1995). The irrigation application efficiency of overhead irrigation averages 26% over a year with a maximum of 80%. The space between containers increases with container size so that even more water is wasted using overhead irrigation with large containers (Beeson et al., 1991).

Irrigation scheduling can improve crop quality while reducing waste water by adjusting irrigation time and volume for specific plant needs. One example would be to water in the afternoon when the plant is actively growing and consuming water. Another example is to water two or three times daily for shorter periods of time (Locascio et al., 1996). Improving irrigation efficiency can reduce irrigation volume and runoff. Several techniques used to achieve this include micro-irrigation, cyclic irrigation and decreased irrigation volume (Tyler et al., 1996a).

Micro-irrigation

A more efficient alternative to overhead irrigation is micro-irrigation (Martin et al., 1989). The universal term micro-irrigation (MI) was adapted by the American Society of Agricultural Engineers and refers to any method of irrigation in which a low volume of water is applied at or just below the soil surface (Haman et al., 1989). MI has been shown to increase water application efficiency compared to overhead irrigation. In some cases, irrigation volumes are reduced without impacting plant quality. Advantages of MI include water conservation, reduced soil erosion, less disease pressure and increased plant growth (Beeson et al., 1995).

Several methods of MI include drip emitters, drip rings and spray stakes. In each system, an emitter (or emitters) is positioned in each container and water is applied directly to the substrate surface. Drip emitters apply water to a small surface area of the substrate resulting in less than uniform wetting of the substrate. Spray stakes apply water to a high percentage of the surface area resulting in more uniform wetting of the substrate compared to drip emitters. Application efficiency of these systems has been found to be between 44 and 72%, twice the efficiency of overhead irrigation (Lamack et al., 1993).

Use of MI methods in smaller containers reduces cost effectiveness (Beeson et al., 1991), however many growers use MI methods to water plants in container sizes 7 gal (27 L) and larger. Studies have shown that the initial cost of installing a MI system for 7 gal (27 L) containers on 0.25 acre is $732, comparable to the $717 spent on an overhead irrigation system for the same area. However, installing a MI for 15 gal (57 L) is $289, much less than the overhead irrigation system. In addition to low installation costs, MI systems use considerably less amounts of water, though water is relatively inexpensive in most areas especially when wells are used (Haydu et al., 1997).

Though more efficient than overhead irrigation, MI methods can result in high amounts of nutrient leaching (Lamack et al., 1992). Some studies have shown that adding certain amendments to pine bark, such as sand and peat moss, will increase water holding capacity and nutrient retention, thus reducing the amount of runoff produced from irrigation (Fare et al., 1996). In addition, irrigating two or more times per day compared to once daily decreases nutrient leaching from substrate which also reduces runoff and possible groundwater contamination (Gray et al., 1998).

Cyclic Irrigation

Another method of reducing water and nutrient loss from containers is to implement cyclic irrigation, dividing the daily irrigation volume and distributing it evenly several times during the day (Karam et al., 1992). The first recorded use of cyclic irrigation at a nursery was recorded in 1986 (Karam et al., 1994a). Cyclic irrigation, a practical method easily implemented with any existing irrigation system, has been shown to increase application efficiency in both overhead and MI systems. Cyclic irrigation improves water quality by reducing runoff and nutrient loss from containers (Lamack et al., 1993; Fain et al., 1998).

Cyclic irrigation has been shown to reduce water runoff by 77% and nutrient runoff by 90% without affecting crop quality. In a study using spray stakes, water application efficiency was 11 to 17% higher for cyclic irrigation compared to a single application (Karam et al., 1994a). Other studies have shown irrigation efficiency increased with cyclic irrigation compared to a single application resulting in reduced irrigation volume, reduced nutrient leaching and increase plant growth (Tyler et al., 1995; Witmer et al., 1998).

Another benefit of cyclic irrigation includes reduced heat and drought stress to plants because water is available during the hottest part of the day. More water is retained in the media due to cyclic irrigation allowing water to be available to the plants for longer periods of time compared to single applications. Cyclic irrigation maintains closer to uniform substrate moisture conditions throughout the day compared to irrigating once daily. Studies have shown this minimizes water stress while optimizing growth (Beeson, 1998).

Nutrient Management

Synthetic fertilizers are the major source of nutrients for container-grown plants. Ammonium and nitrate ions within these materials are readily leached from pine bark due to its low cation exchange capacity. The application of excessive water will only accelerate the nutrient loss and lead to high amounts of ions in runoff (Lamack et al., 1993; Tyler et al., 1996b). In the past, many growers have injected soluble fertilizers into overhead irrigation systems which led to large amounts of nutrient waste and runoff. Most of the nursery industry has abandoned this form of nutrient delivery in favor of controlled release fertilizers (CRF).

CRF's have played a major role in the production of container grown plants during the last 20 years. CRF's are considered more efficient for container production because the nutrients are released over time. This lengthens the life of the fertilizer, reduces sudden loss of nutrients and decreases nutrient concentration in runoff (Rathier et al., 1989; Eakes et al., 1991). The nutrient release rate of CRF varies among products. Factors that could affect nutrient longevity and release rate include fertilizer coating, temperature and irrigation volume (Tyler et al., 1996b). Since the nutrient release rate of CRF is largely dependent on temperature, reapplication of fertilizer may be needed in warmer climates because nutrients are released over a shorter period of time (Wright et al., 1991).

The placement of CRF can affect the performance and growth of container-grown woody ornamentals (Eakes et al., 1990). Several placements of CRF include topdressing, incorporation and dibbling. Temperature of media inside the container remains more uniform than on the media surface resulting in different nutrient release patterns depending on the placement of CRF (Meadows et al., 1986). Regardless, CRF's supply nutrients over longer periods whether topdressed or incorporated (Yeager et al., 1989).

Environmental Topics

Surface water and ground water are primary sources of irrigation for nurseries, especially in Louisiana where water sources are abundant. Although Louisiana has abundant water sources, questionable water quality in certain areas makes water a factor that may limit quality plant production. Contamination of water sources could occur if excessive amounts of fertilizer and pesticide residue are present in the water. Nursery and other industries along with urban areas can contribute to the contamination of surface and ground water sources (Sanders, 2001). For example, ammonium and nitrate ions from fertilizer are readily leached from pine bark substrate leading to high amounts of these nutrients in runoff (Lamack et al., 1993). Also, ground water contamination is a problem in agricultural areas where nitrate levels in runoff are above the drinking water standard of 10 mg/L (Rathier et al., 1989). As a result, reducing irrigation volume and management of runoff have been major issues facing container nurseries in recent years (Groves et al., 1995).

Concerns of depletion and contamination of water sources by nursery and other industries have initiated programs for water conservation and regulation standards (Tyler et al., 1995). In Louisiana, the Ground Water Management Act was established with a long term goal of protecting the states surface and ground water resources. The act requires all new wells be registered with the state and can also limit the number of wells in a critical ground water area, a designated area due to drought, overuse, contamination, etc. (Louisiana Ground Water Commission). Florida and Alabama also regulate new and established wells (Owings, 2003). Florida is divided into Water Management Districts which administer well permits and also keeps records of water usage levels (Olexa et al., 2002).

As urban areas continue to expand, residential areas are encroaching on many nurseries. This has resulted in increased demand on water resources and a heightened awareness of possible ground and surface water contamination from nursery runoff. Growers are learning to practice more responsible water usage techniques to reduce consumption and runoff, understanding the affects excess water usage can have on the environment. Many analysts have predicted that reclaiming irrigation water and collecting runoff in storage ponds would be common practice in the future especially in areas with intense water restrictions (Haydu et al., 1997). Many nurseries currently recycle irrigation water by catching runoff in holding ponds then re-use this water for irrigation purposes (Bailey et al., 1999).

Alternative container production systems should be evaluated for their effectiveness in reducing irrigation volume and runoff along with improving water runoff quality (Fare et al., 1996). These issues have led to research and development of more efficient irrigation methods (Fain et al., 1997).

The purpose of this study was to explore the relationship between fertilizer placement, irrigation frequency and irrigation method for the production of large container-grown woody ornamentals. Past studies have frequently focused on a single component of woody ornamental container production. Studies have been conducted to compare the different placements of controlled release fertilizers. Meadows et al. (1986) compared topdressed, incorporated and dibbled fertilizer placement in pine bark substrate. Warren et al. (1997) compared topdressed and incorporated fertilizer in *Cotoneaster dammeri* 'Skogholm'.

Projects concentrating on cyclic MI have also been conducted. Lamack et al. (1993) conducted an irrigation frequency study comparing cycled irrigation to a single application with spray stakes in *Tagetes erecta* 'Apollo'. Gray et al. (1998) irrigated *Magnolia grandiflora* 'Little Gem' with drip rings and compared a single daily irrigation application to three cycled irrigation regimes of two times, four times and eight times daily.

Also, several research projects have compared overhead irrigation with a type of MI. Weatherspoon et al. (1980) tested four MI systems along with overhead irrigation in *Juniperous conferta*, *Rhododendron obtusum*, *Ilex cornuta* and *Ligustrum japonicum*. Bonaminio et al. (1983) compared drip emitters to overhead irrigation in *Myrica cerifera*, blue rug juniper, *Photinia* x *fraseri*, *Ilex* x 'Nellie R. Stevens' and *Chaenomeles speciosa*.

The following two experiments evaluated topdressed fertilizer versus incorporated, watering once daily versus three times daily and spray stakes versus drip rings. The studies determined differences within several production systems. In Chapter 2, *Ulmus parvifolia* (Chinese elm) were grown for one season then new trees were planted the second season. In Chapter 3, *Lagerstroemia indica* x *fauriei* 'Acoma' ('Acoma' crape myrtle) were grown for two consecutive seasons. In both experiments, the objective was to determine which irrigation and fertilization practices would maximize growth, minimize effluent and reduce the amount of nutrient loss from the container media.

Recommendations for large container production operations based on the results of these studies are presented in Chapter 4.

References

Bailey, D., T. Bilderback and D. Bir. 1999. Water considerations for container production of plants. N.C. Coop. Ext. Ser. HIL #557.

Beeson, R.C. 1998. Effect of cyclic overhead irrigation on the growth of ten species of woody ornamentals grown in #1 containers. Proc. SNA Conf. 43:502-505.

Beeson, R.C., Jr. and G.W. Knox. 1991. Analysis of efficiency of overhead irrigation in container production. HortScience 26:848-850.

Beeson, R.C., Jr. and J. Haydu. 1995. Cyclic microirrigation in container-grown landscape plants improves plant growth and water conservation. J. Environ. Hort. 13:6-11.

Bonaminio, V.P. and R.E. Bir. 1983. Growth of containerized plants under drip or overhead irrigation. 28:20-23.

Eakes, D.J. and J.W. Olive. 1991. Azalea production with 12 to 14 month slow release fertilizers. Proc. SNA Conf. 36:71-73.

Eakes, D.J., W.J. Foster, C.H. Gilliam and J.W. Olive. 1990. Effects of method of application and rate of three slow release fertilizers. Proc. SNA Conf. 35:55-56.

Fain, G.B., K.M. Tilt, C.H. Gilliam, H.G. Ponder and J.L. Sibley. 1997. Effects of cyclic micro-irrigation and media on irrigation application efficiency and growth of Quercus acutissima in pot-in-pot production. Proc. SNA Conf. 42:23-27.

Fain, G.B., K.M. Tilt, C.H. Gilliam, H.G. Ponder and J.L. Sibley. 1998. Effects of cyclic micro-irrigation and substrate in pot-in-pot production. Proc. SNA Conf. 43:87-90.

Fare, D.C., C.H. Gilliam, G.J. Keever and J.W. Olive. 1994. Cyclic irrigation reduces container leachate nitrate-nitrogen concentration. HortScience 29:1514-1517.

Fare, D.C., C.H. Gilliam, G.J. Keever and R.B. Reed. 1996. Cyclic irrigation and media affect container leachate and ageratum growth. J. Environ. Hort. 14:17-21

Gilliam, C.H., G.S. Cobb and C.E. Evans. 1984. Effects of nitrogen concentration and container size on growth of Pyrus calleryana 'Bradford'. J. Environ. Hort. 2:53-56.

Gray, A.L., E.W. Bush and R.I. Edling. 1998. Cyclic irrigation affects on container-grown 'Little Gem' magnolia growth and fertilizer leaching. Proc. SNA Conf. 43:520-525.

Groves, K.M., S.L. Warren and T.E. Bilderback. 1995. Irrigation volume and controlled release fertilizers influence plant growth. Proc. SNA Conf. 40:36-38.

Haman, D.Z. and F.T. Izuno. 1989. Principles of micro irrigation. Fla. Coop. Ext. Ser.Circ. AE-24.

Haydu, J.J. and R.C. Beeson Jr. 1997. Economic feasibility of micro-irrigating container-grown landscape plants. J. Environ. Hort. 15:23-29.

Karam, N.S. and A.X. Niemiera. 1992. Low water application rate and intermittent irrigation increase irrigation efficiency of sprinkler-irrigated container-grown plants. Proc. SNA Conf. 37:41-44.

Karam, N.S. and A.X. Niemiera. 1994. Cyclic sprinkler irrigation and pre-irrigation substrate water content affect water and N leaching from containers. J. Environ. Hort. 12:198-202.

Lamack, W.F. and A.X. Niemiera. 1992. Spray stake irrigation of container-grown plants. Proc. SNA Conf. 37:398-401.

Lamack, W.F. and A.X. Niemiera. 1993. Application method affects water application efficiency of spray stake-irrigated containers. HortScience 28:625-627.

Locascio, S.J. and A.G. Smajstrla. 1996. Water application scheduling by pan evaporation for drip-irrigated tomato. J. Amer. Soc. Hort. Sci. 121:63-68.

Louisiana Goundwater Commision. Critical Ground Water Area Designation Procedure. http://www.dnr.state.la.us/cons/gwater/brochures/cgwadesignation.pdf.

Martin, C.A., H.G. Ponder and C.H. Gilliam. 1989. Effects of irrigation rate and media on growth of Acer rubrum L. in large containers. J. Environ. Hort. 7:38-40.

Meadows, W.A. and D.L. Fuller. 1986. Effect of osmocote placement on release patterns of nitrogen and potassium in a pine bark medium. Proc. SNA Conf. 31:85-89.

Olexa, M.T., L. Minton, D. Miller and S. Corbett. 2002. Handbook of Florida Water Regulation: Water Wells. Fla. Coop. Ext. Ser. Circ. FE 047.

Owings, A. Personal interview. 02 February 2003.

Rathier, T.M. and C.R. Frink. 1989. Nitrate in runoff water from container grown juniper and alberta spruce under different irrigation and N fertilization regimes. J. Environ. Hort. 7:32-35.

Sanders, F.S., 2001. Protecting Louisiana's Waters using Best Management Practices. LA. Coop. Ext. Ser. Pub. 2800.

Tyler, H.H., S.L. Warren and T.E. Bilderback. 1995. Cyclic irrigation increases irrigation efficiency and ammonium retention. Proc. SNA Conf. 40:59-61.

Tyler, H.H., S.L. Warren and T.E. Bilderback. 1996. Cyclic irrigation increases irrigation application efficiency and decreases ammonium losses. J. Environ. Hort. 14:194-198. (b)

Tyler, H.H., S.L. Warren and T.E. Bilderback. 1996. Reduced leaching fractions improve irrigation use efficiency and nutrient efficacy. J. Environ. Hort. 14:199-204. (a)

Warren, S.L., T.E. Bilderback and H.H. Tyler. 1997. Does method of fertilizer application (surface or incorporation) affect nutrient losses of controlled release fertilizers? Proc. SNA Conf. 42:141-143.

Weatherspoon, D.M. and C.C. Harrell. 1980. Evaluation of drip irrigation for container production of woody landscape plants. HortScience 15:488-489.

Witmer, R.K., J.R. Harris, A.X. Niemiera and J. Fanelli. 1998. Frequent irrigation increases the growth of pot-in-pot sugar and red maple. Proc. SNA Conf. 43:516-519.

Wright, R.D. and A.X. Niemiera. 1991. Timing of osmocote reapplication on growth of 'Helleri' holly. Proc. SNA Conf. 36:74-76.

Yeager, T.H., D.L. Ingram and C.A. Larsen. 1989. Nitrate nitrogen and potassium release from surface-applied and growth medium-incorporated osmocote and escote. Proc. SNA Conf. 34:54-56.

CHAPTER 2

EVALUATION OF FERTILIZER PLACEMENT, IRRIGATION SCHEDULE AND TYPE OF IRRIGATION IN LARGE CONTAINER PRODUCTION OF CHINESE ELM

Introduction

Landscape trees and shrubs are now grown in an array of container sizes ranging from one to seven hundred gallons. While the majority of these woody ornamentals are produced in one to five gallon containers, the demand for larger landscape plants has increased significantly in the past 5 to 10 years. Over the last several years, this demand has encouraged many nurseries to modify their production facilities to accommodate large container-grown plants. The practice of producing large container-grown woody ornamentals has required changes in irrigation practices (Gilliam et al., 1984; Gray et al., 1998). Traditionally, these woody ornamentals have been watered once daily with overhead irrigation, a common and practical system for small containers. Though practical, this method often results in large quantities of runoff since water is lost between the containers. This problem is intensified as container size increases because the space between containers also increases. Even more water is lost to runoff using overhead irrigation with large containers (Beeson et al., 1991).

The high volume of water consumed by nurseries along with increased concentrations of fertilizer and pesticide residue present in runoff has increased concerns over water conservation and quality. As a result, water preservation and regulation standards have been initiated in several states including Florida, California and Louisiana (Lamack et al., 1993; Tyler et al., 1995). In response, the nursery industry has placed more emphasis on reducing irrigation volume and nutrient runoff. Therefore, growers have sought alternative irrigation techniques (Fain et al., 1998).

Several methods used to successfully reduce irrigation volume and runoff include micro-irrigation (MI) and cyclic irrigation (Tyler et al., 1996b). MI systems apply water directly to the substrate surface inside each container, a more efficient delivery system compared to overhead irrigation (Martin et al., 1989). Drip emitters, spray stakes and drip rings are all forms of MI, yet irrigation efficiency can differ among them. For example, spray stakes apply water to a high percentage of substrate surface area resulting in a more uniformly wetted substrate compared to drip emitters which apply water to one point on the substrate surface (Lamack et al., 1993).

One disadvantage to MI systems is the excessive nutrient leaching that can occur (Lamack et al., 1992). One method of reducing nutrient leaching is to implement cyclic irrigation, that is irrigating more than one time a day (Karam et al., 1992). Studies have shown that cyclic irrigation reduced irrigation volume and nutrient leaching while increasing plant growth compared to once a day irrigation (Tyler et al., 1995; Witmer et al., 1998).

The placement of controlled release fertilizers can also affect plant growth and nutrient leaching (Eakes et al., 1990; Meadows et al., 1986). The two primary methods of fertilizer placement are incorporated and topdressed. There are benefits and disadvantages to each method and placement varies nursery to nursery. Expensive equipment is required to incorporate the fertilizer into the container substrate, yet the nutrients are near the root zone and easily accessible to the plant. Topdressed fertilizer is easily applied to the substrate surface but if the plant falls, some of the fertilizer is often lost.

Growers have become increasingly interested in methods to reduce water runoff and nutrient loss while producing comparable size plants. This is a key reason alternative large container production systems need to be evaluated for their effectiveness in reducing irrigation volume and runoff, maintaining or improving plant growth and improving runoff water quality. In this experiment, fertilizer placements (incorporated and topdressed), irrigation frequencies [once (1x) and three times (3x) daily] and irrigation method (drip rings and spray stakes) were evaluated. The objective of this study was to determine which irrigation and fertilization components would maximize growth, minimize runoff and reduce the amount of nutrient loss from container substrate.

Materials and Methods

A large container production experiment was conducted at Burden Center in Baton Rouge, LA (latitude 30° 24' 27", longitude 91° 08' 45" and USDA Hardiness Zone 8b) over a two year period. Chinese elm (*Ulmus parvifolia* Jacq.) were grown from April to December of 2000 and the study was repeated using different plants from May to December of 2001. Chinese elm was selected for this work because of its rapid growth rate and its popularity in the landscape industry.

Trees were planted 5 April 2000 and 16 May 2001. Each year, eighty 3-gal (11.4 L) elms were transplanted into 20 gal (76 L) containers (Lerio Corporation, Mobile, AL) containing a 3 pine park : 1 peat : 1 sand (by volume) substrate amended with an incorporated application of 8 lbs/yd^3 (4.7 kg/m^3) dolomitic limestone. Applications of oxyfluorfen + oryzalin (Rout®) at for weed control and imidacloprid (Merit®) for insect control were made as needed using recommended rates broadcast over the container's 2.18 ft^2 (66 cm^2) surface area. Trees were arranged in a randomized complete block design with treatments arranged in a 2x2x2 factorial with 10 replications. Treatments were blocked according to initial plant size using random assignment. Containers were spaced 4 ft (1.2 m) inside each block and 5 ft (1.5 m) in between blocks.

Treatments tested in this experiment included two fertilizer placements (incorporated and topdressed), two irrigation frequencies [one (1x) and three times (3x) per day] and two irrigation methods (spray stake and drip ring).

Fertilizer Placement

Osmocote® 15-9-12 plus minors 12-14 month (Scotts-Sierra Horticultural Products Company, Marysville, OH) was the main source of nutrients and application rates were obtained from the manufacturer. Forty containers were topdressed (top) with 1.14 lb (516 g) Osmocote® and forty were filled with substrate incorporated (inc) with 18 lb/yd^3 (11 kg/m^3) of the same product resulting in 1.8 lb (817 g) per container. Topdressed treatments resulted in 0.171 lb (77 g) N, 0.103 lb (47 g) P and 0.137 lb (62 g) K per container while incorporated treatments resulted in 0.270 lb (122 g) N, 0.162 lb (74 g) P and 0.216 lb (98 g) K per container.

Irrigation Frequency

All containers were irrigated daily with the same volume of water, however irrigation frequency varied. Forty of the containers were irrigated once daily (1x) at 6:00 AM while the remaining forty were irrigated three times daily (3x) at 6:00 AM, 12:00 PM and 6:00 PM. Daily irrigation volume was determined by measuring effluent volume from two of the blocks each month and maintaining a 20% to 40% effluent volume. Effluent was calculated by dividing the effluent volume by the total irrigation volume applied. A Sterling 18 controller (Superior Controls Co., Inc., Valencia, CA) was used to schedule the frequency treatments and operate the 24 V solenoid valves.

Irrigation Method

Forty containers were irrigated with spray stakes (spray) while the remaining forty containers were irrigated using 42 inch (106 cm) drip rings (drip). The spray stakes (Roberts Spot-Spitter®, San Marcos, CA) had a flow rate of 6 gph (22.7 Lph) at 15 psi. The drip rings were constructed from drip tubing (Drip-In Irrigation Co, Fresno, CA) and contained pressure compensated drippers every 6 inch (15 cm). Each ring had a flow rate of 3 gph (11.4 Lph) at 15 psi. Flow rates were measured initially, an average was taken from 10 emitters of each irrigation method. The duration of irrigation was adjusted for irrigation method so each emitter would apply the same volume of water during an irrigation cycle. Each spray stake and drip ring was connected to 0.5" (1.27 cm) polyethylene tubing by a piece of 8' (2.4 m) flexible vinyl tubing.

Data were collected to determine if any of the treatments influenced growth, effluent (excess water which drains from the container after each irrigation cycle) or substrate nutrient content (amount of nutrients available for plant use). Elm growth measurements were taken every 60 d on all eighty trees. Height was measured from the substrate surface to the apical meristem using a surveying rod. Stem caliper measurements were taken 8 inches (20 cm) above the substrate surface to the nearest 1/100 mm using a digital caliper (Mitutoyo®). Overall tree size was evaluated with a growth index (GI), calculated from the following equation: [height (cm) + caliper (mm) x 100] / 2.

Effluent was collected on three consecutive days each month resulting in 32 samples each month. The effluent collection system comprised of a 19 inch (48 cm) square stand 10 inch (25 cm) tall constructed of 1.5 inch (3.8 cm) angled iron (Gray et al., 1998). A 24 inch (61 cm) square neoprene rubber mat with a drain in the center was placed between the container and stand so fluid could be collected in 5 gal (18.9 L) collection basins. Collection basins were weighed after all irrigation cycles were complete and when drainage from the containers ceased. The average daily effluent volume was determined and percent effluent was calculated with the following equation: [effluent volume (L) / irrigation volume (L)] x 100.

Leachates, samples of liquid extracted from the container substrate using the Virginia Tech Extraction Method (Yeager et. al., 1997), were collected every 30 d using the collection system previously mentioned. The process began by irrigating until effluent began to drain from the container bottom at which time irrigation was terminated. After effluent draining ceased, collection basins were placed under the stands and an additional 0.5 gal (1.9 L) of water was poured into the container over the substrate surface. One hour later, after effluent had stopped, the leachate was collected in 4 oz (120 mL) plastic bottles and refrigerated. Leachates were collected within one week following the effluent collection because the water applied during leachate collection could affect percent effluent volume if conducted beforehand.

Each sample was poured through 4.25 inch (11 cm) paper filters (Schleicher & Schuell, Inc., Keene, NH) then pH (Model 410A, Orion Research Inc., Boston, MA) and EC (Model 5800-00, Cole-Parmer Instrument Co., Chicago, IL) analysis was performed. The LSU Agricultural Chemistry Laboratory in Baton Rouge, LA performed an analysis of the substrate nutrient content (N, P, K, Ca, Mg, Cu, Mn, Fe, Zn, S, B, Na). Nitrate and ammonium nitrogen contents were determined by a colorimetric method, a combination of the EPA 351.2A and Technicon 560-79A methods. All other nutrient contents were determined using the EPA 610B method.

The experiment was a completely randomized block design with a three way factorial treatment structure and repeated measurements on the dependent variables (growth index, percent effluent volume, pH, EC, and substrate content of N, P and K). Profile analysis in SAS (PROC GLM) was used to determine the magnitude of both within-subject and between-subject main effects and interactions. In addition, linear contrasts were constructed to test for differences among specific treatment combinations over the course of the entire experiment.

For comparisons of treatment differences within months, analysis of variance was conducted in SAS. When F-values indicated significant treatment effects, Duncan's Multiple Range Test was used to compare pair-wise differences between treatments. For all analyses, a p-value ≤ 0.05 indicated significance.

Results and Discussion

Growth index, effluent volume, pH and EC along with container substrate content of N, P and K resulted in significant differences. The main effects of fertilizer placement, irrigation frequency and irrigation method are mentioned followed by general trends for each treatment regime. The remaining macro and micronutrient data is presented as tables in the Appendix (Tables 4-9).

Plant Growth

Fertilizer placement had a significant main effect on growth in experiment I (2000) and II (2001). Irrigation frequency produced significant main effects only in experiment I, while the main effect for irrigation type resulted in no significance in either experiment (Table 1).

In experiment I, the incorporated treatment produced significantly higher growth indices over the entire growing season compared to the topdressed treatment. A similar trend occurred in experiment II where the incorporated fertilizer resulted in significantly higher growth indices from mid-season thru the termination date compared to the topdressed treatment (Fig. 1a-b). Incorporated fertilizer increased growth by 7% over topdressed fertilizer at the end of each experiment. Though not compared statistically, the differences in final GI between treatments was similar for both years. Similar results were found in *Berberis thunbergii* (Tilt et al., 1990), yet in the same study, no significant differences were found in *Rhododendron* 'Red Ruffles', x *Cupressocyparis leylandii*, *Photinia serrulata*, *Juniperus conferta* or *Ilex* x *attenuata* 'Fosteri'. Another study (Yeager et al., 1989) showed no significant differences in shoot dry weights of *Ligustrum japonicum* or *Rhododendron* 'Mrs. G.G. Gerbing' resulting from Osmocote® placement.

The 3x frequency treatment resulted in significantly higher growth indices (5% by the end of the experiment) than the 1x frequency treatment in experiment I, while no significant growth difference occurred in experiment II (Fig. 2a-b). Studies with *Ulmus alata*, *Acer rubrum*, *Prunus* 'Okame' and *Acer sacharum* found that cycled irrigation produced statistically larger trees compared to a single application. It is believed that cycled irrigation tends to reduce plant water and heat stress encountered under hot southeastern United States summer conditions (Beeson et al., 1995; Fain et al., 1998; Ruter, 1997; Witmer et al., 1998).

Table 1. Repeated Measures Analysis of Variance for growth and effluent of Chinese elm (U. parvifolia). Significance level of $p \leq 0.05$.

		p-values	
Variable	Effect	Experiment I	Experiment II
Growth	Main fertilizer effect	0.0094	0.0007
	Main irrigation effect	0.1926	0.5450
	Main frequency effect	0.0286	0.6073
	Time * fertilizer interaction	0.0148	0.0001
	Time * irrigation interaction	0.0271	0.5046
	Time * frequency interaction	0.0523	0.0090
	"fert" * "irr" interaction	0.6047	0.2920
	"fert" * "freq" interaction	0.1121	0.5625
	"irr" * "freq" interaction	0.5314	0.8467
	"fert" * "irr" * "freq" interaction [y]	0.6851	0.4084
Effluent	Main fertilizer effect	0.1167	0.0001
	Main irrigation effect	0.0016	0.0001
	Main frequency effect	0.0051	0.0058
	Time * fertilizer interaction	0.3670	0.1069
	Time * irrigation interaction	0.2696	0.0001
	Time * frequency interaction	0.0013	0.0001
	fert * irr interaction	0.9827	0.7420
	fert * freq interaction	0.8270	0.6809
	irr * freq interaction	0.4782	0.3090
	fert * irr * freq interaction	0.7532	0.6029

[y] "fert" = fertilizer placement. "irr" = irrigation method. "freq" = irrigation frequency.

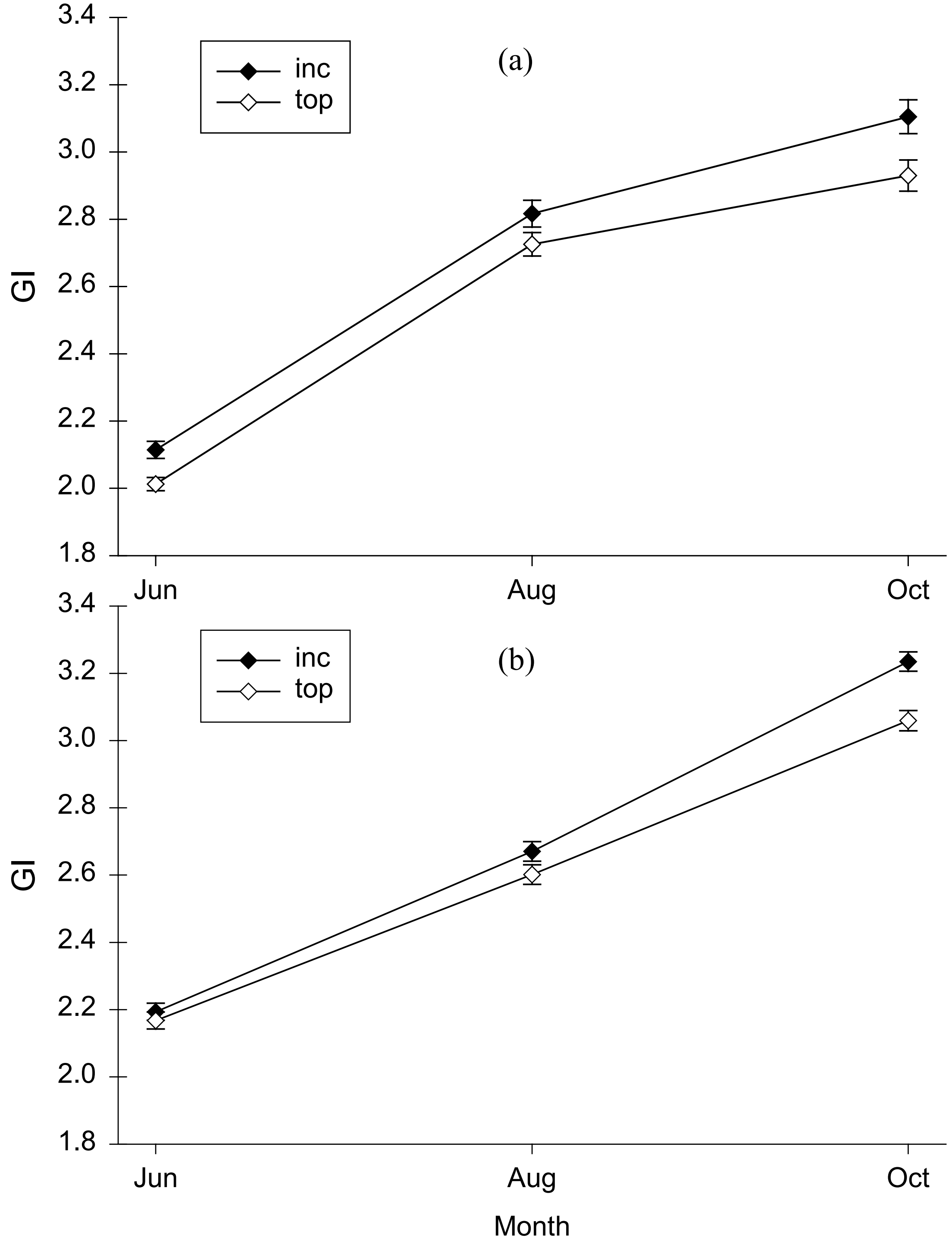

Figure 1. Cumulative growth index (GI) in Chinese elm (U. parvifolia) under two methods of fertilizer placement; incorporated (inc) and topdressed (top). (a) Experiment I and (b) experiment II. Each value represents Mean ± SE, n = 40.

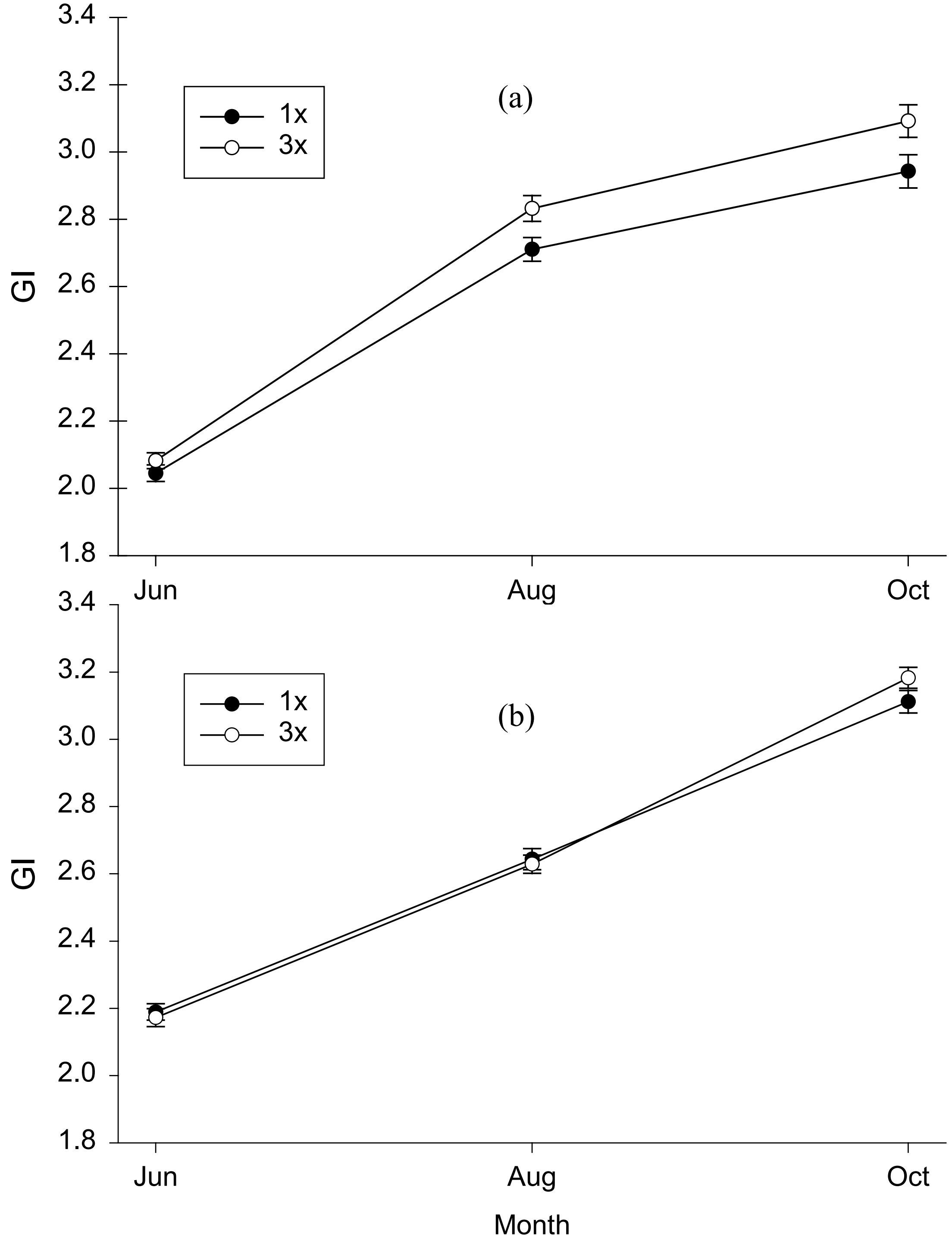

Figure 2. Cumulative growth index (GI) in Chinese elm (U. parvifolia) under two irrigation frequencies; once daily (1x) and three times daily (3x). (a) Experiment I and (b) experiment II. Each value represents Mean ± SE, n = 40.

Neither experiment resulted in a significant growth difference over time between the drip ring and spray stake irrigation treatments (Fig.3a-b).

Effluent Volume

Percent effluent volume was not significantly affected by fertilizer placement in experiment I, but experiment II yielded a significant main effect from fertilizer placement. Irrigation type had a significant main effect on effluent volume in both experiments. Irrigation frequency also resulted in a significant main effect for both experiments (Table 1).

Although the topdressed treatment produced higher effluent in both experiments compared to incorporated, a significant difference was only present in experiment II (Fig. 4a-b). An explanation for this trend could be that since incorporated treatments produced larger trees and possibly a greater root system, more water was taken up by the tree which led to less effluent volume by the incorporated treatments.

In each experiment, the 1x treatment produced significantly more effluent than the 3x treatments for irrigation frequency (Fig. 5a-b). This pattern concludes that the substrate was able to retain more water under cyclic treatments which resulted in less effluent volume compared to the once daily irrigation, a pattern well documented in previous studies using *Ilex* 'Compacta', *Magnolia grandiflora* 'Little Gem' and *Tagetes erecta* 'Apollo' (Fare et al., 1994; Gray et al., 1998; Tyler et al., 1995).

Under irrigation type, the drip ring treatment produced significantly more effluent than the spray stake treatment in both experiments (Fig. 6a-b). A possible reason could be that spray stakes produced wind drift and container overspray which could have reduced the irrigation volume applied to the containers. Another explanation is that the spray

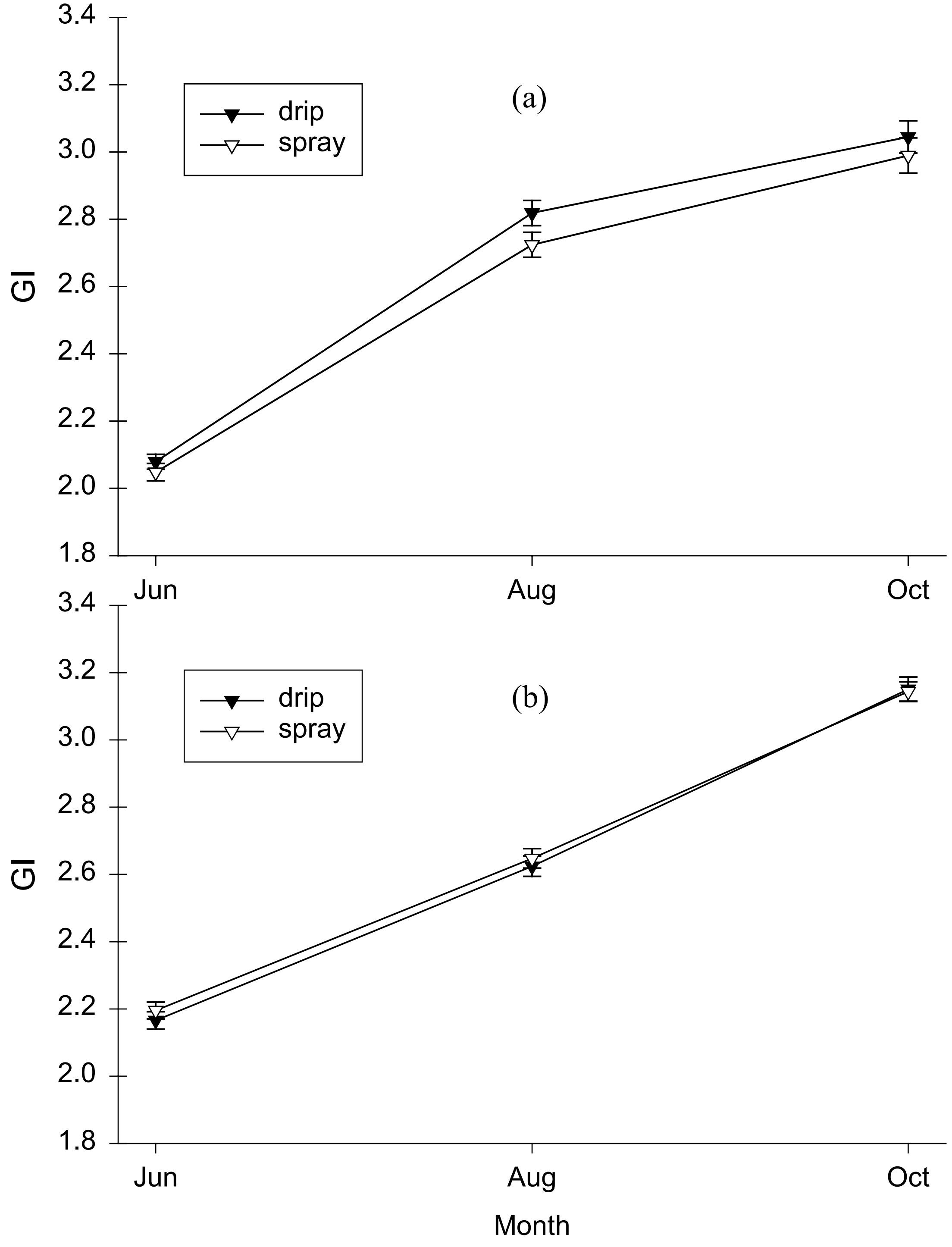

Figure 3. Cumulative growth index (GI) in Chinese elm (U. parvifolia) under two irrigation methods; drip ring (drip) and spray stake (spray). (a) Experiment I and (b) experiment II. Each value represents Mean ± SE, n = 40.

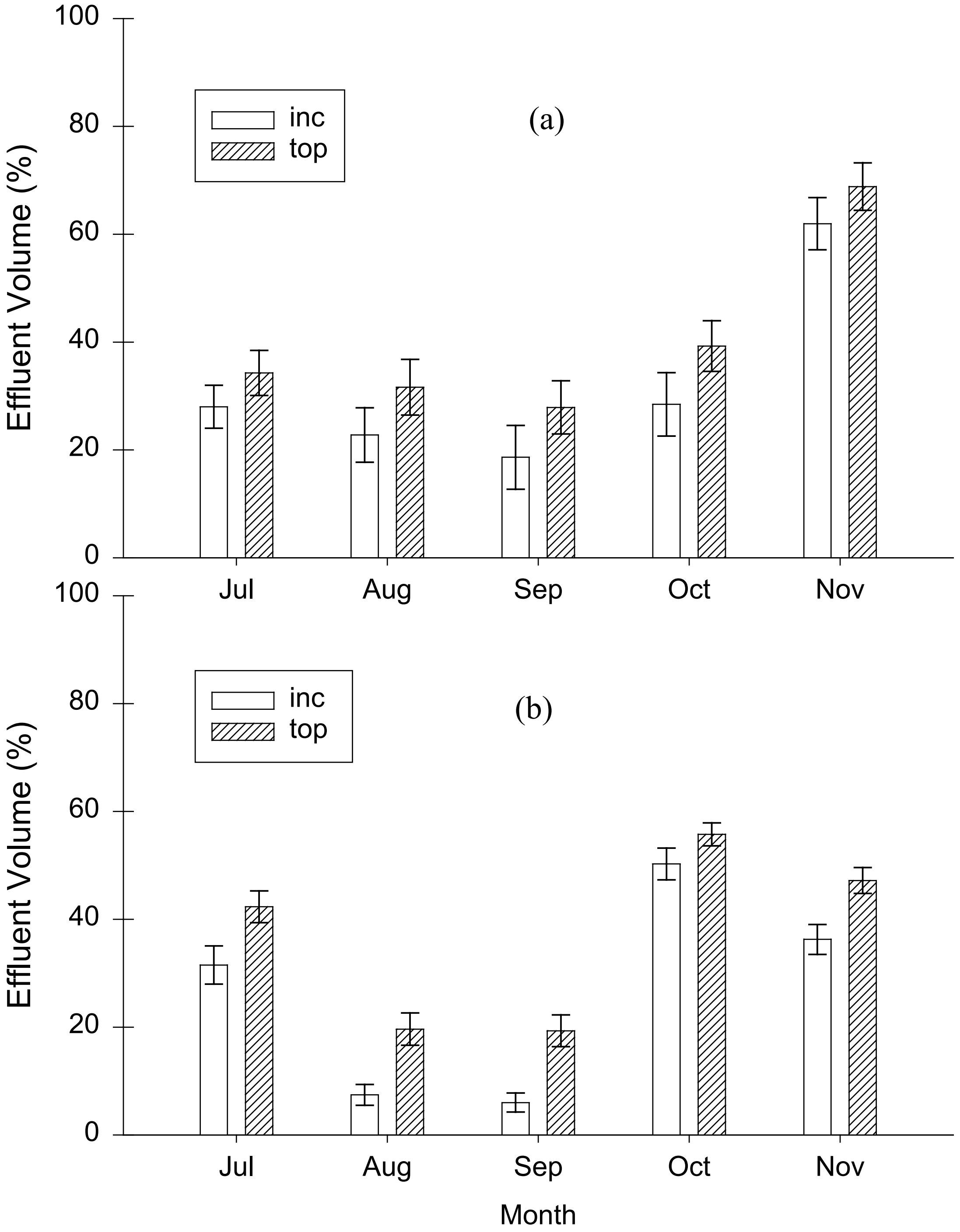

Figure 4. Percent effluent volume in Chinese elm (U. parvifolia) under two methods of fertilizer placement; incorporated (inc) and topdressed (top). (a) Experiment I and (b) experiment II. Each value represents Mean ± SE, n = 16.

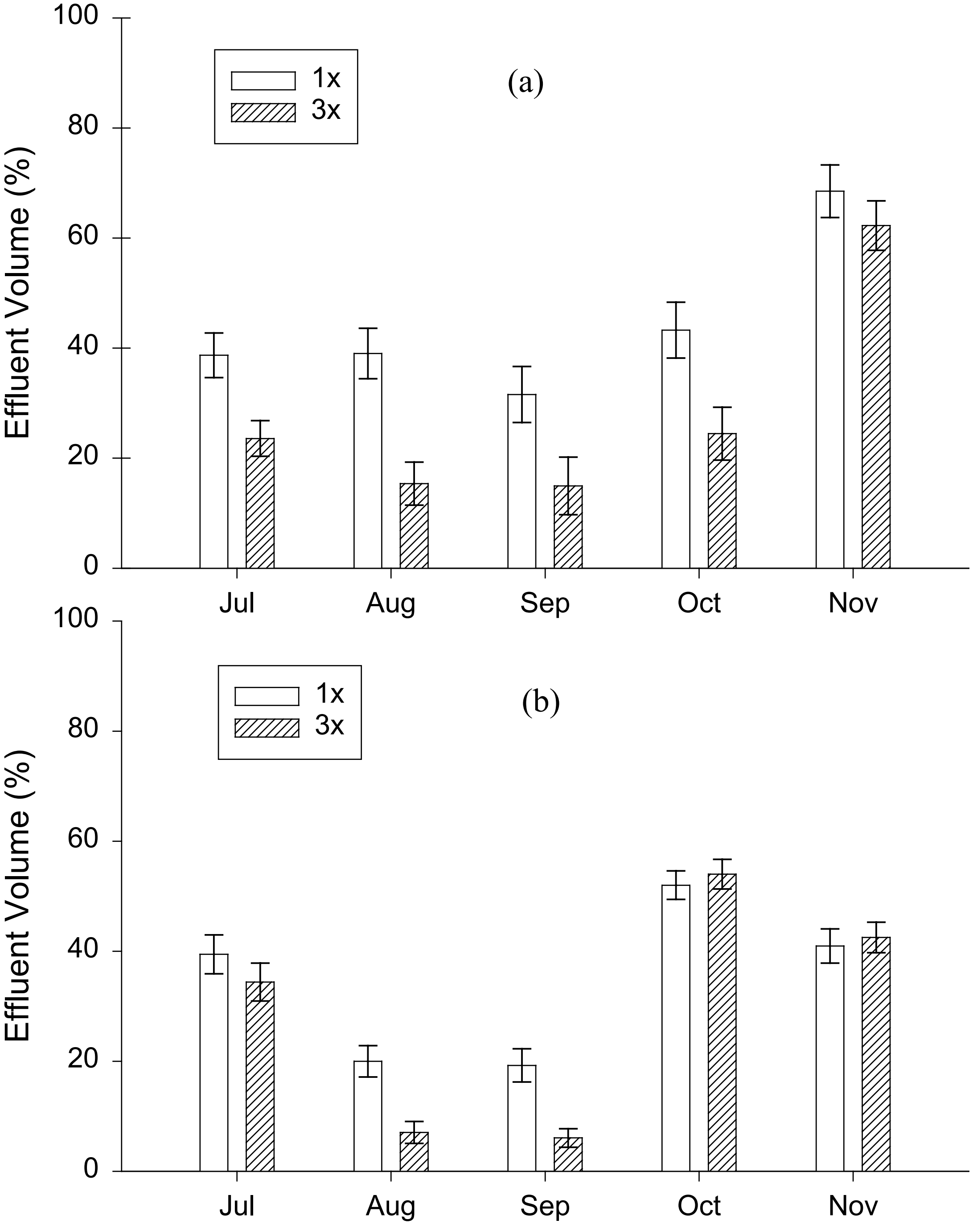

Figure 5. Percent effluent volume in Chinese elm (U. parvifolia) under two irrigation frequencies; once daily (1x) and three times daily (3x). (a) Experiment I and (b) experiment II. Each value represents Mean ± SE, n = 16.

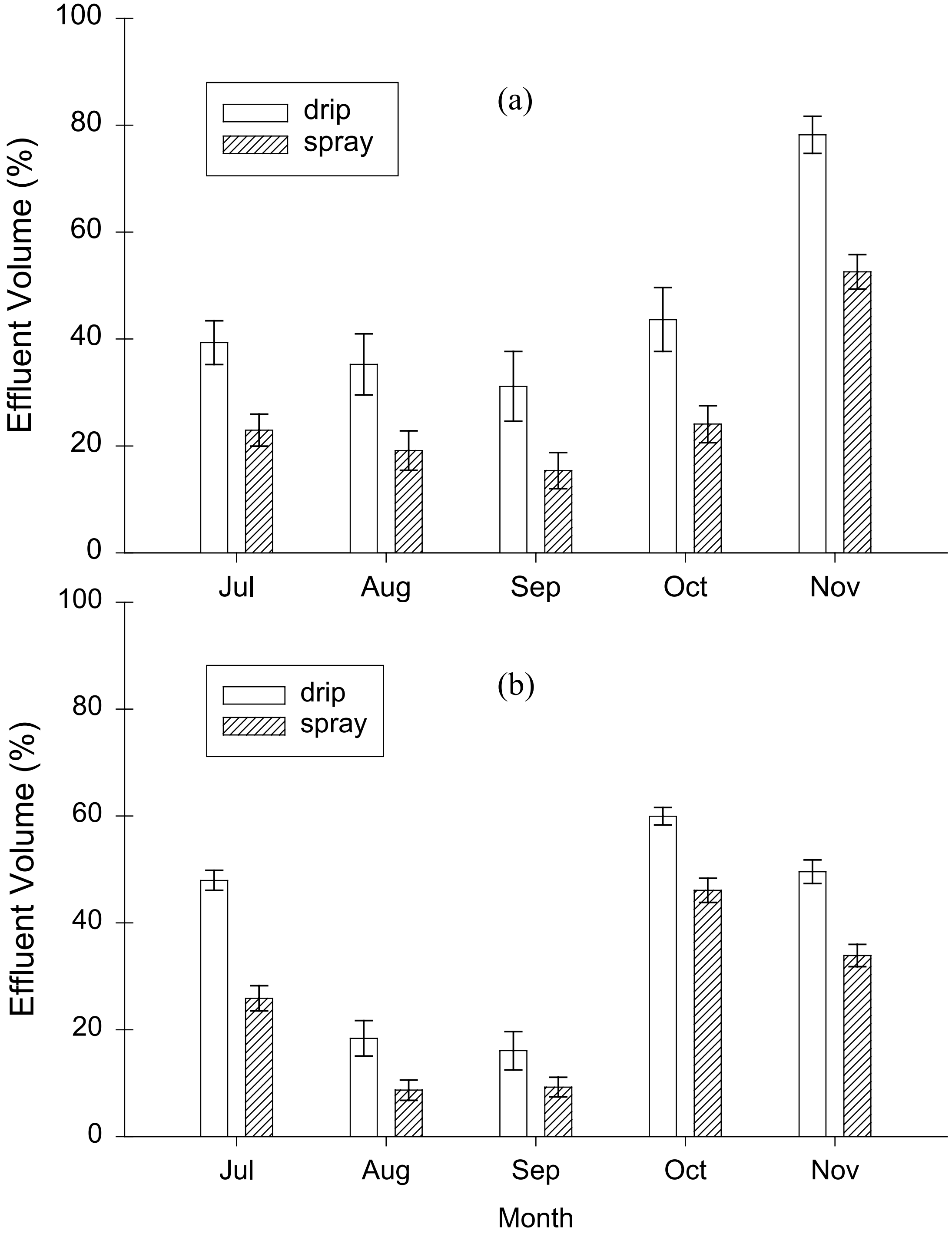

Figure 6. Percent effluent volume in Chinese elm (U. parvifolia) under two irrigation methods; drip ring (drip) and spray stake (spray). (a) Experiment I and (b) experiment II. Each value represents Mean ± SE, n = 16.

stakes saturated the media more efficiently than the drip rings which resulted in less effluent.

pH

Fertilizer placement had a significant main effect on pH in experiment II. pH was significantly affected by the irrigation frequency in experiments I and II. The main effect of irrigation type was significant in experiment II (Table 2). Significant differences were seen in experiment II for fertilizer placement and irrigation type where incorporated and spray stake treatments maintained higher pH, although the standard error was so low that pH levels were relatively the same and within acceptable ranges for nursery crops (Yeager et. al., 1997) (Figs. 7a-b & 9a-b). Irrigation frequencies were significantly different for both experiments where the 1x treatment maintained a higher pH, yet the same explanation can be applied for this result (Fig. 8a-b).

EC

The main effect of fertilizer placement on EC was significant in both experiments. Irrigation frequency had a significant main effect for Experiment I and II. No significant main effect resulted from irrigation type in either experiment. Interactions were observed between fertilizer method and irrigation type in experiment II. An interaction between fertilizer method and irrigation frequency occurred in experiment II (Table 2).

Incorporated fertilizer treatments tended to have a higher EC for both experiments compared to topdressed treatments (Fig. 10a-b). The incorporated fertilizer had a higher rate and wider distribution in the substrate which resulted in a higher EC and increased availability of the fertilizer (Eakes et al., 1990). The irrigation treatment 3x maintained higher EC in experiment I and II than the 1x treatment (Fig. 11a-b). The 1x irrigation

Table 2. Repeated Measures Analysis of Variance for pH, EC N P and K of Chinese elm (U. parvifolia). Significance level of $p \leq 0.05$.

	p-values									
	pH		EC		N		P		K	
Effect	Exp. I	Exp. II	Exp. I	Exp. II	Exp. I	Exp. II	Exp. I	Exp. II	Exp. I	Exp. II
Main fertilizer effect	0.1404	0.0049	0.0001	0.0009	0.0001	0.6272	0.0029	0.2995	0.0001	0.0001
Main irrigation effect	0.2414	0.0001	0.9026	0.8824	0.5493	0.7385	0.2740	0.6425	0.6089	0.3102
Main frequency effect	0.0495	0.0021	0.0001	0.0021	0.0323	0.8056	0.0270	0.7763	0.0058	0.4761
Time * fertilizer interaction	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001	0.0011	0.0001	0.0001	0.0001
Time * irrigation interaction	0.6786	0.1197	0.0263	0.0238	0.3839	0.1301	0.0395	0.0775	0.6636	0.0107
Time * frequency interaction	0.1014	0.1660	0.0021	0.0001	0.2716	0.2971	0.0349	0.2810	0.0009	0.0593
fert * irr interaction	0.4416	0.2351	0.6464	0.0237	0.5192	0.1106	0.2790	0.0732	0.5080	0.0716
fert * freq interaction	0.9828	0.3185	0.1030	0.0006	0.0708	0.0241	0.6640	0.0743	0.0278	0.0062
irr * freq interaction	0.4845	0.7458	0.4876	0.1921	0.7279	0.0899	0.9984	0.0486	0.9525	0.0050
fert * irr * freq interaction[y]	0.3934	0.7255	0.8712	0.0715	0.6899	0.0559	0.6170	0.1710	0.6884	0.0196

[y] "fert" = fertilizer placement. "irr" = irrigation method. "freq" = irrigation frequency.

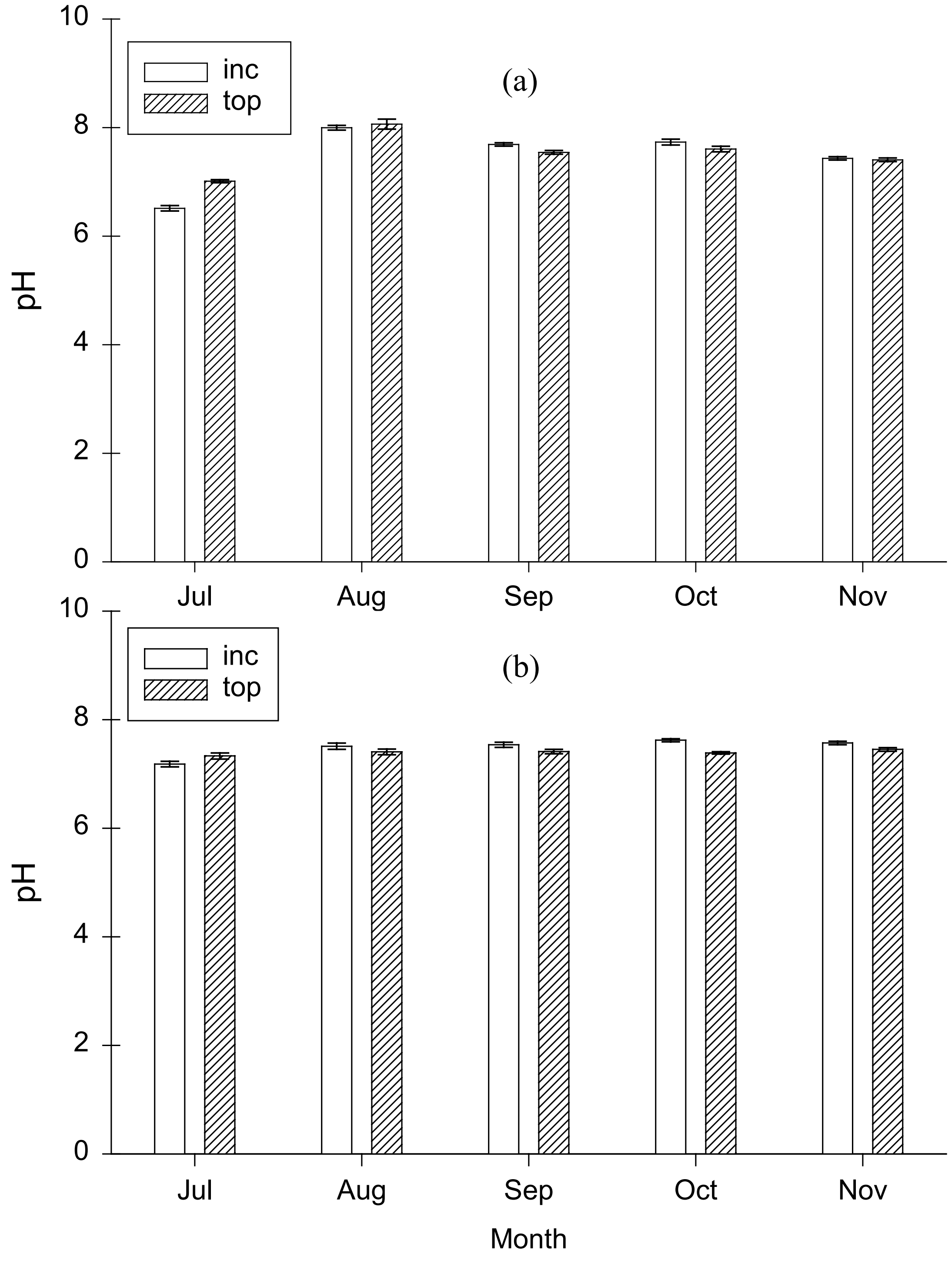

Figure 7. pH of substrate-leachates in Chinese elm (U. parvifolia) under two methods of fertilizer placement; incorporated (inc) and topdressed (top). (a) Experiment I and (b) experiment II. Each value represents Mean ± SE, n = 16. Irrigation water had an average pH of 8.6.

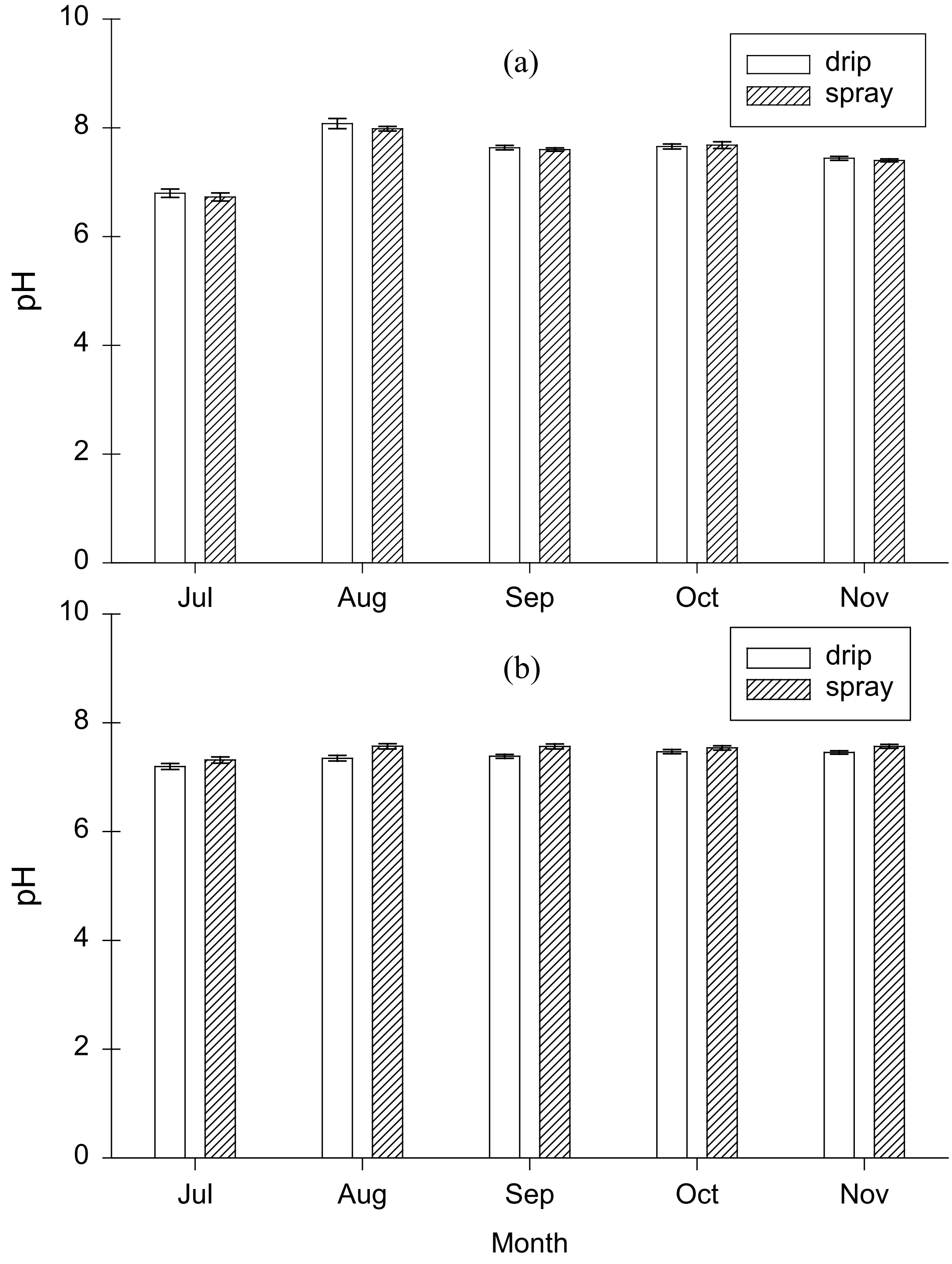

Figure 8. pH of substrate-leachates in Chinese elm (U. parvifolia) under two irrigation methods; drip ring (drip) and spray stake (spray). (a) Experiment I and (b) experiment II. Each value represents Mean ± SE, n = 16. Irrigation water had an average pH of 8.6.

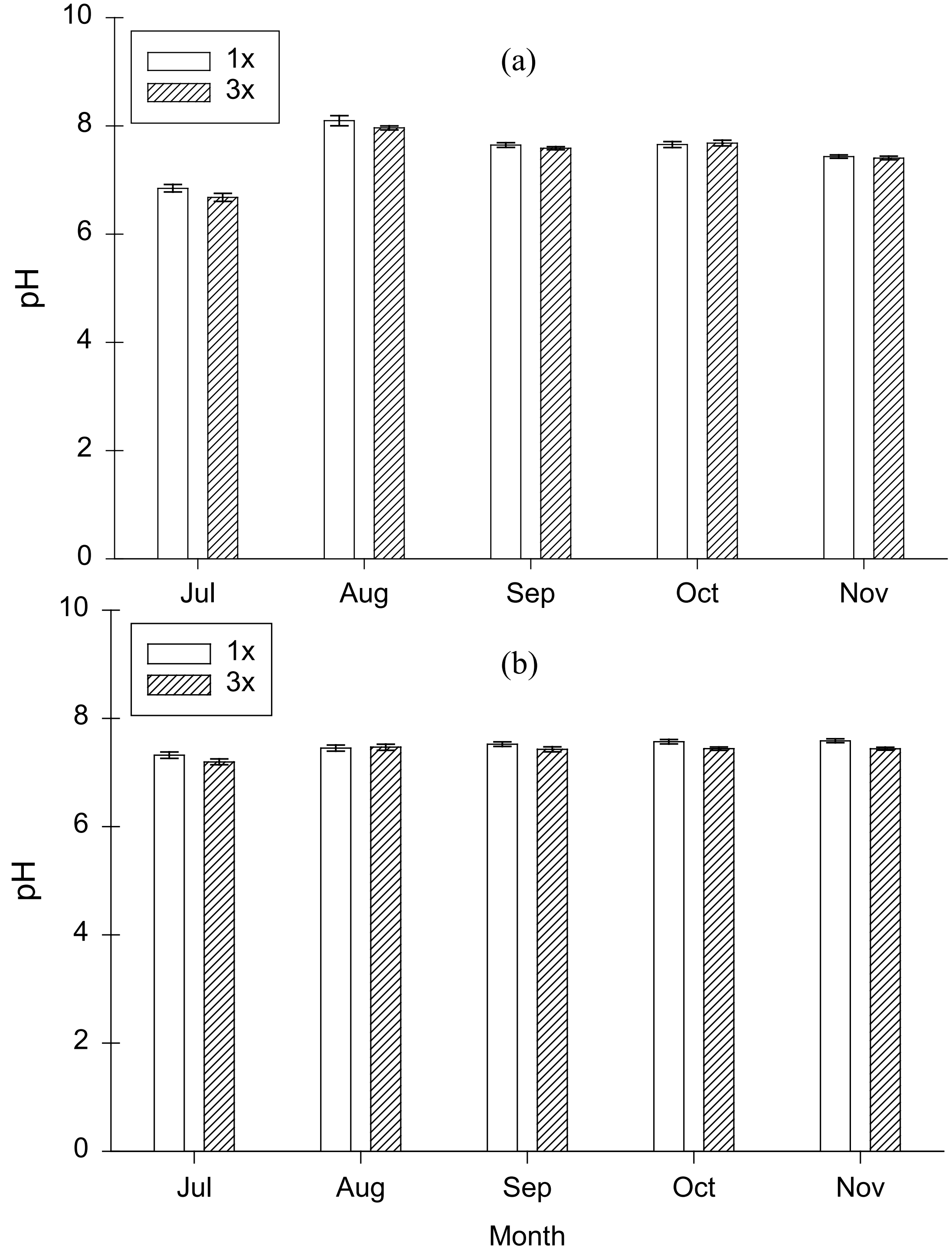

Figure 9. pH of substrate-leachates in Chinese elm (U. parvifolia) under two irrigation frequencies; once daily (1x) and three times daily (3x). (a) Experiment I and (b) experiment II. Each value represents Mean ± SE, n = 16. Irrigation water had an average pH of 8.6.

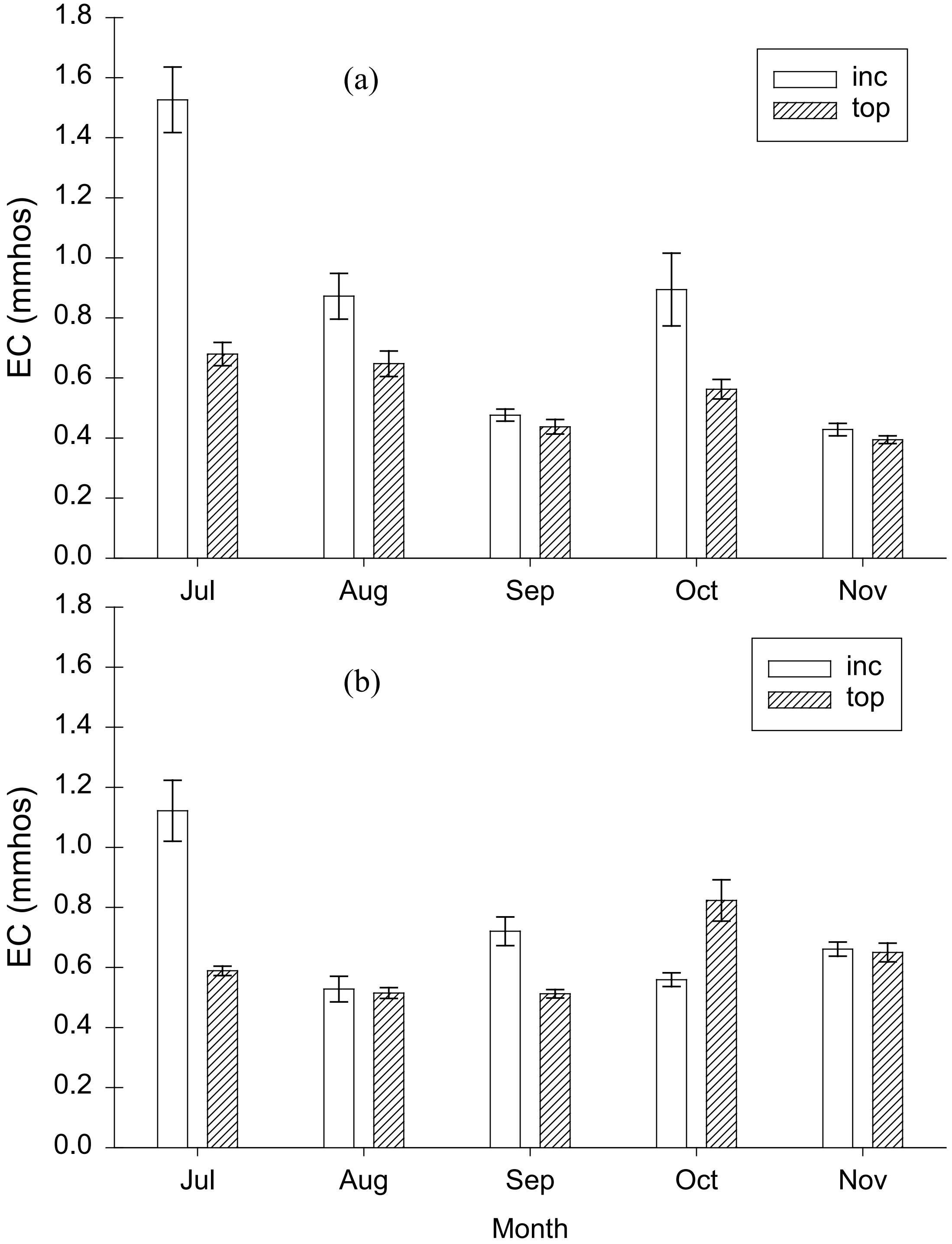

Figure 10. Electrical conductivity (EC) of substrate-leachates in Chinese elm (U. parvifolia) under two methods of fertilizer placement; incorporated (inc) and topdressed (top). (a) Experiment I and (b) experiment II. Each value represents Mean ± SE, n = 16. Irrigation water had an average EC of 0.33 mmhos.

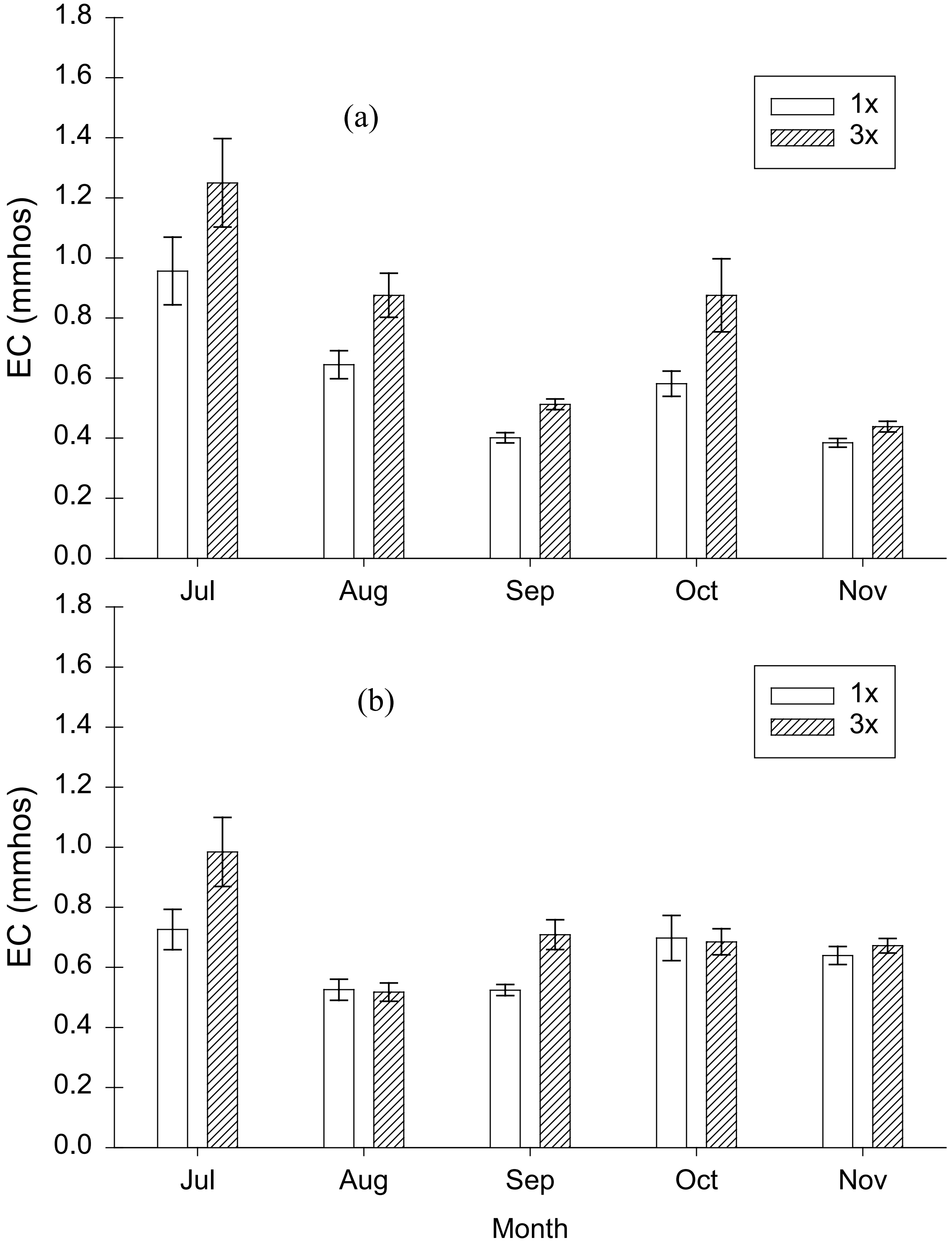

Figure 11.Electrical conductivity (EC) of substrate-leachates in Chinese elm (U. parvifolia) under two irrigation frequencies; once daily (1x) and three times daily (3x). (a) Experiment I and (b) experiment II. Each value represents Mean ± SE, n = 16. Irrigation water had an average EC of 0.33 mmhos.

produced more effluent than 3x which resulted in leaching of soluble salts. Only a few significant differences were observed between irrigation types and no clear trend could be defined (Fig. 12a-b).

Nitrogen (N)

A significant main effect of fertilizer placement resulted in experiment I only. In experiment I, the irrigation frequency main effect was significant while experiment II showed no significance. No significant main effect resulted from irrigation type in either experiment. A fertilizer method and irrigation frequency interaction occurred in experiment II (Table 2).

In experiment I, the incorporated treatment maintained higher N concentrations in July (86% higher than topdressed) and August then evened out in the rest of the season. A similar trend was seen in experiment II where incorporated fertilizer had 96% more N than topdress in July, yet the overall effects were not significant between the treatments (Fig 13a-b). The incorporated fertilizer could be more available for plant use because of its even distribution throughout the media whereas topdressed fertilizer has to migrate through the substrate. Previous research found that incorporated treatments resulted in higher N leachate levels at the beginning of the study compared to topdressed treatments, then leveled out toward the end for both methods (Warren et al., 1997; Yeager et al., 1989).

Using 3x irrigation maintained a higher N in July and August then leveled off the rest of the season in experiment I, while the significant differences in experiment II were very small (Fig. 14a-b). Higher nutrient levels were maintained with 3x irrigation because

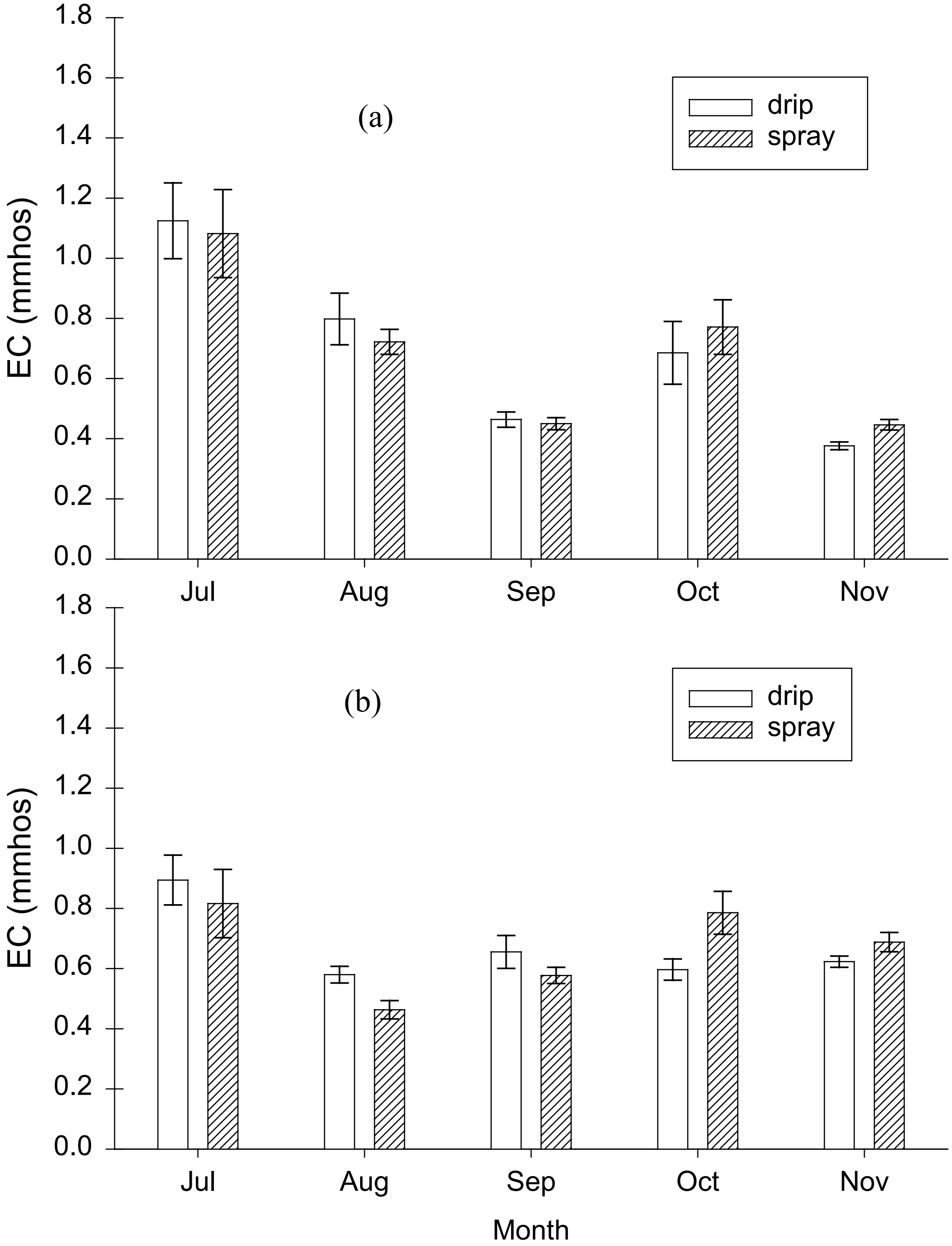

Figure 12. Electrical conductivity (EC) of substrate-leachates in Chinese elm (U. parvifolia) under two irrigation methods; drip ring (drip) and spray stake (spray). (a) Experiment I and (b) experiment II. Each value represents Mean ± SE, n = 16. Irrigation water had an average EC of 0.33 mmhos.

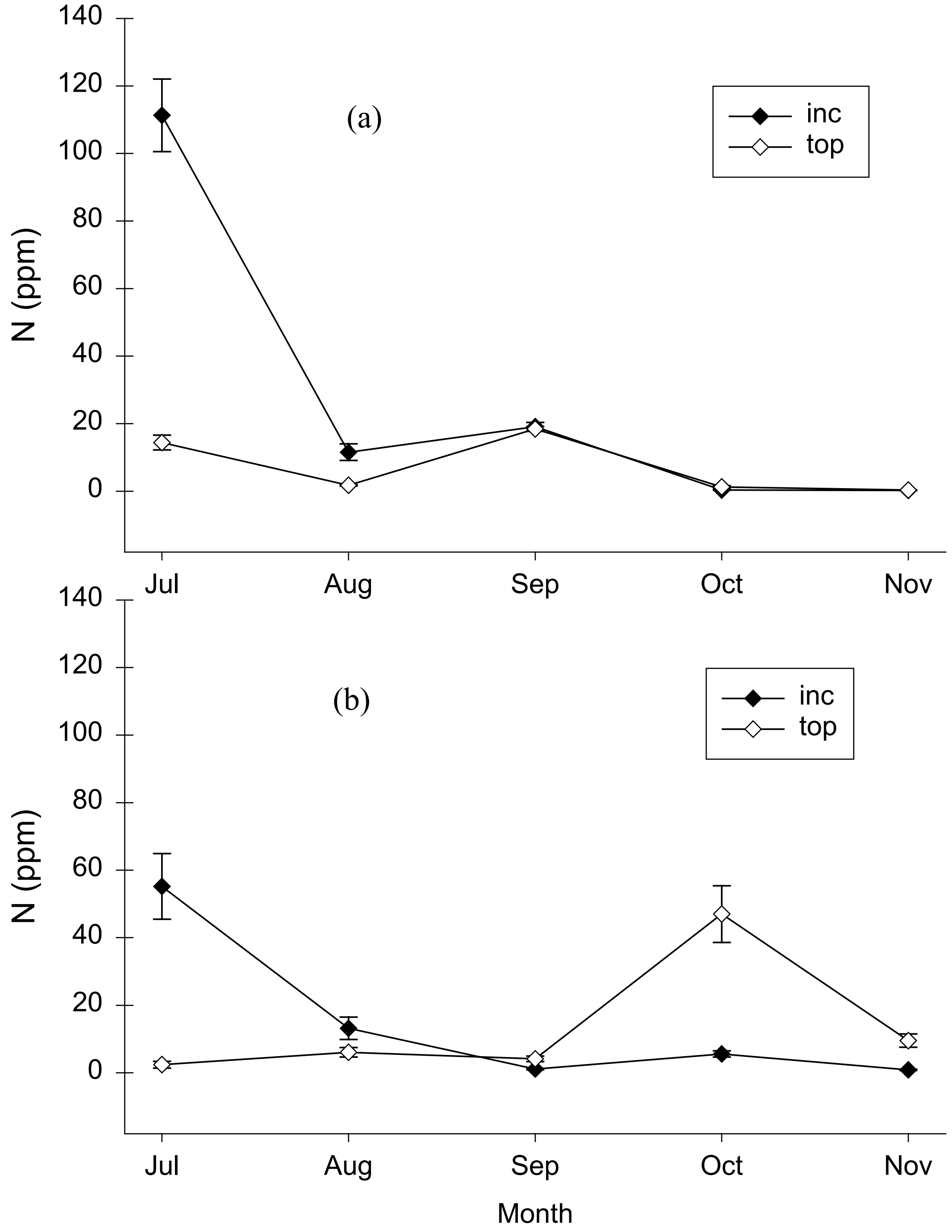

Figure 13. Substrate-leachate nitrogen (N) concentration in Chinese elm (U. parvifolia) under two methods of fertilizer placement; incorporated (inc) and topdressed (top). (a) Experiment I and (b) experiment II. Each value represents Mean ± SE, n = 16.

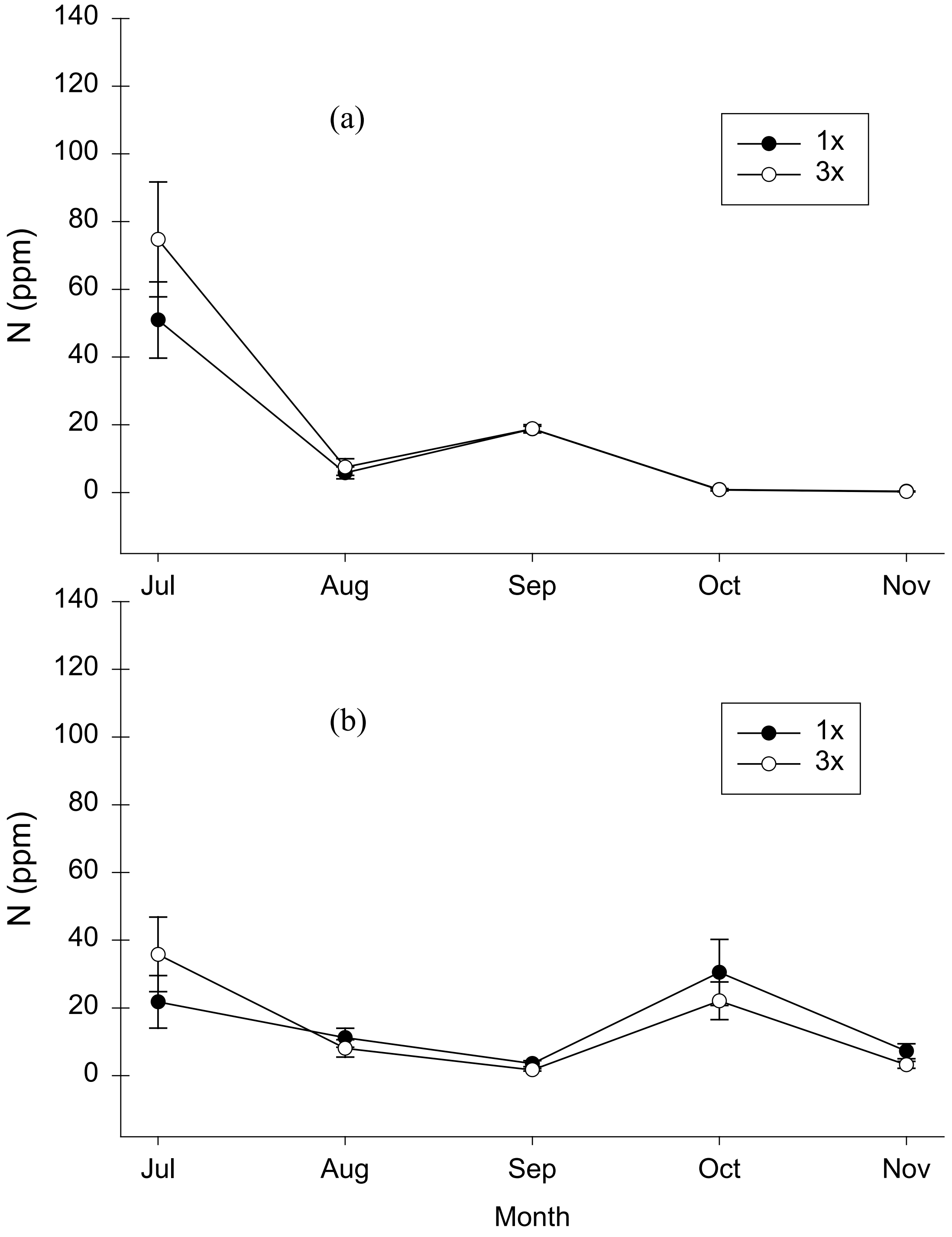

Figure 14. Substrate-leachate nitrogen (N) concentration in Chinese elm (U. parvifolia) under two irrigation frequencies; once daily (1x) and three times daily (3x). (a) Experiment I and (b) experiment II. Each value represents Mean ± SE, n = 16.

it produced less effluent which resulted in reduced leaching of nutrients compared to 1x (Fain et al., 1998; Fare et al., 1994; Fare et al., 1996).

No significant differences were witnessed for irrigation type in either experiment (Fig. 15a-b).

Phosphorus (P)

Leachate P content was effected significantly by fertilizer method only in experiment I. Irrigation frequency also produced a significant main effect on phosphorus in experiment I only. No significant main effect resulted from irrigation type in either experiment (Table 2).

P leachate concentrations followed the same trends as N concentrations mentioned above. The explanations for the N results can be used for the P results. In experiment I, the incorporated treatment maintained a higher P concentration, 35% more than the topdressed treatment. A similar trend was seen in experiment II, yet the overall effects were not significant between the treatments (Fig. 16a-b). Under irrigation frequency, 3x maintained a higher P content in July and August than 1x in experiment I with no significant differences in experiment II (Fig. 17a-b). Overall, there were no significant differences between irrigation types in either experiment (Fig. 18a-b).

Potassium (K)

A significant fertilizer method main effect resulted in each experiment. Irrigation frequency produced a significant main effect in experiment I only. Irrigation type produced no significant effects in either experiment. A fertilizer method and irrigation frequency occurred in both experiments. In experiment II, an irrigation frequency and

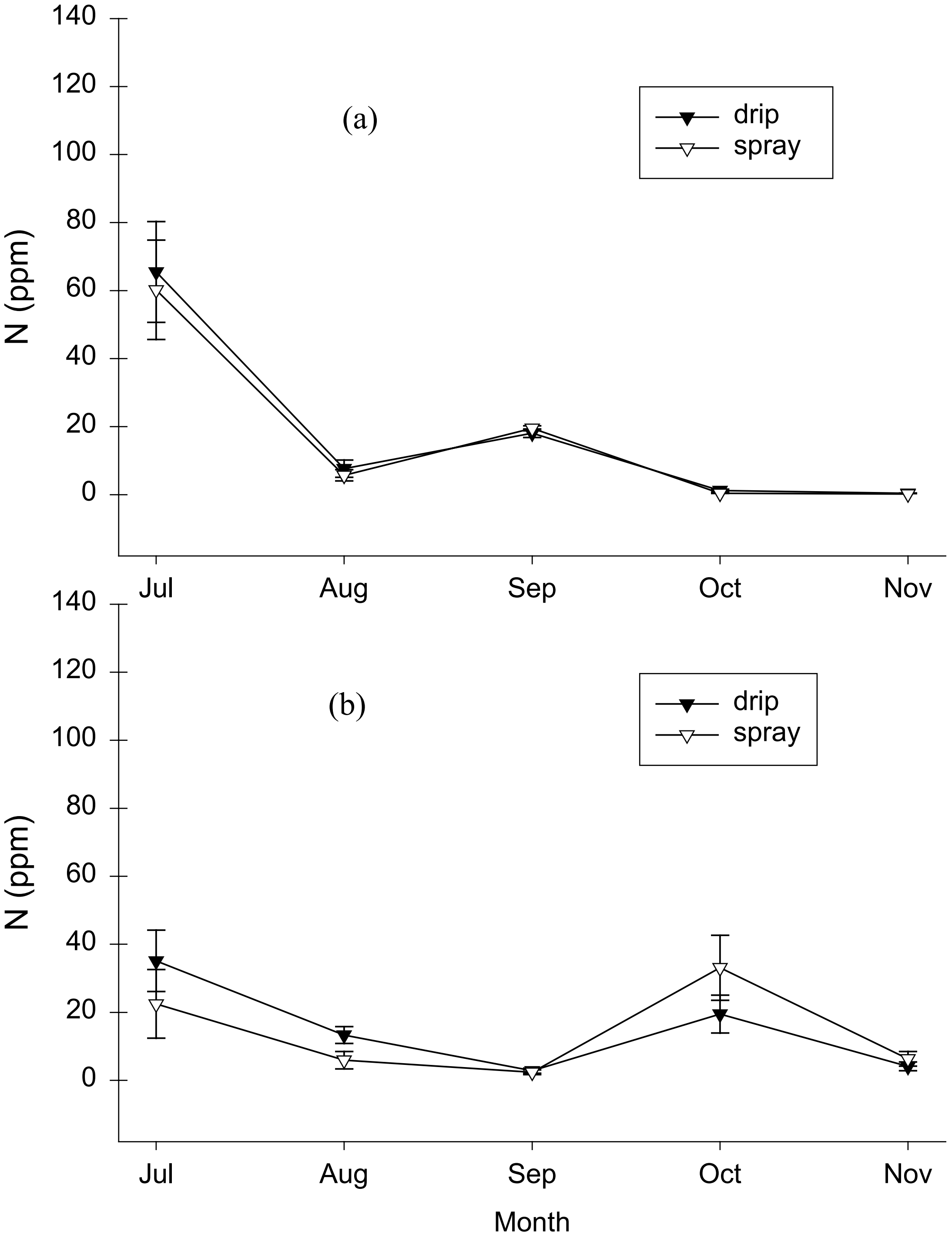

Figure 15. Substrate-leachate nitrogen (N) concentration in Chinese elm (U. parvifolia) under two irrigation methods; drip ring (drip) and spray stake (spray). (a) Experiment I and (b) experiment II. Each value represents Mean ± SE, n = 16.

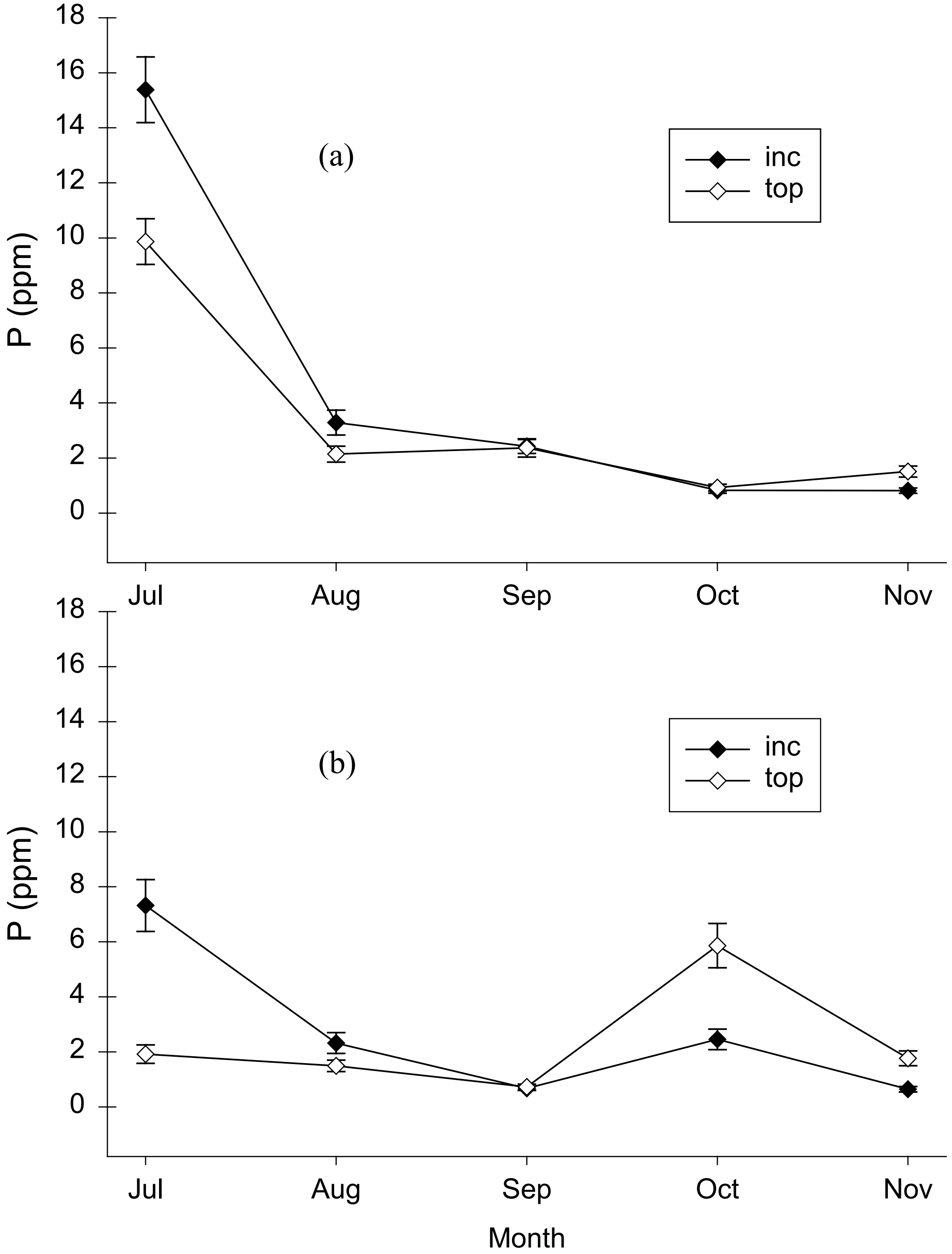

Figure 16. Substrate-leachate phosphorus (P) concentration in Chinese elm (U. parvifolia) under two methods of fertilizer placement; incorporated (inc) and topdressed (top). (a) Experiment I and (b) experiment II. Each value represents Mean ± SE, n = 16.

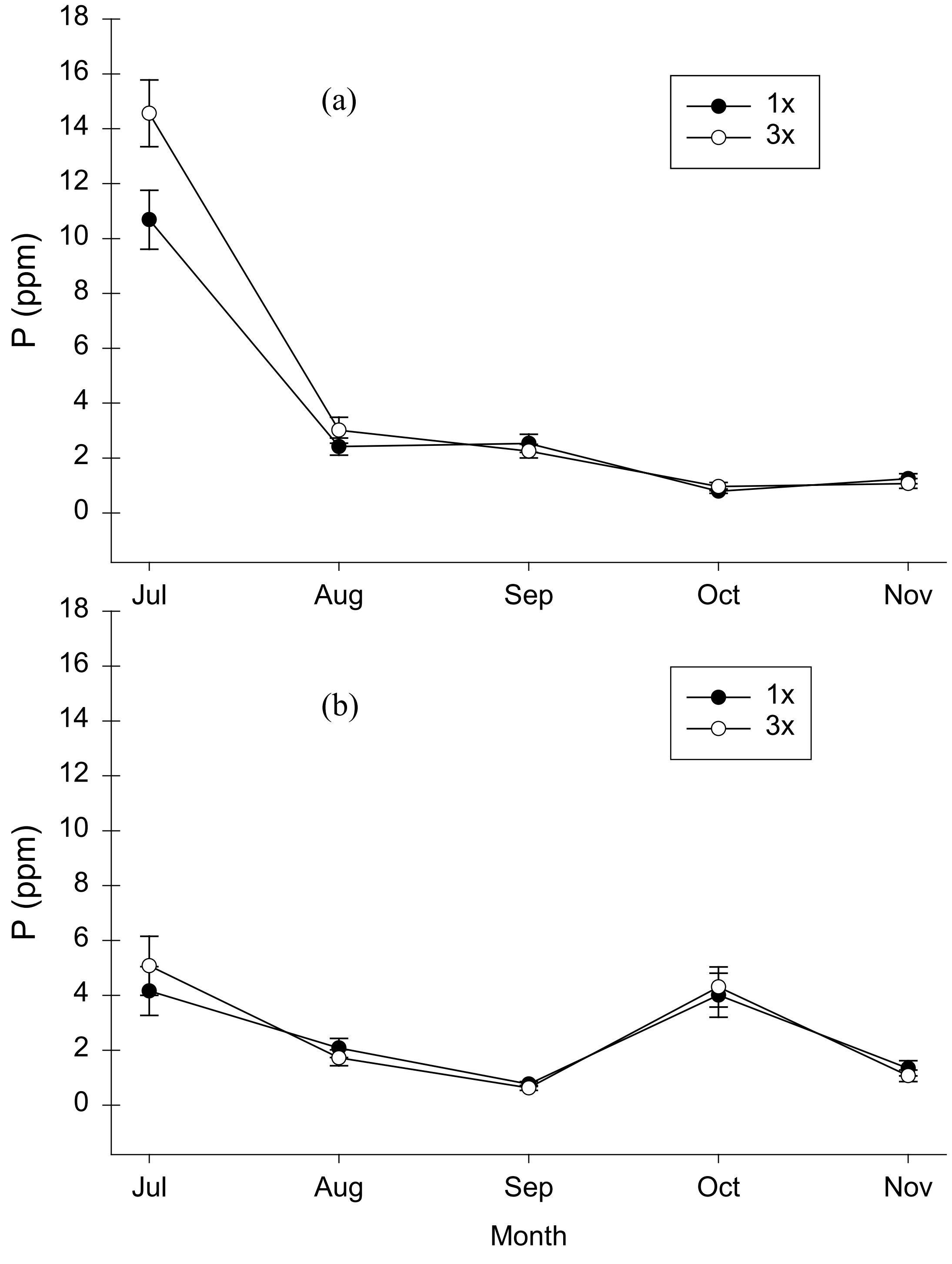

Figure 17. Substrate-leachate phosphorus (P) concentration in Chinese elm (U. parvifolia) under two irrigation frequencies; once daily (1x) and three times daily (3x). (a) Experiment I and (b) experiment II. Each value represents Mean ± SE, n = 16.

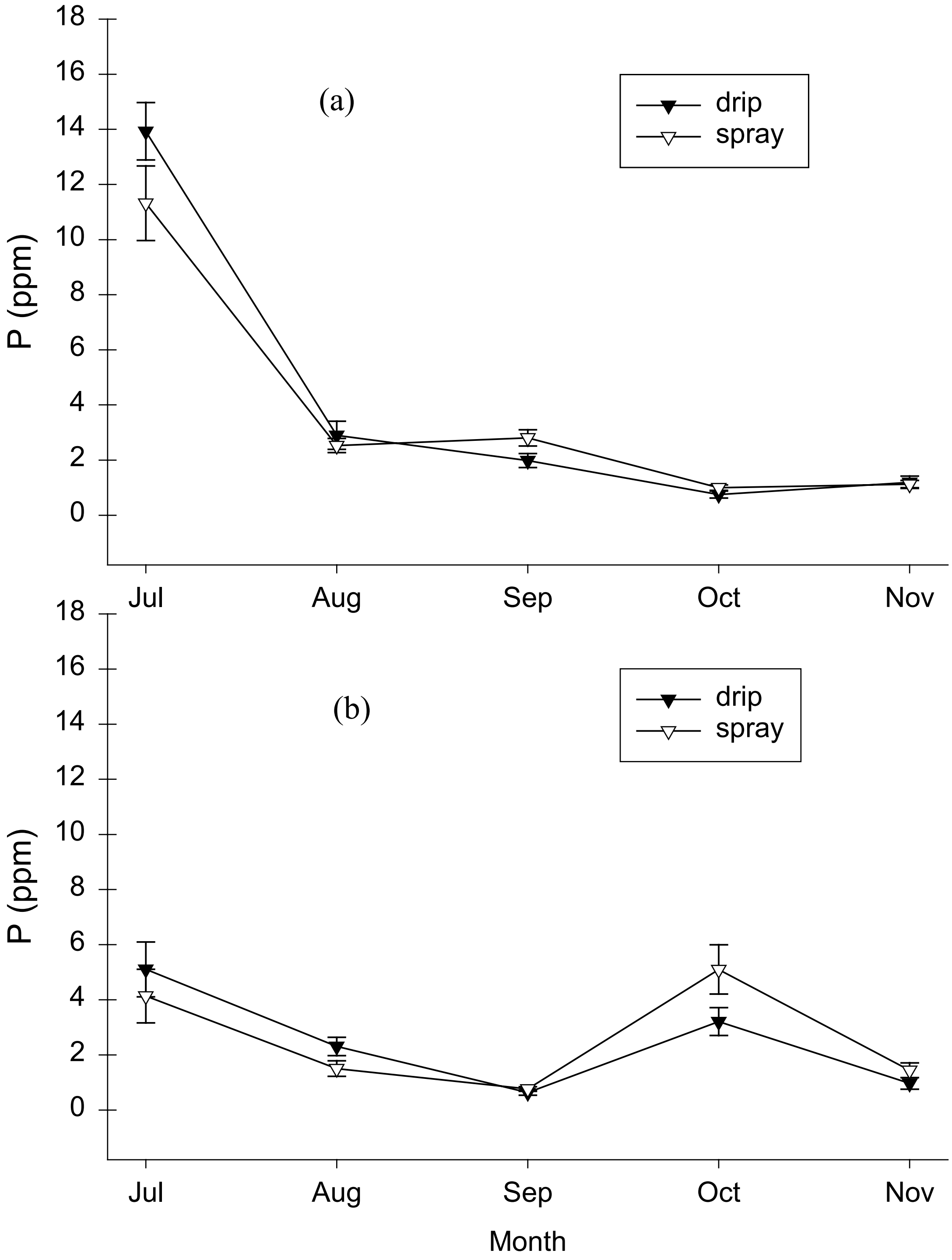

Figure 18. Substrate-leachate phosphorus (P) concentration in Chinese elm (U. parvifolia) under two irrigation methods drip ring (drip) and spray stake (spray). (a) Experiment I and (b) experiment II. Each value represents Mean ± SE, n = 16.

irrigation type interaction occurred along with a three way interaction between all main factors (Table 2).

K leachate content followed the trends of N and P so the explanations mentioned above would apply to K. In both experiments, the incorporated treatment maintained a higher K concentration compared to the topdressed treatment in July and August then leveled off the end of the season (Fig. 19a-b). The 3x treatments maintained higher K concentrations for July and August in experiment I compared to the 1x treatments (Fig. 20a-b). No overall effects were significant between irrigation types for either experiment (Fig. 21a-b).

Conclusions

Our study showed that incorporating fertilizer into the substrate increased plant growth, reduced effluent and maintained higher concentrations of N, P, and K in the substrate. Previous studies found that incorporated fertilizer increased plant growth compared to topdressed fertilizer (Tilt et al., 1990). Increased plant growth for the incorporated treatment was statistically greater in August and October for both experiments. Incorporated fertilizer is distributed evenly throughout the substrate, which makes it more available for plant uptake because the nutrients are concentrated at the root zone. Thus, plants can more readily access the nutrients which yields increased plant growth compared to topdressed treatments.

There have been no reports that indicate fertilizer placement affected effluent volume; however, our study showed differences. In experiment II, incorporated treatments showed reduced effluent volume throughout the year. One possibility is that since incorporated treatments increased plant growth, the larger trees used more water

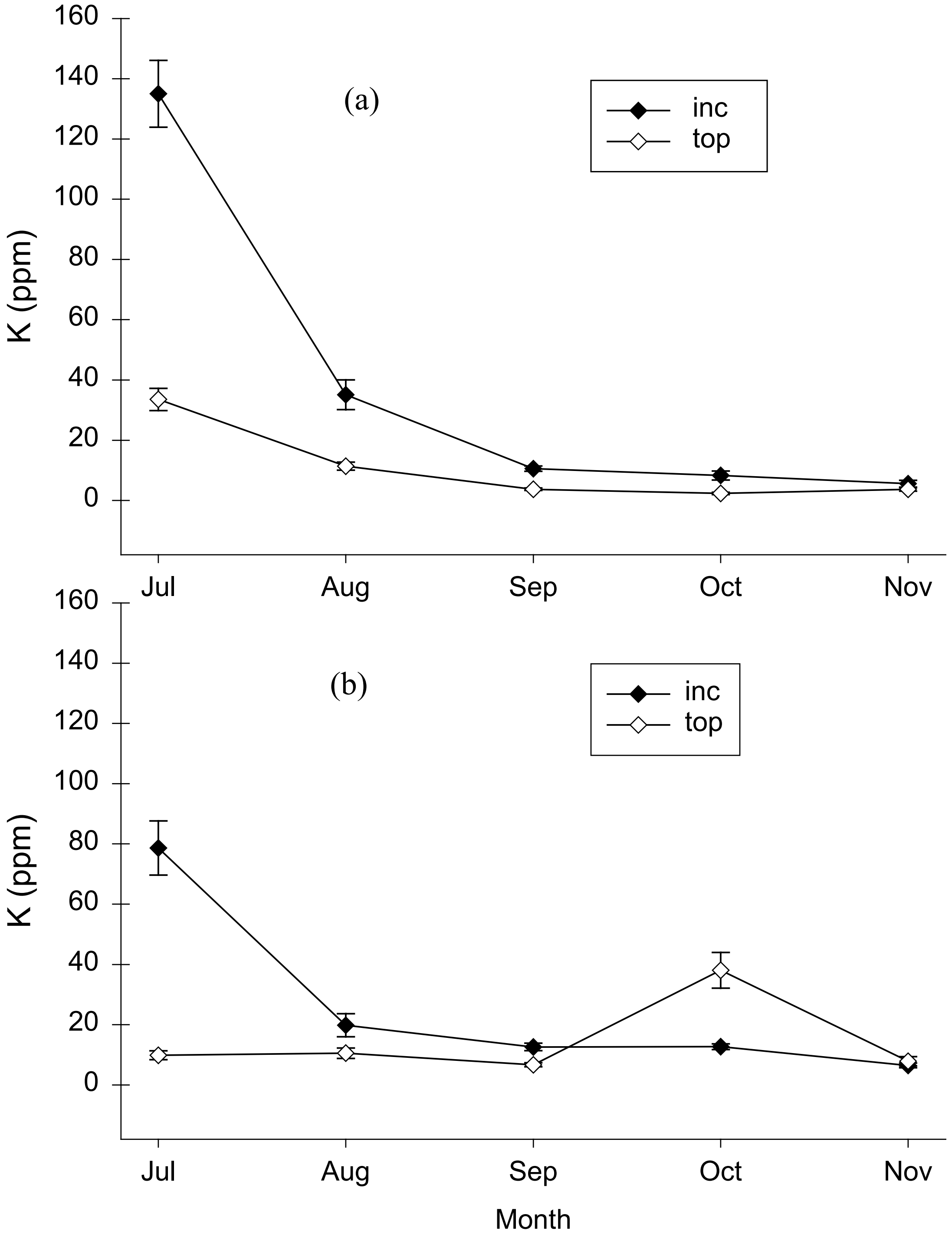

Figure 19. Substrate-leachate potassium (K) concentration in Chinese elm (U. parvifolia) under two methods of fertilizer placement; incorporated (inc) and topdressed (top). (a) Experiment I and (b) experiment II. Each value represents Mean ± SE, n = 16.

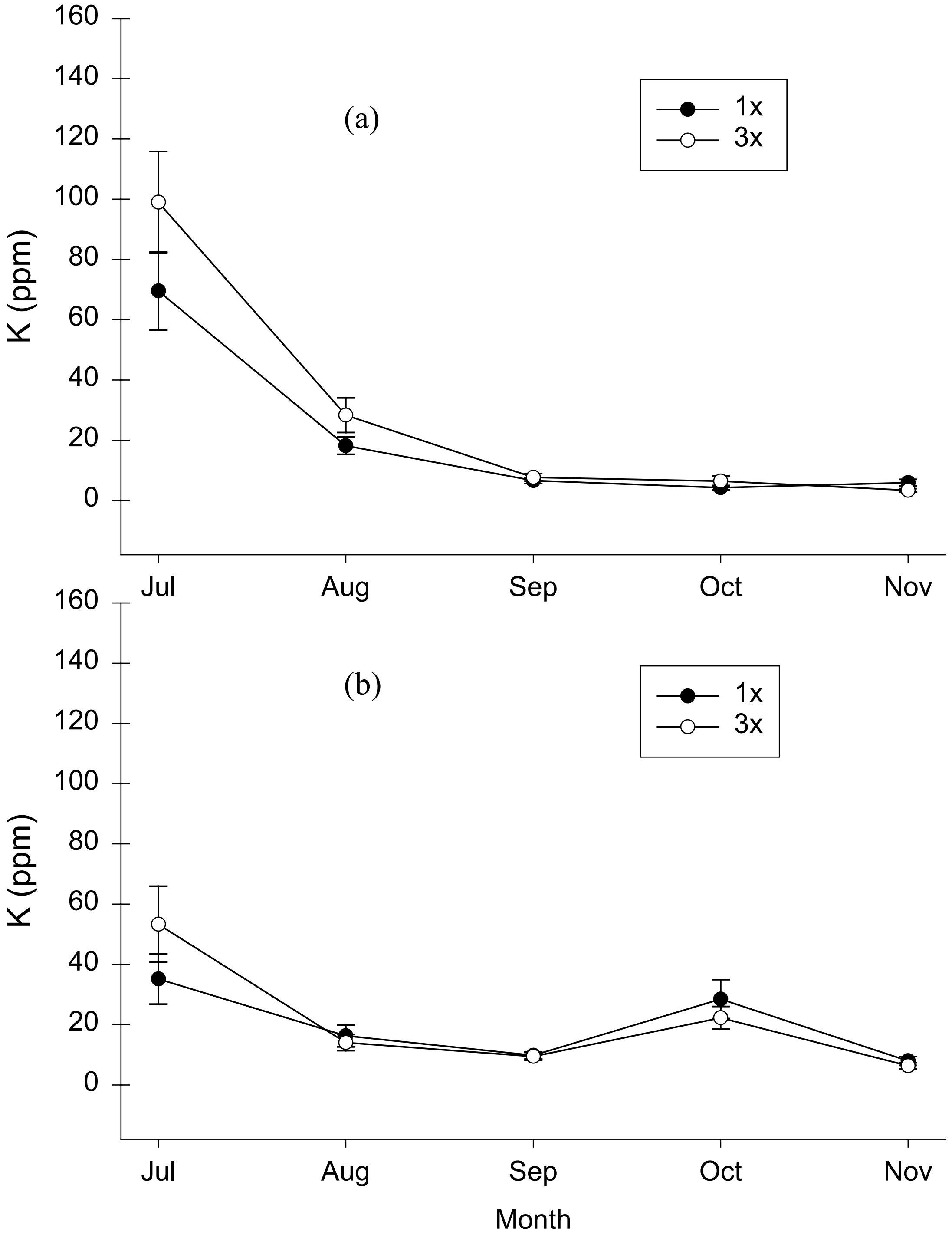

Figure 20. Substrate-leachate potassium (K) concentration in Chinese elm (U. parvifolia)under two irrigation frequencies; once daily (1x) and three times daily (3x). (a) Experiment I and (b) experiment II. Each value represents Mean ± SE, n = 16.

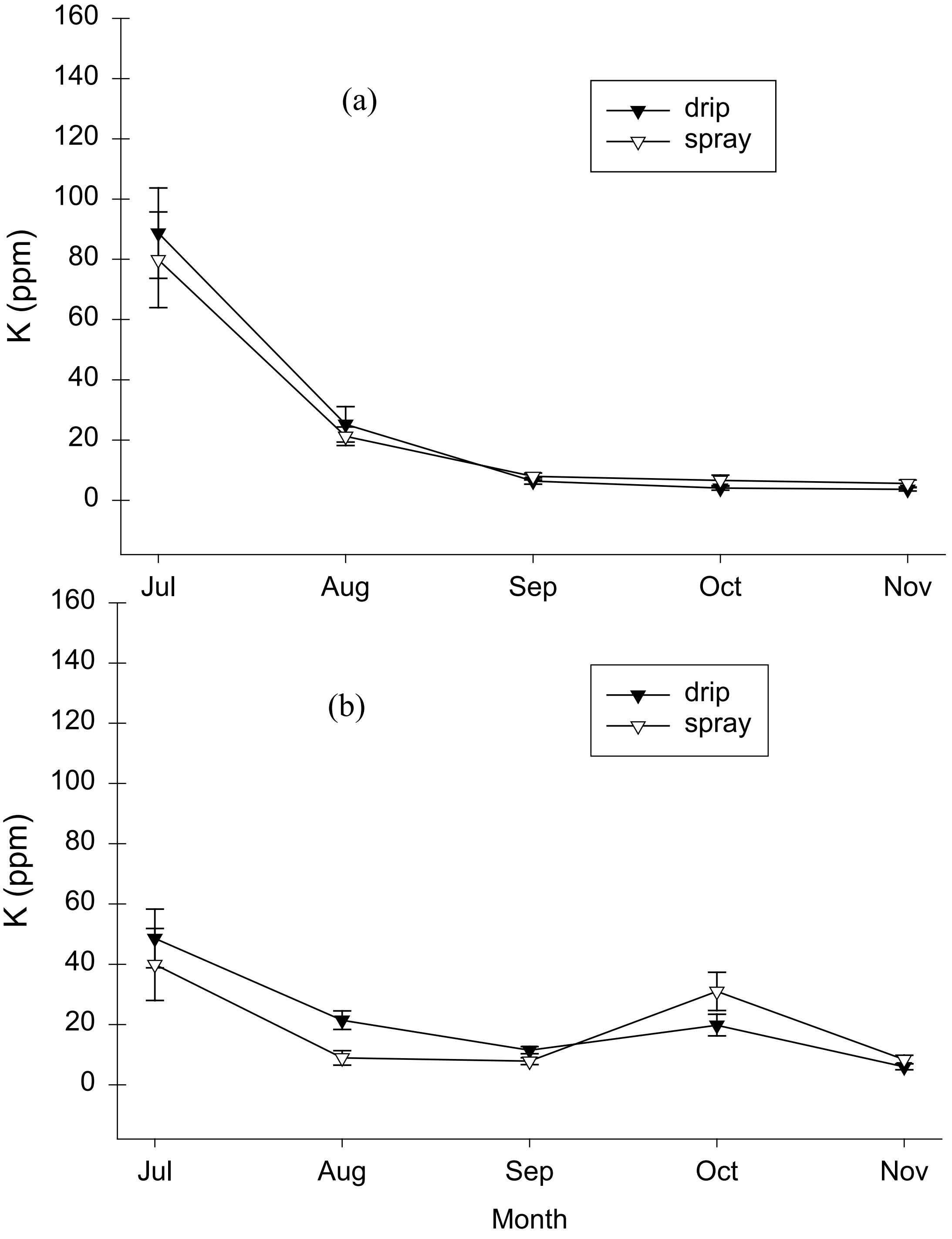

Figure 21. Substrate-leachate potassium (K) concentration in Chinese elm (U. parvifolia) under two irrigation methods; drip ring (drip) and spray stake (spray). (a) Experiment I and (b) experiment II. Each value represents Mean ± SE, n = 16.

which resulted in reduced effluent volume. Although root density was not evaluated, another possibility is the incorporated treatments yielded larger root systems therefore water was used more efficiently by the plant.

Previous studies with *Cotoneaster dammeri* 'Skogholm' and *Ligustrum japonicum* have concluded that incorporated fertilizer maintained higher substrate nutrient levels compared to topdressed fertilizer (Warren et al., 1997; Yeager et al., 1989). The results indicate that the incorporated treatment maintained higher N and P substrate concentrations in experiment I while K substrate concentrations were higher in both experiments compared to topdressed treatments. Incorporated fertilizer is distributed evenly in the substrate where it can be readily accessed by the plant. In the topdressed treatments, nutrients must migrate through the substrate thus leading to less availability. Since higher concentrations of nutrients are present and readily available with the incorporated treatments, this results in increased plant growth.

The irrigation frequency regime indicated that watering three times daily increased plant growth, reduced effluent volume and maintained higher N, P and K substrate concentrations compared to watering once daily. Studies with *Acer rubrum*, *Prunus* 'Okame' and *Acer sacharum* also found that irrigating three times daily increased plant growth compared to irrigating once daily (Fain et al., 1998; Ruter, 1997; Witmer et al., 1998). Irrigating three times during the day provides water to the plant while it's actively growing, when water needs are the greatest. Also, plant stress from heat and drought are reduced by cyclic irrigation, leading to larger plants compared to those watered once daily.

In past studies with *Ilex crenata* 'Compacta', *Magnolia grandiflora* 'Little Gem' and *Tagetes erecta* 'Apollo', effluent volume has been reduced by cyclic irrigation compared to a single application (Fare et al., 1994; Gray et al., 1998; Karam et al., 1992; Tyler et al., 1995). In our study, effluent volume was also significantly reduced with cyclic irrigation. The 1x treatments irrigate once a day in the morning and once the substrate reaches maximum water holding capacity, any water applied after this point results in effluent. The 3x treatment applies water three times during the day, so the substrate is less likely to reach maximum water holding capacity, resulting in less effluent and more availability to the plant.

Cyclic irrigation has reduced nutrient leaching from the substrate compared to a single application in studies with *Acer rubrum* 'Frank's Red', *Ilex crenata* 'Compacta' and *Ageratum houstonianum* 'Blue Puffs' (Fain et al., 1998; Fare et al., 1994; Fare et al., 1996). Although our results showed significant differences in experiment I, only the 3x treatment maintained higher N, P and K substrate concentrations initially in both experiment I and II. Watering three times daily reduced effluent volume therefore decreasing nutrient leaching, leaving more nutrients available for plant use.

Our study was the first to compare the two micro-irrigation methods, drip ring irrigation to spray stake irrigation, in large container production. Effluent volume was the only variable affected by irrigation method. In each experiment, the drip rings produced greater effluent than the spray stakes. The spray stakes produced container overspray and the wind drift of irrigation water could have affected the total irrigation volume applied to the container. Another explanation is that the spray stakes saturated the media more efficiently than the drip rings which resulted in less effluent.

References

Beeson, R.C., Jr. and G.W. Knox. 1991. Analysis of efficiency of overhead irrigation in container production. HortScience 26:848-850.

Beeson, R.C., Jr. and J. Haydu. 1995. Cyclic microirrigation in container-grown landscape plants improves plant growth and water conservation. J. Environ. Hort. 13:6-11.

Eakes, D.J., W.J. Foster, C.H. Gilliam and J.W. Olive. 1990. Effects of method of application and rate of three slow release fertilizers. Proc. SNA Conf. 35:55-56.

Fain, G.B., K.M. Tilt, C.H. Gilliam, H.G. Ponder and J.L. Sibley. 1998. Effects of cyclic micro-irrigation and substrate in pot-in-pot production. Proc. SNA Conf. 43:87-90.

Fare, D.C., C.H. Gilliam, G.J. Keever and J.W. Olive. 1994. Cyclic irrigation reduces container leachate nitrate-nitrogen concentration. HortScience 29:1514-1517.

Fare, D.C., C.H. Gilliam, G.J. Keever and R.B. Reed. 1996. Cyclic irrigation and media affect container leachate and ageratum growth. J. Environ. Hort. 14:17-21.

Gilliam, C.H., G.S. Cobb and C.E. Evans. 1984. Effects of nitrogen concentration and container size on growth of Pyrus calleryana 'Bradford'. J. Environ. Hort. 2:53-56.

Gray, A.L., E.W. Bush and R.I. Edling. 1998. Cyclic irrigation affects on container-grown 'Little Gem' magnolia growth and fertilizer leaching. Proc. SNA Conf. 43:520-525.

Karam, N.S. and A.X. Niemiera. 1992. Low water application rate and intermittent irrigation increase irrigation efficiency of sprinkler-irrigated container-grown plants. Proc. SNA Conf. 37:41-44.

Lamack, W.F. and A.X. Niemiera. 1992. Spray stake irrigation of container-grown plants. Proc. SNA Conf. 37:398-401.

Lamack, W.F. and A.X. Niemiera. 1993. Application method affects water application efficiency of spray stake-irrigated containers. HortScience 28:625-627.

Martin, C.A., H.G. Ponder and C.H. Gilliam. 1989. Effects of irrigation rate and media on growth of Acer rubrum L. in large containers. J. Environ. Hort. 7:38-40.

Meadows, W.A. and D.L. Fuller. 1986. Effect of osmocote placement on release patterns of nitrogen and potassium in a pine bark medium. Proc. SNA Conf. 31:85-89.

Ruter, J.M. 1997. Cyclic irrigation and pot-in-pot production affect the growth of 'Okame' cherry. Proc. SNA Conf. 42:423-425.

Tilt, K., W.T. Witte, M. Halcomb and J. Watkins. 1990. Slow release fertilizers with minor elements topdress vs. incorporation on 100% bark medium. Proc. SNA Conf. 35:111-116.

Tyler, H.H., S.L. Warren and T.E. Bilderback. 1995. Cyclic irrigation increases irrigation efficiency and ammonium retention. Proc. SNA Conf. 40:59-61.

Tyler, H.H., S.L. Warren and T.E. Bilderback. 1996. Cyclic irrigation increases irrigation application efficiency and decreases ammonium losses. J. Environ. Hort. 14:194-198. (b)

Warren, S.L., T.E. Bilderback and H.H. Tyler. 1997. Does method of fertilizer application (surface or incorporation) affect nutrient losses of controlled release fertilizers? Proc. SNA Conf. 42:141-143.

Witmer, R.K., J.R. Harris, A.X. Niemiera and J. Fanelli. 1998. Frequent irrigation increases the growth of pot-in-pot sugar and red maple. Proc. SNA Conf. 43:516-519.

Yeager, T.H., C. Gilliam, T. Bilderback, D. Fare, A. Niemiera and K. Tilt. 1997. Best management practices guide for producing container-grown plants. Southern Nurserymen's Association, Marietta, GA.

Yeager, T.H., D.L. Ingram and C.A. Larsen. 1989. Nitrate nitrogen and potassium release from surface-applied and growth medium-incorporated osmocote and escote. Proc. SNA Conf. 34:54-56.

CHAPTER 3

EVALUATION OF FERTILIZER PLACEMENT, IRRIGATION SCHEDULE AND TYPE OF IRRIGATION IN LARGE CONTAINER PRODUCTION OF CRAPE MYRTLE

Introduction

Landscape trees and shrubs have been grown in an array of container sizes ranging from one gallon to several hundred gallons. The majority of these woody ornamentals are produced in one to five gallon containers, although the demand for larger landscape plants has increased. Over the last several years, this demand has encouraged many nurseries to modify their production facilities to accommodate large container-grown plants. The practice of producing large container-grown woody ornamentals has required changes in irrigation practices (Gilliam et al., 1984 and Gray et al., 1998). Traditionally, these woody ornamentals have been watered once a day with overhead irrigation, a common and practical system for small containers. Though practical, this method often results in large quantities of runoff since water is lost between the containers. This problem is intensified as container size increases because the space between containers also increases. Even more water is lost to runoff using overhead irrigation with large containers (Beeson et al., 1991).

The high volume of water consumed by the nursery and other industries and the increased concentrations of fertilizer and pesticide residue present in runoff has increased concerns over water conservation and quality. As a result, water preservation and regulation standards have been initiated in several states including Florida, California and Louisiana (Lamack et al., 1993 and Tyler et al., 1995). In response, the nursery industry has placed more emphasis on reducing irrigation volume and nutrient runoff, therefore, growers have sought alternative irrigation techniques (Fain et al., 1998).

Several methods used to successfully reduce irrigation volume and runoff include micro-irrigation (MI) and cyclic irrigation (Tyler et al., 1996b). MI systems apply water directly to the substrate surface inside each container, a more efficient delivery system compared to overhead irrigation (Martin et al., 1989). Drip emitters, spray stakes and drip rings are all forms of MI, yet irrigation efficiency can differ among them. For example, spray stakes apply water to a high percentage of substrate surface area resulting in a more uniformly wetted substrate compared to drip emitters which apply water to one point on the substrate surface (Lamack et al., 1993).

One disadvantage to MI systems is the excessive nutrient leaching that can occur (Lamack et al., 1992). One method of reducing nutrient leaching is to implement cyclic irrigation, irrigating more than once daily (Karam et al., 1992). Studies have shown that cyclic irrigation reduced irrigation volume and nutrient leaching while increasing plant growth compared to once daily irrigation (Tyler et al., 1995; Witmer et al., 1998).

The placement of controlled release fertilizers can also affect plant growth and nutrient leaching (Eakes et al., 1990; Meadows et al., 1986). The two primary methods of fertilizer placement are incorporated and topdressed. There and benefits and disadvantages to each method and placement varies nursery to nursery. Expensive equipment is required to incorporate the fertilizer into the container substrate, yet the nutrients are near the root zone and easily accessible to the plant. Topdressed fertilizer is easily applied to the substrate surface but if the plant falls, some of the fertilizer is often lost.

Growers have become increasingly interested in methods to reduce water runoff and nutrient loss while producing comparable size plants. A key reason alternative large container production systems need to be evaluated for their effectiveness in reducing irrigation volume and runoff, maintaining or improving plant growth and improving runoff water quality. In this experiment, fertilizer placements (incorporated and topdressed), irrigation frequencies [once (1x) and three times (3x) daily] and irrigation types (drip rings and spray stakes) were evaluated. The objective of this study was to determine which irrigation and fertilization components would maximize growth, minimize runoff and reduce the amount of nutrient loss from container media.

Materials and Methods

A large container production experiment was conducted at Burden Center in Baton Rouge, LA (latitude 30° 24' 27", longitude 91° 08' 45" and USDA Hardiness Zone 8b) over a two year period. ‘Acoma’ crape myrtles (*Lagerstroemia indica* x *fauriei* 'Acoma') were grown from April, 2000 to December, 2001. ‘Acoma’ crape myrtle was chosen for several reasons including its rapid growth rate and its popularity in the landscape industry.

Trees were planted 6 April 2000. Eighty trade gallon (2.8 L) 'Acoma' crape myrtles were transplanted into 20 gal (76 L) containers (Lerio Corporation, Mobile, AL) containing a 3 pine park : 1 peat : 1 sand (by volume) media amended with an incorporated application of 8 lbs/yd^3 (4.7 kg/m^3) dolomitic limestone. Applications of oxyfluorfen + oryzalin (Rout®) at for weed control and imidacloprid (Merit®) for insect control were made as needed using recommended rates broadcast over the container's 2.18 ft^2 surface area. Trees were arranged in a randomized complete block design with 8 treatments (2x2x2) and 10 replications, blocked using random assignment. Containers were spaced 4 ft (1.2 m) inside each block and 5 ft (1.5 m) in between blocks.

Treatments tested in this experiment included two fertilizer placements (incorporated and topdressed), two irrigation frequencies [one (1x) and three times (3x) daily] and two irrigation types (spray stake and drip ring).

Fertilizer Placement

Osmocote® 15-9-12 plus minors 12-14 month (Scotts-Sierra Horticultural Products Company, Marysville, OH) was the main source of nutrients and application rates were obtained from the manufacturer. Forty containers were topdressed (top) with 1.14 lb (516 g) Osmocote® and forty were filled with substrate incorporated (inc) with 18 lb/yd^3 (11 kg/m^3) of the same product resulting in 1.8 lb (817 g) per container. Topdressed treatments resulted in 0.171 lb (77 g) N, 0.103 lb (47 g) P and 0.137 lb (62 g) K per container while incorporated treatments resulted in 0.270 lb (122 g) N, 0.162 lb (74 g) P and 0.216 lb (98 g) K per container. Since the trees were grown over a two-year period, supplemental fertilizer was needed. In March 2001, all containers were topdressed with 1.14 lb (516 g) Osmocote® 15-9-12 plus minors (12-14 month).

Irrigation Frequency

All containers were irrigated daily with the same volume of water, however irrigation frequency varied. Forty of the containers were irrigated once daily (1x) at 6:00 AM while the remaining forty were irrigated three times daily (3x) at 6:00 AM, 12:00 PM and 6:00 PM. Daily irrigation volume was determined by measuring effluent volume from two of the blocks each month and maintaining a 20% to 40% effluent volume. Effluent was calculated by dividing the effluent volume by the total irrigation volume applied. A Sterling 18 controller (Superior Controls Co., Inc., Valencia, CA) was used to schedule the frequency treatments and operate the 24 V solenoid valves.

Irrigation Method

Forty containers were irrigated with spray stakes (spray) while the remaining forty containers were irrigated using 42 inch (106 cm) drip rings (drip). The spray stakes (Roberts Spot-Spitter®, San Marcos, CA) had a flow rate of 6 gph (22.7 Lph) at 15 psi. The drip rings were constructed from drip tubing (Drip-In Irrigation Co, Fresno, CA) and contained pressure compensated drippers every 6 inch (15 cm). Each ring had a flow rate of 3 gph (11.4 Lph) at 15 psi. Flow rates were measured initially, an average was taken from 10 emitters of each irrigation method. The duration of irrigation was adjusted for irrigation method so each emitter would apply the same volume of water during an irrigation cycle. Each spray stake and drip ring was connected to 0.5" (1.27 cm) polyethylene tubing by a piece of 8' (2.4 m) flexible vinyl tubing.

Data were collected to determine if any of the treatments influenced growth, effluent (excess water which drains from the container after each irrigation cycle) and substrate nutrient content (amount of nutrients available for plant use). Crape myrtle growth measurements were taken every 60 d on all eighty trees. Height was measured from the substrate surface to the apical meristem using a surveying rod. Stem caliper measurements were taken 8 inches (20 cm) above the substrate surface to the nearest 1/100 mm using a digital caliper (Mitutoyo®). Overall tree size was evaluated with a growth index (GI), calculated from the following equation: [height (cm) + caliper (mm) x 100] / 2.

Effluent was collected on three consecutive days each month resulting in 32 samples. The effluent collection system included a 19 inch (48 cm) square stand 10 inch (25 cm) tall constructed of 1.5 inch (3.8 cm) angled iron (Gray et al.,1998). A 24 inch (61 cm) square neoprene rubber mat with a drain in the center was placed between the container and stand so fluid could be collected in 5 gal (18.9 L) collection basins. Collection basins were weighed after all irrigation cycles were complete and when drainage from the containers ceased. The average daily effluent volume was determined and percent effluent was calculated with the following equation: [effluent volume (L) / irrigation volume (L)] x 100.

Leachates, samples of liquid extracted from the container substrate using the Virginia Tech Extraction Method (Yeager et. al., 1997), were collected every 30 d using the collection system previously mentioned. The process began by irrigating the containers until effluent began to drain from the container bottom at which time irrigation was terminated. After effluent draining ceased, collection basins were placed under the stands and an additional 0.5 gal (1.9 L) of water was poured into the container over the substrate surface. One hour later, after effluent had stopped, the leachate was collected in 4 oz (120 mL) plastic bottles and refrigerated. Leachates were collected within one week following the effluent collection because the water applied during leachate collection could affect percent effluent volume if conducted beforehand.

Each sample was poured through 4.25 inch (11 cm) paper filters (Schleicher & Schuell, Inc., Keene, NH) then a pH (Model 410A, Orion Research Inc., Boston, MA) and electrical conductivity (EC) (Model 5800-00, Cole-Parmer Instrument Co., Chicago, IL) analysis was performed. The LSU Agricultural Chemistry Laboratory in Baton Rouge, LA performed an analysis of the substrate nutrient content (N, P, K, Ca, Mg, Cu, Mn, Fe, Zn, S, B, Na). Nitrate and ammonium nitrogen contents were determined by a colorimetric method, a combination of the EPA 351.2A and Technicon 560-79A methods. All other nutrient contents were determined using the EPA 610B method.

The experiment was a completely randomized block design with a three way factorial treatment structure and repeated measurements on the dependent variables (growth index, percent effluent volume, pH, EC, and substrate content of N, P and K). Profile analysis in SAS (PROC GLM) was used to determine the magnitude of both within-subject and between-subject main effects and interactions. In addition, linear contrasts were constructed to test for differences among specific treatment combinations over the course of the entire experiment.

For comparisons of treatment differences within months, analysis of variance was conducted in SAS. When F-values indicated significant treatment effects, Duncan's Multiple Range Test was used to compare pair-wise differences between treatments. For all analyses, a p-value ≤ 0.05 indicated significance.

Results and Discussion

Growth index, effluent volume, pH and EC along with container substrate content of N, P and K resulted in significant differences. The main effects of fertilizer placement, irrigation frequency and irrigation method are mentioned followed by general trends for each treatment regime. The remaining macro and micronutrient data is presented as tables in the Appendix (Tables 10-15).

Growth

No significant main effect in tree growth resulted from fertilizer placement. Significant main effects from irrigation frequency and type were observed in tree growth index. An interaction occurred between fertilizer placement and irrigation frequency in addition to one between irrigation type and frequency (Table 3).

The incorporated treatment had higher average tree growth throughout the study but not significantly (Fig. 22). A study with x *Cupressocyparis leylandii* and *Ilex crenata* 'Fosteri' (Tilt et al., 1990) yielded no significant differences in GI between topdressed and incorporated fertilizer placements. Another study (Yeager et al., 1989) showed no significant differences in shoot dry weight of *Ligustrum japonicum* or *Rhododendron* 'Mrs. G.G. Gerbing' resulting from Osmocote® placement.

The 3x irrigation frequency treatment produced statistically larger trees during the second year of the study (Fig. 23). Studies with *Ulmus alata*, *Acer rubrum*, *Prunus* 'Okame' and *Acer sacharum* also found that cycled irrigation produced statistically larger trees compared to a single application. It is believed that cycled irrigation tends to reduce plant water and heat stress encountered under hot southeastern United States summer conditions (Beeson et al., 1995; Fain et al., 1998; Ruter, 1997; Witmer et al., 1998).

Drip irrigation produced statistically larger trees the second year of the study (Fig. 24). Previous research comparing spray stake and drip ring irrigation is lacking.

Effluent

No significant main effect in percent effluent resulted from any of the three treatment regimes. Topdressed fertilizer treatments resulted in higher effluent volumes throughout the study while no clear trends could be defined from the irrigation frequency and irrigation method treatments (Figs. 25-27).

Table 3. Summary of p-values for Chapter 3. Repeated Measures Analysis of Variance for growth, effluent, pH, EC, N, P and K of 'Acoma' crape myrtle (Lagerstroemia x fauriei 'Acoma'). Significance level of $p \leq 0.05$.

	p-values						
Effect	Growth	Effluent	pH	EC	N	P	K
Main fertilizer effect	0.0790	0.2912	0.0008	0.0001	0.0001	0.5170	0.0001
Main irrigation effect	0.0488	0.6494	0.1330	0.9428	0.2488	0.1987	0.8440
Main frequency effect	0.0019	0.9231	0.0003	0.0009	0.3926	0.2871	0.5591
Time * fertilizer interaction	0.3024	0.8364	0.0274	0.0009	0.0030	0.0046	0.0010
Time * irrigation interaction	0.0250	0.0024	0.3045	0.0194	0.4345	0.0051	0.1220
Time * frequency interaction	0.0006	0.0004	0.0211	0.0008	0.1896	0.3748	0.3143
fert * irr interaction	0.1094	0.4748	0.2662	0.3212	0.4246	0.5973	0.7833
fert * freq interaction	0.0313	0.4606	0.4186	0.1615	0.4466	0.1216	0.4782
irr * freq interaction	0.0175	0.6936	0.7680	0.6953	0.7091	0.9838	0.7535
fert * irr * freq interaction[y]	0.1823	0.7487	0.9253	0.7498	0.8509	0.1758	0.2724

[y] "fert" = fertilizer placement. "irr" = irrigation method. "freq" = irrigation frequency.

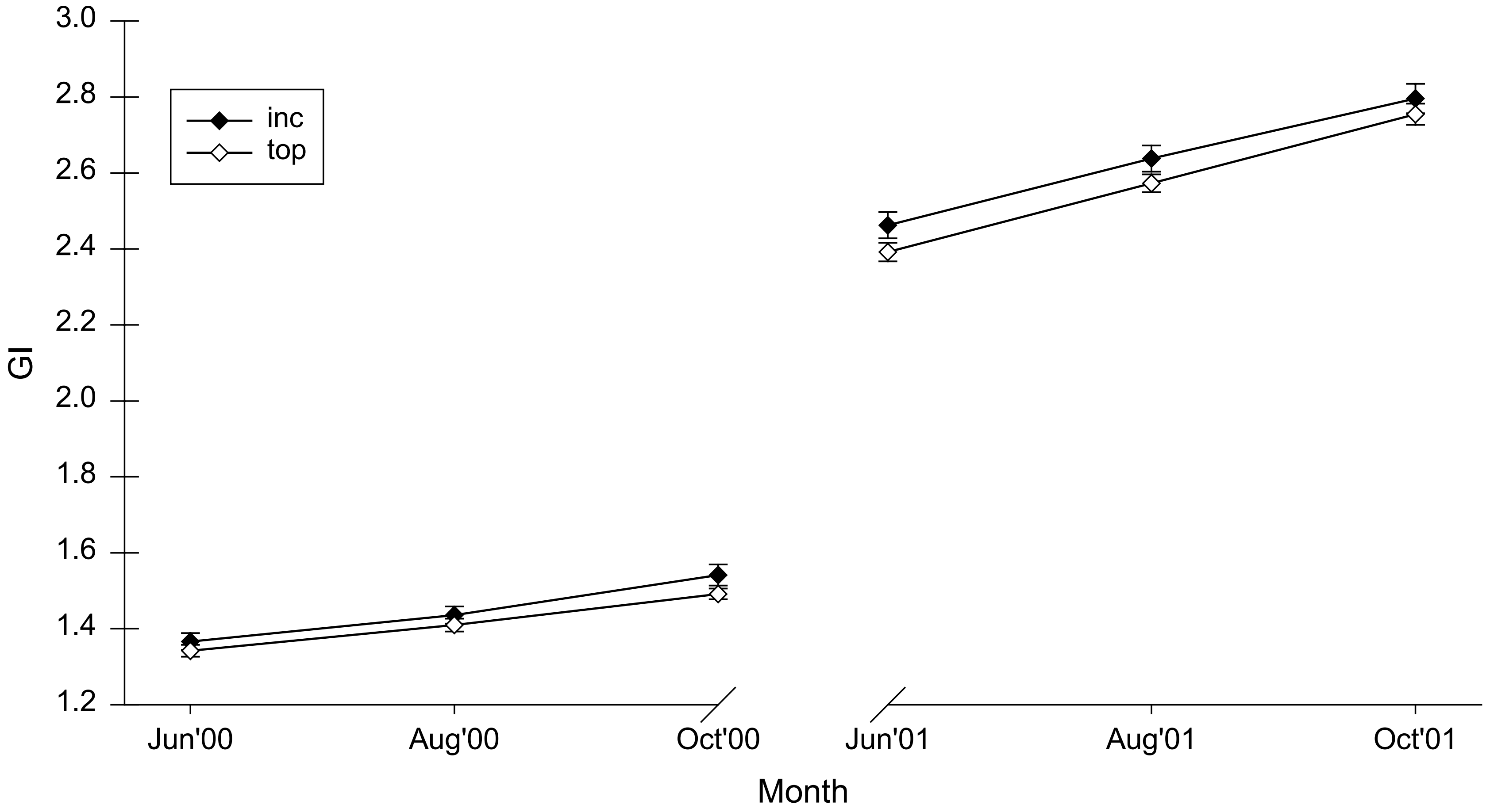

Figure 22. Cumulative growth index (GI) in 'Acoma' crape myrtle (L. indica x fauriei 'Acoma') under two methods of fertilizer placement; incorporated (inc) and topdressed (top). Each value represents Mean ± SE, n = 39.

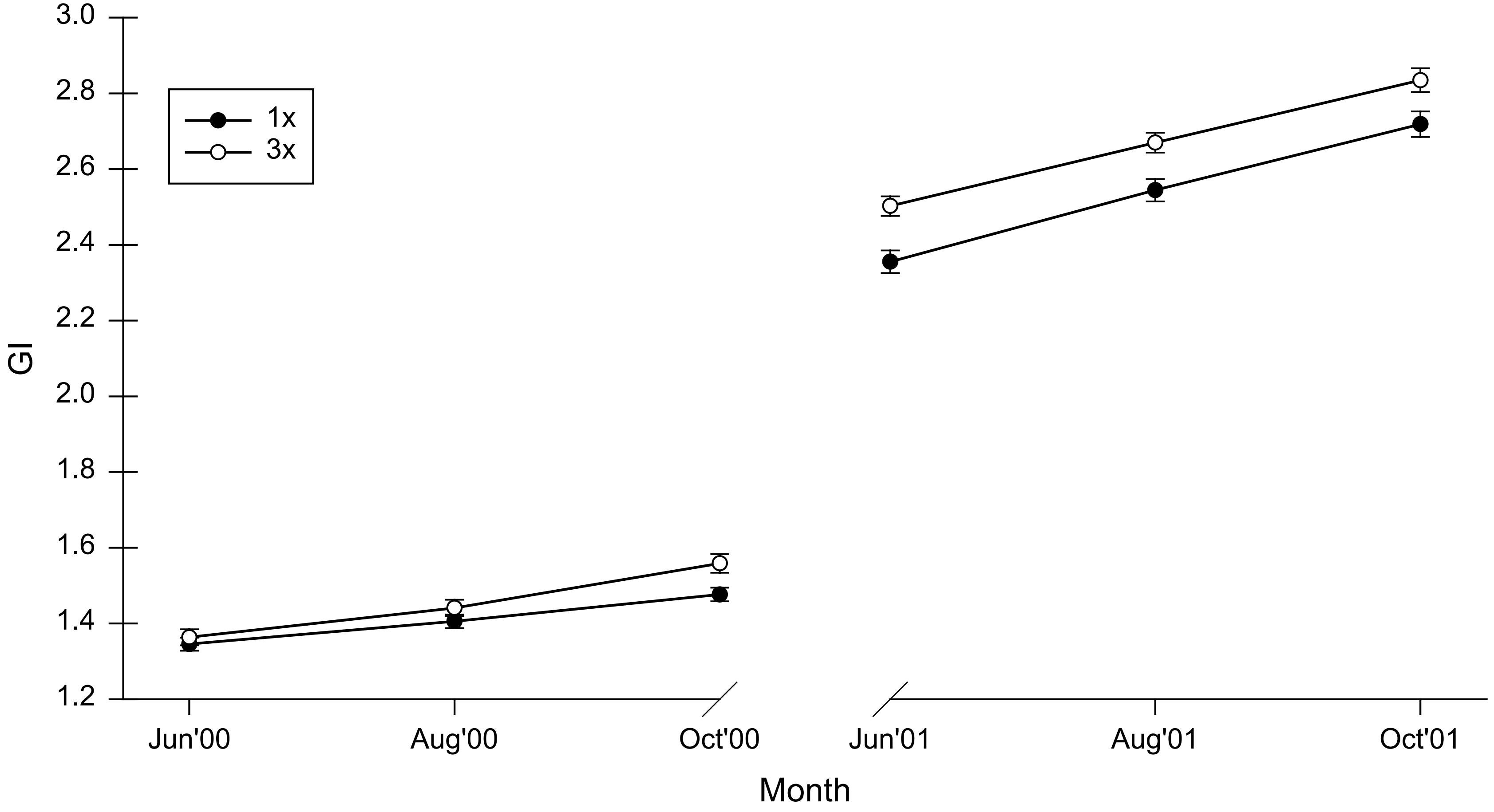

Figure 23. Cumulative growth index (GI) in 'Acoma' crape myrtle (L. indica x fauriei 'Acoma') under two irrigation frequencies; once daily (1x) and three times daily (3x). Each value represents Mean ± SE, n = 40 (1x), n = 38 (3x).

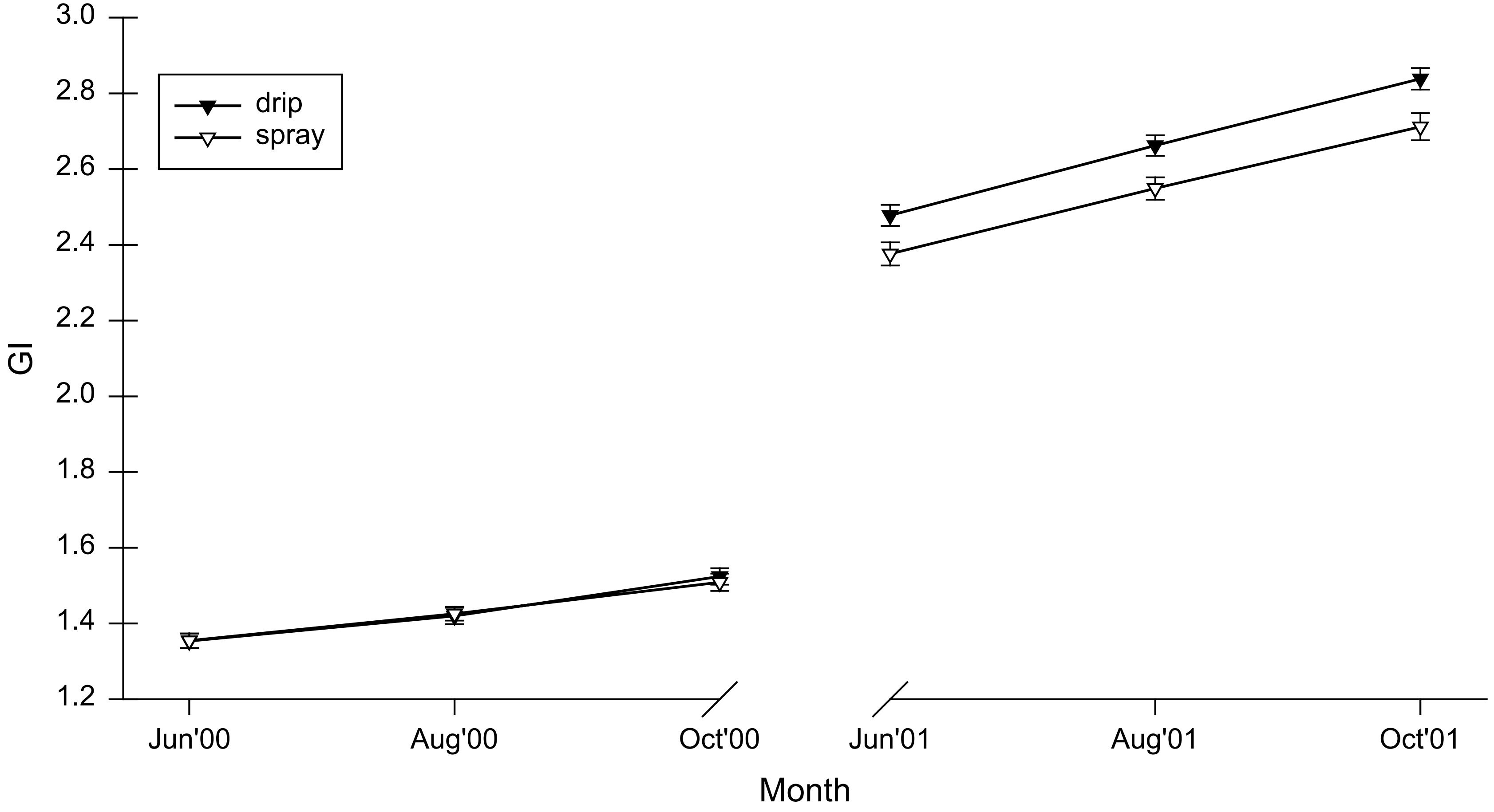

Figure 24. Cumulative growth index (GI) in 'Acoma' crape myrtle (L. indica x fauriei 'Acoma') under two irrigation methods; drip ring (drip) and spray stake (spray). Each value represents Mean ± SE, n = 39 (drip), n = 39 (spray).

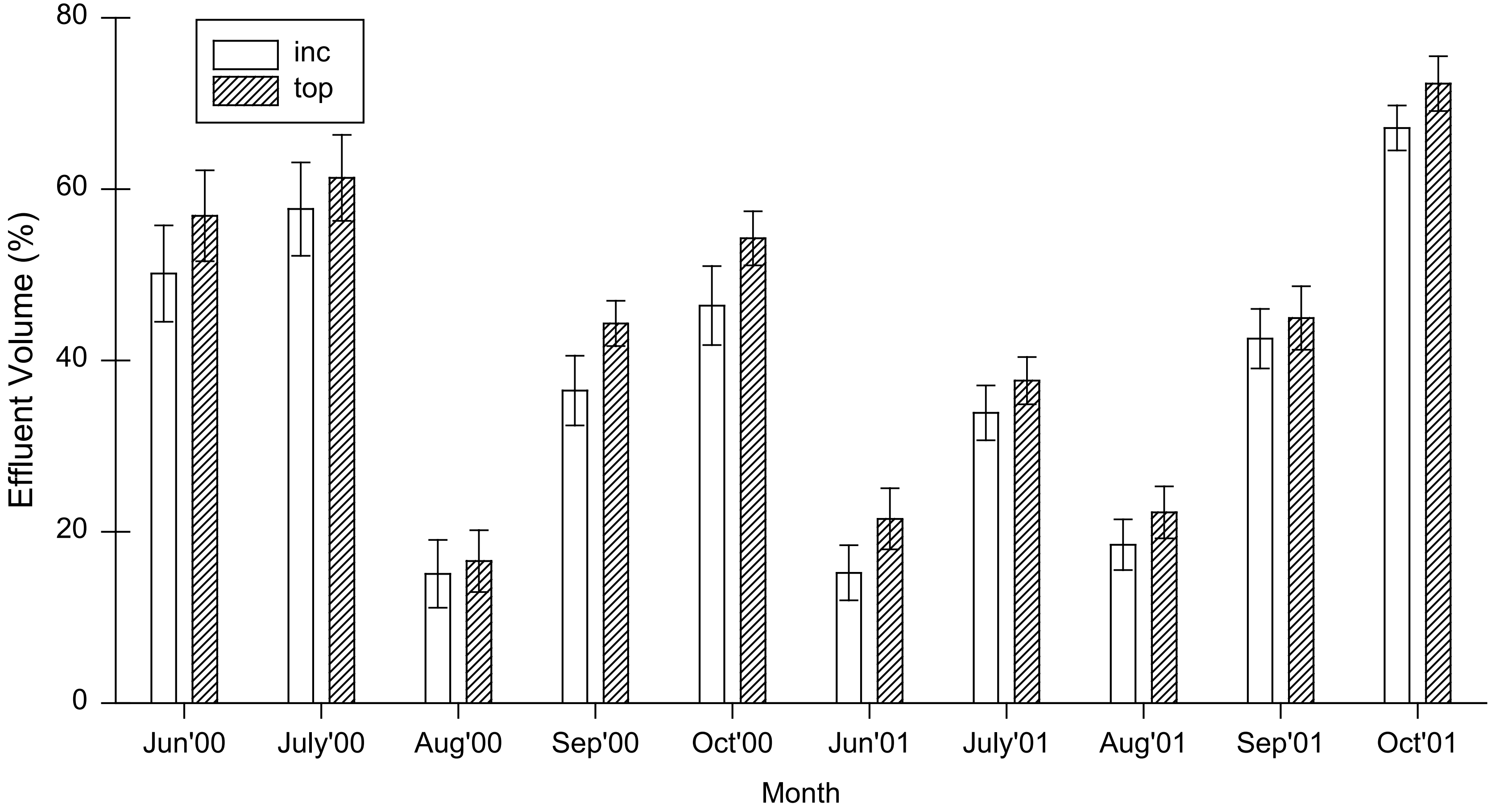

Figure 25. Percent effluent volume in 'Acoma' crape myrtle (L. indica x fauriei 'Acoma') under two methods of fertilizer placement; incorporated (inc) and topdressed (top). Each value represents Mean ± SE, n = 15 (inc), n = 16 (top).

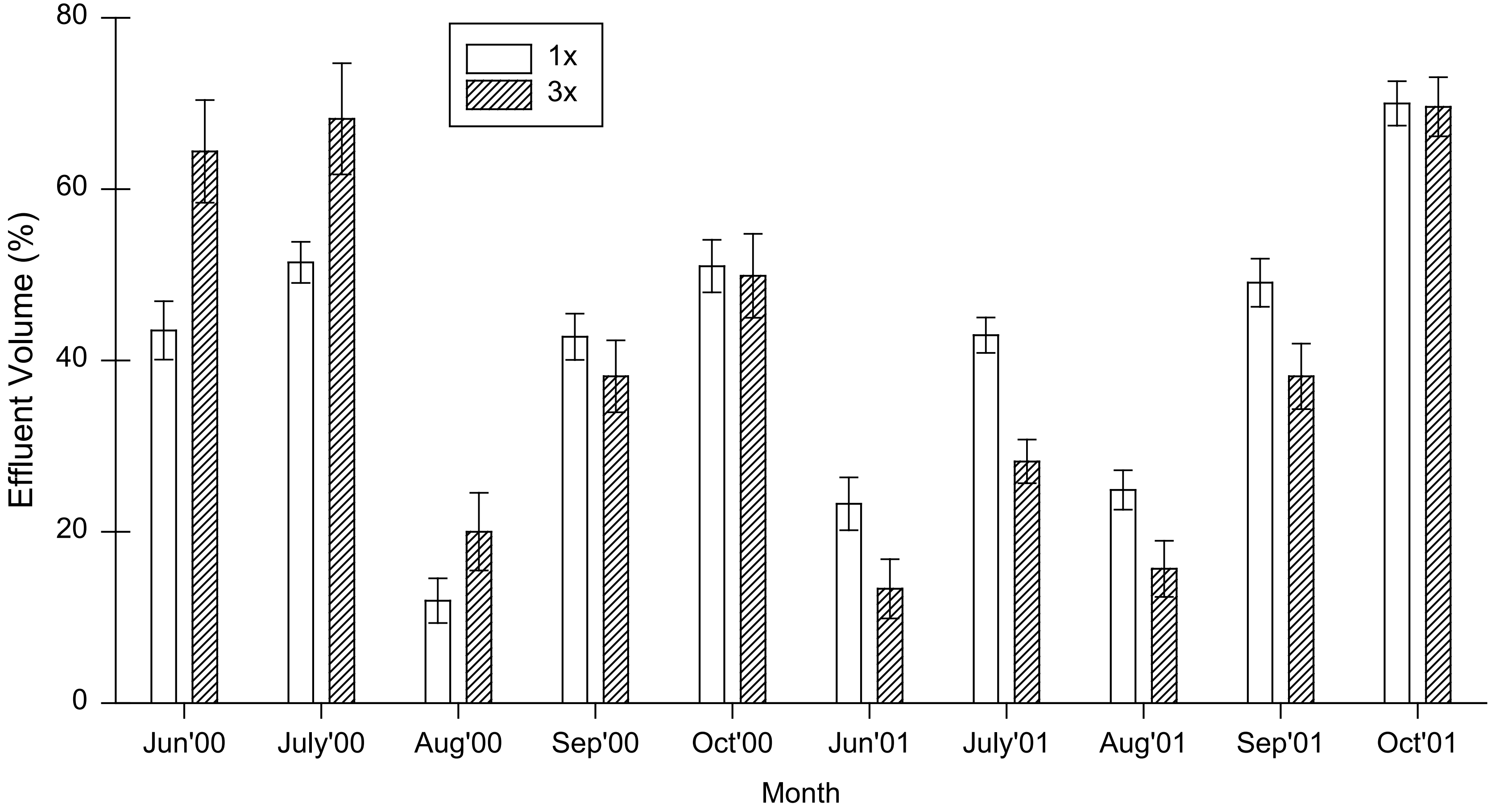

Figure 26. Percent effluent volume in 'Acoma' crape myrtle (L. indica x fauriei 'Acoma') under two irrigation frequencies; once daily (1x) and three times daily (3x). Each value represents Mean ± SE, n = 16 (1x), n = 15 (3x).

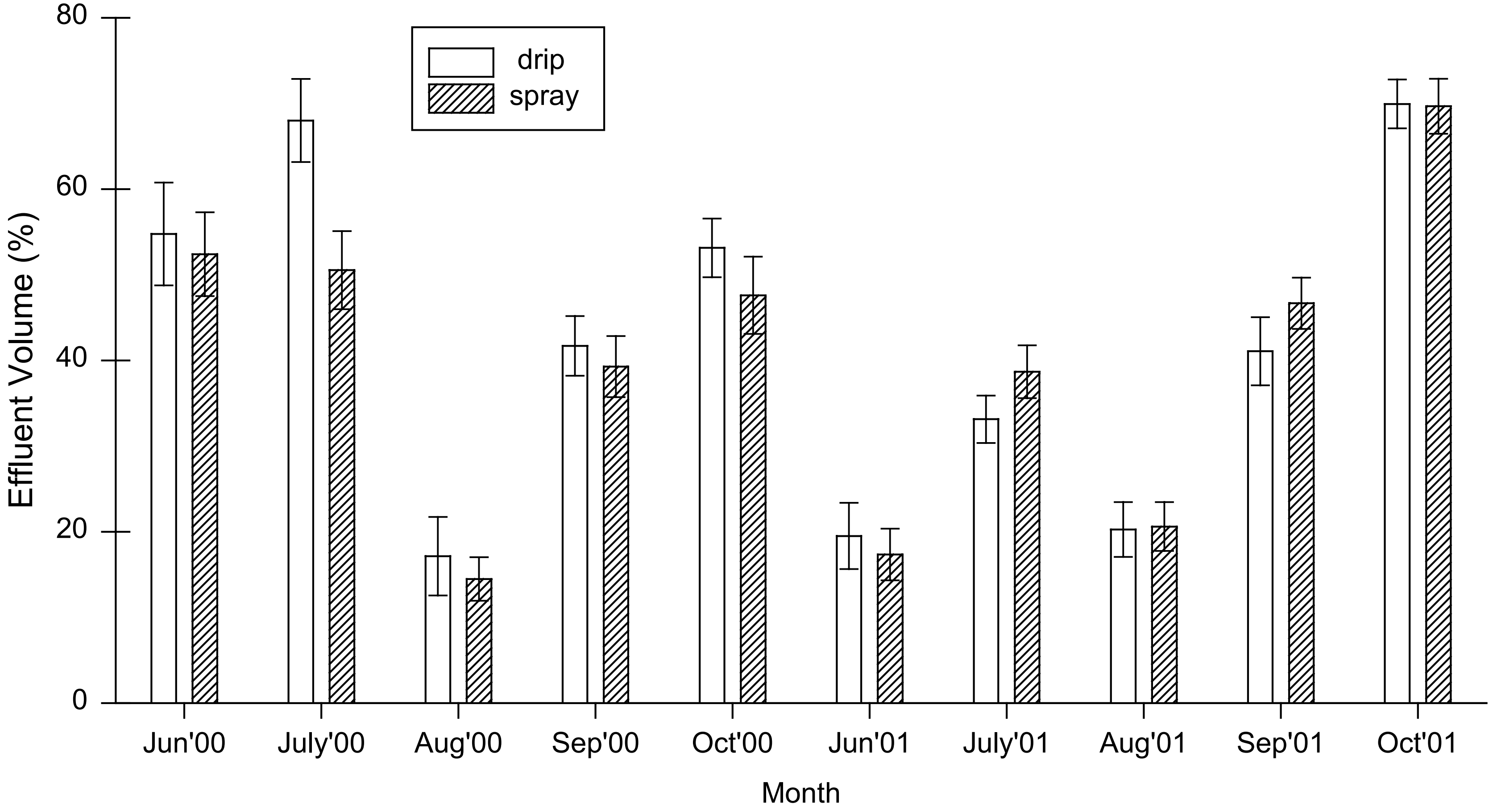

Figure 27. Percent effluent volume in 'Acoma' crape myrtle (L. indica x fauriei 'Acoma') under two irrigation methods; drip ring (drip) and spray stake (spray). Each value represents Mean ± SE, n = 16 (drip), n = 15 (spray).

pH

Fertilizer placement produced a significant main effect on pH as did irrigation frequency. The main effect of irrigation type produced no significant effects (Table 3). Topdressed fertilizer and 1x frequency treatments maintained higher pH throughout the study. Although significant differences were observed the standard error was very low and pH levels remained in an acceptable range for healthy plant (Yeager et. al., 1997) (Figs. 28-30).

EC

Significant main effects for EC resulted from fertilizer placement and irrigation frequency. EC was not significantly affected by irrigation type (Table 3). Incorporated fertilizer treatments had a higher EC compared to topdressed treatments in all months except November (Fig. 31). The incorporated fertilizer had a wider distribution in the media which resulted in a higher EC and increased availability of the fertilizer (Eakes et al., 1990). The 3x irrigation frequency treatment maintained higher EC than the 1x treatment (Fig. 32). The 1x irrigation produced more effluent than 3x which resulted in leaching of soluble salts. A clear trend was not observed between the irrigation methods (Fig. 33)

Nitrogen (N)

A significant fertilizer placement main effect was observed for substrate N content. The main effect of irrigation frequency and type were not significant (Table 3). Incorporated fertilizer maintained higher N concentrations at the beginning of the project, then levels evened out toward the end of year one and throughout year two (Fig. 34). This result was expected since all trees were topdressed with fertilizer the second year. The

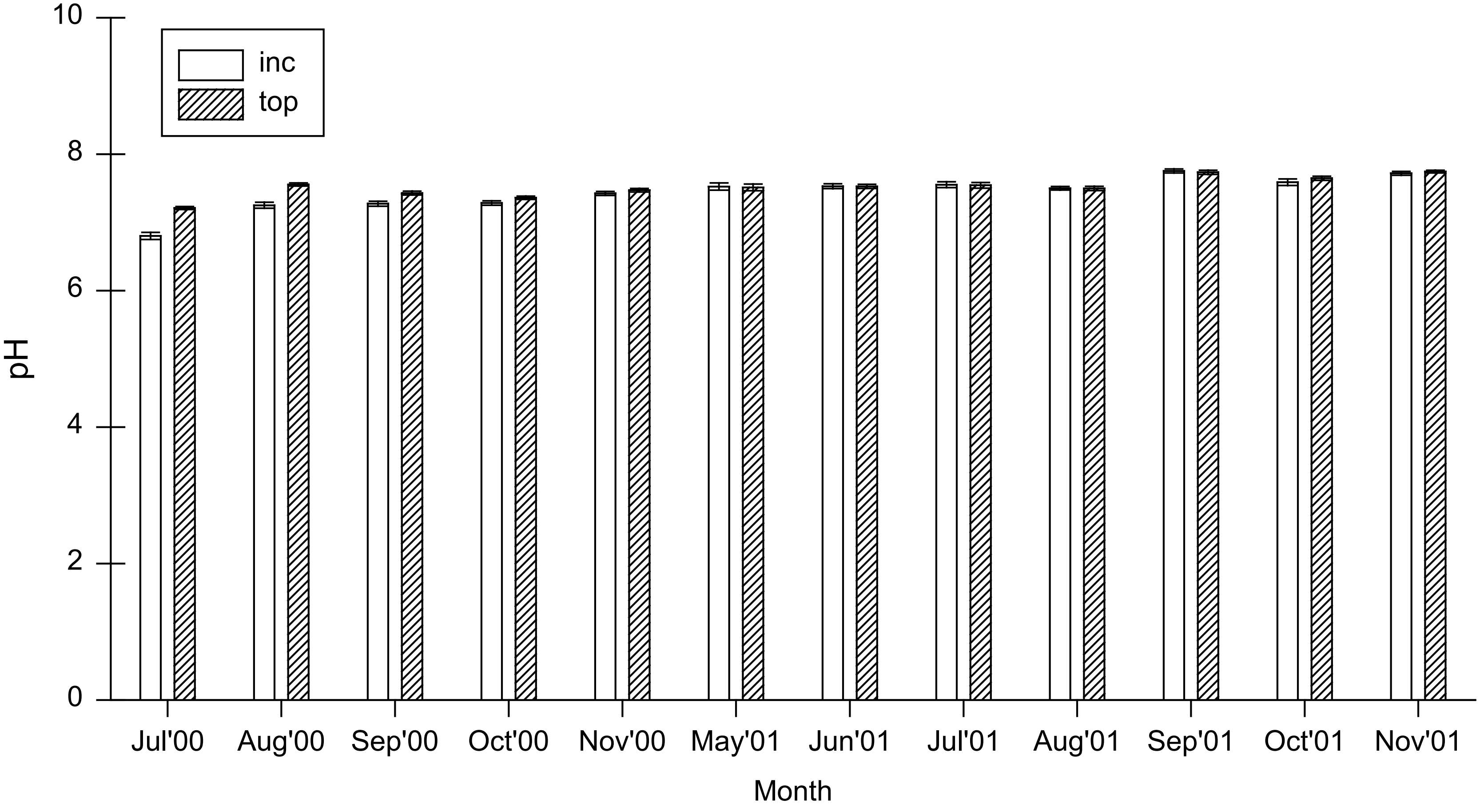

Figure 28. pH of substrate-leachates in 'Acoma' crape myrtle (L. indica x fauriei 'Acoma') under two methods of fertilizer placement; incorporated (inc) and topdressed (top). Each value represents Mean ± SE, n = 15 (inc), n = 16 (top). Irrigation water had an average pH of 8.6.

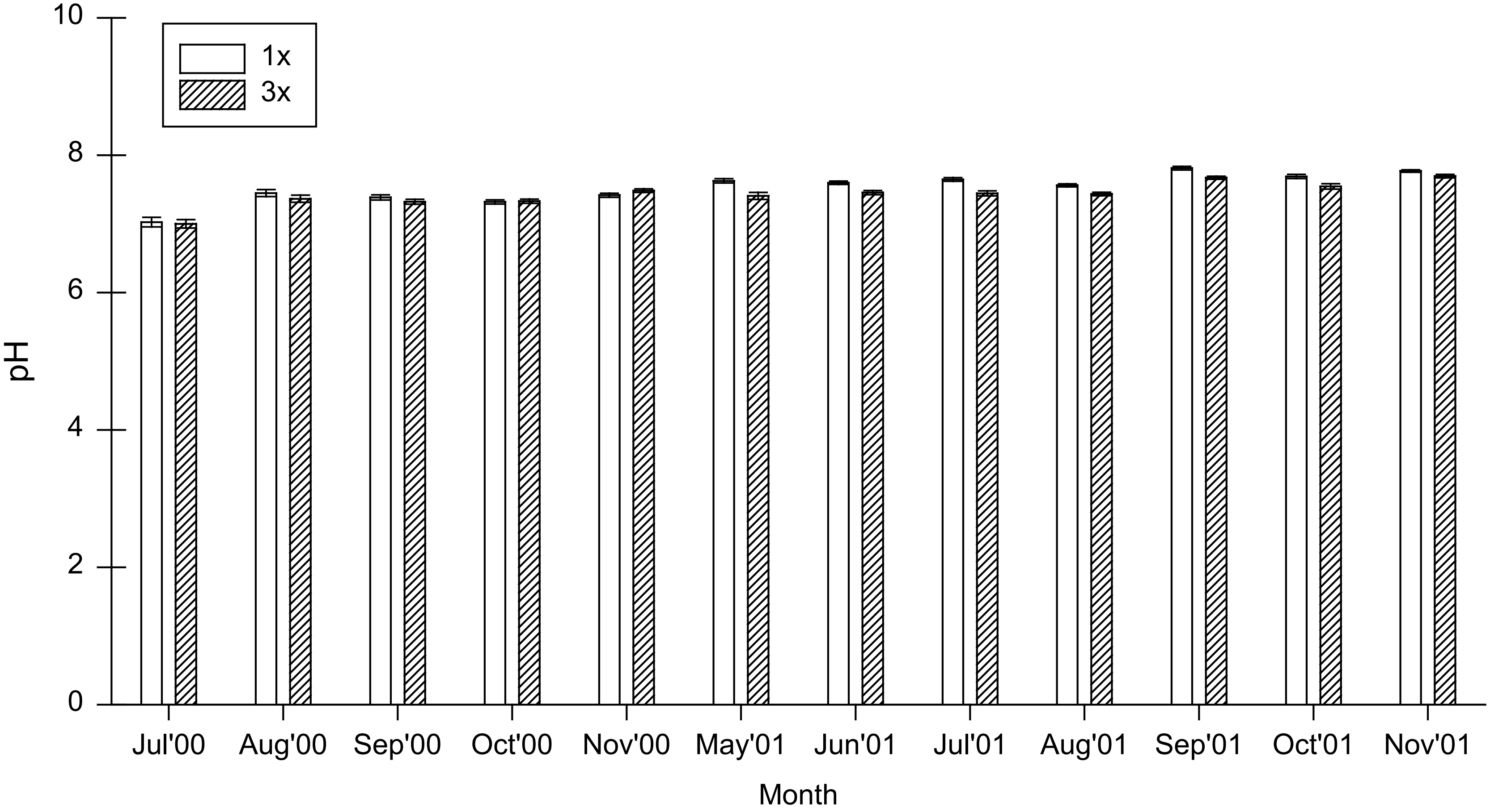

Figure 29. pH of substrate-leachates in 'Acoma' crape myrtle (L. indica x fauriei 'Acoma') under two irrigation frequencies; once daily (1x) and three times daily (3x). Each value represents Mean ± SE, n = 16 (1x), n = 15 (3x). Irrigation water had an average pH of 8.6.

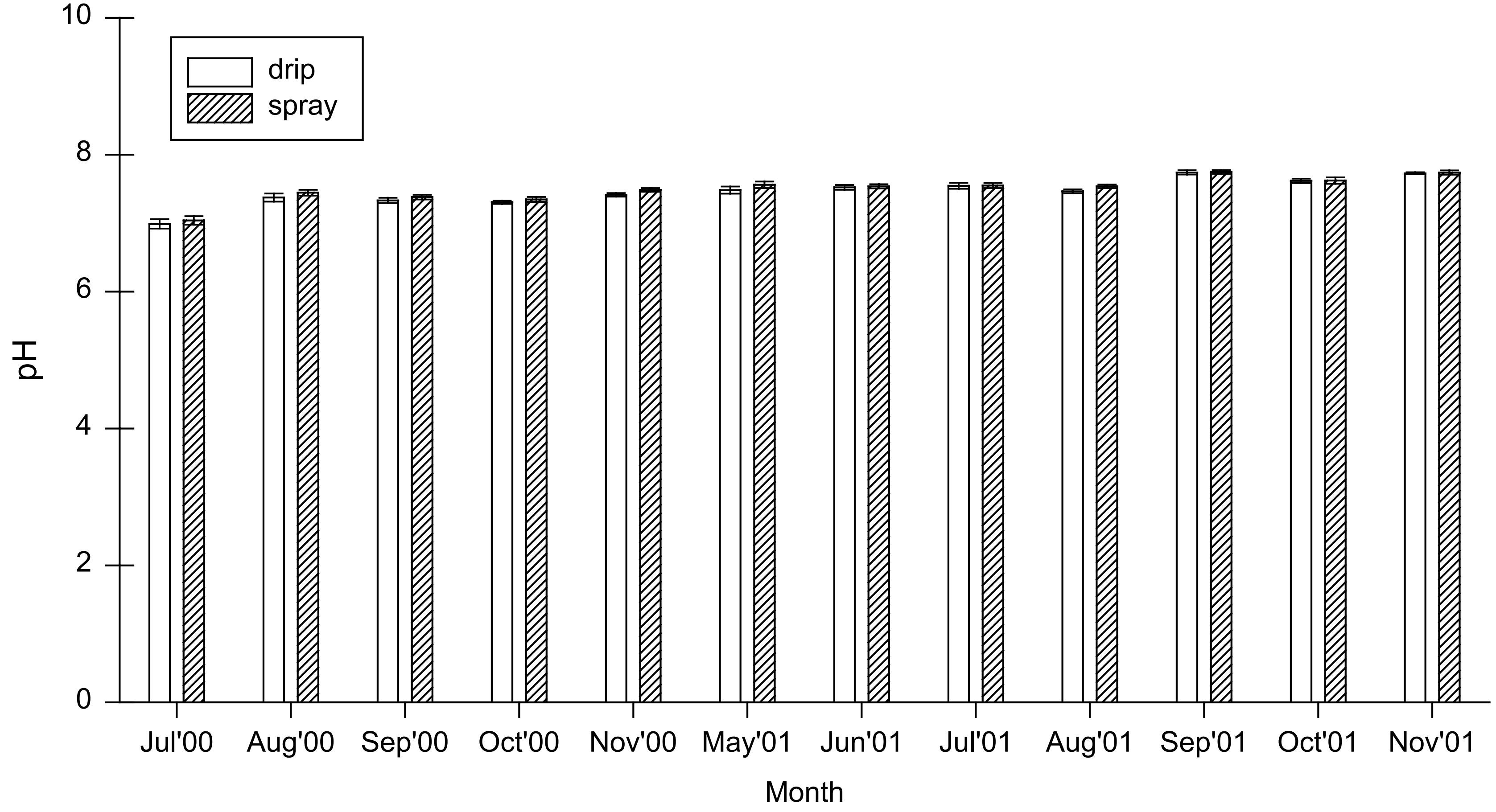

Figure 30. pH of substrate-leachates in 'Acoma' crape myrtle (L. indica x fauriei 'Acoma') under two irrigation methods; drip ring (drip) and spray stake (spray). Each value represents Mean ± SE, n = 16 (drip), n = 15 (spray). Irrigation water had an average pH of 8.6.

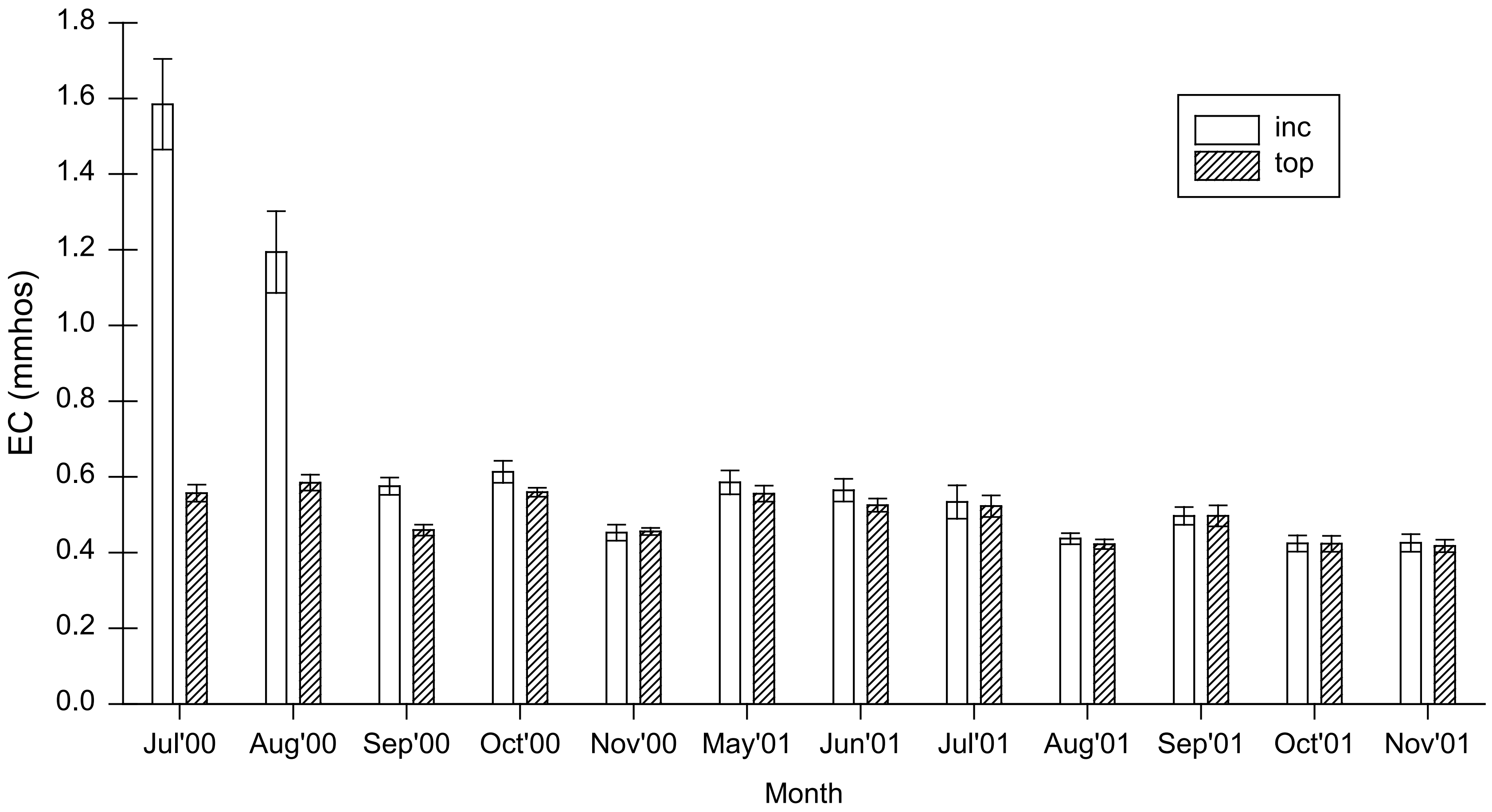

Figure 31. Electrical conductivity (EC) of substrate-leachates in 'Acoma' crape myrtle (L. indica x fauriei 'Acoma') under two methods of fertilizer placement; incorporated (inc) and topdressed (top). Each value represents Mean ± SE, n = 15 (inc), n = 16 (top). Irrigation water had an average EC of 0.33 mmhos.

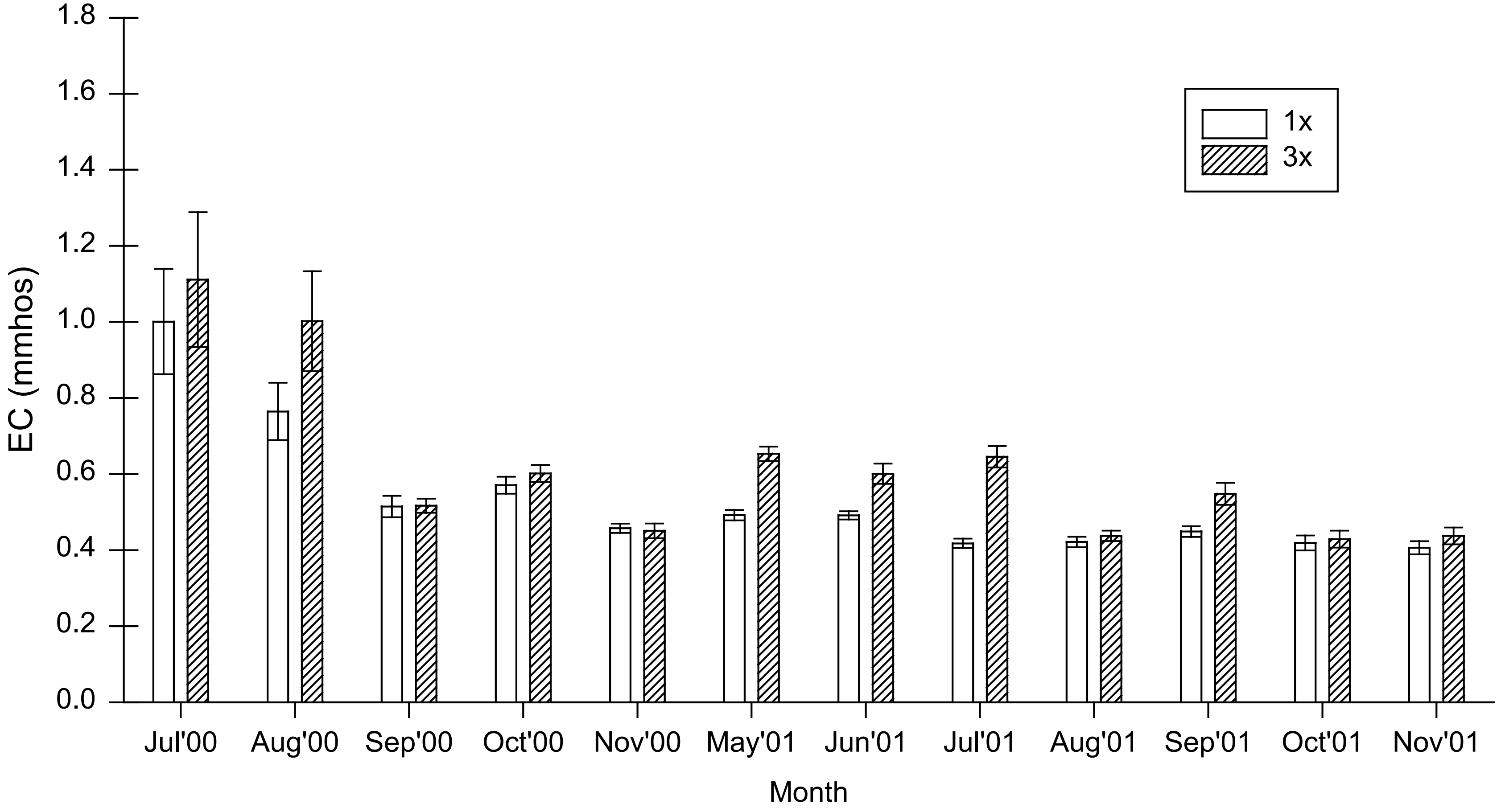

Figure 32. Electrical conductivity (EC) of substrate-leachates in 'Acoma' crape myrtle (L. indica x fauriei 'Acoma') under two irrigation frequencies; once daily (1x) and three times daily (3x). Each value represents Mean ± SE, n = 16 (1x), n = 15 (3x). Irrigation water had an average EC of 0.33 mmhos.

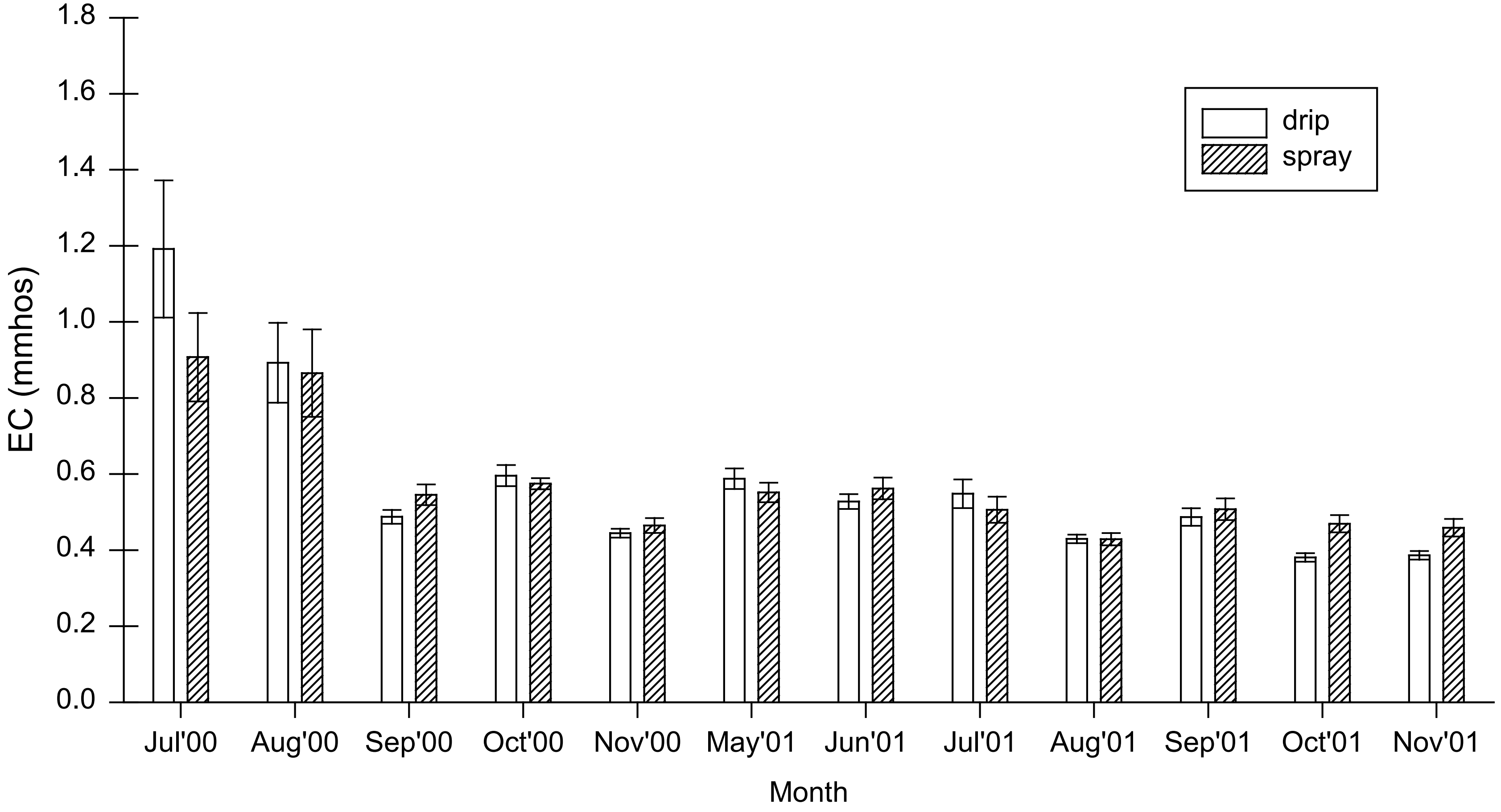

Figure 33. Electrical conductivity (EC) of substrate-leachates in 'Acoma' crape myrtle (L. indica x fauriei 'Acoma') under two irrigation methods; drip ring (drip) and spray stake (spray). Each value represents Mean ± SE, n = 16 (drip), n = 15 (spray). Irrigation water had an average EC of 0.33 mmhos.

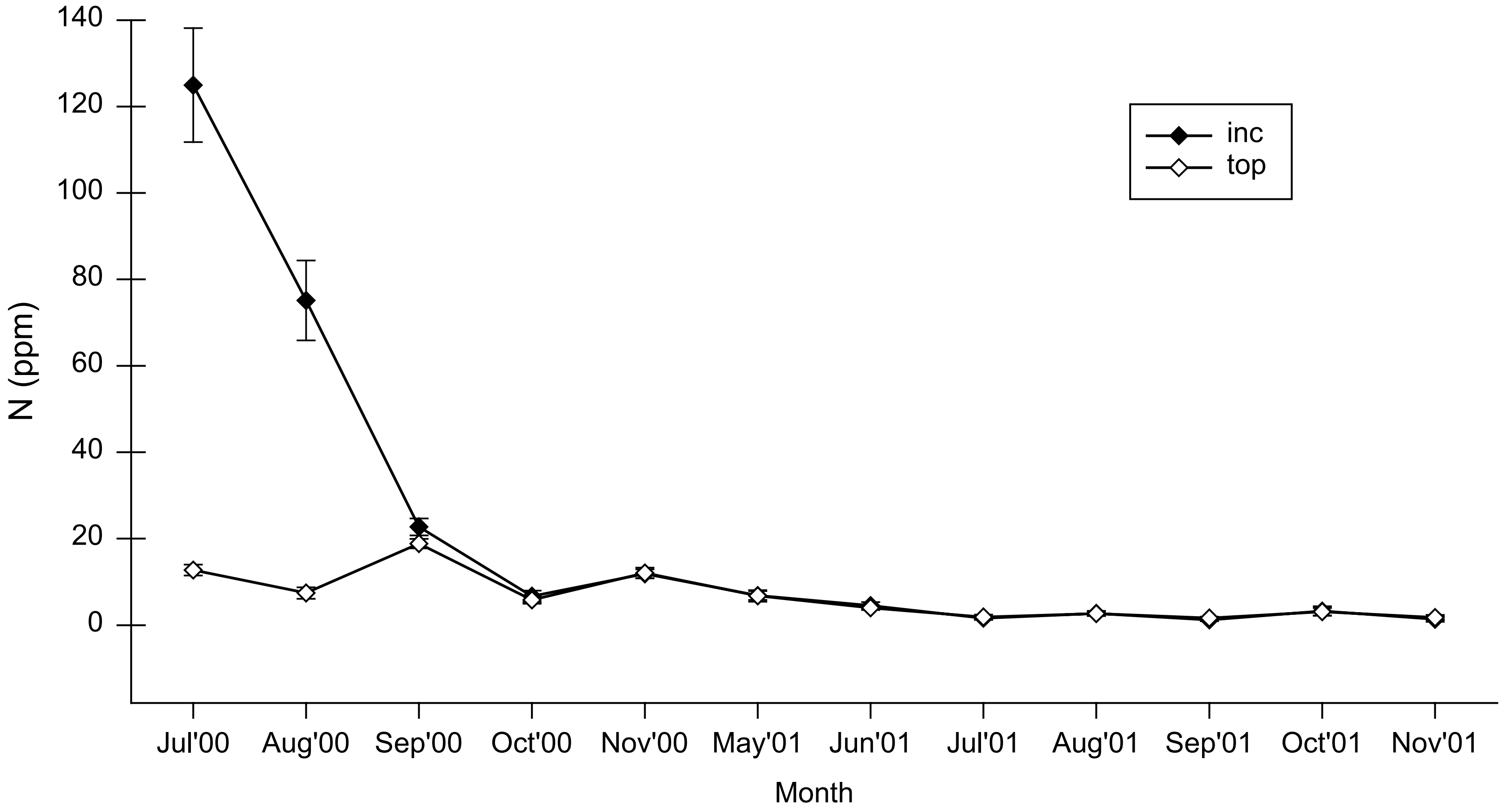

Figure 34. Substrate-leachate nitrogen (N) concentration in 'Acoma' crape myrtle (L. indica x fauriei 'Acoma') under two methods of fertilizer placement; incorporated (inc) and topdressed (top). Each value represents Mean ± SE, n = 15 (inc), n = 16 (top).

incorporated fertilizer could be more available for plant use because of its even distribution throughout the media whereas topdressed fertilizer has to travel down through the media. Previous research found that incorporated treatments resulted in higher N leachate levels at the beginning of the study compared to topdressed treatments, then leveled out toward the end for both methods (Warren et al., 1997; Yeager et al., 1989). 3x treatments tended to be higher in N for only the first two months of the experiment even though there was no significance (Fig. 35). Drip ring irrigation maintained higher N concentrations in July and August of 2000 but not significantly (Fig. 36).

Phosphorus (P)

None of the factors resulted in significant main effects for phosphorus in any of the treatment categories (Table 3). No clear trends could be established between treatments (Figs. 37-39).

Potassium (K)

Fertilizer method main effect was significant for potassium. The main effects of irrigation frequency and method did not result in significant differences (Table 3). K leachate concentrations resulted in the same outcome as N concentration, so the previous explanation would apply. Incorporated fertilizer maintained higher K concentrations at the beginning of the project, then levels evened out toward the end of year one and throughout year two (Fig. 40). Major trends were absent for the frequency and irrigation type treatments (Figs. 41-42).

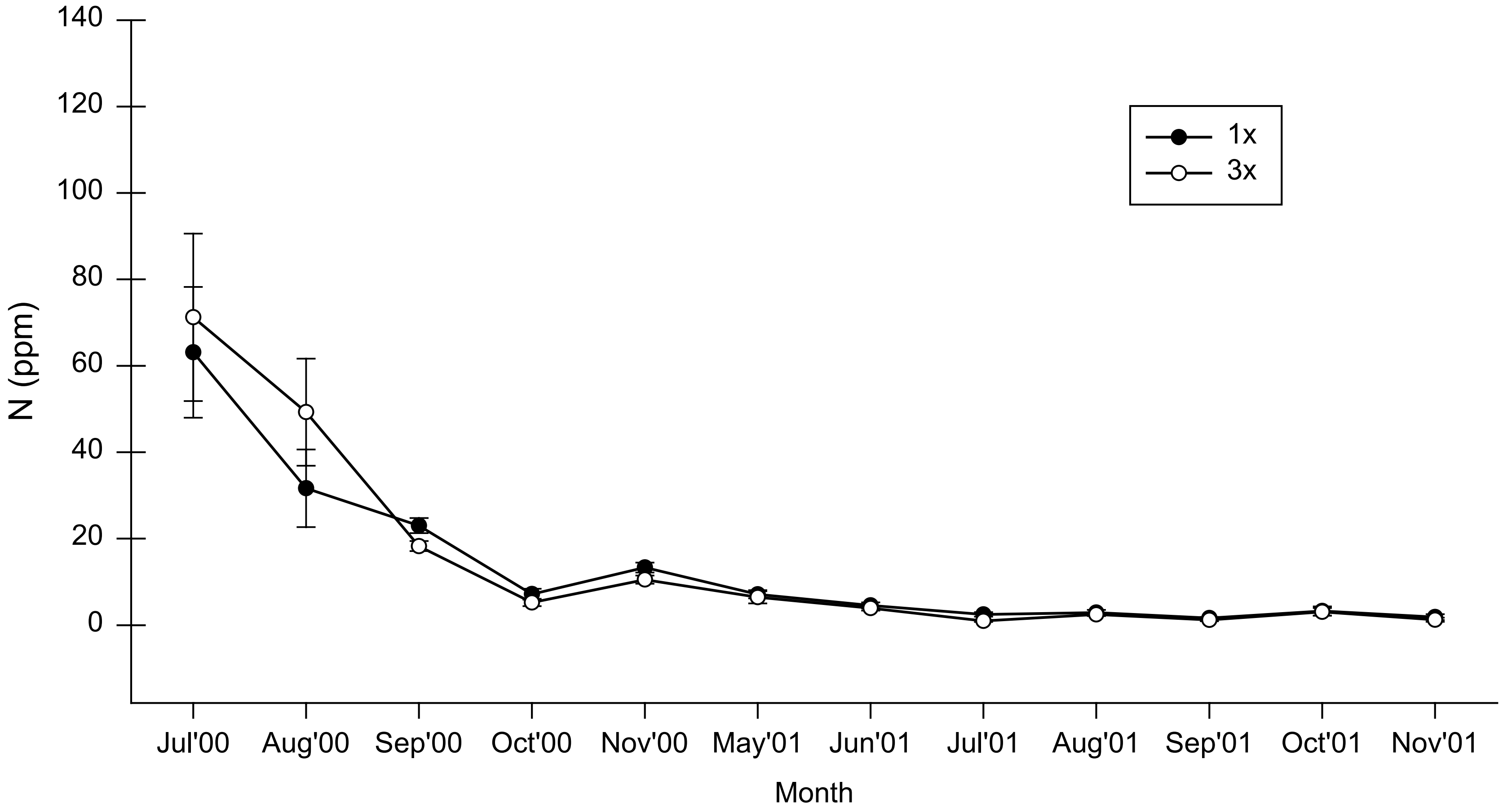

Figure 35. Substrate-leachate nitrogen (N) concentration in 'Acoma' crape myrtle (L. indica x fauriei 'Acoma') under two irrigation frequencies; once daily (1x) and three times daily (3x). Each value represents Mean ± SE, n = 16 (1x), n = 15 (3x).

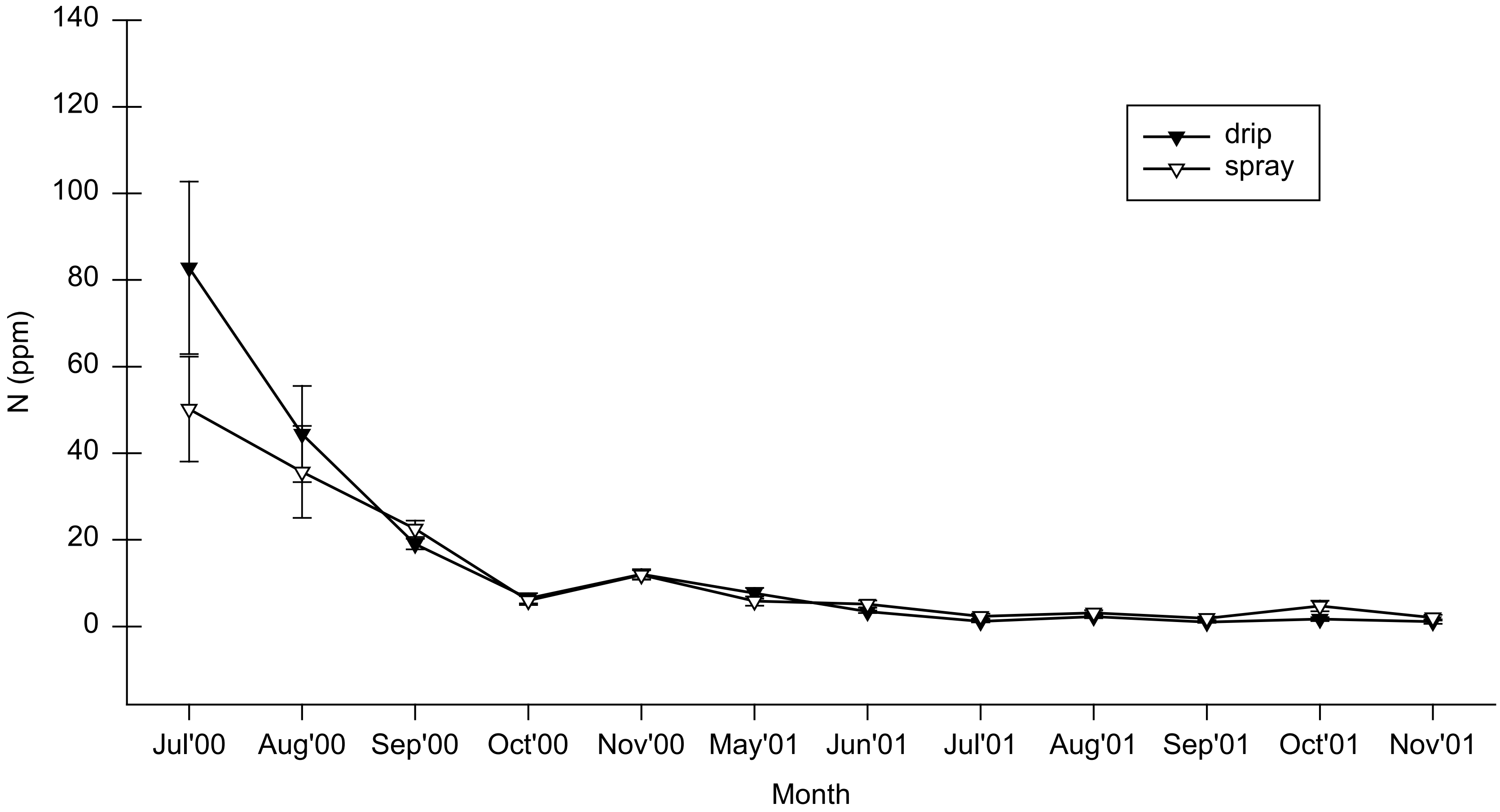

Figure 36. Substrate-leachate nitrogen (N) concentration in 'Acoma' crape myrtle (L. indica x fauriei 'Acoma') under two irrigation methods; drip ring (drip) and spray stake (spray). Each value represents Mean ± SE, n = 16 (drip), n = 15 (spray).

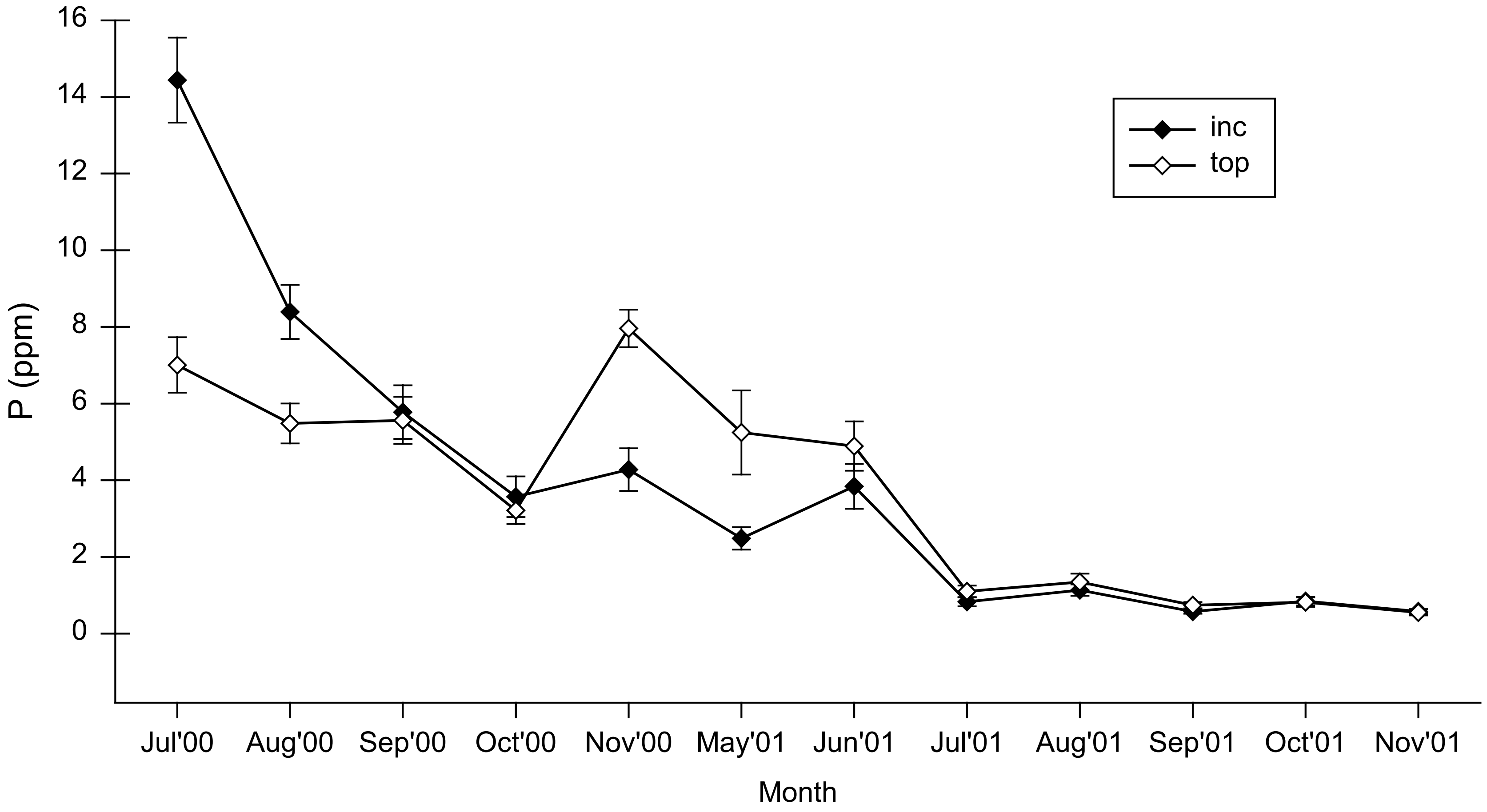

Figure 37. Substrate-leachate phosphorus (P) concentration in 'Acoma' crape myrtle (L. indica x fauriei 'Acoma') under two methods of fertilizer placement; incorporated (inc) and topdressed (top). Each value represents Mean ± SE, n = 15 (inc), n = 16 (top).

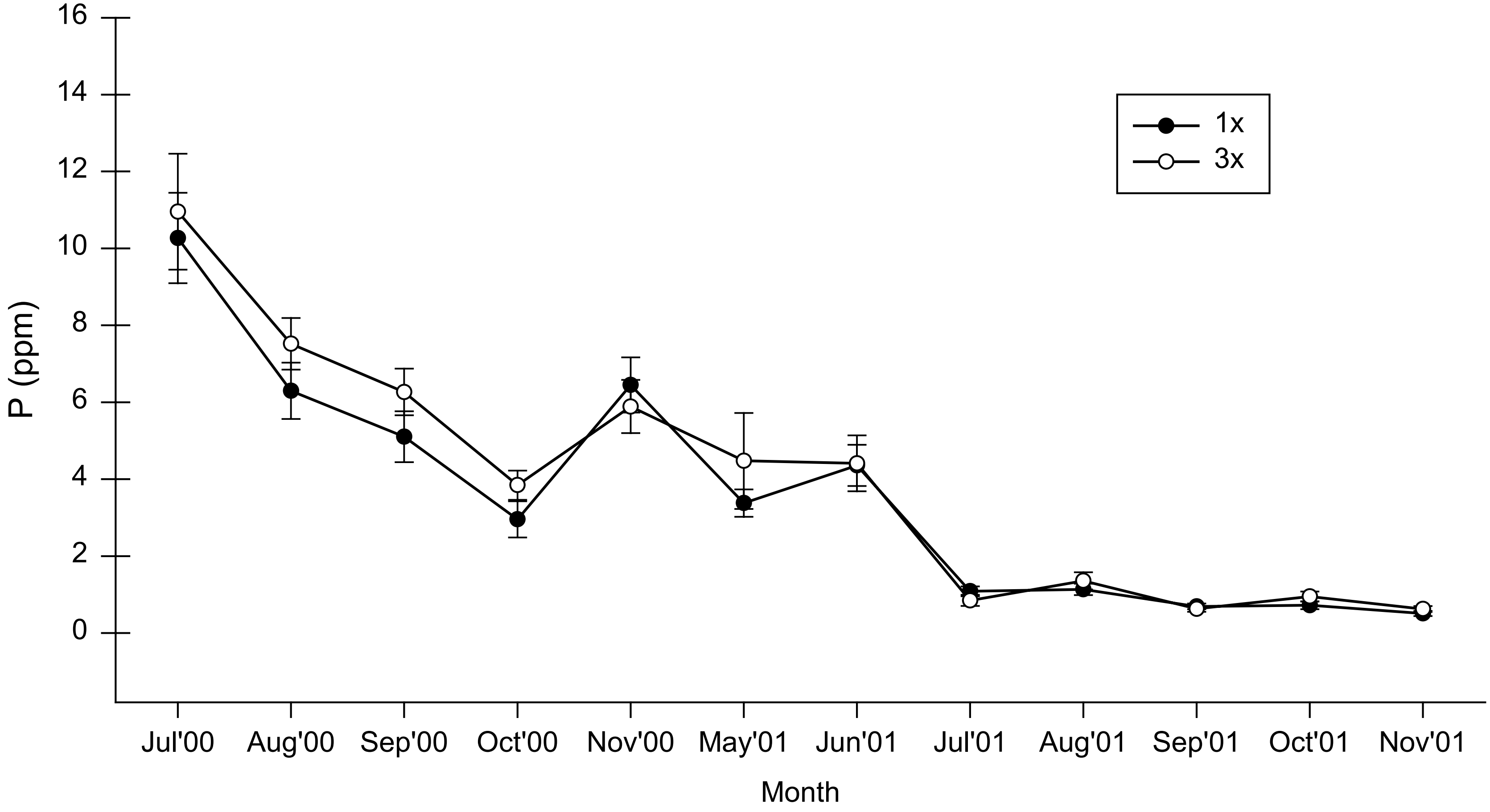

Figure 38. Substrate-leachate phosphorus (P) concentration in 'Acoma' crape myrtle (L. indica x fauriei 'Acoma') under two irrigation frequencies; once daily (1x) and three times daily (3x). Each value represents Mean ± SE, n = 16 (1x), n = 15 (3x).

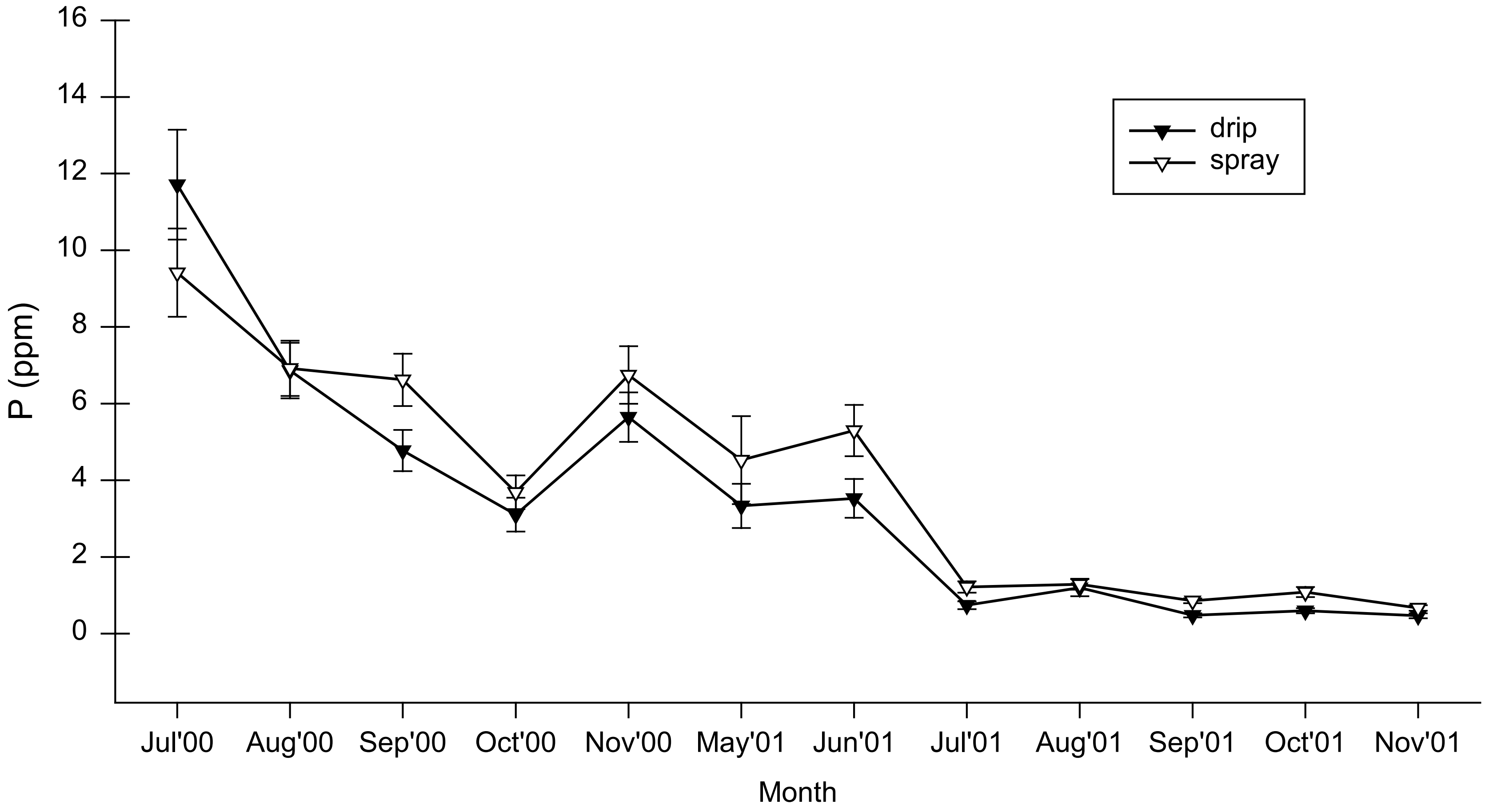

Figure 39. Substrate-leachate phosphorus (P) concentration in 'Acoma' crape myrtle (L. indica x fauriei 'Acoma') under two irrigation methods; drip ring (drip) and spray stake (spray). Each value represents Mean ± SE, n = 16 (drip), n = 15 (spray).

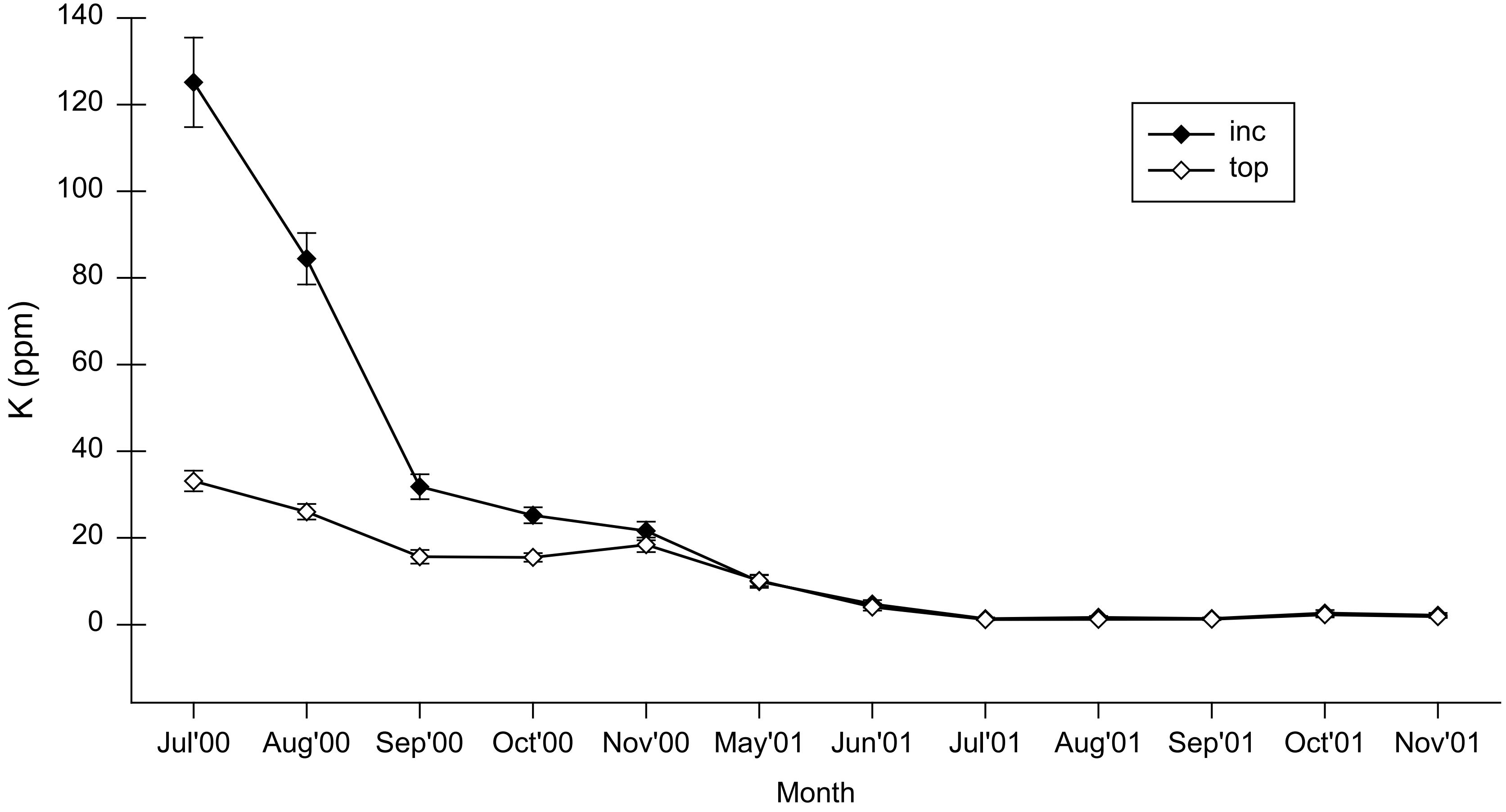

Figure 40. Substrate-leachate potassium (K) concentration in 'Acoma' crape myrtle (L. indica x fauriei 'Acoma') under two methods of fertilizer placement; incorporated (inc) and topdressed (top). Each value represents Mean ± SE, n = 15 (inc), n = 16 (top).

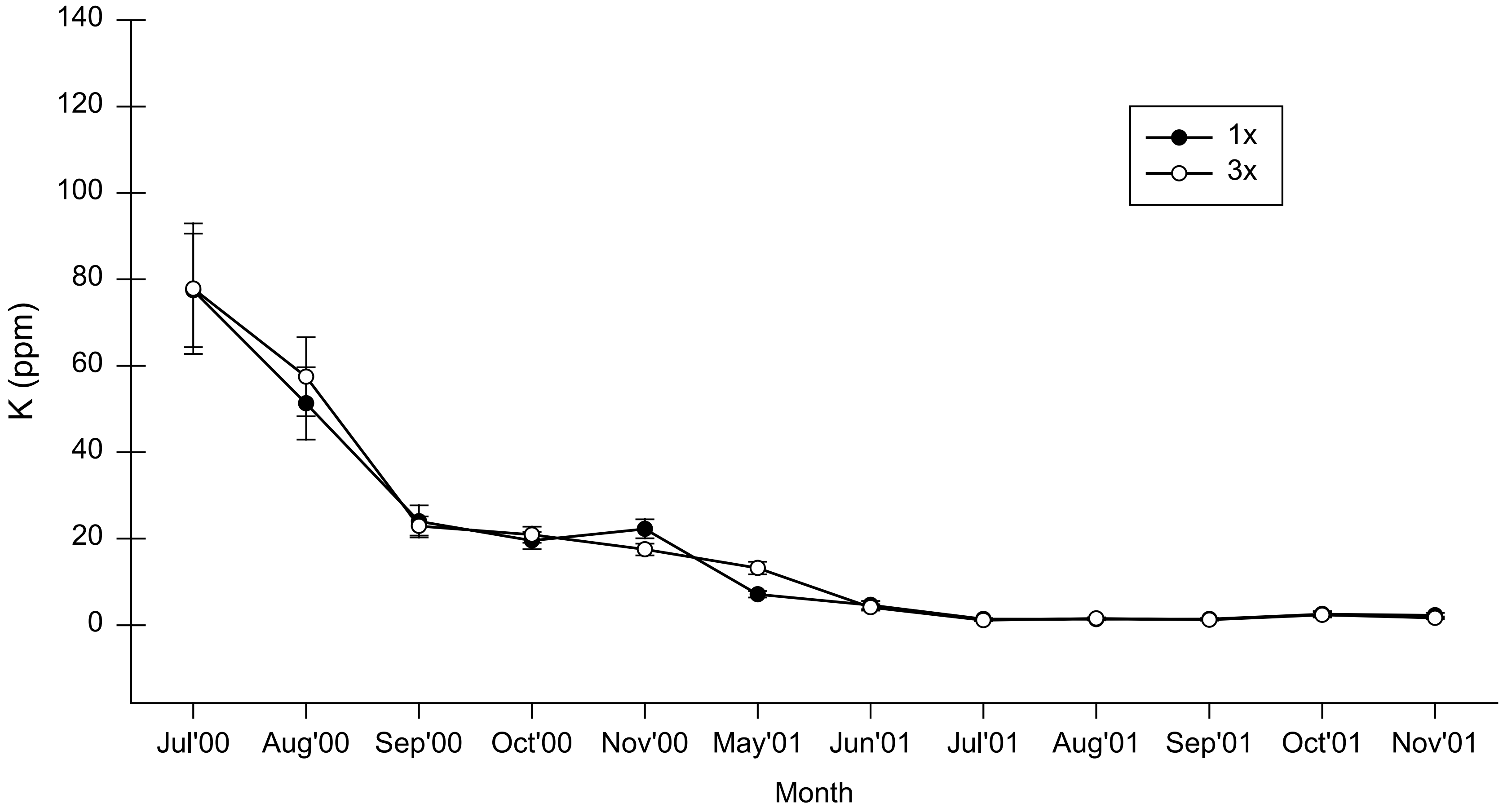

Figure 41. Substrate-leachate potassium (K) concentration in 'Acoma' crape myrtle (L. indica x fauriei 'Acoma') under two irrigation frequencies; once daily (1x) and three times daily (3x). Each value represents Mean ± SE, n = 16 (1x), n = 15 (3x).

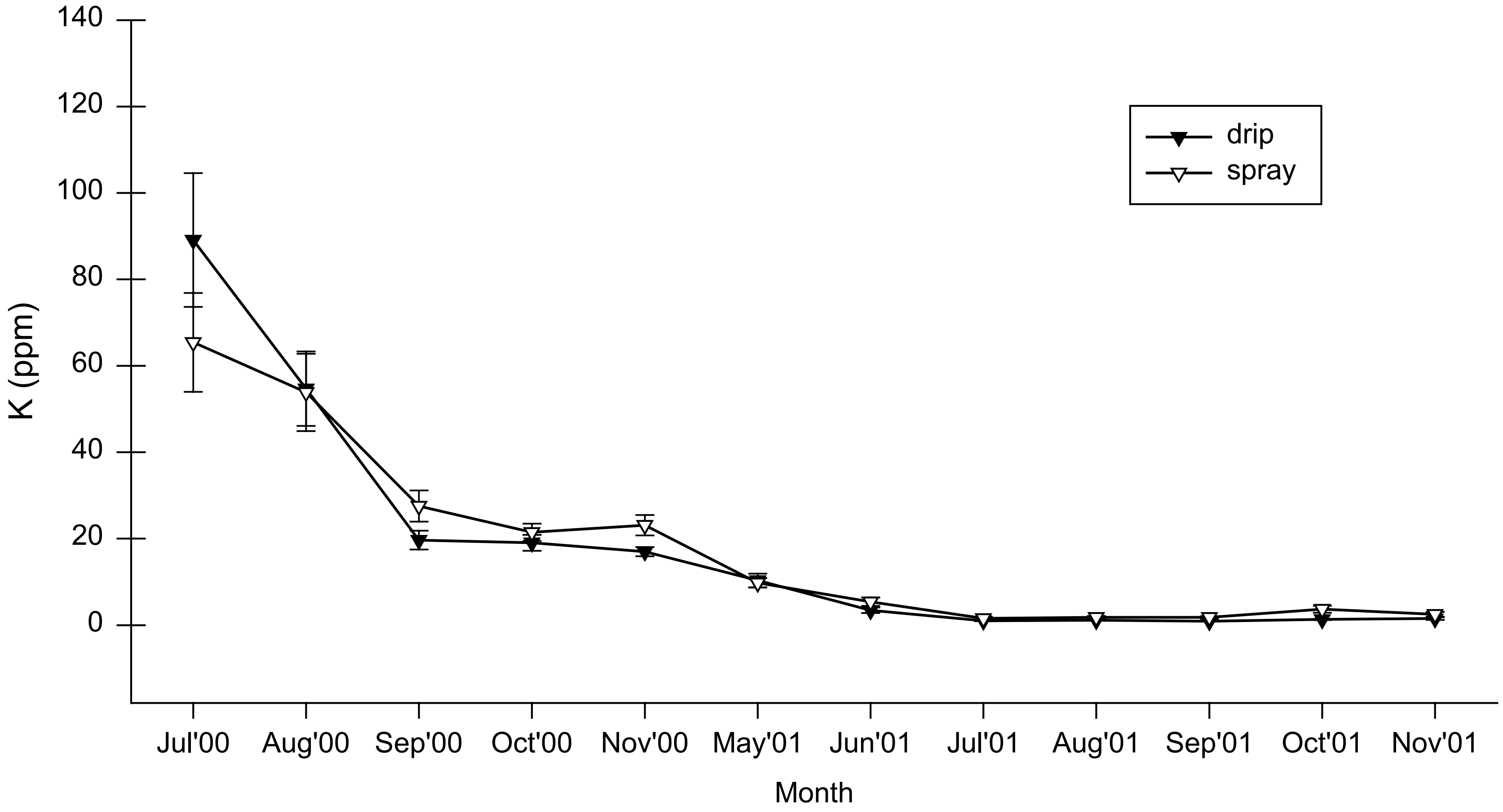

Figure 42. Substrate-leachate potassium (K) concentration in 'Acoma' crape myrtle (L. indica x fauriei 'Acoma') under two irrigation methods; drip ring (drip) and spray stake (spray). Each value represents Mean ± SE, n = 16 (drip), n = 15 (spray).

Conclusions

Our study showed that incorporating fertilizer maintained significantly higher concentrations of N and K in the substrate compared to topdressing fertilizer. The differences occurred during the first year of the study because the second year all plants were topdressed with fertilizer. The even distribution of incorporated fertilizer results in nutrients being available to the root system throughout the growing season. In the topdressed treatment, nutrients must travel down through the substrate which leads to less availability to the plant.

The irrigation frequency treatment in our study showed that watering three times daily increased crape myrtle growth. Water distribution during the day, when the plant is actively growing, helps reduce plant stress from heat and drought resulting in larger plants compared to those watered once daily.

Our study was the first to compare the two micro-irrigation methods, drip ring irrigation and spray stake irrigation, in large container production. Larger trees resulted from drip ring irrigation compared to spray stake irrigation although the difference was not noticeable until the second year of the study.

References

Beeson, R.C., Jr. and G.W. Knox. 1991. Analysis of efficiency of overhead irrigation in container production. HortScience 26:848-850.

Beeson, R.C., Jr. and J. Haydu. 1995. Cyclic microirrigation in container-grown landscape plants improves plant growth and water conservation. J. Environ. Hort. 13:6-11.

Eakes, D.J., W.J. Foster, C.H. Gilliam and J.W. Olive. 1990. Effects of method of application and rate of three slow release fertilizers. Proc. SNA Conf. 35:55-56.

Fain, G.B., K.M. Tilt, C.H. Gilliam, H.G. Ponder and J.L. Sibley. 1998. Effects of cyclic micro-irrigation and substrate in pot-in-pot production. Proc. SNA Conf. 43:87-90.

Gilliam, C.H., G.S. Cobb and C.E. Evans. 1984. Effects of nitrogen concentration and container size on growth of Pyrus calleryana 'Bradford'. J. Environ. Hort. 2:53-56.

Gray, A.L., E.W. Bush and R.I. Edling. 1998. Cyclic irrigation affects on container-grown 'Little Gem' magnolia growth and fertilizer leaching. Proc. SNA Conf. 43:520-525.

Karam, N.S. and A.X. Niemiera. 1992. Low water application rate and intermittent irrigation increase irrigation efficiency of sprinkler-irrigated container-grown plants. Proc. SNA Conf. 37:41-44.

Lamack, W.F. and A.X. Niemiera. 1992. Spray stake irrigation of container-grown plants. Proc. SNA Conf. 37:398-401.

Lamack, W.F. and A.X. Niemiera. 1993. Application method affects water application efficiency of spray stake-irrigated containers. HortScience 28:625-627.

Martin, C.A., H.G. Ponder and C.H. Gilliam. 1989. Effects of irrigation rate and media on growth of Acer rubrum L. in large containers. J. Environ. Hort. 7:38-40.

Meadows, W.A. and D.L. Fuller. 1986. Effect of osmocote placement on release patterns of nitrogen and potassium in a pine bark medium. Proc. SNA Conf. 31:85-89.

Ruter, J.M. 1997. Cyclic irrigation and pot-in-pot production affect the growth of 'Okame' cherry. Proc. SNA Conf. 42:423-425.

Tilt, K., W.T. Witte, M. Halcomb and J. Watkins. 1990. Slow release fertilizers with minor elements topdress vs. incorporation on 100% bark medium. Proc. SNA Conf. 35:111-116.

Tyler, H.H., S.L. Warren and T.E. Bilderback. 1995. Cyclic irrigation increases irrigation efficiency and ammonium retention. Proc. SNA Conf. 40:59-61.

Tyler, H.H., S.L. Warren and T.E. Bilderback. 1996. Cyclic irrigation increases irrigation application efficiency and decreases ammonium losses. J. Environ. Hort. 14:194-198. (b)

Warren, S.L., T.E. Bilderback and H.H. Tyler. 1997. Does method of fertilizer application (surface or incorporation) affect nutrient losses of controlled release fertilizers? Proc. SNA Conf. 42:141-143.

Witmer, R.K., J.R. Harris, A.X. Niemiera and J. Fanelli. 1998. Frequent irrigation increases the growth of pot-in-pot sugar and red maple. Proc. SNA Conf. 43:516-519.

Yeager, T.H., C. Gilliam, T. Bilderback, D. Fare, A. Niemiera and K. Tilt. 1997. Best management practices guide for producing container-grown plants. Southern Nurserymen's Association, Marietta, GA.

Yeager, T.H., D.L. Ingram and C.A. Larsen. 1989. Nitrate nitrogen and potassium release from surface-applied and growth medium-incorporated osmocote and escote. Proc. SNA Conf. 34:54-56.

CHAPTER 4

CONCLUSIONS

Fertilization and irrigation management influence the growth of trees grown in large container production and are integral in the growth and development of a healthy, salable plant. Container-grown plants require high volumes of water and a steady supply of nutrients to develop into uniform, high quality specimens. Over the years, this excessive water usage and the resulting runoff has caused concerns over the possible depletion and pollution of ground water resources. The use of cyclic irrigation has reduced runoff and nutrient loss in studies while different fertilizer placements have been studied for their affects on nutrient availability and longevity. Fertilizer and irrigation methods which minimize effluent and nutrient loss while maximizing plant growth need to be incorporated into large nursery container production systems. The results of this study indicate that incorporated fertilizer produces statistically larger plants and maintains higher substrate nutrient content compared to topdressed fertilizer. The results also indicate cyclic irrigation significantly reduces effluent and increases plant growth compared to irrigating once daily. Also, cyclic irrigation maintains higher substrate nutrient contents compared to once daily irrigation.

Chinese elms (3 gallons) transplanted into 20 gal containers resulted in a 7 to 8 month crop time. We found that incorporated fertilizer treatments increased plant growth and maintained higher substrate nutrient content compared to topdressed treatments. Although a mixer is required to incorporate the fertilizer and lime, growers should consider the benefits gained from this method. We also discovered that irrigating three times daily increased plant growth, reduced runoff and maintained higher nutrient levels in the container substrate. Cyclic irrigation can be easily implemented into any existing irrigation system, especially if an automated timing device is already utilized.

One gallon 'Acoma' crape myrtles were transplanted into 20 gal containers resulting in a 16 to 18 month crop time. Results suggested that incorporated fertilizer maintained higher nutrient content in the substrate compared to topdressed fertilizer. In addition, irrigating three times daily produced larger plants compared to irrigating once daily. Since the plants were grown over a two year period, supplemental fertilizer was applied as a topdress the second year. Incorporating fertilizer into the substrate for long term crops did not effect growth in the first or second year. Therefore, incorporation did not seem to improve crape myrtle growth. Cyclic irrigation did increase plant growth.

The results of these studies indicate that either irrigation method was sufficient for optimum growth. However, spray stakes required more attention than the drip rings. Spray stakes had to be monitored regularly to make any necessary adjustments to the spray pattern and to also replace any stakes which were dislodged from the containers. Drip rings, on the other hand, always remained in the containers and never needed adjustments. However, a single drip emitter costs $0.70 while a spray stake costs $0.20. A grower needs to consider the price and maintenance of each method before making a decision.

A large container production system consists of several important components. A grower needs to consider the benefits and drawbacks to all of the components to make an educated decision. Growers have the ability to choose components which promote plant health and the environment while maintaining cost effectiveness.

APPENDIX

MICRONUTRIENT, IRRIGATION AND WEATHER DATA

Table 4. Average nutrient content in substrate-leachate of Chinese elm (U. parvifolia) under different fertilizer placements in 2000.

		ppm								
Month	Treatment[y]	Ca	Mg	Cu	Mn	Fe	Zn	S	B	Na
July	inc	84.69a[z]	17.41a	0.11a	0.02	0.62a	0.73a	56.13a	0.33a	161.9a
	top	32.66b	6.51b	0.02b	0.02	0.28b	0.28b	23.60b	0.10b	110.9b
August	inc	20.48	3.61	0.05a	0.02b	0.39a	0.24a	24.84a	0.16	173.0a
	top	19.13	3.44	0.01b	0.04a	0.24b	0.12b	14.09b	0.12	137.1b
September	inc	8.60	1.49b	0.03a	0.01	0.26a	0.13a	13.91a	0.08a	113.6
	top	9.79	1.85a	0.01b	0.01	0.18b	0.07b	10.55b	0.06b	105.6
October	inc	14.26	2.38	0.03a	0.01	0.51a	0.11a	20.04a	0.08a	203.3a
	top	10.77	2.12	0.01b	0.01	0.16b	0.05b	7.71b	0.06b	123.2b
November	inc	6.02	1.50	0.01a	0.01	0.19a	0.07a	6.68	0.07a	92.9a
	top	6.19	1.66	0.01b	0.01	0.11b	0.03b	6.10	0.05b	79.2b

[y] inc = incorporated fertilizer. top = topdressed fertilizer.

[z] Duncan's Multiple Range Test was reported only when the ANOVA test indicated significant ($P \leq 0.05$) treatment effect, means ($n = 16$).

Table 5. Average nutrient content in substrate-leachate of Chinese elm (U. parvifolia) under different irrigation frequencies in 2000.

		ppm								
Month	Treatment[y]	Ca	Mg	Cu	Mn	Fe	Zn	S	B	Na
July	1x	45.59b[z]	9.44b	0.05b	0.02	0.33b	0.43b	30.82b	0.20	123.5b
	3x	71.76a	14.48a	0.07a	0.02	0.58a	0.59a	48.91a	0.23	149.3a
August	1x	14.05b	2.59b	0.02b	0.02b	0.26	0.14b	14.64b	0.13	133.0b
	3x	25.57a	4.46a	0.04a	0.04a	0.37	0.22a	24.29a	0.15	177.2a
September	1x	7.88b	1.47b	0.02	0.01	0.20	0.09	10.10b	0.07	97.1b
	3x	10.51a	1.86a	0.02	0.01	0.23	0.10	14.36a	0.08	122.1a
October	1x	5.21b	1.37b	0.01	0.01	0.16	0.05	6.20	0.06	81.8
	3x	7.00a	1.79a	0.01	0.00	0.14	0.05	6.58	0.06	90.3
November	1x	9.66b	1.81b	0.02	0.01	0.26	0.08	9.58b	0.07	129.6b
	3x	15.37a	2.69a	0.02	0.01	0.41	0.08	18.17a	0.07	196.9a

[y] 1x = once daily irrigation. 3x = three times daily irrigation.

[z] Duncan's Multiple Range Test was reported only when the ANOVA test indicated significant ($P \leq 0.05$) treatment effect, means ($n = 16$).

Table 6. Average nutrient content in substrate-leachate of Chinese elm (U. parvifolia) under different irrigation methods in 2000.

		ppm								
Month	Treatment[y]	Ca	Mg	Cu	Mn	Fe	Zn	S	B	Na
July	drip	61.19[z]	12.23	0.06	0.01	0.38b	0.47	37.46	0.23	140.3
	spray	56.16	11.69	0.07	0.02	0.52a	0.54	42.27	0.20	132.5
August	drip	22.99a	4.01	0.03	0.03	0.30	0.17	22.21	0.13	162.4
	spray	16.62b	3.05	0.03	0.03	0.33	0.19	16.72	0.15	147.7
September	drip	10.13a	1.82a	0.02	0.01	0.20	0.09	12.05	0.07	112.4
	spray	8.26b	1.51b	0.02	0.01	0.23	0.11	12.42	0.07	106.8
October	drip	12.00	2.16	0.02	0.01	0.23	0.07	12.42	0.07	151.9
	spray	13.03	2.33	0.02	0.01	0.44	0.08	15.33	0.07	174.6
November	drip	5.69	1.46	0.01	0.01	0.14	0.05	6.13	0.06	76.7b
	spray	6.52	1.69	0.01	0.01	0.16	0.05	6.64	0.06	95.4a

[y] drip = drip ring irrigation. spray = spray stake irrigation.

[z] Duncan's Multiple Range Test was reported only when the ANOVA test indicated significant ($P \leq 0.05$) treatment effect, means ($n = 16$).

Table 7. Average nutrient content in substrate-leachate of Chinese elm (U. parvifolia) under different fertilizer placements in 2001.

		ppm								
Month	Treatment[y]	Ca	Mg	Cu	Mn	Fe	Zn	S	B	Na
July	inc	59.58a[z]	8.96a	0.10a	0.16	0.42a	0.60a	51.89a	0.20a	128.86a
	top	35.11b	4.48b	0.02b	0.07	0.18b	0.04b	9.02b	0.07b	99.75b
August	inc	13.79b	2.03	0.05a	0.02	0.26a	0.17a	23.48a	0.15a	92.49
	top	19.78a	2.73	0.02b	0.02	0.16b	0.05b	15.39b	0.11b	96.06
September	inc	15.35	2.09b	0.05a	0.02	0.31a	0.12a	30.21a	0.09a	156.94a
	top	16.85	2.46a	0.02b	0.03	0.09b	0.03b	9.99b	0.06b	100.53b
October	inc	6.52b	1.46b	0.03a	0.02	0.17	0.10a	18.21b	0.09	114.74
	top	15.11a	3.35a	0.02b	0.02	0.02	0.04b	25.00a	0.09	114.87
November	inc	8.33b	1.32b	0.03a	0.02	0.20a	0.06a	18.14a	0.09a	146.44a
	top	11.40a	1.91a	0.02b	0.03	0.21b	0.03b	12.89b	0.06b	126.94b

[y] inc = incorporated fertilizer. top = topdressed fertilizer.

[z] Duncan's Multiple Range Test was reported only when the ANOVA test indicated significant ($P \leq 0.05$) treatment effect, means (n = 16).

Table 8. Average nutrient content in substrate-leachate of Chinese elm (U. parvifolia) under different irrigation frequencies in 2001.

		ppm								
Month	Treatment[y]	Ca	Mg	Cu	Mn	Fe	Zn	S	B	Na
July	1x	34.01b[z]	4.88b	0.05b	0.05b	0.25b	0.25b	23.51b	0.13	103.20b
	3x	60.68a	8.56a	0.07a	0.18a	0.35a	0.39a	37.41a	0.13	125.41a
August	1x	15.91	2.35	0.03	0.02	0.19	0.10	17.14	0.13	94.81
	3x	17.66	2.42	0.04	0.02	0.22	0.11	21.74	0.13	93.74
September	1x	10.61b	1.66b	0.03b	0.02	0.16b	0.04b	14.31b	0.08	110.26b
	3x	21.59a	2.89a	0.03a	0.03	0.24a	0.10a	25.89a	0.07	147.21a
October	1x	9.04b	2.20	0.02b	0.02	0.14b	0.05b	19.45b	0.09	113.04
	3x	12.58a	2.62	0.03a	0.02	0.24a	0.08a	23.76a	0.09	116.56
November	1x	8.03b	1.46	0.03	0.02	0.17	0.04b	16.54	0.08	129.00
	3x	11.70a	1.77	0.03	0.02	0.15	0.05a	14.50	0.08	144.38

[y] 1x = once daily irrigation. 3x = three times daily irrigation.

[z] Duncan's Multiple Range Test was reported only when the ANOVA test indicated significant ($P \leq 0.05$) treatment effect, means (n = 16).

Table 9. Average nutrient content in substrate-leachate of Chinese elm (U. parvifolia) under different irrigation methods in 2001.

		ppm								
Month	Treatment[y]	Ca	Mg	Cu	Mn	Fe	Zn	S	B	Na
July	drip	49.59[z]	6.91	0.07	0.11	0.38a	0.34	31.53	0.14	117.63
	spray	45.10	6.53	0.05	0.12	0.22b	0.29	29.39	0.13	110.98
August	drip	20.98a	2.92a	0.04a	0.02	0.29a	0.15a	24.36a	0.15a	100.18
	spray	12.59b	1.84b	0.03b	0.02	0.13b	0.07b	14.51b	0.11b	88.36
September	drip	20.63a	2.80a	0.04a	0.03	0.27a	0.10a	24.53a	0.08	135.17a
	spray	11.58b	1.75b	0.03b	0.02	0.12b	0.05b	15.68b	0.07	122.30b
October	drip	10.94a	1.70	0.03	0.02	0.17	0.05	14.13	0.07	127.81b
	spray	8.79b	1.53	0.03	0.02	0.15	0.04	16.91	0.08	145.56a
November	drip	11.46	2.39	0.03	0.02	0.22a	0.07	19.34b	0.08	101.83b
	spray	10.16	2.43	0.03	0.02	0.15b	0.06	23.88a	0.10	127.78a

[y] drip = drip ring irrigation. spray = spray stake irrigation.

[z] Duncan's Multiple Range Test was reported only when the ANOVA test indicated significant ($P \leq 0.05$) treatment effect, means (n = 16).

Table 10. Average nutrient content in substrate-leachate of 'Acoma' crape myrtle (L. indica x fauriei 'Acoma') under different fertilizer placements in 2000.

		ppm								
Month	Treatment[y]	Ca	Mg	Cu	Mn	Fe	Zn	S	B	Na
July	inc	95.54 a[z]	20.15 a	0.08 a	0.08	0.46 a	0.63 a	43.44 a	0.29 a	145.48 a
	top	29.98 b	5.88 b	0.01 b	0.05	0.13 b	0.24 b	8.36 b	0.13 b	82.34 b
August	inc	63.89	12.58 a	0.06 a	0.14 a	0.51 a	0.45 a	32.92 a	0.24 a	120.19
	top	40.99	5.00 b	0.01 b	0.06 b	0.23 b	0.23 b	9.72 b	0.11 b	100.34
September	inc	27.51 a	5.18 a	0.05 a	0.07 a	0.42 a	0.37 a	19.56 a	0.13 a	88.06
	top	18.88 b	3.40 b	0.01 b	0.02 b	0.21 b	0.17 b	12.05 b	0.09 b	89.76
October	inc	30.21	5.12	0.05 a	0.09 a	0.66 a	0.37 a	16.75 a	0.08	103.64
	top	25.29	4.54	0.01 b	0.04 b	0.32 b	0.19 b	9.02 b	0.07	100.54
November	inc	13.24	2.63	0.03 a	0.03 a	0.36 a	0.21 a	10.73 a	0.06	77.33
	top	13.20	2.99	0.01 b	0.02 b	0.14 b	0.10 b	7.80 b	0.06	79.63

[y] inc = incorporated fertilizer. top = topdressed fertilizer.

[z] Duncan's Multiple Range Test was reported only when the ANOVA test indicated significant ($P \leq 0.05$) treatment effect, means n = 15 (inc) and n = 16 (top).

Table 11. Average nutrient content in substrate-leachate of 'Acoma' crape myrtle (L. indica x fauriei 'Acoma') under different irrigation frequencies in 2000.

		ppm								
Month	Treatment[y]	Ca	Mg	Cu	Mn	Fe	Zn	S	B	Na
July	1x	57.22[z]	12.05	0.05	0.07	0.28	0.45	23.87	0.21	107.86
	3x	66.48	13.57	0.05	0.06	0.30	0.41	26.88	0.21	118.26
August	1x	53.18	7.51 b	0.04	0.09	0.36	0.34	18.66	0.18	94.78
	3x	50.88	9.90 a	0.04	0.10	0.36	0.33	23.39	0.17	126.11
September	1x	21.33	4.09	0.03 b	0.04	0.27 b	0.22 b	14.28 b	0.11	88.96
	3x	24.89	4.44	0.04 a	0.04	0.36 a	0.31 a	17.18 a	0.11	88.91
October	1x	25.81	4.56	0.03	0.06	0.43	0.27	12.23	0.08	98.34
	3x	29.65	5.10	0.04	0.07	0.54	0.28	13.33	0.07	105.99
November	1x	13.59	2.87	0.02	0.03 a	0.24	0.17	9.29	0.07	77.13
	3x	12.83	2.76	0.02	0.02 b	0.25	0.14	9.13	0.06	79.99

[y] 1x = once daily irrigation. 3x = three times daily irrigation.

[z] Duncan's Multiple Range Test was reported only when the ANOVA test indicated significant ($P \leq 0.05$) treatment effect, means n = 16 (1x) and n = 15 (3x).

Table 12. Average nutrient content in substrate-leachate of 'Acoma' crape myrtle (L. indica x fauriei 'Acoma') under different irrigation methods in 2000.

		ppm								
Month	Treatment[y]	Ca	Mg	Cu	Mn	Fe	Zn	S	B	Na
July	drip	72.79 a[z]	15.33 a	0.05	0.07	0.33 a	0.43	28.43	0.23 a	121.71
	spray	49.87 b	10.07 b	0.04	0.06	0.25 b	0.43	22.03	0.19 b	103.48
August	drip	50.26	9.60	0.04	0.12 a	0.42 a	0.34	22.10	0.18	104.36
	spray	54.00	7.68	0.03	0.07 b	0.30 b	0.33	19.72	0.17	115.90
September	drip	22.76	4.11	0.04 a	0.04	0.36 a	0.28	16.30	0.11	86.54
	spray	23.37	4.42	0.03 b	0.04	0.27 b	0.25	15.03	0.11	91.49
October	drip	29.93	5.12	0.04	0.08 a	0.52	0.29	13.05	0.07	104.66
	spray	25.26	4.50	0.03	0.05 b	0.44	0.26	12.46	0.08	99.25
November	drip	12.56	2.71	0.02	0.02	0.26	0.14	9.10	0.05 b	78.49
	spray	13.93	2.93	0.02	0.03	0.23	0.16	9.33	0.08 a	78.54

[y] drip = drip ring irrigation. spray = spray stake irrigation.

[z] Duncan's Multiple Range Test was reported only when the ANOVA test indicated significant ($P \leq 0.05$) treatment effect, means n = 16 (drip) and n = 15 (spray).

Table 13. Average nutrient content in substrate-leachate of 'Acoma' crape myrtle (L. indica x fauriei 'Acoma') under different fertilizer placements in 2001.

		ppm								
Month	Treatment[y]	Ca	Mg	Cu	Mn	Fe	Zn	S	B	Na
July	inc	7.27[z]	1.09	0.04 a	0.02 a	0.41 a	0.13	12.86	0.08	121.25
	top	7.06	1.14	0.02 b	0.02 b	0.29 b	0.10	11.63	0.08	119.76
August	inc	7.09	0.92	0.04 a	0.02	0.61 a	0.15	18.10	0.10	104.04
	top	6.90	1.03	0.02 b	0.02	0.47 b	0.12	17.00	0.10	102.20
September	inc	4.44	0.76	0.02 a	0.02	0.31	0.08	9.52	0.06	116.15
	top	4.95	0.86	0.02 b	0.02	0.24	0.06	10.36	0.06	117.34
October	inc	5.01	0.87	0.03 a	0.02	0.37 a	0.09	10.55	0.09	100.14
	top	5.32	0.85	0.02 b	0.02	0.26 b	0.06	10.20	0.08	100.03
November	inc	3.92	0.71	0.02	0.02	0.32	0.08	5.84	0.09	100.69
	top	4.74	0.80	0.02	0.02	0.30	0.06	7.02	0.08	99.83

[y] inc = incorporated fertilizer. top = topdressed fertilizer.

[z] Duncan's Multiple Range Test was reported only when the ANOVA test indicated significant ($P \leq 0.05$) treatment effect, means n = 15 (inc) and n = 16 (top).

Table 14. Average nutrient content in substrate-leachate of 'Acoma' crape myrtle (L. indica x fauriei 'Acoma') under different irrigation frequencies in 2001.

		ppm								
Month	Treatment[y]	Ca	Mg	Cu	Mn	Fe	Zn	S	B	Na
July	1x	3.75 b[z]	0.59 b	0.03 b	0.02 b	0.23 b	0.11	8.87 b	0.08	95.74 b
	3x	10.79 a	1.68 a	0.04 a	0.02 a	0.49 a	0.12	15.80 a	0.09	146.87 a
August	1x	5.92 b	0.82 b	0.03	0.02	0.47 b	0.14	14.81 b	0.10	104.24
	3x	8.13 a	1.14 a	0.04	0.02	0.61 a	0.13	20.44 a	0.10	101.86
September	1x	3.11 b	0.51 b	0.02	0.02	0.23	0.06	9.57	0.06	105.41 b
	3x	6.39 a	1.13 a	0.02	0.02	0.31	0.07	10.37	0.06	128.87 a
October	1x	4.23 b	0.66 b	0.02	0.02	0.26 b	0.07	8.85 b	0.08	102.06
	3x	6.17 a	1.07 a	0.02	0.02	0.37 a	0.08	11.99 a	0.09	97.97
November	1x	3.42 b	0.60 b	0.02	0.02	0.27	0.08	5.83	0.08	98.46
	3x	5.33 a	0.93 a	0.02	0.02	0.35	0.06	7.11	0.08	102.15

[y] 1x = once daily irrigation. 3x = three times daily irrigation.

[z] Duncan's Multiple Range Test was reported only when the ANOVA test indicated significant ($P \leq 0.05$) treatment effect, means n = 16 (1x) and n = 15 (3x).

Table 15. Average nutrient content in substrate-leachate of 'Acoma' crape myrtle (L. indica x fauriei 'Acoma') under different irrigation methods in 2001.

		ppm								
Month	Treatment[y]	Ca	Mg	Cu	Mn	Fe	Zn	S	B	Na
July	drip	8.33 a[z]	1.27 a	0.03	0.02 a	0.42 a	0.12	12.55	0.09	127.11 a
	spray	5.92 b	0.95 b	0.03	0.02 b	0.28 b	0.11	11.88	0.08	113.41 b
August	drip	7.90 a	1.10 a	0.04 a	0.02	0.70 a	0.14	18.19	0.10	104.83
	spray	6.02 b	0.84 b	0.03 b	0.02	0.37 b	0.13	16.83	0.10	101.24
September	drip	4.51	0.79	0.02	0.02	0.29	0.06	8.20 b	0.06	115.36
	spray	4.90	0.84	0.02	0.02	0.25	0.08	11.83 a	0.06	118.27
October	drip	4.69	0.80	0.02	0.02	0.34	0.07	8.57 b	0.07 b	91.83 b
	spray	5.69	0.92	0.02	0.02	0.29	0.08	12.29 a	0.10 a	108.89 a
November	drip	4.04	0.69	0.02	0.02	0.32	0.06	5.05 b	0.08	93.01 b
	spray	4.67	0.83	0.02	0.02	0.30	0.08	7.94 a	0.08	107.97 a

[y] drip = drip ring irrigation. spray = spray stake irrigation.

[z] Duncan's Multiple Range Test was reported only when the ANOVA test indicated significant ($P \leq 0.05$) treatment effect, means n = 16 (drip) and n = 15 (spray).

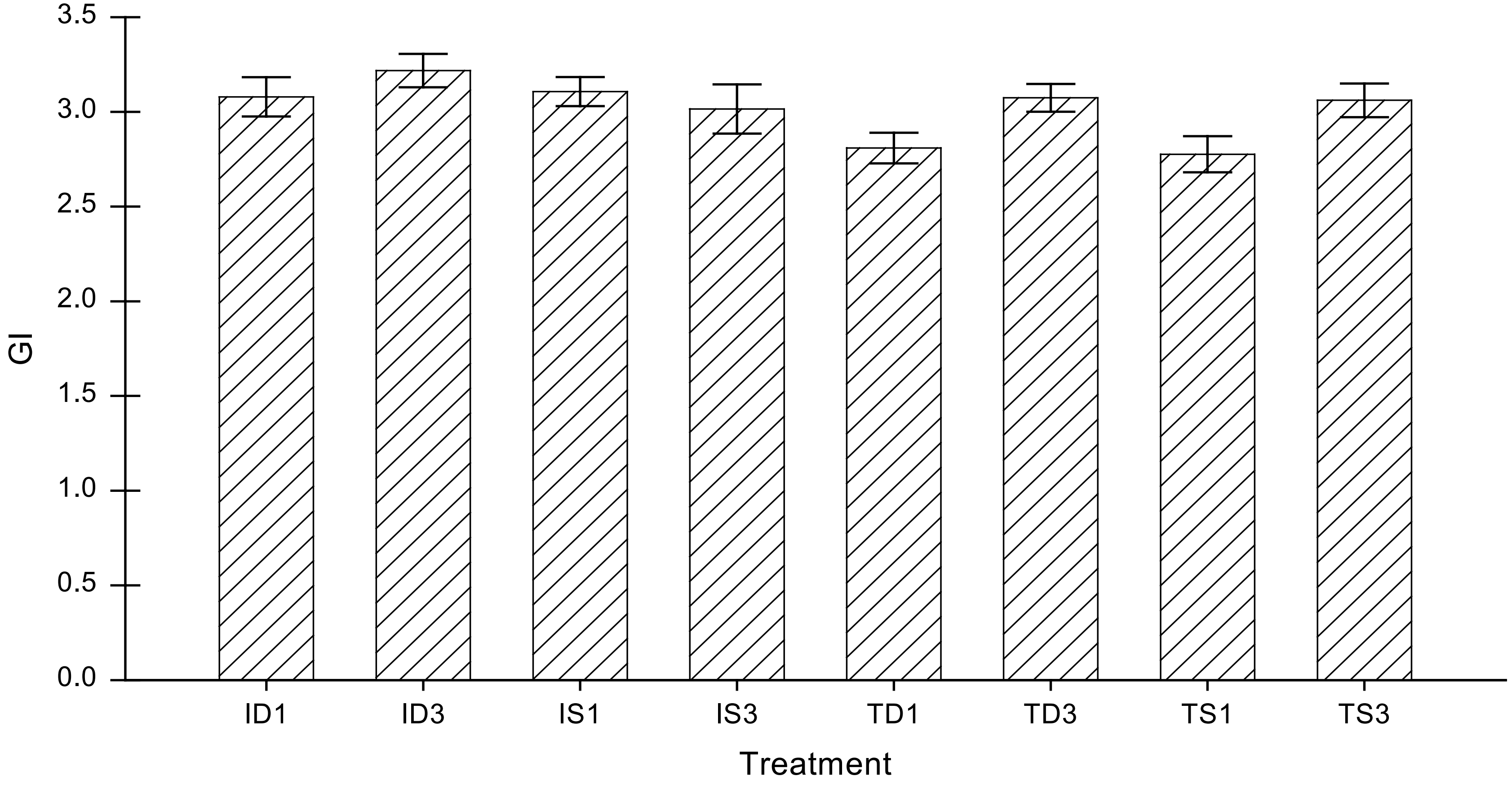

Figure 43. Final cumulative growth index (GI) of Chinese elm (U. parvifolia) in 2001 under eight production systems: I = incorporated fertilizer; T = topdressed fertilizer; 1 = once daily irrigation; 3 = three times daily irrigation; D = drip ring irrigation method; S = spray stake irrigation method. Each value represents Mean ± SE, n = 10.

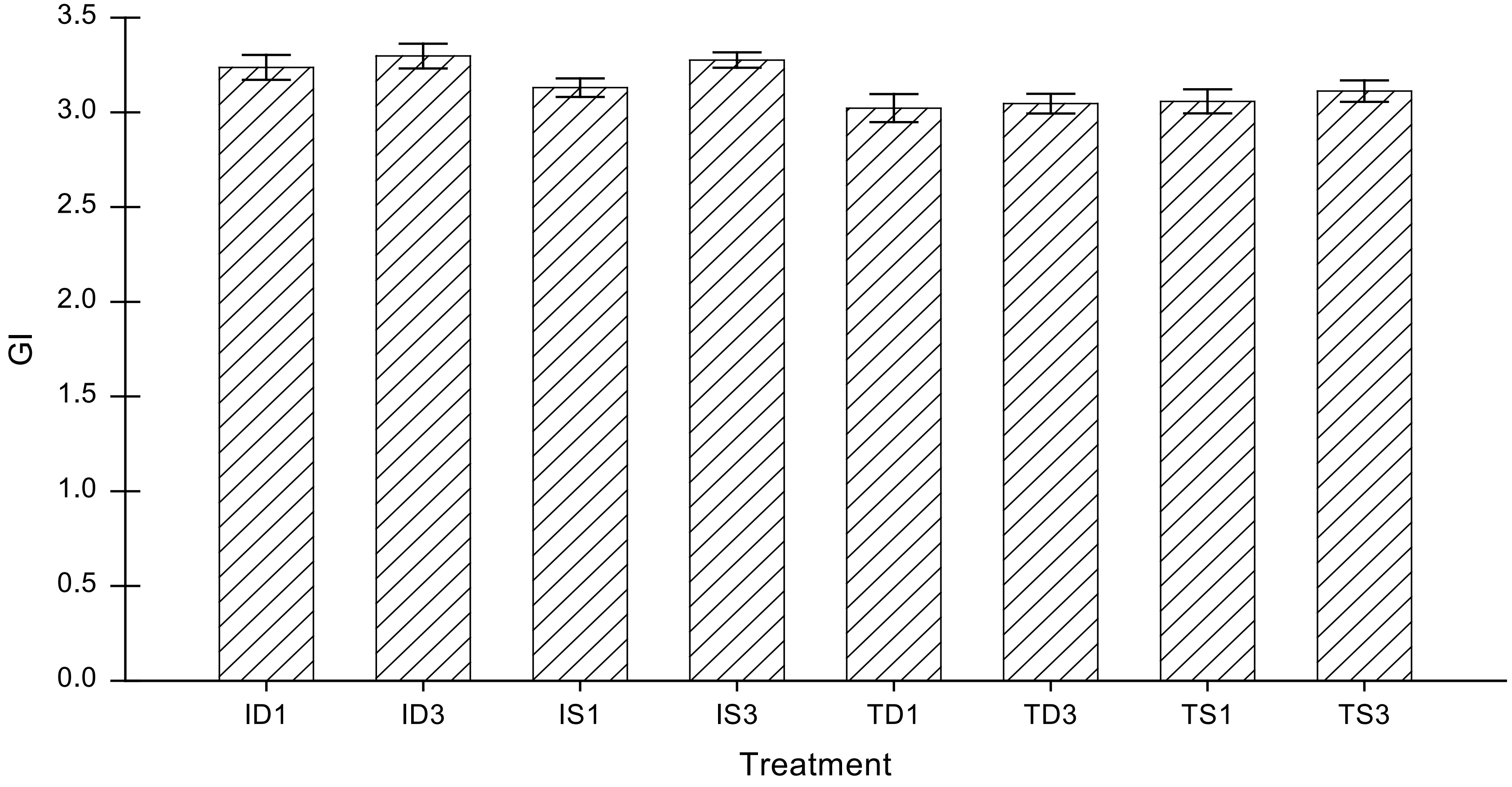

Figure 44. Final cumulative growth index (GI) of Chinese elm (U. parvifolia) in 2001 under eight production systems: I = incorporated fertilizer; T = topdressed fertilizer; 1 = once daily irrigation; 3 = three times daily irrigation; D = drip ring irrigation method; S = spray stake irrigation method. Each value represents Mean ± SE, n = 10.

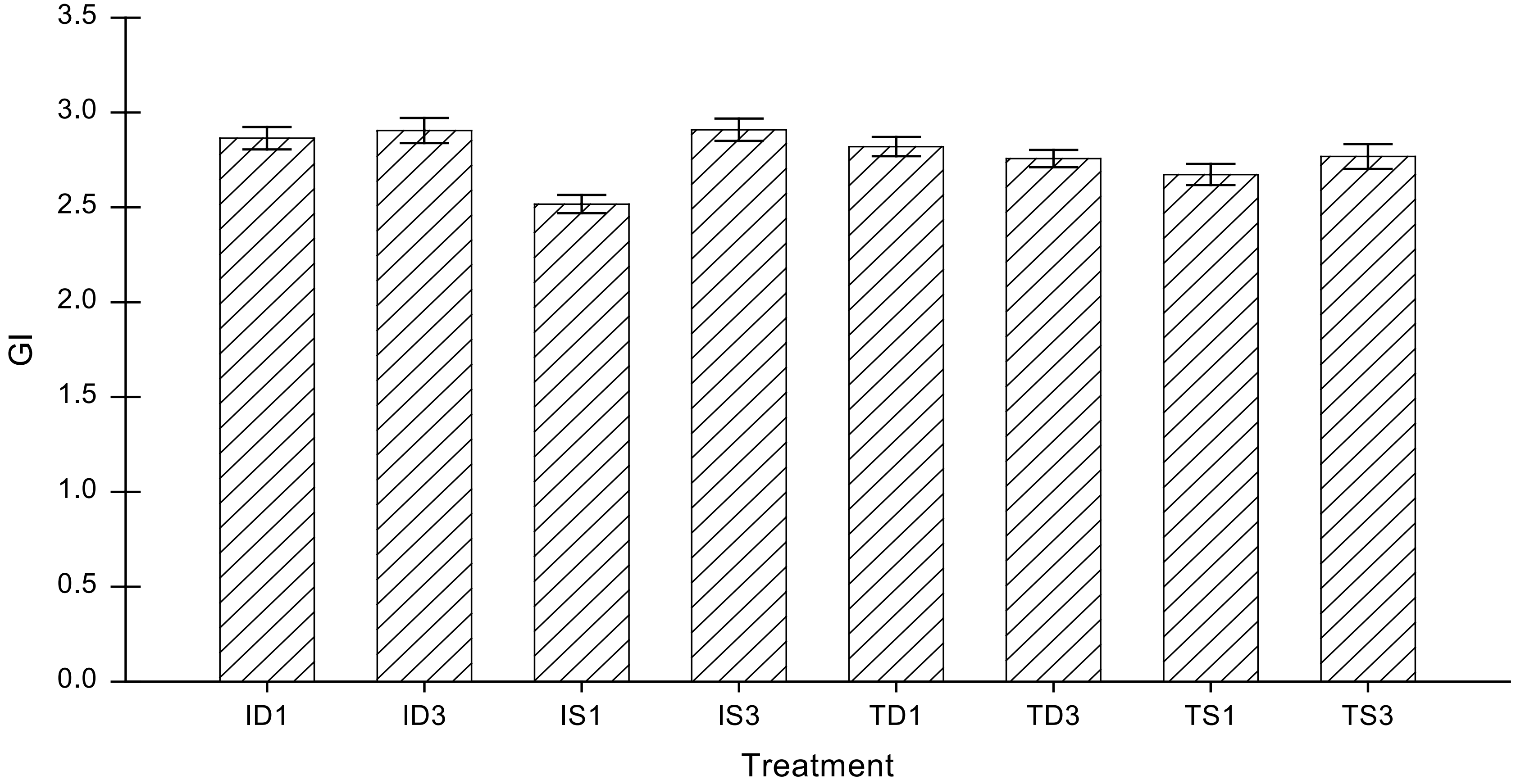

Figure 45. Final cumulative growth index (GI) of 'Acoma' crape myrtle (L. indica x fauriei 'Acoma') under eight production systems: I = incorporated fertilizer; T = topdressed fertilizer; 1 = once daily irrigation; 3 = three times daily irrigation; D = drip ring irrigation method; S = spray stake irrigation method. Each value represents Mean ± SE, n = 10 except TD3 and IS3 (n = 9).

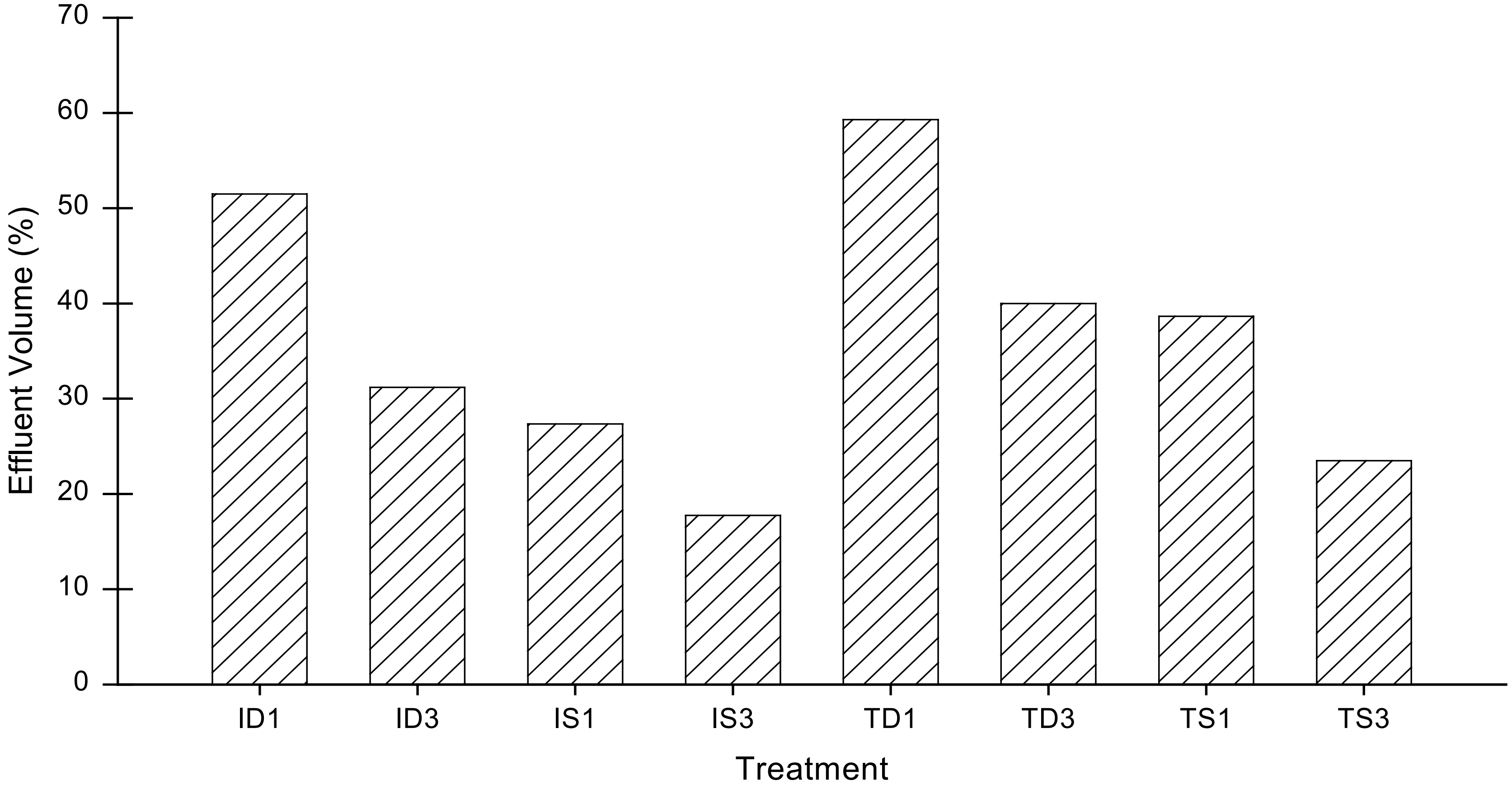

Figure 46. Mean percent effluent volume of Chinese elm (U. parvifolia) in 2000 under eight production systems: I = incorporated fertilizer; T = topdressed fertilizer; 1 = once daily irrigation; 3 = three times daily irrigation; D = drip ring irrigation method. Each value represents Mean, n = 10.

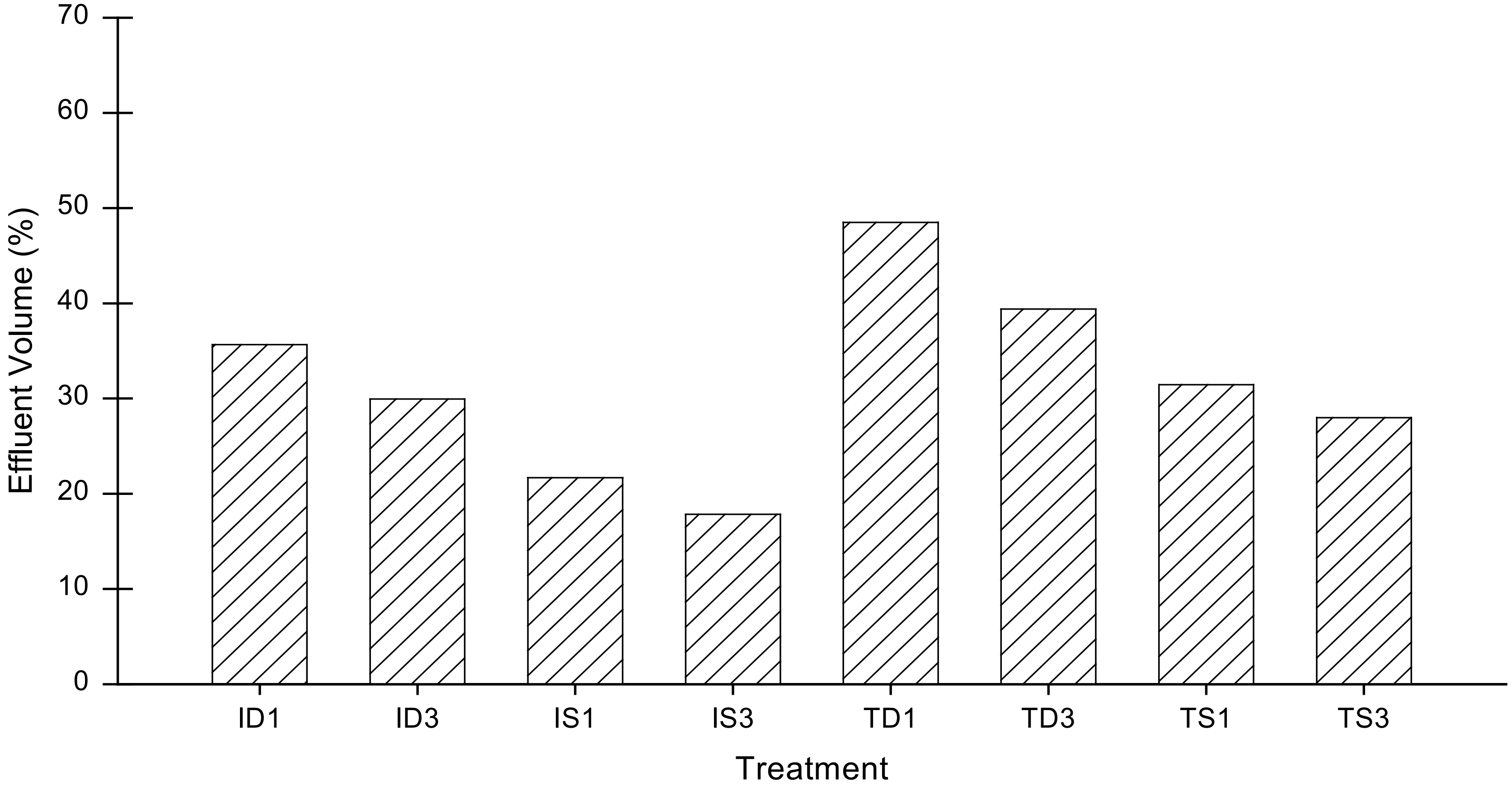

Figure 47. Mean percent effluent volume of Chinese elm (U. parvifolia) in 2001 under eight production systems: I = incorporated fertilizer; T = topdressed fertilizer; 1 = once daily irrigation; 3 = three times daily irrigation; D = drip ring irrigation method; S = spray stake irrigation method. Each value represents Mean, n = 10.

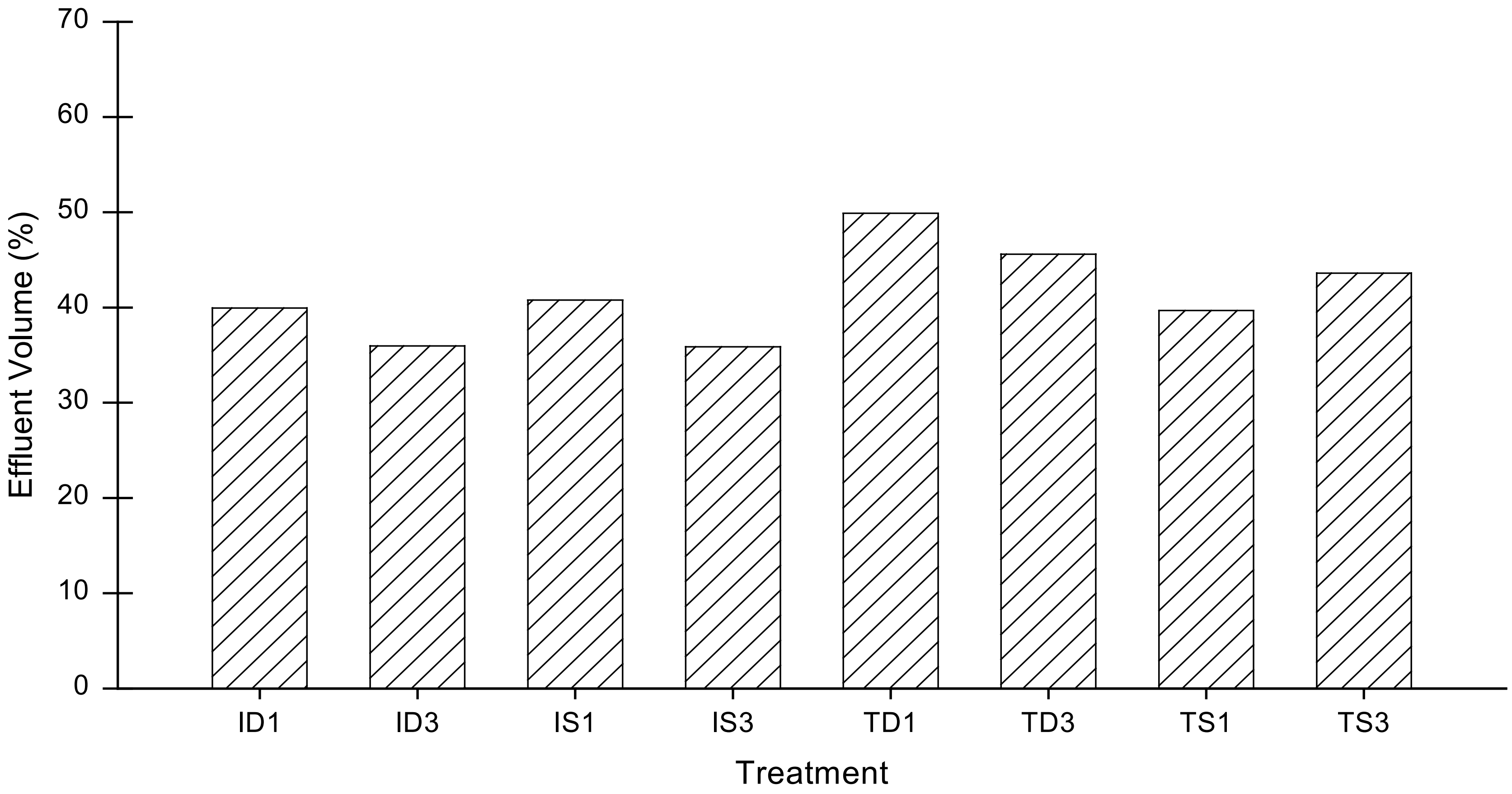

Figure 48. Mean percent effluent volume of 'Acoma' crape myrtle (L. indica x fauriei 'Acoma') under eight production systems: I = incorporated fertilizer; T = topdressed fertilizer; 1 = once daily irrigation; 3 = three times daily irrigation; D = drip ring irrigation method; S = spray stake irrigation method. Each value represents Mean, n = 10 except TD3 and IS3 (n = 9).

Table 16. Final height and caliper of Chinese elm (U. parvifolia) at the termination of experiments I and II.

	Experiment I		Experiment II	
Treatment^{y}	Height (cm)	Caliper (mm)	Height (cm)	Caliper (mm)
inc	280 a^{z}	34 a	326	32 a
top	265 b	32 b	322	29 b
1x	273	32 b	322	30 b
3x	272	35 a	326	31 a
drip	271	34	322	31
spray	274	32	326	30

^{y}inc = incorporated fertilizer. top = topdressed fertilizer. 1x = once daily irrigation. 3x = three times daily irrigation. drip = drip ring irrigation. spray = spray stake irrigation.
^{z}Duncan's Multiple Range Test was reported only when the ANOVA test indicated significant ($P \leq 0.05$) treatment effect, means n = 40.

Table 17. Final height and caliper of 'Acoma' crape myrtle (L. indica x fauriei 'Acoma') at the termination of the experiment.

Treatment^{y}	Height (cm)	Caliper (mm)
inc	203	36
top	199	35
1x	200	34 b
3x	202	37 a
drip	203	37 a
spray	200	34 b

^{y}inc = incorporated fertilizer. top = topdressed fertilizer. 1x = once daily irrigation. 3x = three times daily irrigation. drip = drip ring irrigation. spray = spray stake irrigation.
^{z}Duncan's Multiple Range Test was reported only when the ANOVA test indicated significant ($P \leq 0.05$) treatment effect. Means n = 39 (inc, top, drip and spray); n = 40 (1x) and n = 38 (3x).

Table 18. Irrigation volumes of drip rings and spray stakes used for initial calibration.

	Drip Ring		Spray Stake	
Emitter	mL/min	gal/hr	mL/min	gal/hr
1	420	6.66	201	3.2
2	360	5.71	197	3.12
3	360	5.71	201	3.2
4	350	5.55	199	3.15
5	410	6.50	201	3.2
6	370	5.87	201	3.2
7	410	6.5	201	3.2
8	400	6.34	201	3.2
Average	385	6.1	200	3.18

Table 19. Irrigation water analysis data for Burden Center (average 2000 to 2001).

pH	8.5
Salts	194.7
Sodium	71.4
Potassium	0.3
Magnesium	0.1
Calcium	0.3
Iron	0.01
Manganese	0.01
Chloride	9.6
Nitrate	2.7
Sulfur	0.4
Alkalinity	175.7
SAR	29.5

Table 20. Temperature and rainfall data for Baton Rouge in 2000.

Month	Days	Average High (ºF)	Average Low (ºF)	Total Rainfall (in)
Jan	1-15	71	46	1.64
	16-31	60	40	1.14
Feb	1-15	68	44	0.00
	16-29	77	50	0.64
Mar	1-15	75	51	0.90
	16-31	77	53	2.46
Apr	1-15	74	51	0.89
	16-30	82	55	0.66
May	1-15	86	65	1.15
	16-31	92	69	0.00
Jun	1-15	91	68	0.30
	16-30	91	72	4.48
Jul	1-15	93	73	2.40
	16-31	93	73	1.21
Aug	1-15	94	72	1.46
	16-31	97	74	1.22
Sep	1-15	92	73	2.82
	16-30	85	61	0.22
Oct	1-15	79	52	1.04
	16-31	83	55	0.03
Nov	1-15	72	51	4.62
	16-30	62	40	6.09
Dec	1-15	59	38	1.63
	16-31	53	32	1.10

Table 21. Temperature and rainfall data for Baton Rouge in 2001.

Month	Days	Average High (ºF)	Average Low (ºF)	Total Rainfall (in)
Jan	1-15	56	34	0.54
	16-31	60	40	3.46
Feb	1-15	68	46	0.61
	16-28	74	50	1.22
Mar	1-15	69	48	5.36
	16-31	66	45	1.99
Apr	1-15	85	66	0.01
	16-30	78	53	0.54
May	1-15	84	60	0.52
	16-31	88	65	0.31
Jun	1-15	86	71	19.47
	16-30	88	67	1.89
Jul	1-15	91	72	2.15
	16-31	91	73	1.05
Aug	1-15	89	73	4.34
	16-31	89	73	1.43
Sep	1-15	87	70	6.35
	16-30	84	62	0.76
Oct	1-15	80	57	5.48
	16-31	74	48	0.01
Nov	1-15	78	51	0.00
	16-30	75	48	0.58
Dec	1-15	71	50	2.83
	16-31	62	38	1.42

VITA

Anthony Lynn Witcher, the only child of Jeff and Kaye Witcher, was born March 2, 1977, in Monroe, Louisiana. He attended St. Frederick High School in Monroe, Louisiana, from 1991 to 1995. He enrolled at Louisiana Tech University in 1995 and graduated in 1998 with a Bachelor of Science degree in plant science. After graduation, he moved to Baton Rouge, Louisiana, and soon began work as a research associate in ornamental horticulture for the Louisiana State University Agricultural Center at Burden Center. In September 1999, he entered graduate school in the Department of Horticulture at Louisiana State University to pursue a master's degree in ornamentals. He will receive that degree in May, 2003.