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PRACTICES TO MINIMIZE CONTAMINATION OF GROUNDWATER AND RUNOFF WATER IN GREENHOUSE AND NURSERY PRODUCTION OF CONTAINER-GROWN PLANTS

- **Situation Statement**

Production of container-grown plants with traditional production methods uses relatively large quantities of irrigation water, fertilizers and other agricultural chemicals. Much of the container stock is fertilized with soluble nitrogen fertilizers delivered through overhead irrigation systems at an annual rate in excess of 450-530 lbs/acre (Rathier and Frink, 1989). And, container crops are often grown on areas where topsoil has been removed, thus hastening the flow of soluble fertilizer to ground or surface water and increasing the potential for nitrate-nitrogen pollution (Rathier and Frink, 1989). In production of field-grown plants, lower annual rates of nitrogen application are used: General fertilizer recommendations for field-grown woody plants are 22-44 pounds of N per acre for lining out stock and 75-100 lbs per acre for established field stock (Lumis, unpublished).

Because nitrogen is required in large quantities by the plant and is subject to loss by leaching, it is the most difficult nutrient element to manage in a container production system. Downward movement of cations that are attracted to cation exchange sites and of anions that form relatively insoluble compounds (for example phosphorous) is relatively restricted by the reactivity of the cations and phosphorous with the soil. However, a study by Sommers et al. (1979) found that on a sandy loam soil, 37% of the extractable P was below 6 inches (15 cm), and some had moved to 24 inches (60 cm), the limit of sampling. This may indicate possible long-term effects on groundwater that might be expected from sprinkler application of P and other chemicals with low-solubility.

The average leachate N concentration corresponding to maximum yield of container-grown, woody landscape plants is between 100 and 200 mg N / liter *(Jarrell et al, 1983).*

Other researchers have also reported maximum plant growth of a wide-range of plants occurs when nitrogen is available in solution for root uptake in concentrations of 100-200 ppm (Green, et al., 1971; Hadas et al., 1979; Hershey and Paul, 1982; Hoagland and Arnon, 1950). High growth rates of nursery plants are associated with nitrogen concentrations in solution of 100 to 200 mg N/liter.

10 mg NO_3-N per liter is considered potentially harmful by the Public Health Service.

The implications for environmental quality are not encouraging since greatest plant growth is obtained with 100 - 200 mg N/ liter (200 ppm), but concentrations greater than 10 mg NO_3-N per liter are considered potentially harmful by the Public Health Service. The leachate from these containers must either be diluted, reused, or the nitrogen denitrified. Undiluted leachate should not be allowed to enter surface or groundwater supplies utilized for drinking-water by humans *(Jarrell et al., 1983, Stewart, et al., 1981).*

Overhead Irrigation with Recirculation of Runoff: With overhead irrigation, the combination of nontargeted application and overirrigation may result in application of 40,000 gallons of water per acre per day with losses of 16,000 to 36,000 gallons of water per acre as evaporation during application and as runoff (Bir 1988). One acre-inch of water is 27,154 gallons/acre. Collection and recirculating leachate from containers can result in a 50% reduction in water and fertilizer requirements of overhead irrigation systems (Skimina, 1987).

"Although early community demands were for recycling as '<u>the solution</u>'; recycling addressed only a few of many environmental issues that El Modeno believed needed to be addressed if a true long-term solution was to be achieved" *(Whitesides, 1989).*

Computer-controlled, Pulsed-trickle Fertigation: One alternative to recirculating runoff water from overhead irrigation is to change irrigation systems and reduce the total amount of water and fertilizer initially applied. El Modeno Gardens (Whitesides, 1989) has reduced fertilizer use by 50%, cut labor needs, reduced water use by 30%, and reduced nitrogen in runoff by 91% through computer control of pulsed-trickle fertigation; to date, the 95 acre nursery has installed over 900,000 drip emitters, 64 separate irrigation zones, and 535 computer-controlled solenoid valves. Whitesides (1989) reported positive response to the computer-controlled, pulsed-fertigation system from government agencies.

Diminishing supplies of high-quality water and increased water costs, as well as the necessity of managing and maintaining quality waste water, necessitate improved water and chemical management techniques and practices to enable the nursery industry to maintain high environmental standards. "It is not a question of how, but when your greenhouse or nursery runoff will be monitored and regulated" (Whitesides, 1989). To address current challenges may require development and adoption of innovative production technology.

To meet proposed standards will likely require development of a new, closed, integrated production system.

After reviewing current technology and practices, it appears that applying best-known management practices to existing production systems can significantly reduce the quantities of irrigation water and chemicals applied with consequent reduction in potential contamination of runoff and ground water. However, to dramatically reduce potential contamination of runoff and ground waters to meet proposed standards will likely require development of a new, closed, integrated production system. The economic-engineering analyses and the risk-benefit analyses of any proposed modifications of existing systems and of any proposed new, closed, integrated production system should be developed as a basis for decision making. Introduction of new, innovative systems must be planned and done in cooperation with a few, selected, innovative nurseries.

Adopting innovation is an important means of adjusting to changing conditions. Acceptance and speed of acceptance of innovation depend on several factors *(Kupschus and Storck, 1987)*.

Innovation will be adopted if it meets three criteria: 1) It is compatible with the ideas of the decision maker and the conditions of the firm: a degree of modernity of the firm is usually a prerequisite. 2) it will diminish economic or regulatory pressure; and, 3) it solves a pressing problem: the necessity to solve a pressing problem has a positive effect on adoption of innovation (Kupschus and Storck; 1987).

Some firms quickly adopt new innovations; others are more reluctant to change. Knowledge of reasons responsible for differences in adoptive behavior among firms can shape scientific research to accelerate diffusion of innovative results within the industry. Early adopters of innovation maybe classified as follows: 1) firms or individuals that are opinion leaders; 2) firms perceived by the industry as being examples for imitation; 3) firms with a higher level of technology (firms favoring technical solutions); 4) firms deviating in their reference system from the majority of their colleagues; firms that are actively gathering information from various sources; 5) firms exhibiting progressive problem-oriented decision making; 6) firms constructing new facilities (Kupschus and Storch 1987).

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- **National Implications**

Water contamination with pesticides and fertilizers from container nurseries is significant. Whether you agree with this statement or not, the problem of water quality is an environmental and political issue the nursery industry must address. As stated by Urbano (1989a), "In this industry, public perception is everything. If I had to pick one reason for you to become a full-blown environmental activist, it would be the age-old adage `The Customer is always right.' Your customer cares about the environment. Your community's assessment of your stand will eventually make or break your business."

Water quality is an environmental and political issue that the nursery industry must address.

Industry members are concerned about the environment: When asked in a survey to name the single most important environmental issue that the nursery industry must address, response was conclusively "water" (Urbano, 1989). According to Urbano (1989b), the survey indicated, 'Across the board everyone agrees that contaminated runoff and the resulting potential for polluted groundwater must be the industry's foremost concern." Nurserymen stated that pesticide residues in the soil are their next concern. Retailers stated that their next most important concern was employee exposure to chemicals. An owner of one large nursery declared "**We must not take the attitude that we are no worse than any other industry or that we are much better in terms of the way our business activities impact the environment. We must take a position of leadership in protecting and conserving the environment. Our livelihood depends on it".**

The survey of the nursery industry indicated that companies are willing to make capital improvements in their facilities or equipment

to ensure environmental preservation
(*Urbano, 1989b*).

There is considerable homogeneity in container production systems throughout the United States; information resulting from research in one region is generally transferable to other regions. Wayne Mezitt, vice president of Weston Nurseries (Hopkinton, MA) with regard to water use in nurseries states, 'An issue of this magnitude deserves a major effort and requires significant grass roots initiative. This industry-wide problem requires coordinated efforts" (Mezitt, 1987). Mezitt recommended development of an implementation program that would include: Facts on how nursery water use can adversely affect water quality. Details of water conservation and quality preservation practices appropriate for nurserymen. Specific factors to consider when a nursery is making water-related decisions. Suggestions for alternative water-use practices. Information on proper water testing (what to test for, how to do it, when, how often, etc).

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- **Fertilization Technology and Management Practices to reduce the potential for contamination of runoff and ground waters by firms producing container-grown plants.**

To minimize nitrogen losses, the fertilization system should replenish plant-available nitrogen in the form and at the time, and at the site and rate it is taken up by the plant roots.

- **Timing Nitrogen Applications to Plant Growth**

If fertilizer were applied only at optimum times and optimum concentrations for plant uptake, the potential for leaching and contamination would be significantly reduced.

Fertilizer is more efficiently used when applied
during specific growth phases.

Generally, very broad recommendations have been made concerning the timing of fertilizer application to trees and shrubs, with fall and spring being the recommended periods for fertilizer application. However, fertilizer applications may be more efficiently utilized when applied during specific growth phases (Wright and Niemiera, 1987).

The optimum time for providing fertilizer to *Ilex crenata* 'Helleri' corresponded to a period of root elongation that occurred after the cessation of shoot elongation and 1-2 weeks before the next shoot flush (Mertens and Wright, 1978). The rate of fertilizer to apply to *Ilex crenata* 'Helleri' during the active root growth periods to facilitate maximum plant growth and efficient fertilizer utilization was determined by Yeager, et al. (1980). Periods of active and inactive root growth were easily determined by visual observation; the fertilizer treatments were continued through 3 successive growth flushes. Shoot growth of plants fertilized twice at 500 ppm N only during the active root growth was comparable to growth of plants fertilized weekly with 300 ppm N. Extract soluble salt levels for the former treatment remained high for only a short period of time following fertilization while the soluble salts for the 300 ppm N weekly treatment remained high throughout the experiment indicating the plant's uptake of fertilizer ions predominates during periods of active root growth. 44% more N, P and K were applied at the 300 ppm weekly treatment than at the 500 ppm applied only during the two periods of active root growth. Plants fertilized twice at 500 ppm N utilized 28.2%, 26.6%, and 27.9% of the total applied N, P and K respectively. Plants receiving 300 ppm N weekly utilized 19.2%, 19.1% and 17.6% of the total applied N, P, and K respectively; these values would be even lower for regimes in which fertilizer is applied with each watering, a practice employed by many container nurseries. These data demonstrate that application of fertilizer only during active root growth requires less fertilizer and increases plant uptake efficiency.

Shoot elongation of many plants is not continuous but episodic, alternating between phases of shoot elongation and bud set. Woody ornamentals such as oaks, pines, Japanese holly, *Pittosporum Tobira*, *Ligustrum japonicum* and *Euonymus japonica*, as well as most tropical trees, exhibit episodic growth (Hershey and Paul, 1983). Hershey and Paul (1983) reported that when rooted cuttings of *Euonymus japonica* Thunb. were grown in solution culture for 3 months, rates of absorption of nitrate, calcium and potassium declined during shoot elongation to near zero and increased after shoot elongation ended.

Some plants have only one flush of growth per year. Plants in this category include burning bush, most spruce, fir and others. The spring flush of growth is primarily a result of stored carbohydrates and nutrients in the roots and stems. Consequently, nutrients should be added prior to the beginning of growth in the spring; this may be accomplished by a fall application of fertilizer after shoot growth has ceased or by an early spring application (early spring applications should be made 4-6 weeks prior to the beginning of new growth).

Once shoot growth begins, nutrient uptake is not as effective due to relative inactivity of the roots (Smith, 1986).

For plants with a second growth flush annually, a second fertilizer application about the time the first growth flush slows or ceases elongation should induce a vigorous second growth flush. Plants with a continuous growth pattern, such as juniper, should have a more constant rate of fertilization. (Smith, 1986)**. Maximum fertilizer uptake by woody plants occurs when shoot elongation is not occurring and the shoot appears to be inactive**.

Constant fertilization by application of liquid fertilizers through irrigation or incorporation of controlled release fertilizers into the medium is a fairly common practice in container-production nurseries. Soluble fertilizer ions in the root zone, when uptake by the root is not occurring, will likely be leached from the container.

With regard to herbaceous plants with continuous growth, Hershey and Paul (1982) followed nitrogen concentrations in leachates with time from container-grown chrysanthemums receiving Osmocote (14-14-14); most rapid N release from Osmocote and lowest N uptake by chrysanthemums during the early part of the crop cycle resulted in substantial leaching losses. The efficiency of N recovery with Osmocote was very low during the first half of the crop cycle, but increased to nearly 100% during the final 4 weeks when increased plant uptake rate nearly equalled the decreased N release-rate of the Osmocote.

- **Application Methods**

Application methods (broadcast, liquid, topdress, incorporated) can significantly effect potential for leaching and misapplication. In a survey of container nursery fertilizer application practices, Yeager, et al. (1986) reported four methods of application were generally used:

1) **Topdressing** was most frequently used and one-gallon container plants were topdressed at a yearly rate of 0.0171 pounds of N (10839 1-gallon containers per acre = 185 pounds N/acre/year).

2) **Incorporation** was the second most frequently used method of application. No waste during application of fertilizer was reported with topdressing and incorporation.

However, van der Boon and Niers (1983) caution that preplant incorporation does not adjust the amount of fertilizer given to the uptake pattern of the crop: In the first months of growth, uptake is low, especially with small plants, and the commonly incorporated rates are far too high with a definite risk of leaching. Fertilizing the potting soil only with calcium, magnesium and trace elements and starting after potting with light topdressing would give more efficient use of fertilizers, better growth of rooted cuttings or seedlings, and less risk of leaching (van der Boon and Niers, 1983).

3) **Liquid feed** was the third most common method of application. If liquid fertilizer application through overhead sprinkler systems is used, 2,146 pounds of liquid fertilizers are applied per acre to 10839 1-gallon containers (average analysis was 10% N resulting in 215 pounds N/acre). **Approximately 81% of the overhead, liquid-applied fertilizer was wasted** (not in the container).

The major disadvantage of liquid feed systems is that nutrients are applied to the area between containers and on aisles and roadways, and this leads to nutrient runoff and weed control problems.

4) **Broadcast application.** 1,994 pounds of fertilizer are broadcast per acre each year on 1-gallon containers (12% N = 239 pounds N/acre). **Approximately 90% of the broadcast-applied fertilizer was wasted** (not in the container).

5) Closed Systems mean adopting innovation, but according to data of van der Boon and Niers (1983) the amount of fertilizer used and fertilizer costs can be reduced by half.

- **Nitrogen Fate after Application: Nitrogen Budgets**

After placement in the container medium, fertilizer ions may be lost through leaching or volatilization.

Leaching: 100% of applied nitrate ions were leached from pine-bark media; 6% of applied ammonium ions were leached from pine-bark media at pH 5.8 (Foster, et al. 1983). Similar effects of leaching were reported by Jarrell et al. (1983) who stated that 32% and 29% of the N was leached from containers of 18-6-12 (8-9 month Osmocote) and 40-0-0 (8-9 month resin-coated urea) respectively at maximum plant growth rates of application of nitrogen and irrigation water. **As much as 64% of the added N was leached at the highest rate of 18-6-12 addition (2.4 kg N/m3) under the high leaching irrigation regime.**

Nitrate leaching rates were approximately equal regardless of the original source of N.

The leaching results suggest that microbes rapidly oxidized ammonium and urea-derived ammonium to nitrate, and that nitrate leaching rates were approximately equal regardless of the original source of N. Likewise, Hershey and Paul (1982) reported that leaching losses of N from pot chrysanthemums fertilized with either "Osmocote" (Controlled Release Fertilizer, CRF) or a continuous liquid feed (LF) measured over an 11-week crop cycle averaged 27% for both CRF and LF treatments: Leaching losses were compared for treatments where the N released from CRF was the same as the N applied with LF. With CRF, most of the N leaching loss occurred during the first half of the experiment (declining from 300-600 mg N/L at week one to 0-50 mg N/L by week six).

Poor correlation between N release from Osmocote and N uptake by chrysanthemums during the early part of the crop cycle clearly resulted in substantial leaching losses.

With LF application concentration of 98 ppm N, leaching losses of N were constant throughout the crop cycle and averaged 40 mg N/L. With LF at the two higher rates (196 and 294 mg N/L), water absorption was greater relative to nitrate uptake and nitrate concentrations in the leachate increased above those in the applied solutions and by week six reached as high as 300 and 600 mg N/1 of leachate, respectively; at week six, they appeared to level off.

Van der Boon and Niers (1983), reported 40-60% of N incorporated into the potting media and applied as a weekly liquid topdress was leached during the growing season by pyracantha and one-year old chamaecyparis respectively. With the initial incorporation rate of 1.5 g NPK/Liter of medium, a high amount of fertilizer was present when uptake of the plant was rather low; a high concentration of nutrients was present in the leachate and a considerable amount leached out, roughly 75% of the nitrogen, during the first three months.

Organic media such as pine bark have the capacity to absorb 1.5 mg NH4-N/g bark; on the basis of a 3-liter container, this amount of absorbed nitrogen (1500 mg N/3-liters of medium) is equivalent to twice the amount that an *Ilex crenata* 'Helleri' cutting would adsorb (750 mg N) from the medium during a 4-5 month growing season (Foster et al. 1983). Approximately 3000-6000 mg of N would have been initially incorporated as fertilizer addition to the container medium (Jarrell, etal., 1983; Yeager, etal., 1986).

Effect of Irrigation Practices on Leaching: A nitrogen budget was developed for container-grown privet (Table 1). Treatment variables affecting the budget were irrigation frequency (daily vs. every 2 days), container type (plastic vs. clay), media (redwood-sand; pine-sand; pine-soil; or sphagnum peat perlite sand). Liquid fertilizer solutions containing both ammonium nitrate and potassium nitrate were applied by Stewart, et al. (1981).

N that could be accounted for by Stewart (1981) consisted of:
(1) **N-uptake by plants** (4.1-6.8% of total applied N);
(2) **N adsorbed or absorbed by the mix** (16.1-30.9% of total applied N);
(3) **N absorbed or adsorbed by the container** (0.1%/plastic, 47.6%/clay pot of total applied N); and, N leached (17.544.3% of total applied N).

Table 1. Nitrogen Balance Sheet for Container-Grown Privet, Ligustrum japonicum (Stewart, et al. 1981).

Factors	*Plants*	*Media*	*Leachate*	*Contamer*	*Unaccounted*
Irrigation					
Daily	**6.8b**[2]	16.1a	**44.3b**	23.1a	9.7a
Bidaily	5.1a	**30.9b**	22.0a	24.7a	**17.3b**
Container					
plastic	**7.8b**	**27.1b**	**48.8b**	00.1a	**16.2b**
clay	4.1a	19.9a	17.5a	**47.6b**	10.8a
Soil mix					
Redwood	6.5a	**25.0bc**	**34.8b**	24.4ab	9.3A
pine-sand	6.4a	**27.0c**	26.7a	22.2a	**17.7b**
pine-soil	4.6a	22.4ab	**34.4b**	19.7a	**18.9b**
peat	6.4a	19.6a	36.8b	29.1b	.8.1a

[1]Unaccounted = The percentage of nitrogen, applied that was not accounted for in the plants, media, leachate or, container. Stewart hypothesized that this unaccounted for nitrogen was lost through denitrification.

[2]Mean separation in columns for each factor was done with Duncan's multiple range test. Values within a column, for each factor, followed by the same letter are not significantly different from each other at the 1% level.

8.1 to 18.9% of total applied N was not recovered or accounted for and was asssumed lost through denitrification.

The treatment with the greatest percentage of the total applied N lost in the leachate was the daily irrigation, plastic container, peat mix combination where over 56% of the total applied N was lost in the leachate. The liquid fertilizer solution with which the plants were irrigated had an average initial concentration of 200 ppm of nitrogen**. There was 282 ppm nitrogen in leachate from the treatment with the greatest plant growth (the leachate of the daily irrigation treatment).** In the alternate-day irrigation treatment (the treatment with the least plant growth) the nitrogen concentration in the leachate was 332 ppm.

According to Stewart, et al. (1981*), "The plants irrigated daily grew faster and a commercial product could be obtained in a shorter period of time. For daily irrigation, recirculating leachate is necessary if off-site contamination with high-N water is to be avoided. If the leachate water could be collected and recycled without causing significant salt problems, then the daily irrigation treatment would be more desirable than the alternate day irrigation treatment."* Twice as much water was applied in the daily irrigation treatment, but the amount of water leached was more than 4 times as much as from the alternate day irrigation. The use of plastic containers was recommended to avoid loss of applied N that is absorbed/adsorbed by the clay container walls; however, to reduce the greater denitrification losses occurring in plastic containers, the use of more resistant mixes, such as the redwood and peat mixes, is recommended.

Cox (1985, 1988) developed nitrogen balance sheets **(Table 2)** showing what happens to different forms of nitrogen fertilizer after it is applied to a container-grown plant. **Cox found significant differences among nitrogen fertilizers in the amount of nitrogen used by the plant, lost by leaching, and retained by the growing medium.** Unaccounted for nitrogen in the reported research may have been lost as a gas through ammonia volatilization or through denitrification. Concentration of total nitrogen in the leachate was calculated by dividing the total nitrogen recovered in the leachate by the volume of leachate. Nitrogen concentration in the leachates ranged from 120 ppm N in the Osmocote fertilized treatment to 280 ppm N in the nitrate fertilized treatment.

In the experiment by Cox (1985), unsterilized medium (1 part sphagnum peat moss: 1 pine bark: 2 perlite by volume) was used. The experiment, conducted in a polyethylene greenhouse, was terminated 90 days after transplanting**. Although the medium was unsterilized, little nitrification of ammonium sulfate or urea was apparent since little nitrate-N was found in the leachate**. Some nitrification did occur since the initial formulation of Osmocote 14 -6.2 -11.6 contains 60% ammonium-N and 40% nitrate-N and the leachate averaged 30% ammonium-N and 70% nitrate-N.

Table 2. Nitrogen Balance Sheet for 4-inch Pots of `Jackpot' Geranium (Cox, 1985)

Nitrogen Fertilizer	Recovery of N (%) plant	leachate	media	unacctd[1]	leachate (ppmN)
Ammonium sulfate	26	43	19	12	190
Ammonium nitrate	**47**	32	18	3	196
Calcium Nitrate	33	**46**	18	3	**280**
Urea	37	21	19	**23**	120
Osmocote	38	30	**26**	6	184

lUnaccounted = The percentage of the total nitrogen applied that was not recovered in the plants, media, or leachate. It may have been lost through ammonia volatilization or denitrification.

- **Concentration of Nitrogen Associated with Maximum Plant Growth:**

Jarrel et al. (1983) reported that as much as 64% of the added N was leached at the highest rate of 18-6-12 (8-9 month Osmocote, a controlled release fertilizer) under the high-leaching treatment (40% leaching/irrigation). Maximum plant growth was obtained at the medium rate of 18-6-12 Osmocote (1.8 kg N/cubic meter of media) and high- leaching treatment; in this treatment, 32% of the added nitrogen was leached from the containers. The percentage of N that leached through the pots increased markedly as the fertilizer application rate increased. The average leachate N concentration corresponding to maximum yield was between 100 and 200 mg N/liter; the average leachate N concentration was estimated by dividing the total N leached by the total water leached (Jarrell et al, 1983). The implications for environmental quality are not encouraging. It appears that high yields required from 100 to 200 mg N/L in solution around the roots and consequently in the leachate waters. Since more than 10 mg $N0_3$-N/L is considered potentially harmful by the Public Health Service, leachates with this high a concentration of N should not be allowed to enter surface or groundwater supplies utilized for drinking-water by humans. Leachate water from these pots must either be diluted, reused, or denitrified.

Furuta (1976) compared N concentration in leachate from containers fertilized with Osmocote (a controlled-release fertilizer, 427 g N/cubic meter) with the N concentration in leachate from containers with liquid fertilization (172 ppm nitrate-N) in the irrigation water (Furuta, 1976). Furuta's rate of Osmocote application (0.427 kg/cubic meter) is considerably lower than the 1.8 kg N/cubic meter used by Jarrell, et al., 1983). In Furuta's experiment, when water was placed in the container using a spitter irrigation system (25% leaching/irrigation), the following nitrate-nitrogen concentrations occurred in the leachates (ammonium nitrogen content or total nitrogen were not determined): 1) 2.1 ppm nitrate-nitrogen in leachate from unfertilized containers; 2) 4.9 ppm nitrate-N in leachate from containers with Osmocote; 3) 277 ppm nitrate-N in runoff from containers without Osmocote, but with constant liquid fertilization in the irrigation water (form of nitrogen in the liquid feed was 172 ppm nitratenitrogen). Using Osmocote alone resulted in plants as large as using liquid fertilization alone.

Placement of controlled release fertilizers in the root zone, under Furuta's conditions of low rates of fertilizer application and low leaching rates (25% leaching/irrigation) resulted in a lower concentration of N in the leachate than that reported by Jarrell, et al. (1983) and by Cox (1985). Both Cox and Jarrell, however, analyzed for total nitrogen concentration in the leachate; Furuta only analyzed for nitrate-N which did not include the ammonium or urea that might have been present in the leachate, especially in the leachate from the Osmocote fertilized containers. Cox (1985) reported that leachate from Osmocote 14-6.2-11.6 was composed of 30% ammonium-nitrogen and 70% nitrate nitrogen. From Osmocote 18-6-12 (47% nitrate-N and 53% ammonium-N) 32% of the total N applied was leached from the container, and 79% of the total nitrogen in the leachate was in the nitrate-N form (Jarrell, 1983). In the same experiment (Jarrell, 1983), leachate from urea-fertilized containers contained 80% of the total leached nitrogen in the nitrate-N form; this result suggests that microbes rapidly oxidized urea-derived ammonium to nitrate. However, in the experiment of Cox (1985) when nitrogen was applied as urea and leachate was collected and analyzed over a 9 week period, 51% of the total nitrogen in the leachate remained as urea, 46% was ammonium-N, and only 3% was in the nitrate form; this indicated considerable urease activity in the medium, but little nitrification.

As previously noted, the rate of fertilizer to apply to *Ilex crenata* 'Helleri' during the active root growth periods to facilitate maximum plant growth and efficient fertilizer utilization was determined by Yeager, et al. (1980**). Shoot growth of plants fertilized twice at 500 ppm N only during the active root growth was comparable to growth of plants fertilized weekly with 300 ppm N.**

Wright and Niemiera (1987) reviewed published research results regarding concentrations of soluble nitrogen associated with maximum plant growth. Reported optimal nitrogen concentrations ranged from 50 ppm to 500 ppm depending upon plant species, root medium, and frequency (timing) of application with regard to stage of plant growth.

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