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Effect of Split Fertilizer Application and Irrigation Volume on Nitrate-Nitrogen Concentration in Container Growing Area Soil[1]

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Abstract

Outdoor-grown, containerized, *Aronia melanocarpa* (Michx.) Ell. and *Rhododendron* 'Roseum Elegans' were grown atop soil-filled boxes that had been recessed into a grassed field in separate studies. *Aronia* were fertilized with either a single application of controlled-release fertilizer (CRF) or a split application of CRF separated by 36 days. *Rhododendron* were supplied a single application of CRF and either a standard or excessive irrigation volume on each irrigation day. Soil samples were taken in 30 cm (12 in) layers to a depth of 90 cm (36 in) beneath containers at 14-day intervals and soil NO_3-N concentrations were determined. Accumulation of NO_3-N was immediate in the 0–30 cm (0–12 in) layer for both species with accumulation of NO_3-N in the deeper soil layers occurring later. Split application of a CRF was somewhat effective at reducing NO_3-N accumulation at specific times and in specific soil layers, but reductions were not as substantial as studies on NO_3-N concentrations in leachate have indicated. The large irrigation volumes used in the irrigation volume study resulted in NO_3-N moving rapidly through the soil profile beneath containers.

Index words: *Aronia melanocarpa, Rhododendron* 'Roseum Elegans', controlled-release fertilizer, leaching, slow-release fertilizer, groundwater.

Significance to the Nursery Industry

Nursery crop management practices that contribute to nitrate-N loading to soil beneath container crops are regarded as a threat to groundwater quality and are of concern to the nursery industry and the public. Use of controlled-release fertilizers (CRFs) is considered to be more environmentally sound than use of soluble fertilizers and split applications of CRFs are thought to cause less NO_3-N leaching than a single, large CRF application. In this study we showed that CRFs can contribute substantial amounts of NO_3-N to the soil profile beneath a container production area even when a split CRF application is used. Furthermore, the large and frequent irrigation volumes typically applied to container crops, combined with the intensive nature of container production, may cause NO_3-N to leach deep into the soil profile. These data suggest that growers must be careful to avoid excessive irrigation volumes which are the result of continuing irrigation beyond the time needed to supply an adequate amount of water to the crop. This study is applicable to growers having container production on gravel or porous fabric-covered areas, but not to production on plastic-covered areas.

Introduction

Nursery crops are increasingly grown in containers due to the economic benefits of container production and consumer demand. This trend away from field production is likely to continue. Container crops are grown in porous, highly organic media that require frequent irrigation and large irrigation volumes to optimize crop growth (6). Large irrigation volumes supplied to containerized crops have been shown to increase the volume of leachate and quantity of NO_3-N exiting the container (10, 12). A recent survey of container nursery operations revealed that some samples of irrigation

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runoff exceeded the 10 ppm limit for NO_3-N in drinking water (14, 15).

Several investigations have focused on the use of CRFs to reduce the release of NO_3-N into the environment (3, 4, 7, 11, 12). A 1989 study concluded that NO_3-N in runoff from container crops could be reduced by the use of CRFs rather than water soluble fertilizers (12). In 1993, a survey of production nurseries found that runoff from areas using only CRFs contained less NO_3-N than did similar areas using CRFs supplemented with solution fertilizers (15).

However, other studies investigating NO_3-N leaching from container crops have found that CRFs can contribute substantial amounts of NO_3-N to leachate or to soil beneath containers (3, 4, 7, 8). NO_3-N levels in leachate from CRF fertilized containers can be as high or higher than when water soluble fertilizers are used (4, 7). Further, leachate from a container crop, that has received an early season application of CRF, may contain NO_3-N concentrations well in excess of the 10 ppm drinking water limit (8). One of the few studies to characterize the fate of NO_3-N in the soil profile underlying a containerized nursery crop fertilized with a CRF reported that NO_3-N levels in the 30–60 cm (12–24 in) deep soil layer could approach 40 mg/kg (6.36×10^{-4} oz/lb) of soil by the middle of the growing season (3).

Conventional use of CRFs in nursery production involves applying a single, large dose of CRF to the growing medium. This practice limits labor costs by attempting to meet the total nutrient requirement of the crop in a single application. A single application of CRF may lead to significant early-season NO_3-N leaching, due to poor matching of nutrient release patterns and crop nutrient demands (3, 4, 7). Additionally, nursery crops are often grown in excessively large pots at the beginning of the growing season to avoid the labor costs incurred when plants must be potted into larger containers. These production practices may further contribute to high amounts of NO_3-N leaching in the early part of the season (3).

Many container production operations use overhead irrigation systems which have been shown to be only 20% to 30% efficient, with much of the water missing the pots altogether (5). In addition, these systems are often left running for extended periods of time, frequently beyond the duration needed to fully irrigate a crop. The inefficiency of overhead irrigation and poor management may cause NO_3-N leached from containers to move deep into the soil profile, possibly affecting groundwater quality.

The objective of this study was to quantify changes over time in the NO_3-N concentration found in different layers of the top 90 cm (36 in) of soil underlying a container crop that had been provided different fertilizer or irrigation volume treatments.

Materials and Methods

This paper presents the results for two separate studies using similar experimental methods. The first experiment examined NO_3-N concentrations in the soil beneath a crop fertilized with either a single or split application of CRF and the second study examined NO_3-N concentrations in the soil beneath a crop fertilized with CRF and provided either a standard or excessive irrigation volume. Materials and methods described below are common to both studies.

Experiments were conducted outdoors under full exposure at the University of Connecticut, Department of Plant Science Research Farm, Storrs. Plants were grown on top of bottomless, soil-filled, wooden boxes. The inside dimensions of each box were 1 m (3.3 ft) depth by 1 m (3.3 ft) length by 0.5 m (1.6 ft) width. Boxes were recessed 0.6 m (2.0 ft) into a grassed field and filled with native field soil (Woodbridge fine sandy loam) that had been screened through expanded steel with approximately 3 cm by 5 cm (1.2 in by 2.0 in) diamond-shaped openings. Boxes were bottomless to allow contact with the subsoil. Soil in the boxes had a mean bulk density of 1.3 g/cm^3 (0.8 oz/in^3) and 5.1% organic matter. The soil boxes had been in place for two years and had been fallow for one year prior to use in experiments. This helped to insure that the soil had settled, been recolonized by soil organisms and contained ambient nitrogen concentrations. Residual NO_3-N levels were determined at the beginning of each experiment (day 0) by sampling the soil profile before applying treatments.

Samples were taken at 14-day intervals from the day treatments were applied each season. A soil profile in 30 cm (12 in) layers was obtained from each box using a 1.9 cm (0.8 in) diameter Dutch auger. Boxes were divided into 209 cm^2 (32.4 in^2) rectangles providing 24 possible sample sites, two of which were randomly selected in each box on each sampling date. Samples were kept cold during collection and were then immediately spread in a 1 cm (0.4 in) layer and dried overnight at 20 to 25C (68–77F) in a continuously ventilated room. Dried samples were screened and stored in acid washed bottles for future analysis. After removing samples, auger holes were refilled with screened, native field soil at baseline (day 0) NO_3-N concentrations. Refill soil was compacted into the auger holes to prevent channeling. Previous sample sites were not resampled. Plant growth was evaluated by measuring plant height and two plant widths (at 90° from each other) at the beginning and end of each growing season. Air temperature and precipitation was quantified using a CR10 Measurement and Control Module, 107 Temperature probe and TE525 Tipping Bucket Rain Gauge (Campbell Scientific, Inc., Logan, UT).

Nitrate-N was extracted from soil samples with 2 M KCl. Samples were shaken for 30 min in the extract solution before filtering. Nitrate-N was quantitatively analyzed using the copperized cadmium reduction method (9) according to the automated procedure for the continuous flow auto analyzer (Scientific Instruments Corp., Pleasantville, NY). Total nitrogen in plant tissue samples was determined with a thermal conductivity N determinator (LP-428; LECO Corp., St. Joseph, MI).

The statistical design for both years was a randomized complete block design with 8 blocks. Data was analyzed using the general linear models procedure of SAS (13).

Study 1: Single vs. split fertilizer application. Uniform 4- to 6-branch *Aronia melanocarpa*, with an average height of 45.1 cm (17.8 in), were potted into blow-molded number 3 containers with 26 cm (10.2 in) top inner diameter, 22 cm (8.7 in) bottom inner diameter and 24 cm (9.5 in) depth. The potting media consisted of composted pine bark:sphagnum peat:sand (3:2:1 by vol) amended with dolomitic limestone at 3.6 kg/m^3 (0.2 lbs/ft^3). Plants were potted on May 20, 1992. *Aronia* were 18 months old from tissue culture and had been grown and overwintered in number one containers with 16 cm (6.3 in) top inner diameter, 14 cm (5.5 in) bottom inner diameter and 16 cm (6.3 in) depth. Each number one container was topdressed in May 1991 with Sierrablen 17N–2.6P–8.3K (17–6–10) 8 to 9 month formulation CRF (Grace-Sierra) at 15 g (0.5 oz) per container.

On May 27, 1992, the repotted *Aronia* were placed atop the 16 soil boxes at a density of 6 containers/m^2 (6 containers/10.8 ft^2), with the containers covering 22% of the surface area of each box. Each container on half of the boxes received the recommended rate (60 g (2.1 oz)) of Sierrablen 17N–2.6P–8.3K (17–6–10) 8 to 9 month formulation as a topdressing on May 27, 1992, and half received a 30 g (1.1 oz) topdressing on May 27, 1992, and 30 g (1.1 oz) on July 3, 1992. The CRF used contained 9.1% ammoniacal nitrogen and 7.9% nitrate nitrogen.

Plants were irrigated when the top 2 cm (0.8 in) of the potting medium became dry, as might be done in a commercial setting. During the first 6 weeks (10 irrigations in total) and the last 4 weeks (6 irrigations in total) of the study, irrigation was provided every 4 days, on average. During the middle 12 weeks (40 irrigations in total), irrigation was required every other day, on average. Irrigation was applied by hand using a water breaker and a crossing pattern. At each irrigation, individual boxes received 4 cm (1.6 in) (5.3 gal) of water. Water was applied from above, to both the plant canopy and interplant spaces, to simulate typical nursery overhead irrigation.

Soil samples were taken (2 per box) at 14-day intervals from May 27, 1992, to October 28, 1992. Foliar samples were collected at the end of the growing season (September 12, 1992). 18 recently matured leaves were harvested from plants on each box. Tissue was dried at 70C (158F) and ground to pass a 40 mesh screen. Ground samples were stored in sealed, acid-washed vials for future % total N analysis. Plant fresh mass and dry mass were recorded at the beginning and end of the experiment.

Study 2: Standard vs. excessive irrigation volume. On June 6, 1994, uniform *Rhododendron* 'Roseum Elegans' with an average height of 30 cm (12 in), were potted into blow-molded number 3 containers as previously described. These *Rhododendron* had been grown from rooted cuttings and were overwintered in number 1 containers prior to use in this study as previously described. The repotted *Rhododendron* were placed atop 16 soil boxes as previously described. All plants received a recommended rate of 40 g (1.4 oz) of Sierra 17N–2.6P–8.3K (17–6–10), 8 to 9 month CRF as a topdressing on June 6, 1994.

Plants were irrigated every other day on average from June 6, 1994, to September 1, 1994. Plants were then watered on an as needed basis until the end of the study on November 10, 1994. Irrigation was applied in the same manner as described for the *Aronia* plants. A standard irrigation of 1.9 cm (0.75 in) (2.5 gal) per box was applied to half of the boxes and an excessive irrigation volume of 7.6 cm (3.0 in) (10 gal) per box was applied to the remaining half of the boxes at each irrigation. The standard irrigation volume represents an optimal overhead irrigation volume and the excessive irrigation volume is representative of the large irrigation volumes that result when an overhead irrigation system is left running for an extended period of time.

Soil samples were taken at 14-day intervals from June 6, to November 10, 1994. Foliar samples were collected on September 12, 1994, to examine possible differences in nitrogen use between treatments. Six recently matured leaves were taken from each plant, and processed as described for *Aronia*.

Results and Discussion

Study 1: Single vs. split fertilizer application. Baseline soil NO_3-N concentrations at the beginning of the study were low, approximately 2.5 mg/kg (4.0 × 10^{-5} oz/lb), throughout the 0–90 cm (0–36 in) soil profile (Fig. 1). By day 14, NO_3-N levels in the soil increased, particularly in the 0–30 cm (0–12 in) and to a lesser degree in the 30–60 cm (12–24 in) layer. Differences in NO_3-N loading between single and split fertilizer applications were detectable at day 14 in the upper soil layer, with the single fertilizer application contributing more NO_3-N than the split fertilizer application (Table 1, Fig. 1). By day 28, NO_3-N concentrations had increased at all depths, for both treatments. In the 0–30 cm (0–12 in) layer, NO_3-N concentrations resulting from a single application of CRF were still higher than those resulting from the split CRF treatment. By day 56, NO_3-N concentrations in the 30–60 cm (12–24 in) layer were higher for the single CRF application than for the split application (Table 1, Fig. 1).

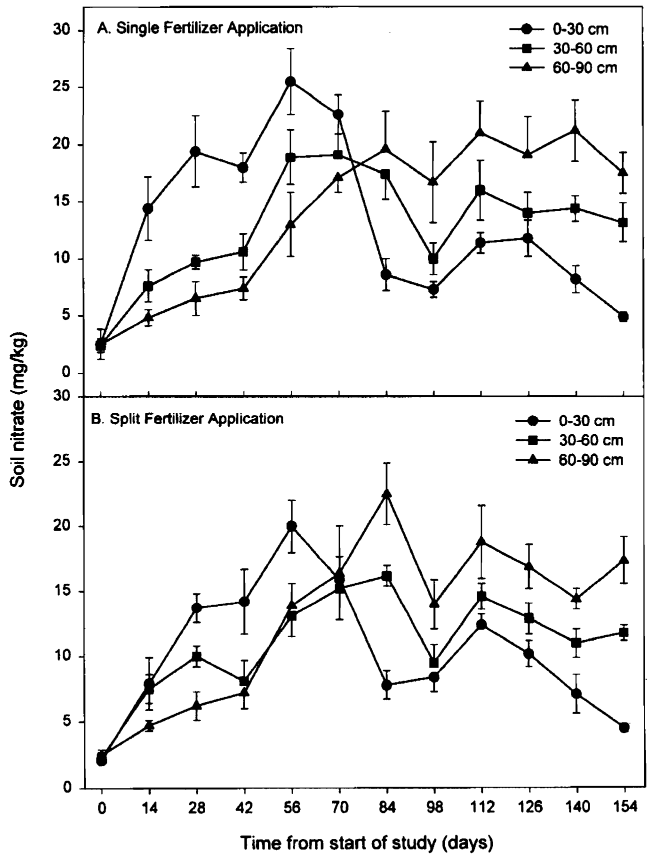

Fig. 1. Nitrate-nitrogen concentration in the top 90 cm (36 in) of soil beneath containerized *Aronia melanocarpa*. Vertical bars represent the standard error of the mean; error bars that do not appear on the graphs are smaller than the symbols. A. Receiving a single application of controlled release fertilizer (Sierrablen 17N–2.6P–8.3K (17–6–10) 8 to 9 month formulation (Grace-Sierra) at 60 g (2.1 oz) per container). B. Receiving a split application of controlled release fertilizer (Sierrablen 17N–2.6P–8.3K (17–6–10) 8 to 9 month formulation (Grace-Sierra) at 30 g (1.1 oz) per container on May 27, 1992, and 30 g (1.1 oz) per container on July 3, 1992.

Table 1. **Summary of significant fertilizer treatment (single vs. split application of CRF) effects by soil sample depth over time for soil nitrate-nitrogen concentration (mg/kg).**

	Sample depth (cm)		
Time interval	0–30	30–60	60–90
day 0	ns	ns	ns
day 14	*	ns	ns
day 28	*	ns	ns
day 42	ns	ns	ns
day 56	ns	*	ns
day 70	*	ns	ns
day 84	ns	ns	ns
day 98	ns	ns	ns
day 112	ns	ns	ns
day 126	ns	ns	ns
day 140	ns	*	ns
day 154	ns	ns	ns

* significant at the $P < 0.05$ level.

A maximum NO_3-N concentration for the study, over 25.5 mg/kg (4.0×10^{-4} oz/lb), occurred at day 56 (July 22, 1992) in the 0–30 cm (0–12 in) layer (Fig. 1). Relatively high (over 15 mg/kg (2.4×10^{-4}oz/lb)) NO_3-N concentrations were found in all three soil layers at day 70 (August 5, 1992). Day 70 appeared to be the pivotal point in the season for NO_3-N accumulation in the 0–90 cm (0–36 in) profile. Before day 70, highest NO_3-N levels were in the 0–30 cm (0–12 in) profile. After this point, highest NO_3-N levels were found in the 60–90 cm (24–36 in) profile. From day 70 to the end of the study, NO_3-N in the 60–90 cm (24–36 in) profile remained between 15 and 23 mg/kg (2.4×10^{-4}oz/lb). During the period from day 70 to day 154, differences between the NO_3-N concentrations of single and split fertilizer applications could only be detected on day 140 (Table 1. Fig. 1) when NO_3-N levels in the 30–60 cm (12–24 in) profile were higher in the single CRF application treatment than in the split treatment.

When examined over time, NO_3-N moved into and through the soil in a wavelike fashion. Nitrate nitrogen levels increased quickly in the 0–30 cm (0–12 in) soil layer in the early part of the growing season and began to decrease by mid-season (day 70). Nitrate nitrogen levels in the 30–60 cm (12–24 in) layer increased more slowly than in the surface layer and tended to remain elevated (12–15 mg/kg (1.9×10^{-4} to 2.4×10^{-4}oz/lb)) throughout much of the growing season, decreasing slightly near the end of the season. In the 60–90 cm (24–36 in) soil layer, NO_3-N levels rose even more slowly than the shallower profiles, but once elevated they remained so until measurements were terminated on day 154.

Aronia growth was similar under both fertilizer application treatments. At the conclusion of the study, stem dry mass and relative growth rates for plant height, plant width and plant size were all statistically similar. Only stem fresh mass was significantly higher for plants receiving a single dose of CRF when compared to those receiving a split CRF application (results not shown). Foliar samples taken on September 12, 1992, and analyzed for % total N indicated that there were no differences between single and split fertilizer treatments (2.74 ± 0.04 % N vs. 2.76 ± 0.05 % N). Plants from both treatments were visually similar, marketable, and of high quality.

The NO_3-N loading patterns observed in this study clearly showed that CRF applications typical of those used in commercial practice provide nitrogen in excess of the crop's requirements during the early part of the growing season as has been reported previously for other systems (4, 7, 12). NO_3-N deposited in the upper soil layer appears to move steadily downward through the soil profile throughout the growing season. By the end of the crop cycle, NO_3-N contributed by CRFs resides primarily in soil layers deeper than 30 cm (12 in). Apparently, the high irrigation frequency and volume needed to support optimum growth in bark:peat moss-based container media is primarily responsible for moving NO_3-N loaded into the upper soil layer to deeper soil layers.

To minimize excessive early season NO_3-N leaching from CRFs, split applications have been suggested and analyzed for their effectiveness at reducing NO_3-N in leachate, although no reports are available for NO_3-N in soil beneath containers. The benefit of split application of CRFs in this study was not as pronounced as previous studies have indicated. The greatest differences in NO_3-N concentrations between split and single application that were detected were all less than 7.7 mg/kg (1.23×10^{-4} oz/lb). Using a split application of CRF rather than a single large application, only reduced point in time NO_3-N accumulation by approximately 30%. Rathier and Frink (12), using a CRF similar to that used in this study, found reductions in NO_3-N concentrations in leachate close to 60% when a nursery crop was provided a split application rather than a single application.

Daily precipitation and temperature are two variables that can have a significant effect on the release and movement of NO_3-N from CRFs. Although precipitation and temperature data are difficult to relate to the movement of NO_3-N through the soil profile, some observations can be made. The dramatic drop in NO_3-N concentrations in the 0–30 cm (0–12 in) soil layer between days 70 and 84 (Fig. 1) may be due, in part, to a rainy period from day 74 to 84 (Fig. 2A). Further-

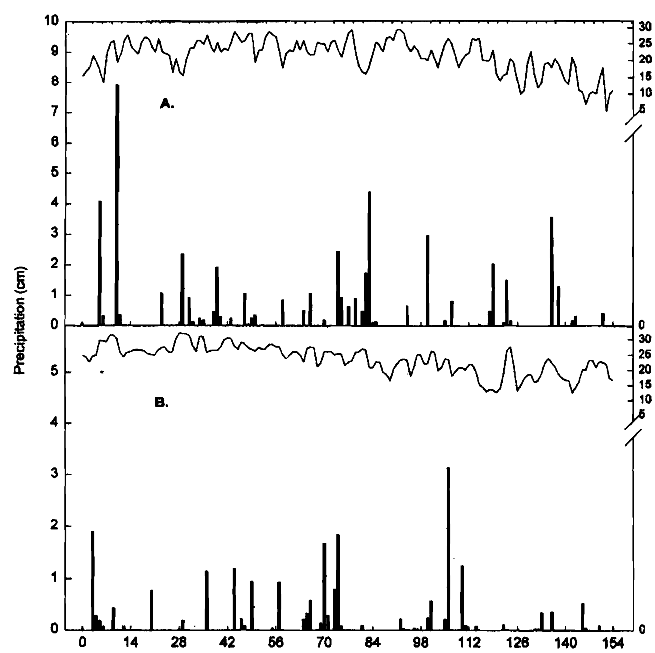

Fig. 2. **Daily precipitation and maximum temperature during the experimental periods. A. From May 27, to October 28, 1992, for the single vs. split fertilizer application study. B. From June 6, to November 10, 1992, for the standard vs. excessive irrigation treatment study.**

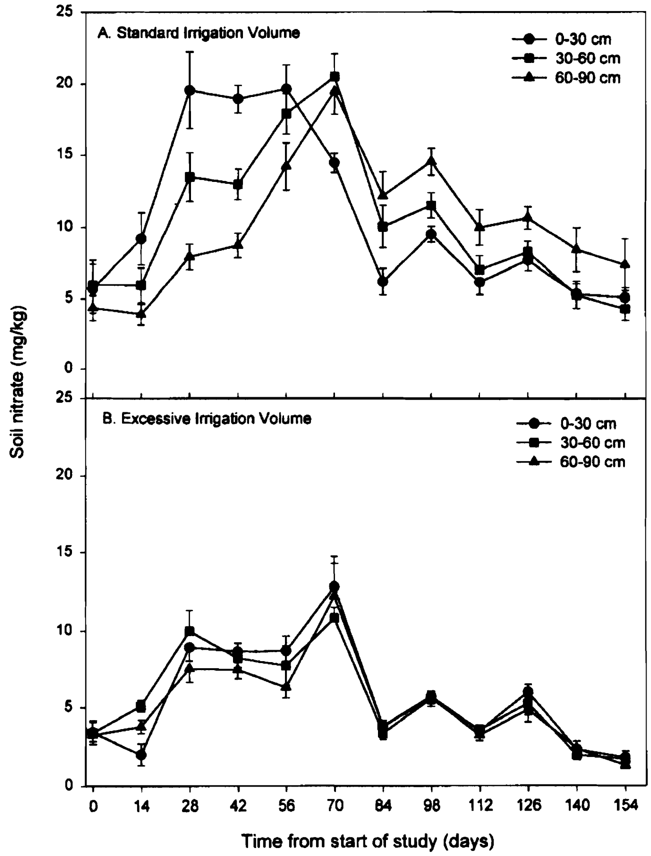

Fig. 3. Nitrate-nitrogen concentration in the top 90 cm (36 in) of soil beneath containerized *Rhododendron* 'Roseum Elegans'. Vertical bars represent the standard error of the mean; error bars that do not appear on the graphs are smaller than the symbols. A. Receiving a standard irrigation of 1.9 cm (0.75 in) (2.5 gal) per irrigation. B. Receiving an excessive irrigation volume of 7.6 cm (3.0 in) (10 gal) per irrigation.

more, NO_3-N levels in the 30–60 cm (12–24 in) and 60–90 cm (24–36 in) layers dropped significantly between day 84 and 98 (Fig. 1 and 2A). This response may also be due to the same precipitation event, logically lagging behind the response in the upper soil layers.

Study 2: Standard vs. excessive irrigation volume. Soil NO_3-N concentrations increased in all soil layers by day 28 in both irrigation treatments (Fig. 3). Differences in NO_3-N concentrations between the two irrigation treatments occurred by day 28 with the highest levels of NO_3-N present in the 0–30 cm (0–12 in) layer of the standard irrigation treatment (Table 2, Fig. 3). The NO_3-N levels in the 30–60 cm (12–24 in) and 60–90 cm (24–36 in) profiles of the standard irrigation treatment were higher than the same profiles under excessive irrigation volume by days 42 and 56 respectively (Table 2, Fig. 3). From day 56 until the end of the study, soil NO_3-N concentrations in the standard irrigation treatment were higher than soil NO_3-N concentrations in the excessive irrigation treatment. This was true for all three soil layers, except on day 70 and 126 when there were no differences between the 0–30 cm (0–12 in) profiles (Table 2).

Under the standard irrigation volume, soil NO_3-N levels reached 19.5 mg/kg (3.1×10^{-4} oz/lb) for soil in the 0–30 cm (0–12 in) layer on day 28 and remained relatively constant until day 56, after which, NO_3-N concentrations declined rapidly (Fig. 3). After day 56, soil NO_3-N concentrations in the 0–30 cm (0–12 in) layer remained between 14.4 and 5.1 mg/kg (2.3×10^{-4} and 8.2×10^{-5} oz/lb) soil. Soil NO_3-N concentrations in the 30–60 cm (12–24 in) and 60–90 cm (24–36 in) layers under standard irrigation volume lagged behind the 0–30 cm (0–12 in) layer, but rose steadily until day 70 when NO_3-N concentrations in these deeper layers peaked at 20.5 and 19.5 mg/kg (3.3×10^{-4} and 3.1×10^{-4} oz/lb) soil respectively. Soil NO_3-N concentrations in all sample layers then gradually decreased until the end of the study. This pattern was nearly identical to that observed in the split vs. single fertilizer application study. By day 154, all sample layers receiving the standard irrigation volume had returned to near baseline NO_3-N levels.

In the excessive irrigation volume treatment, NO_3-N levels followed a similar overall pattern, but only reached 8.9 mg/kg (1.4×10^{-4} oz/lb) soil in the 0–30 cm (0–12 in) layer by day 28 (Fig. 3). The soil NO_3-N concentrations in the 0–30 cm (0–12 in), 30–60 cm (12–24 in) and 60–90 cm (24–36 in) layers peaked on day 70 at 12.9, 10.8 and 12.3 mg/kg (2.1×10^{-4}, 1.7×10^{-4} and 2.0×10^{-4} oz/lb) soil, respectively. After day 70, all sample layer concentrations decreased rapidly from approximately 12 mg/kg (1.9×10^{-4} oz/lb) soil to approximately 3.6 mg/per kg (5.8×10^{-5} oz/lb) soil.

Foliar samples taken at the end of the season (September 12, 1994) and analyzed for % total N, indicated that plants under the excessive irrigation treatment were lower in % total N than those receiving standard irrigation volumes (1.14 ± 0.01 % N vs. 1.31 ± 0.01 % N). However, there were no significant differences in plant height, plant width and visual quality between irrigation treatments.

The pattern of soil NO_3-N concentration over time for the excessive irrigation treatment was similar to the standard irrigation treatment, however, lower NO_3-N concentrations in all soil layers were observed throughout the growing season. Differences in NO_3-N concentrations between sample layers were minimal in the excessive irrigation treatment when compared to the large variation in NO_3-N concentration between sample layers in the standard irrigation treatment. Low soil NO_3-N concentrations in the excessive irrigation treatment were likely due to a higher rate of leaching than in the standard irrigation treatment which received only ¼ of the water

Table 2. Summary of significant irrigation treatment (standard vs. excessive volumes) effects by soil sample depth over time for soil nitrate-nitrogen concentration (mg/kg).

	Sample depth (cm)		
Time interval	**0–30**	**30–60**	**60–90**
day 0	ns	ns	ns
day 14	ns	ns	ns
day 28	*	ns	ns
day 42	*	*	ns
day 56	*	*	*
day 70	ns	*	*
day 84	*	*	*
day 98	*	*	*
day 112	*	*	*
day 126	ns	*	*
day 140	*	*	*
day 154	*	*	*

* significant at the $P < 0.05$ level.

received by the excessive irrigation treatment. NO_3-N in the soil under the excessive irrigation treatment most likely leached to soil depths deeper than 90 cm and was therefore not measurable with our point in time sampling procedure. Over-irrigation, which can occur frequently in production, may increase the probability of NO_3-N coming into contact with groundwater.

Heavy rainfall between days 60 and 80 may have caused the rapid decrease in NO_3-N in all soil layers in both irrigation treatments (Fig. 2B and 3) The decrease in NO_3-N concentrations in the entire 90 cm (36 in) soil profile toward the end of the experimental period may have also been due to a heavy period of rain from day 90 to day 112 (Fig. 2B).

In these studies a considerable amount of nitrogen may have been lost from the soil and/or container medium in a gaseous form due to denitrification. Frequent heavy irrigations applied to plants in all four experimental treatments caused the soil beneath and medium within containers to remain chronically moist and to possibly have reduced oxygenation. Denitrification is enhanced under low oxygen conditions (1) and can result in large losses of nitrogen (2). The low NO_3-N concentrations seen in the excessive irrigation volume treatment may be due in part to denitrification losses.

The use of container leachate data to evaluate the efficacy of treatments designed to minimize NO_3-N lost to the environment, may not always fully or accurately reflect NO_3-N accumulation or depth of movement in soil. This is especially true where specific cultural practices modify the production environment. Further research is required to show exact correlations between NO_3-N in leachate from containers and NO_3-N accumulation and movement in soil.

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