Nitrate Non-point Pollution Potential in Midwestern Bareroot Nurseries[1]

Richard C. Schultz, Janette R. Thompson, Paul Ovrom, Charles A. Rodrigues[2]

Abstract—Non-point source (NPS) pollution is a major contributor to poor surface and groundwater quality in the United States. Agriculture is the major contributor to NPS pollution, with NO_3-N, certain pesticides, and sediment being the major pollutants. Bareroot nurseries manage the land more intensively than most cultivated agricultural systems. High levels of nitrogen fertilizer, numerous chemical pesticides, and surface erosion from fallow beds and paths can contribute to surface and groundwater pollution. The Hardwood Nursery Cooperative conducted a study during the 1992 growing season to determine the fate of nitrogen fertilizers applied to nursery beds. Results suggest that the potential for NPS pollution from nitrogen fertilizer applications exists under present fertilizer regimes. NO_3-N concentrations as high as 35 mg/L (ppm) were consistently found at 15 cm (6 in) depths and concentrations between 15 and 20 mg/L (ppm) were found at 1 m (3 ft) depths. The results of this study indicate that bareroot nurseries may be a source of NPS pollution for NO_3-N. Nursery managers should determine the effect of fertilizer applications on NPS pollution and modify fertilizer application regimes accordingly.

INTRODUCTION

As the world population continues to increase greater demands are placed on natural resources that are on a smaller and smaller land area. To increase the productivity of these natural resources modern management techniques depend heavily on chemical inputs. These chemical inputs create a potential for pollution of surface and groundwater systems.

The bareroot nursery industry, in an attempt to produce high quality seedlings, has depended on high inputs of inorganic and organic fertilizers which may be resulting in local pollution of the water system. Although this source of non-point source (NPS) pollution does not cover a major land area, fertilizer rates per unit of area often exceed those used in agriculture and thus create a potentially hazardous situation. In an attempt to understand the fate of nitrogen fertilizer, the most frequently added nutrient in nurseries and agriculture, the Hardwood Cooperative, consisting of the state forest nurseries of Illinois, Iowa (two nurseries), Minnesota, Missouri, and Ohio, conducted a study, during the 1992 field season, to determine what happens to applied nitrogen fertilizer. The purpose of this paper is to report the preliminary results of that study.

However, before describing those results a brief review of the concepts of pollution, water quality, transport of nitrogen through the ecosystem, and the possible fate of nitrogen in bareroot nurseries will be presented. A more in-depth review is presented by Landis et al. (1992). The discussion of the study will identify levels of NO_3-N nitrogen in the top meter (3 ft) of nursery bed soil, the quantity of nitrogen uptake by seedlings, the resulting growth of the seedlings, and the implications of these results for NPS pollution and seedling production.

A major looming global crisis is the shortage of high quality water needed to sustain human life. Although regionally the supply of water may be a problem, globally the major concern is the quality of available water. Both surface and groundwater quality are being impacted by human activities. Worsening groundwater quality is a particular problem because of the slow movement of groundwater. Once it is contaminated it tends to stay that way because dilution is very slow (Biernbaum and Fonteno, 1989). The increasing global population and the mismanagement of the present water supplies threatens one of the most limiting resources on the planet.

Water quality can be defined as it's physical, chemical, and biological characteristics with re-

---

[1] *Paper presented at the Northeastern and Intermountain Forest and Conservation Nursery Association Meeting, St. Louis, Missouri, August 2-5, 1993*

[2] *Department of Forestry, 251 Bessey Hall, Iowa State University, Ames, IA 50011 (Phone: 515-294-7602, Fax: 515-294-2995)*

gards to a particular use. The physical characteristics of water include such items as: a) suspended sediment which can modify the turbidity or clarity of the water and which can carry adsorbed chemicals; b) water temperature which effects both chemical and biological activity in the water; c) dissolved oxygen which can determine the ability of water to maintain certain species of animal life; and d) pH and alkalinity which indirectly indicate the nutrient carrying capacity of water and its chemical activity. Dissolved chemical constituents of water come from atmospheric inputs such as dryfall and wet fall, geological weathering of rocks and soil constituents, biological inputs such as nitrogen fixing microbes, and human derived chemicals from land management activities. Major chemicals that readily move through the system include nutrients and pesticides. The biological characteristics of water are concerned with beneficial and harmful micro- and meso-organisms.

Pollution is the process of degrading water in some way resulting in an undesirable change for a particular use. The key to the definitions of water quality and pollution is the concept of particular use. The quality of water used simply for crop irrigation can be substantially less than water used for human consumption. The problem is that water moves continuously through soils, plants, streams, lakes, and oceans creating the hydrologic cycle. The continuously connected reservoirs of that cycle are tapped in many places for drinking water which must be of the highest possible quality. Thus the U.S. Environmental Protection Agency (EPA) has established drinking water standards called maximum contaminant levels (MCL's) for various chemicals that apply to all water in the hydrologic cycle that is directly tapped for human use.

Because water applied to bareroot nursery beds moves through the unsaturated soil to the groundwater table and then to the nearest stream or lake it must meet drinking water standards or be considered a source of potential pollution. For decades fertilizer use in agriculture or nurseries was low enough not to overwhelm the dilution effect of water bodies. However, under present management scenarios this is no longer true.

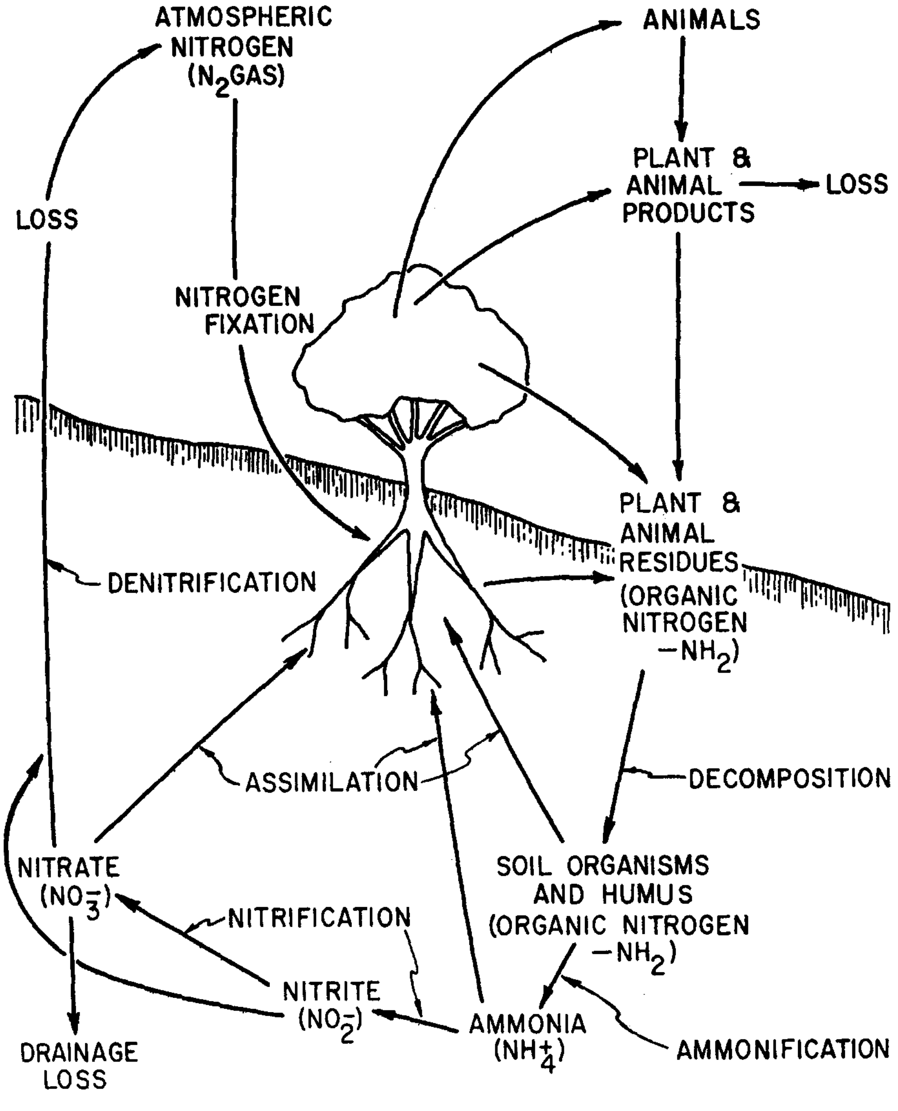

Figure 1. **Nitrogen cycle in a forest nursery. Taken from USDA Forest Service Handbook on Soils - 2512.5 (June 1961).**

The sources of pollutants of diffuse water bodies such as streams, lakes, and groundwater aquifers are often difficult to identify. When an industry or municipality releases wastewater into a surface body of water it is easy to identify the pollution source as a point source that can be modified. However, when looking for the source of contamination of bodies of water in agricultural landscapes it is difficult to pin-point a specific source. Instead, the source is leachate in water which is moving through cultivated fields, over logging roads and log decks, or from feedlots and is considered NPS pollution because of the diffuse nature of the source. Land management activities that reduce water movement, slow down or immobilize potential pollutants, while maintaining high productivity are called best management practices (BMP's).

BMP's are designed to limit the introduction of pollutants into the ecosystem or to intercept them as they move through the hydrologic cycle. Nutrient cycles are closely linked to the hydrologic cycle because nutrients move as dissolved or suspended solutes from one storage reservoir to the next. For example, nitrogen in organic matter in the nursery bed is released in decomposition as NH4, a cation which can be adsorbed to soil particles (Figure 1). These insoluble cations can be transported with detached eroding soil particles which are deposited in surface water bodies. Or the NH_4 can be converted to NO_3 by bacteria. In this soluble anion form nitrogen is dissolved in the water and can be rapidly transported in the hydrologic cycle into plants, in unsaturated subsurface flow, or in the groundwater below the water table. It is this nitrogen which can make its way rapidly into surface water bodies or into shallow groundwater aquifers thus contaminating them above EPA MCL's of 10 mg/L (10 ppm). This brief example shows that pollutants can move as soluble or insoluble components of surface runoff to water bodies or can be leached as soluble components of unsaturated subsurface or groundwater.

There are numerous site characteristics which influence the movement of chemicals. For example soil texture can determine if soluble chemicals in the water will move rapidly through the profile as in a course sand or slowly as in a heavy clay in which there may be adsorption to the clay particles. Soil structure is a function of the gluing of soil textural particles into large aggregates which produce the pore spaces in the profile. Large macropores, which are found between aggregates allow water and solutes to move rapidly through the profile. Micropores, found mainly within the aggregates, allow only slow movement. Macropores also encourage aeration, root development, and micro- and meso-faunal activity which can increase the size of the macropores resulting in even more rapid water movement.

Soil organic matter is very important in providing adsorption sites for cations and for developing soil structure. There is often a positive correlation between soil organic matter content and soil nutrient content, soil structure, and therefore water movement. In soils with a very high organic matter content, above 10%, water movement may be hindered because of microsite topography. Under such conditions there is often no slope and water has no place to drain. As slope increases the rates of both surface and subsurface water movement increases. The depth to the water table also can play an important role in the movement of chemicals to the groundwater aquifer. A shallow water table means that nutrient rich water has only a short distance to move before reaching the water table. When the water table is deeper moving water is subjected to more microbial activity and plant root uptake whereby nutrients can be at least temporarilly immobilized in the biomass.

Finally, the vegetative cover on a site can greatly influence the movement of chemicals through the landscape. Under most native vegetation growing in areas of rainfall of 50 cm (20 in) or more there is little leaching of nutrients such as nitrogen. This is because the biogeochemical cycle is a tightly closed cycle where nutrients released by decomposition are rapidly taken up by the plant community and immobilized. When such areas are converted to cultivated crop production vegetative cover is only present for a part of the year. Both above- and below-ground biomass is greatly reduced because of harvesting and the annual nature of the crop. The below-ground biomass of annual crops is significantly less than that of perennial species exacerbating the problems of chemical movement. As a result there are long periods of time when the site is not occupied by living plants and leaching and

Table 1. Nitrogen fertilizer applications by state during 1992

STATE	APPLICATION SCHEDULE	FERTILIZER
1	Every 2 weeks @ 20 lbs/ac	Granular 34-0-0 or 21-0-0
2	Every 3 weeks @ 50 lbs/ac	34-0-0 or 21-0-0
3	Every 3 weeks @ 30 lbs/ac	34-0-0
4	Initial application incorporated @40 lbs/ac	
	Subsequently every 3 weeks @ 50-100 lbs/ac	34-0-0
5	Every 6 weeks @ 200 lbs/ac	34-0-0

surface runoff can carry both soluble and insoluble chemicals from the site. Cultivation also requires frequent entry on the site by large machinery which further complicates the problems by compaction.

Bareroot nurseries mimic cultivated agricultural fields. They lie fallow between crops, often over the winter and spring when low evaporation rates and high rainfall and runoff rates can occur. Because crops are removed almost every year, soil organic matter is often very low. This is especially a problem if nurseries are located on sandy soils which are often inherently low in organic matter. The high percolation and low organic matter content are conducive to conditions of rapid leaching. In heavier nursery soils, the frequent cultivation and bed forming activities destroy structure and result in very poor infiltration, puddling and surface runoff. In addition to these conditions, applications of fertilizers, which often exceed agricultural rates, can produce situations where large quantities of fertilizers may be leaving the nursery in surface water or groundwater.

Because the land area used by the nursery industry is relatively small in comparison to that in row-crop agriculture, regulatory agencies have not investigated nursery runoff. But because of the potential problems with NPS pollution the nursery industry should take a proactive role in determining the potential of NPS pollution from nursery sites and develop BMP's that will minimize the potential problems while producing high quality seedlings. To that end, the Hardwood Nursery Cooperative conducted an initial one-year study to determine the fate of nitrogen fertilizers under routine nursery management conditions. It was hoped that the results from that study could be used to develop fertilizer regimes that would produce target seedlings in the shortest time possible while minimizing the potential for surface and groundwater pollution.

METHODS

The general approach taken at each of the six nurseries where studies were conducted was to use present fertilizer regimes and a control with no nitrogen addition for the seedlings being grown. Fertilizer application rates and schedules at each of the nurseries is shown in Table 1.

The movement of NO_3-N through the first 1 m (3 ft) of soil was monitored using tension lysimeters. The tension lysimeters used were 2.54 cm diameter PVC pipes with porous ceramic cups on the bottom end. A cork with a tygon tube that reaches down into the ceramic cup is placed on the top end of the lysimeter. When samples are desired a negative tension is placed on the tube with a vaccum pump. The negative tension causes water-to be pulled into the lysimeter from the soil solution. The water which is pulled into the tube is water which is held by tension in the micropores of the soil. Lysimeters were placed at 15 cm (6 in) and 1 m in the soil below replicated plots (Figure 2). A weather station also was installed at each experimental site to monitor rainfall and other common climatic variables. Water samples were collected at regular intervals during the growing season. Periodic water sampling continued 1-2 months after the last fertilizer applications were made. Seedling heights and diameters were measured twice per month on seedlings in perma-

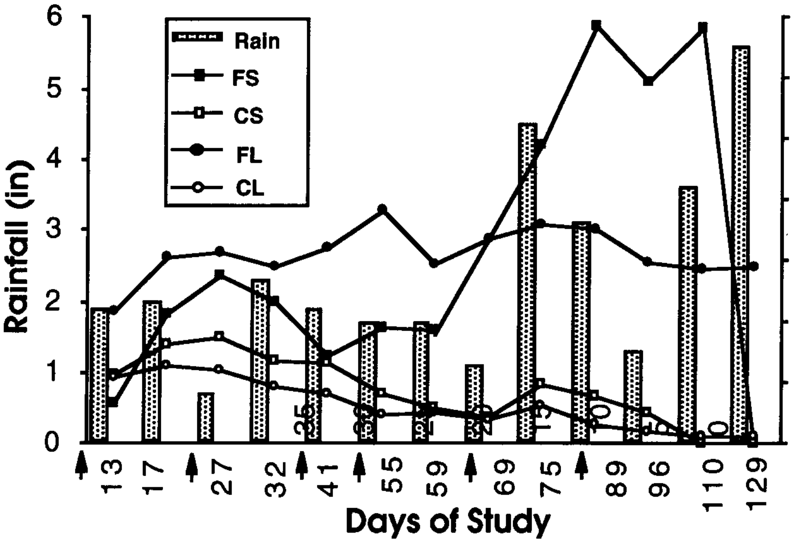

Figure 2. Nitrate-nitrogen concentrations and rainfall/irrigation data for State 1 between 5/21-9/24/92. Nitrogen fertilizer was added every 2 weeks at a rate of 22 kg/ha (20 lbs/ac) as 34-0-0 or 21-0-0. Nitrate nitrogen concentrations: FS = fertilized - 15 cm (6 in); CS = unfertilized - 15 cm (6 in); FL = fertilized - 1 m (3 ff); CL = unfertilized - 1 m (3 ff).

nent plots and whole seedlings were removed from the plots at monthly intervals to determine biomass and nitrogen concentrations of the plant tissue.

WATER QUALITY RESULTS

In fertilized plots NO_3-N levels at 15 cm (6 in) were often higher than those at 1 m (3 ft) (Figures 2 and 3). In state 1 (Figure 2) NO_3-N levels at 15 cm (6 in) exceeded those at 1 m (3 ft) for about half of the first 130 days of the study. Increased moisture from rainfall seemed to move the surface applied nitrogen to the 15 cm (6 in) depth. At 1 m NO_3-N levels remained almost constant throughout the period suggesting that if NO_3-N had been removed from the water by the plants then the source of the water at 1 m represented more soil volume than the fertilized soil of the bed or block just above.

In State 2 (Figure 3) NO_3-N concentrations at 15 cm (6 in) were almost always higher than those at 1 m (3 ft). Once again, NO_3-N levels at 1 m remained almost constant throughout the period. At both depths and in both nurseries, soil water NO_3-N concentrations exceeded EPA MCL's for most of the growing season. In both nurseries concentrations at 15 cm (6 in) reached as high as 35 mg/L (ppm) while concentrations at 1 m (3 ft) ranged between 15-20 mg/L (ppm). This would suggest that the plant soil system was able to immobilize at least 15-20 mg/L (ppm) of NO_3-N between the 15 cm (6 in) and 1 m (3 ft) depths.

In the control plots NO_3-N concentrations at 15 cm (6 in) usually were the same as or below those at 1 m (3 ft) (Figures 2 and 3). NO_3-N concentrations at 15 cm (6 in) in the control plots of both States 1 and 2 were always below EPA MCL's. Because beds represent a relatively narrow soil surface width (1.2 m or 4 ft wide) soil water concentrations at the 1 m (3 ft) depths may have represented soil water percolating

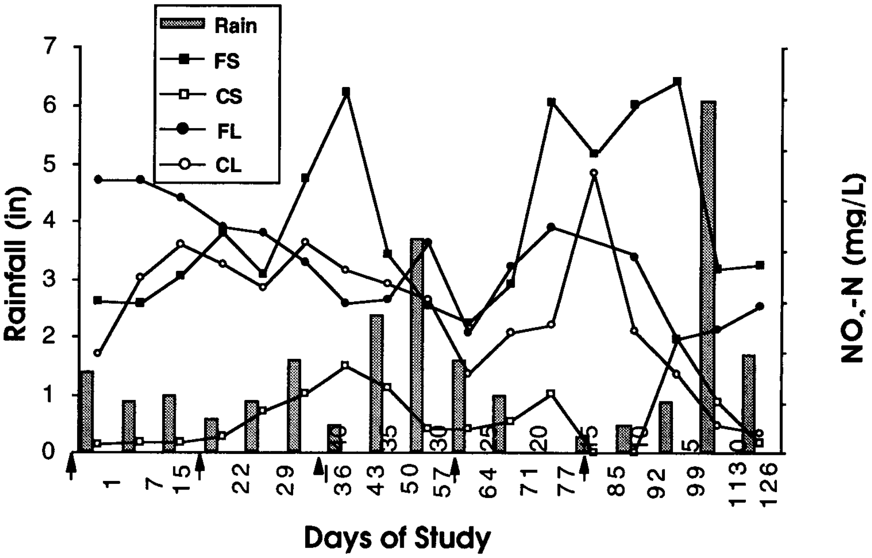

Figure 3. Nitrate-nitrogen concentrations and rainfall/irrigation amounts for State 2 between 5/21-9/24/92. Nitrogen fertilizer was added every 3 weeks at 56 kg/ha (50 lbs/ac) as 34-0-0 or 21-0-0. Nitrate-nitrogen concentrations: FS = fertilized - 15 cm (6 in); CS = unfertilized - 15 cm (6 in); FL = fertilized - 1 m (3 ft); CL = unfertilized - 1 m (3 ft).

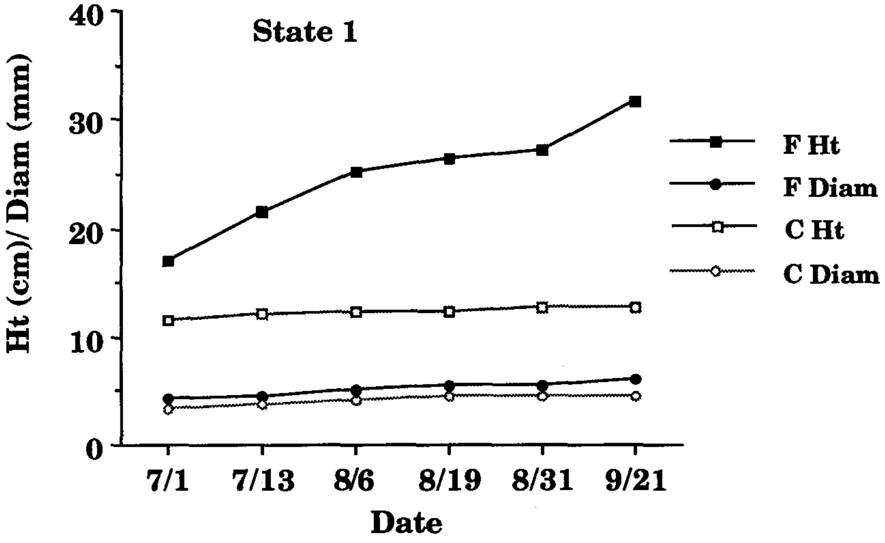

Figure 4. Height and diameter growth of red oak between 7/1 /92 and 9/ 21 /92 in State 1. Seedlings were fertilized with nitrogen fertilizer that was added every 2 weeks at a rate of 22 kg/ha (20 lbs/ac) as 34-0-0 or 21-0-0.

through several neighboring beds. As a matter of fact, in three states, NO_3-N levels at 1 m (3 ft) in the control plots were approximately the same as those in the fertilizer plots suggesting lateral movement of water at that depth. Figure 4 shows that phenomenon for State 2. This kind of data suggests that there was a lateral gradient for water movement that might be related to restrictive percolation rates or presence of the water table.

The NO_3-N at the 15 cm (6 in) depth responded more directly to rainfall or irrigation water inputs than those at 1 m (3 ft) again because the water at that depth was close to the source of both the water and the nitrogen. With each rainfall event a plume of NO_3-N could be seen moving through the nursery bed. It is speculated that most irrigation water was not sufficient enough to push the NO_3-N plume to 1 m (3 ft) depths. However, with high rainfall events, that nitrogen could be percolated to the greater depths.

Soil water NO_3-N concentrations were lowest in the fertilized plots of the States 1 and 3 that added the lowest levels of 34-0-0 in the study (Table 1). In those two states NO_3-N concentrations came closest to meeting the EPA MCL with concentrations lower than the EPA MCL for part of the growing season.

SEEDLING GROWTH AND NUTRIENT CONTENT

The red oak seedling response from State 1 will be used as an example of seedling responses that were identified in most states. Fertilized red oak seedlings averaged three times the height of control seedlings at the end of the growing season in State 1 where 22.4 kg/ha (20 lbs/ac) of 34-0-0 or 21-0-0 were applied every two weeks (Figure 4). The fertilized red oak seedlings in State 1 also had slightly larger diameters at the end of the growing season than control seedlings. The differences between the heights of the fertilized and unfertilized control seedlings indicates that height growth of seedlings could be controlled by fertilizer application.

Fertilized red oak seedlings averaged 2.3 times the number of leaves of control seedlings although dry weights of the leaves

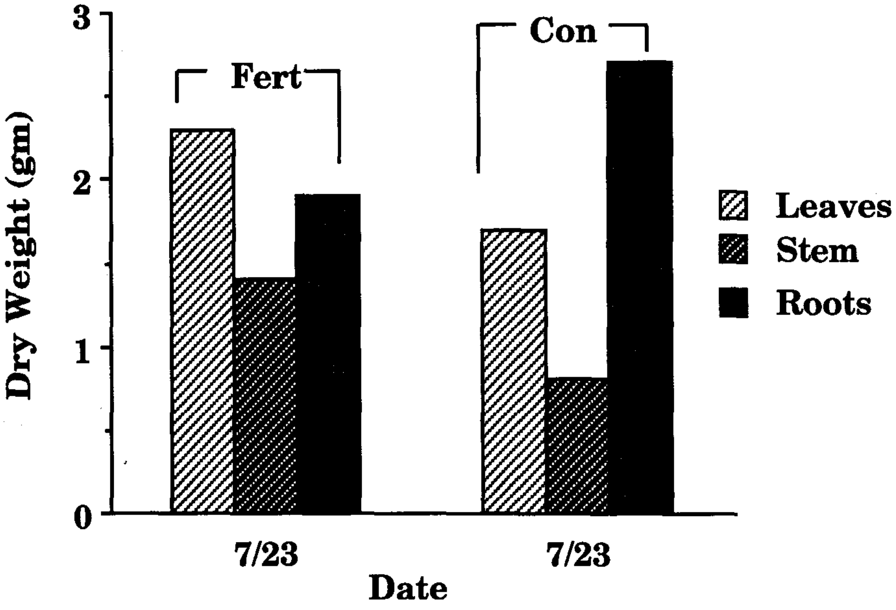

Figure 5. Dry weights of leaves, stems, and roots of red oak seedlings on 7/23/92 in State 1. Seedlings were fertilized with nitrogen fertilizer that was added every 2 weeks at a rate of 22 kg/ha (20 lbs/ac) as 34-0-0 or 21-0-0.

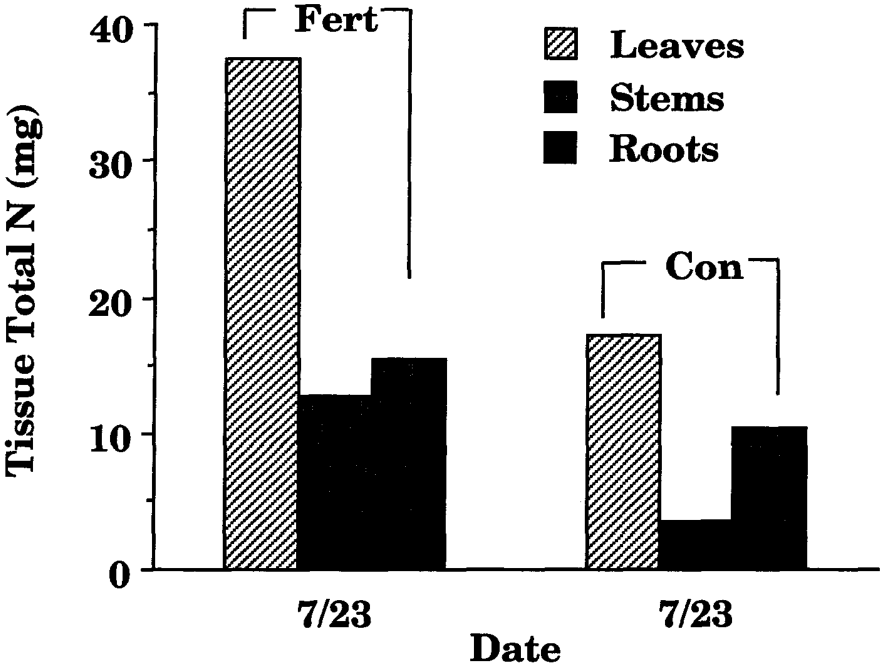

Figure 6. Average nitrogen content per red oak seedling in State 1. Seedlings were fertilized with nitrogen fertilizer that was added every 2 weeks at a rate of 22 kg/ha (20 lbs/ac) as 34-0-0 or 21-0-0.

for the fertilized seedlings were not 2.3 times heavier than those of the control seedlings. This would suggest that the leaves on the fertilized seedlings were smaller than those on the control seedlings (Figure 5).

Dry weights of control red oak seedling roots were 30% greater than those of the fertilized seedlings while stem weights of the control seedlings were about 60% of those for fertilized seedlings. The stem weight data seems to support the differences that can be seen in the height growth differences of the seedlings. The larger root mass of the control seedlings may be indicative of stressed seedlings that have been seen under sites with low nutrient levels (unpublished data).

Nitrogen concentrations for the fertilized seedlings were greater than those for the controls; leaves 1.6% vs 1%, stems 0.9% vs 0.5%, and roots 0.8% vs 0.3%, respectively. Using these values the total nitrogen content per seedling can be calculated (Figure 6). The ratios of nitrogen content to total biomass for the leaves and stems are similar between the fertilized and control seedlings. However, the ratios for the roots are reversed. The control seedling roots, although having a larger biomass than those of the fertilized seedlings, had only 66% of the nitrogen content of the fertilized seedlings. It would seem that roots can serve as a major sink for nitrogen, when it is available, during the latter part of July when these measurements were made.

Some preliminary estimates of the fate of the nitrogen fertilizer can be made using the nitrogen contents found in the fertilized seedlings. If a density of 86 seedlings per m^2 (8 seedlings/ft^2) and a nitrogen content of 65 mg per seedling are assumed then approximately 56 kg/ha (50 lbs/ac) of N ended up in the seedlings. Using the rate of 134 kg/ha (120 lbs/ac) of N over the growing season that State 1 added, the lowest of all five states, 40% of the N ended in the plants and 60% ended elsewhere. Although these data for plant sequestering are supported by the literature (Eaton and Patriquin, 1990) they should be viewed very carefully. Simply saying that 60% of the N ended somewhere other than in the plants does not mean that it all ended up in the soil water as a potential pollutant. Under many situations a sizable amount of that N could have been denitrified by anaerobic bacteria and released to the atmosphere as harmless N gas. However, in agricultural systems 20-40% of the nitrogen applied as fertilizer may be lost from the site during the growing season (Power, 1981) and these losses increase with increasing fertilizer application rates (Barraclough et al. 1984). Since bareroot nurseries are intensively managed like agriculture fields it is possible that a large part of the nitrogen that is found at the 1 m (3 ft) depth may indeed reach the nearby surface and groundwater.

IMPLICATIONS

It is obvious that fertilizer is needed to produce target seedlings. An intensive production system where seedlings and their associated biomass and nutrients are removed every year or two can rapidly drain the reservoir of soil nitrogen. The nitrogen is also being removed at a rate faster than is being naturally added to the system by microbial nitrogen fixation and atmospheric inputs. It is therefore necessary to supplement soils with nitrogen to produce high quality seedlings.

However, the results of this study would suggest that fertilizer is being added that is not being utilized by the plants and is therefore moving through the soil toward the groundwater. It is safe to assume that it is impossible to capture all or even most of the added nitrogen fertilizer in the plants under the best of conditions. There will always be some leaching of added nitrogen from a cultivated system which is devoid of well balanced plant-microbial-soil system. It would seem likely that fertilizer losses to the groundwater could be reduced if fertilizer additions were tied to plant demands for the nutrient. Thus, adding the same quantity of fertilizer at each application throughout the growing season does not seem to be biologically sound.

Fertilizer applications should be tied to the size and phenology or stage of growth of the seedlings (O'Hara, 1992). Applications to oaks might be timed to leaf expansion and the leaf linear phase of flushing when demand for nitrogen is greatest. For continuous growing species smaller amounts of nitrogen should be applied at the beginning of the season and steadily increased until it is desired to begin slowing growth in late summer. It also would seem feasible to add smaller amounts more frequently to the beds. To that end foliar applications of fertilizer or applications through the irrigation lines might be considered.

Nitrogen fertilizer might best be added as ammonium (NH_4) than as NO_3 and should never be added in the fall for over winter leaching. It might be time to again investigate soil organic matter management as organic matter contains approximately 5% nitrogen of which 2-5% is mineralized each year (O'Hara, 1992). If a soil contained 4% organic matter as much as 55 kg (120 lbs) of ammonium could be released each year.

It is recommended that nurseries consider routinely monitoring soil water nitrogen contents and try experimenting with reduced or differently spaced nitrogen fertilizer applications. This could be done by cutting the present rates of fertilizers in half and adding both the normal and reduced rates at twice the frequencies that are normally used. Monitor the NO_3-N in the rooting zone and minimize the concentrations except during the growing season. Although 10 mg/L (10 ppm) of NO_3-N is the EPA MCL a level of 5 mg/L (5 ppm) below the rooting zone should turn on the warning light (O'Hara, 1992). Sooner or later regulatory agencies will impose tough standards on the nursery industry if the industry is not willing to control itself. The potential costs associated with cleanup liability can be astronomical. Future legislation may require cleanup of contamination activities that were legal at the time they occurred (Feitshans, 1990). It is important that a proactive program be developed by nursery managers to identify the fate of added nitrogen fertilizers and to modify the rates of addition if and when potential problems arise (Landis et al., 1992).

ACKNOWLEDGEMENTS

The authors wish to thank Stu Pequignot and Al Stauder - Mason Nursery, IL; Jerry Grebasch, Roger Jacob, and Bruce Blair - Iowa DNR Nursery, IA; Miles Wiegand and Spenser Stone - General Andrews, MN; Bill Yoder - George O. White, MO; and Chuck Bathrick - Zanesville Nursery, OH for their support and assistance with this project. The Hardwood Cooperative has been supported by USDA Forest Service Focus Funding.

LITERATURE CITED

Biernbaum, J. and W. Fonteno. 1989. Minimize groundwater contamination. Greenhouse Grower 7:90-95.

Feitshans, T.A. 1990. Liability issues in groundwater quality protection. J. Soil and Water Conserv. 45:211-215.

Landis, T.D., S. Campbell, and F. Zensen. 1992. Agricultural pollution of surface water and groundwater in forest nurseries. Proc. Intermountain Forest Nursery Association, pp. 1-15.

O'Hara, K.R. 1992. Managing fertilizer and pesticide leaching and runoff in bareroot nurseries. Proc. Intermountain Forest Nursery Association, pp. 39-46.