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LAND USE AND FIELD NURSERY FERTILIZATION EFFECTS ON NITRATE-N IN GROUNDWATER AND SOIL WATER IN SOUTHWEST MICHIGAN

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LAND USE AND FIELD NURSERY FERTILIZATION EFFECTS ON NITRATE-N IN GROUNDWATER AND SOIL WATER IN SOUTHWEST MICHIGAN

By

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ABSTRACT

LAND USE AND HORTICULTURAL FERTILIZATION EFFECTS ON NITRATE-N IN GROUNDWATER AND SOIL WATER IN SOUTHWEST MICHIGAN

By

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Health concerns stem from nitrate-N in drinking water, particularly in infants under 6 months of age. The United States Environmental Protection Agency has therefore set a maximum contaminant level (MCL) of 10 mg nitrate-N/L in drinking water.

Nitrate-N concentrations in shallow groundwater were measured beneath four differing land uses in 2001 and 2002. Land uses consisted of mature, unfertilized forests, older *Taxus* (yew) fields not fertilized in 4 years, fertilized fields of young *Taxus* or *Euonymus* (burning bush), and fertilized fallow or cover cropped areas being prepared for seedlings. We found nitrate-N concentrations in shallow groundwater beneath forested and older *Taxus* areas were very low. Nitrate-N beneath some fertilized fields was above the MCL, indicating fertilization could be reduced, an economic advantage.

Fertilization based on the relative addition rate (RAR) practice was compared to unfertilized plots, and plots receiving standard fertilization practices in two cooperating nurseries to determine if nitrate-N concentrations in shallow groundwater and soil water collected just below the root zone were reduced. Nitrate-N beneath the RAR plots was reduced, especially in 2002, implying that the nurseries could reduce fertilization and be more cost effective. This was particularly true in determinate species (*Euonymus*), at younger ages, with manure applied previously during site preparation.

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CHAPTER ONE

INTRODUCTION AND LITERATURE REVIEW

Introduction

Shallow groundwater and soil water were sampled beneath areas of forest and horticultural land in 2001 and 2002 to research nitrogen (N) management and nitrate leaching. The following is a literature review on major topics we considered essential to our research. Literature explaining proper techniques for the installation of porous ceramic cups and shallow groundwater wells, as well as sampling procedures, was reviewed in order to follow a well-published procedure. Literature discussing nitrate concentrations beneath forested areas as well as heavily managed areas was also reviewed in order to develop hypotheses for our research.

Nitrogen Cycle

There are five major steps to the nitrogen (N) cycle, 1) N Fixation, 2) Mineralization, 3) Nitrification, 4) Immobilization, and 5) Denitrification. N fixation converts N_2 gas from the atmosphere to ammonia and then to organic forms (Foth, 1990). N can be fixed by lightning, but mostly, N fixation occurs biologically through N-fixing plants such as legumes. Up to 99% of N in the soil is in an organic form (Foth, 1990). Mineralization is the process that breaks down organic forms of N to release ammonium, an inorganic form of N that can be taken up by plants (Burt et al., 1993). Once the N is in the ammonium form, it is adsorbed to the soil surface and can be converted to nitrite and nitrate by nitrifying bacteria during nitrification. Nitrification is an aerobic process and is inhibited in saturated soils (Foth, 1990). Ammonium and nitrate are both readily available for plant uptake. When taken up by the organisms, these forms must be converted back into organic N through a process called immobilization. Nitrate is continually supplied to a soil system by nitrification and mineralization (Randall and Mulla, 2001). The mineralization, nitrification, and immobilization cycle can be repeated several times with the same soil N (Foth, 1990). To complete the cycle, the denitrification process may reduce nitrate or nitrite back to N oxides through anaerobic microbial activity (Foth, 1990). The products of denitrification are in a gaseous phase and a majority of it is released back to the atmosphere.

Nitrate

Nitrate is readily available for plant uptake and flows with water to the root zone. Because nitrate is highly mobile, it is the most common contaminant in groundwater (Burt et al., 1993; US EPA, 2000). Ammonium, nitrite, and organic nitrogen can also be present in groundwater; however, nitrate is more susceptible to leaching because it does not adsorb to negative charges at the soil surface (Burt et al., 1993). Nitrate is especially mobile in sandy soils low in organic carbon and is also affected by moisture content. Ninety percent of N present in most soils is in an organic form (Burt et al., 1993) however; this percentage can be decreased significantly in agricultural soils due to an increased inorganic inputs and management.

Human Health Concerns

Nitrate leaching into the groundwater has become an increasingly important problem since the introduction of synthetic fertilizers. In the United States, N fertilizer use has increased twenty-fold in the last 50 years (Nolan and Stoner, 2000). This increase in fertilizer use has also increased awareness to the contamination of groundwater by nitrate. Groundwater provides drinking water for nearly half of the US population (Nolan and Stoner, 2000; Pye and Patrick, 1983; US EPA, 2000). Nitrate contamination to drinking water can negatively affect human health. The most widely publicized disease related to high nitrate concentrations in drinking water is methemoglobinemia. Methemoglobinemia, more commonly referred to as 'blue-baby syndrome', effect infants under 6 months of age. In infants, nitrate is converted to nitrite in the digestive tract due to low levels of acid (Mahler et al., 1989). Nitrite combines with hemoglobin to produce methemoglobin, which cannot carry oxygen (Mahler et al., 1989; Burt et al., 1993). With increased levels of methemoglobin, the lack of oxygen can lead to suffocation (Spalding and Exner, 1993). Older children and adults have higher acidity within the digestive tract and can convert nitrite back to nitrate, which can be excreted. The first reported case of methemoglobinemia was in Iowa in the 1940s. The World Health Organization reported 2000 cases of methemoglobinemia between 1945 and 1986 (Burt et al., 1993), but cases have diminished in recent years.

High nitrate levels in drinking water have been suspected to be carcinogenic in adults, possibly causing stomach and bladder cancer (Burt et al., 1993). Nitrosamine compounds are known to be carcinogenic, but the link between nitrosamines and nitrate is not yet clear (Magee, 1982). High nitrate concentrations in drinking water have also cause spontaneous abortions in laboratory animals and livestock (FDA, 1972; Sund et al., 1957). There is little support that high nitrate levels in drinking water can cause spontaneous abortions in humans. One reported case however, occurred in Indiana from 1991 - 1994. Three women in close proximity were reported to have six spontaneous abortions; all were reported to have consumed nitrate-contaminated water from private wells.

Because of human health concerns, the United States Environmental Protection Agency (US EPA) set a maximum contaminant level (MCL) for nitrate in drinking water at 10 mg/L (US EPA, 2002). This regulation on drinking water was amended in 2002 to entitle each state to allow nitrate levels up to 20 mg/L in non-community water systems if the following requirements were met, 1) the water would not be available to children under 6 months of age, 2) the public is notified of the increased maximum contaminant level, including posting the potential health effects of increased nitrate levels, 3) Local and state authorities must be notified of the exceeded 10 mg/L nitrate level annually, and 4) adverse health effects do not result (US EPA, 2002).

Naturally Occurring Nitrate

Nitrate occurs naturally in groundwater at concentrations less than 2 mg/L (Nolan et al., 1998; Mueller, 1995). Di and Cameron (2002) state that many forest soils are acidic, which is not an ideal environment for nitrifying bacteria. Without these bacteria present, nitrification cannot occur and nitrate will not be produced. Williams and Gresham (2001) reported that nitrate concentrations in shallow groundwater below natural pine are less than 0.5 mg nitrate-N/L.

Low nitrate concentrations in shallow groundwater occur in areas that are not intensively managed, mainly forested areas. Many unmanaged forests predominantly receive fixed N from atmospheric inputs and mineralized organic material. The large biomass of the older, larger plants causes these systems to be naturally N-limited, which makes nitrate leaching minimal. Large nitrate leaching events can occur when trees are cut down (Smith et al., 1994; Di and Cameron, 2002). Fenn et al. (1998) also speculated that mature forest soils could reach a N saturation point after receiving continuous N input from atmospheric deposition. If the soil became saturated with N, Fenn et al. (1998) suggested that nitrate leaching would likely occur.

Nitrate saturation has not been widely accepted and is contested by results reported by Hedin et al. (1995) and Perakis and Hedin (2002). Both of these studies determined nitrate leaching from mature forest sites. In 1994, Hedin et al. proposed that atmospheric pollution along with human activities, increased N deposition inputs. In order to test this hypothesis, they researched N levels in water in a remote area of South America where old growth temperate forests did not receive increased N deposition from pollution. They found 95% of N recovered was dissolved organic nitrogen (DON) and only 0.2% was in the form of nitrate. Nitrate concentrations in stream water were six times higher in areas with high levels of atmospheric pollution (Hedin et al., 1995). Perakis and Hedin (2002) found similar results. Forested areas are highly N deficient and any available inorganic N is most likely taken up by the plant before it leaves the root zone by leaching.

Nitrate Inputs

Nitrate can be added to ecosystems via inorganic fertilizers, animal manures, and septic systems. Nitrogen (N) can also be deposited on land in precipitation and dry particles from industry and automobile exhausts. Contamination from point sources, such as industrial plants, can be regulated because the source may be easily determined. Contamination resulting from non-point sources, such as agriculture and horticulture, is not as easily managed. Agriculture is the leading non-point source of nitrate contamination in the United States (US EPA, 2000). In the UK, less than 0.2 million ha are used for horticulture crops as compared to the 4.5 million ha used for arable crops, but can leach large amounts of nitrate (Goulding, 2000). Use of inorganic fertilizers and animal manures at high rates incorporate an excess of nitrate in the soil. These additions have historically been applied in excess due to the low cost and the assurance that the crop would reach maximal growth without a N deficiency. Although this strategy maximized yield, it also introduced excess nitrate that saturated the soil. Nitrate is highly mobile in soil, increasing the likelihood of leaching to occur. Kolpin and Burkart (1991) measured nitrate from 303 wells in the Midwest US and found that 6% of the sampled wells exceeded the MCL of 10 mg nitrate/L. Kraft and Stites (2003) measured nitrate concentrations in shallow groundwater below sweet corn and potato fields. They found the average nitrate concentration in the upper 3m of groundwater was 20 mg/L, ranging from < 0.2 to 50.5 mg nitrate/L. These results were similar to findings in 1999 in the same area of the Wisconsin Central Sand Plain. Kraft et al. (1999) found groundwater average nitrate concentrations of 13.7 mg/L beneath irrigated vegetable crops compared to 0.5 mg nitrate/L in unaffected groundwater areas.

In order to reduce nitrate leaching, growers have begun to attempt to more closely match fertilization applications with plant demand in some cropping systems. Randall and Mulla (2001) reported corn yields were highest with a split application of N fertilizer. Matching fertilizer applications with the crop plant demand is a generally agreed upon strategy to reduce nitrate leaching (Randall and Mulla, 2001; Goulding, 2000; Kirchmann et al., 2002; Casey et al., 2002). Sanchez and Blackmer (1988) found that 49 to 64% of fall-applied N fertilizers were lost from the upper 1.5m of the soil profile in ways other than plant uptake. Randall (1997) found that changing fall applications to spring could dramatically decrease leaching as well as increase efficiency. Nitrate losses were decreased by 36% on average and N efficiency increased by 20% simply by changing the timing of fertilizer applications to the spring (Randall et al., 1992; Randall, 1997).

Studies have shown that proper N management (Albus and Knighton, 1998) and irrigation management (Casey et al., 2002) can significantly reduce nitrate concentrations in shallow groundwater. Casey et al. (2002) determined that although nitrate concentrations in shallow groundwater increased at the initiation of irrigation due to residual soil N, concentrations eventually dropped and returned to the original levels. Casey et al. (2002) also suggested that although the initial increase in nitrate in shallow groundwater may not be avoidable because without a precipitation event the nitrate will build up in the soil, reduced fertilization rates can shorten the duration of the increased levels and reduce the size of the build up within the soil. Sylvester-Bradley (1993) found the crop does not take up 10-60% of applied N fertilizer and 90% of yield could be obtained with half of the fertilizer. Goulding (2000) found that predicting the amount of N a crop needs and the timing of the applications are most important in reducing nitrate leaching. Goulding (2000) also noted that applying the required fertilizer in several smaller doses is effective in minimizing losses. This was also the strategy used by Alt. Alt (1998a) noted that most fertilizer trials with nursery crops showed small responses to N implying that nursery crops had been over-fertilized. The large over estimation in N demand in nursery crops could be due to possible N storage in the stems and roots of perennials unlike annual crops (Alt, 1998a). This possible storage also makes yearly fertilizer recommendations difficult to calculate. N applications should be done carefully in order to avoid leaching events (Alt, 1998b). Alt (1998c) stated that timing of the fertilization application may reduce nitrate leaching. By applying N just prior to the peak of root growth, more N should be taken up and would not leach through the root zone to the groundwater. Other reasons why over fertilization could be costly to nursery crops include the possibility of reduced frost hardiness, increased sensitivity to plant disease, and delayed leaf dropping in the autumn (Alt, 1998b). Over-fertilization could also lead to luxury consumption (Alt, 1998c). Luxury consumption occurs when an increase in N uptake does not increase growth.

'Relative Addition Rate'

The 'Relative Addition Rate' (RAR) method was developed by Ingestad and Agren in the 1970s. The RAR method is based on the principle that under steady-state conditions, relative growth rates were equivalent to the relative uptake rate. The RAR method is to schedule N fertilization of the crop to supply its N demand and thus prevent excess leaching below the root zone. Ingestad and Agren (1988) added nutrients using a spray technique based on the RAR, which closely corresponded to the relative uptake rate. The RAR replaced the nutrients that were taken up by the plant. A linear relationship between nutrient status and the relative growth rate was found (Ingestad and Agren, 1988, 1992). The RAR would also lead to less nutrient losses from soil because the only N additions were those required for maximum growth of the plant. The RAR method was further analyzed in soil media by Xu and Timmer in 1998, who found that the plants required a nutrient supplement at the beginning of the season prior to the initiation of the RAR in order to reduce a 'lag phase' that was found in plants that did not receive the supplemental nutrient addition. The 'lag phase' limited seedling growth by reducing root elongation early in the growing season. The RAR method agrees with common findings that reduced fertilization applications that are timed to the plant demand will lead to less N loss to the groundwater (Alt, 1998 a,b,c; Goulding, 2000). Rios (2002) reported the RAR method of fertilization resulted in lower nitrate-N concentrations in soil water sampled just below the root zone in horticultural fields as compared to the nurseries current fertilization practices.

Shallow Groundwater Sampling Methodology

The most direct and common method of monitoring shallow groundwater quality is by the use of sampling wells. Shallow groundwater wells must be developed once constructed at a determined location. The most accepted method to develop a monitoring well includes surging and pumping (Wilson, 1995). A surger is a heavy object that is rapidly lowered into the groundwater and then forcefully pulled out of the water. This repeated motion forces water back and forth through the well screen loosening fine particles from the well point (Wilson, 1995). Periodically, the well is pumped out to remove the fine material from the well.

Once a well is developed, there are several ways to collect a water sample, dependent upon the hydraulic characteristics of the aquifer, diameter of the well, sampling depth, and cost (Wilson, 1995). A peristaltic pump or a bailer are two of the best instruments for pulling a sample from a shallow groundwater well. When sampling shallow groundwater, the well should be purged prior to sample because groundwater within the upper portion of the well casing becomes stagnant and is not representative of the aquifer (Wilson, 1995). According to Wilson (1995), the water in the upper portion of the well and the water remaining in the screen normally have a different temperature, pH, redox potential, and chemical composition than the aquifer being sampled. To remove stagnant water, three well casing volumes are removed (Wilson, 1995). Karr et al. (2001) reports a similar procedure for well sampling, taking a sample using a bailer or a peristaltic pump after one to three well volumes had been purged. Kraft and Stites (2003) also followed this method, purging three times the static volume within the multilevel piezometers installed for their study prior to taking a sample using a peristaltic pump. Nelson et al. (1995) and Burkart and Kolpin (1993) also followed this method, purging until the pH, temperature, and specific conductance had stabilized.

To ensure that stagnant water has been removed prior to taking a representative sample, Wilson (1995) recommends measuring pH (± 0.1 pH units), specific conductance (± 10.0 μs/cm), and temperature (± 0.5 °C) in the last portions of the purged water. If these criteria are met, the water coming from the well is representative of the aquifer and a sample can be collected.

Soil Water Sampling Methodology

Soil water samples can show patterns of nutrient flux more clearly than groundwater samples (Williams and Gresham, 2001). The sampling can be done closer to the source of contamination because the soils do not have to saturate to move the contaminant to the groundwater and dilution is not a factor (Linden, 1977). Soil water can be sampled using porous ceramic samplers because a vacuum can be placed on the sampler that can overcome the suction holding the water to the soil (Linden, 1977). Linden (1977) states that the vacuum has to be continuous in order to achieve volumetric sampling and that it must be controlled to prevent convergence or divergence of water flow to the vicinity of the sampler.

In order for the sampler to successfully pull water from the soil, good soil contact must be made at the installation of the sampler. To do this, the pores within the ceramic cup should be saturated at the installation (Linden, 1977). A slurry of silica flour can also be used to ensure that good soil contact is achieved. The slurry mixture is poured into the augured hole and then the sampler is firmly pressed into the hole (Linden, 1977; Webster et al., 1993; Rios, 2002).

Webster et al. (1993) found that porous ceramic cup samplers gave a good direct measurement of mineral N and worked equally well to monolith lysimeters in the second and third year of soil water nitrate estimation. In the first year, he observed discrepancies in the nitrate levels that were accredited to soil disturbances during the installation process.

Deep Percolation Estimation

Deep percolation (DP) estimates can be used to research when nitrate is potentially leaving the root zone and entering the subsoil and groundwater. These estimates can be compared to the high nitrate concentrations found in the soil water data to examine the correlation. These estimates can also be compared to the shallow groundwater to see the length of time that it takes the nitrate to enter the groundwater. Daily DP below the rooting zone may be estimated from plant AWC (available soil water storage capacity of the soil root zone), daily PET (potential evapo-transpiration for the crop vegetation), and daily precipitation (P) + irrigation (IRR) using water balance methodology.

Saxton et al. (1986) analyzed extensive data and developed equations that may be used to predict field capacity, wilting point and available water storage capacity from sand, clay, organic matter and gravel content. These equations were used to compute the amount of plant available water that would be retained in a 30cm deep surface soil.

Conclusions

The assessment of nitrate concentrations in shallow groundwater and soil water was done following procedures and methodology above. Through this literature review, we have hypothesized that shallow groundwater below forested areas will have low nitrate concentrations and that the nitrate concentrations beneath the horticultural production areas will be largely dependent on the management practices. It is also hypothesized that any seasonal trends that may be present will be seen more clearly through the soil water samples because nitrate concentrations are less diluted as compared to the shallow groundwater samples.

Thesis Organization

The thesis is organized into two chapters that are suitably organized for submission as manuscripts in peer review journals, and a summary chapter. Chapter 2 discusses the impacts that land use can have on nitrate-N concentrations in shallow groundwater and chapter 3 examines fertilization practices within horticultural production areas to determine if the RAR fertilizer method would reduce nitrate-N concentrations in soil water and shallow groundwater. Chapter 4 summarizes the results from chapters 2 and 3, and makes recommendations for nursery management and further research. Literature used is cited at the end of each chapter.

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CHAPTER TWO

LAND USE EFFECTS ON NITRATE-N LEVELS IN SHALLOW GROUNDWATER

Abstract

Nitrate-N concentrations in shallow groundwater were measured below various horticultural areas and in forested areas in southwestern Michigan in 2001 and 2002. Nitrate-N concentrations in shallow groundwater beneath fertilized woody ornamental fields varied according to the species present. Shallow groundwater below *Taxus* (yew) did not show seasonal means that were significantly greater than the 10 mg nitrate-N/L maximum contaminant level (MCL); however, nitrate-N under *Euonymus* (burning bush) was significantly higher than the MCL in 2001. Nitrate-N beneath both species decreased in 2002, implying that with larger plant size, nitrate-N is less likely to percolate to the groundwater. This theory is supported by low nitrate-N concentrations measured below older *Taxus* fields that had not received fertilizer in 4 years. Nitrate-N below the older *Taxus* as well as the forested areas was considerably lower than the MCL in 2001 and 2002. Our research suggests that increased plant biomass and decreased fertilization will result in lower nitrate-N levels in groundwater and that levels can decrease in 1-4 years.

Introduction

Human Impacts

Groundwater supplies drinking water for 46% of the U.S. population and 99% of the nation's rural population (Mueller et al., 1995; Solley et al., 1993). Nitrate-N contamination of groundwater has become an increasingly important issue in recent years. Nitrate-N contamination of drinking water was first recognized because high levels of nitrate-N in drinking water could negatively affect human health. These concerns prompted the United States Environmental Protection Agency (US EPA) to set a maximum contaminant level (MCL) in the United States at 10 mg/L nitrate-N in drinking water (US EPA, 2002). Data discussed by Di and Cameron (2002) and DeRoos et al. (2003) suggests that high levels of nitrate-N may be carcinogenic to adults. However, nitrates are known to cause methemoglobinemia in infants. Methemoglobinemia, commonly called 'blue-baby syndrome' usually affects children under the age of 6 months by interfering with the transport of oxygen by the red blood cells (Spalding and Exner, 1993). Cases of methemoglobinemia due to high nitrate-N concentrations in drinking water were first reported in the 1940s and 1950s, but have diminished in recent years (Di and Cameron, 2002).

Environmental Impacts

Agriculture

According to the US EPA's water quality assessment, contamination from urban and agricultural land is the leading source of non-point source pollution affecting groundwater quality (US EPA, 2000). Excessive use of fertilizers is a large factor in nitrate-N leaching (Dinnes et al., 2002; Di and Cameron, 2002; Power et al., 2001). Historically, there has been little consideration of groundwater quality. Fertilizers were used in excess to ensure that a N deficiency within the crop did not occur. The agriculture industry has recently attempted to alleviate nitrate-N contamination of groundwater by reducing fertilizer applications and matching the applications to crop demand (Goulding, 2000; Randall and Mulla, 2001; Kirchmann et al., 2002; Casey et al., 2002). Nitrate-N leaching, however, is affected by several other factors in addition to agricultural practices, including land use, soil type, climate, topography, and hydrology (Kirchmann et al. 2002,).

Horticulture

Groundwater quality has also become a concern of the horticulture industry. Historically, woody ornamental field production within this industry has also over-fertilized crops with application rates approaching corn fertilization recommendations. Goulding (2000) noted that although horticulture only occupies a small acreage in the UK compared to arable cropping systems, it could still lead to large nitrate-N leaching events. Goulding (2000) observed that keys to minimizing nitrate-N leaching consist of 1) identifying crops, soil characteristics and practices with high leaching potential, and 2) adopting strategies to optimize the use of nitrogen fertilizers. Improving the nitrogen use efficiency of crops, combined with measures to avoid nitrate-N leaching during periods of heavy precipitation are key ways to minimize nitrate-N leaching.

In Michigan, horticulture is an important and growing industry. Michigan is the fourth largest producer of landscape nursery plants in the United States (USDA, 2002). In 1999, 43% of this industry was located in Ottawa, Allegan, and Berrien counties (USDA, 2000) in southwest Lower Peninsula of Michigan because the predominance of level fertile sandy soils makes the area ideal for horticulture production. Although these soils are close to optimal for nursery crops, when matched with a shallow water table (1-3 m), they make the area very susceptible to increased nitrate-N leaching and groundwater contamination. Understanding the potential impact of field nursery production on groundwater quality is critical for the environmental well being of southwest Michigan.

It is also critical for the continued use of these areas for horticulture production, a mainstay of the local economy.

Background and Rationale

In 2000, the Michigan Nursery and Landscape Association (MNLA) recognized the importance of protecting groundwater quality and identified means to reduce groundwater contamination as a research priority. Michigan State University responded to MNLA concerns by implementing research to assess nitrate-N concentrations in subsurface soil water and groundwater. Preliminary research was conducted during 2000 in fields of two woody ornamentals, burning bush (*Euonymus alatus* 'Compactus') and yew (*Taxus* spp.). These species were chosen because they represent two of the most important plants in Michigan's nursery production. *Euonymus*, a broad-leaved deciduous species, and *Taxus*, a coniferous evergreen species, also represent contrasting growth habits. *Euonymus* is a determinate grower, predominantly taking up N early in the growing season to produce one flush of growth. *Taxus* is an indeterminate grower that continues to take up N throughout the growing season. Preliminary data from wells specifically installed for this research revealed that these horticultural areas were leaching nitrate-N into the shallow groundwater at levels above the 10 mg/L MCL.

In 2001, we installed wells in two adjacent mature forested areas to determine nitrate-N concentrations in unmanaged areas. Omernik et al. (1977) suggested that forested areas are less susceptible to leaching events. Omernik et al. (1977) also reported total N concentrations were nearly nine times greater downstream of agricultural lands compared to forested lands. To date, research has been inconclusive about the factors causing these differences. Di and Cameron (2002) stated that the amount of nitrate-N leached from differing land uses is dependent on soil, climate, and management practices.

To better understand factors influencing nitrate-N fluctuations under field nursery production, we measured nitrate-N concentrations of groundwater for areas of similar soils but varying land use. Land uses included fertilized young woody ornamentals, older woody ornamentals not receiving fertilization, forested areas, and fallow/cover crop/seedling rotation. These land use areas were chosen based on diverse fertilization histories and plant age/size variations common within the industry.

Objectives and Hypotheses

With a strong foundation from literature and preliminary results, we hypothesized that nitrate-N concentrations in shallow groundwater will vary with land use. The following objectives were based on this hypothesis.

Objective 1: Determine if the fertilization history of an area influences nitrate-N levels and seasonal trends in groundwater.

Based on published findings by Alt (1998 a, b, c) and Goulding (2000), and on preliminary data, we hypothesize that the operationally fertilized[1] woody ornamental (OPER) areas will have high nitrate-N concentrations in groundwater. Nitrate-N levels beneath forested (FOR) areas will be low because forest systems are naturally N-limited. In forested areas, any N that is available is most likely taken up before it can reach the groundwater. Fallow/cover crop/seedling rotational fields (FCS) will show similar to higher nitrate-N levels than OPER due to the range of fertilization management practices within these fields. Some of the rotational fields received manure applications or were in

[1] Operationally fertilized is defined as the fertilization application equivalent to the nursery cooperator's practices (134 kg N/ha in 2001 and 168 kg N/ha in 2002).

fallow for a longer duration, which could increase nitrate-N. In old *Taxus*[2] fields (OTX) that have not received fertilization in 4 years, nitrate-N will be lower than in OPER and FCS, but higher than in FOR. Seasonal trends will be more prevalent in areas that are currently receiving fertilizer. Peaks will be seen in early spring and late autumn when precipitation events are more likely to occur and saturate the soil leading to leaching events.

Objective 2: Determine if nitrate-N concentrations in the groundwater are affected by plant age and size.

We hypothesize that as plant age and size increases, nitrate-N concentrations in the groundwater will decrease. Increased plant size leads to increased demand for N; increasing the N uptake of the plant will decrease the amount of nitrate-N in the soil that could leach through the root zone to the groundwater. We hypothesize the FOR and OTX will have lower nitrate-N levels than OPER and FCS due to an increased N demand of the larger biomass of the plants due to increased age, as well as the lack of fertilization inputs within the last 40 and 4 years, respectively. Nitrate-N levels of groundwater in the OTX land use will also indicate if the nitrate-N contamination of the groundwater can be reduced within a short period of time by larger, more nutrient demanding crops.

Quantifying the effects of fertilization and plant size on nitrate-N concentrations in groundwater will allow us to determine if nitrate-N contamination of groundwater can be decreased with reduced fertilization and increased biomass due to older plants. The results obtained from this study will determine if management practices need to be

[2] Old *Taxus* are plants that have been in the field for 10-12 growing seasons.

adjusted to decrease nitrate-N leaching that may be occurring. With these results, we will assess the potential impact of field nursery production and the potential for N management to contribute to decreased groundwater contamination.

Materials and Methods

Study Area Description

Four different land use categories were studied based on their fertilization history, and age and size of the vegetation present. All study sites were located in Robinson or Holland Township in the southwest portion of the Lower Peninsula in Michigan, where soils are predominantly Granby loamy sand (USDA, 1972). The groundwater table in these areas is very shallow, ranging between 1-3 m. The combination of sandy, permeable soils and a shallow groundwater table make these areas susceptible to frequent leaching events and rapid movement to the groundwater. Land uses consisted of 1) young woody ornamental fields being fertilized (OPER), 2) field nursery areas with older and larger plants not currently receiving fertilizer (OTX), 3) mature, unmanaged forest areas (FOR), and 4) a rotational category consisting of fallow, cover crops, and seedlings (FCS).

Land Uses

The OPER land use consisted of two fields of yews (*Taxus cuspidate* 'Dark Green Spreader' in field 1 and *Taxus x media* 'Runyan' in field 2) and two fields of burning bush (*Euonymus alatus* 'Compactus' in fields 3 and 4). The plants had received an operational (20-0-10 ammonium nitrate based N) fertilization (current nursery practice) in each year of production (Table 1) and had been growing in the field for up to 4 years (Table 2).

Table 1. Fertilization rates for OPER and FCS land uses by field in 2001 and 2002. The last year that the field received a manure application is also listed.

		Fertilizer Applications (N kg/ha)					**Manure application**
		2001	**2001**	**2002**	**2002**	**2001-2002**	**Last Year of application**
Use	**Field**	**May, July**	**Total**	**May, July**	**Total**	**Total**	(if applicable)
OPER	1	67	134	84	168	**302**	N/A
OPER	2	67	134	84	168	**302**	1998
OPER	3	67	134	84	168	**302**	N/A
OPER	4	67	134	84	168	**302**	2000
FCS	1	0	0	67	134	**134**	N/A
FCS	2	67	134	0	0	**134**	N/A
FCS	3	0	0	0	0	**0**	1998
FCS	4	0	0	84	168	**168**	2001

In 2001, the *Taxus* plants occupied 21.5% and 13.1% (canopy area x ground area / 100) of fields 1 and 2, respectively (Rios, 2002). *Taxus* plants were similar in size in both fields, averaging 22 cm in height. The *Euonymus* fields were not as similar as the *Taxus* fields in site occupancy in 2001. Plants in field 3 occupied 31.9% of the area, where plants in field 4 only occupied 6.7% of the field (Rios, 2002). Plants in fields 3 and 4 averaged 26 cm and 22 cm in height, respectively.

The OTX locations were fields of *Taxus* being maintained for periodic TAXOL® harvests. These fields had been growing in the field for 10-12 years and had not received fertilization for the last 4 years of production (last fertilized 1996). The older *Taxus* fields contained 2.5-3.6 plants per square meter that were at least 1.5 m in height and occupied nearly the entire site in 2002. OTX probably received manure prior to the planting and operational fertilization during the first 3-8 years in the field. Mature forests (FOR) had not been fertilized for at least 40 years. Two of the forest sites were composed of hardwoods, one was a pine plantation, and one was predominantly red pine with a hardwood understory of trees 3-5 m in height. Trees within these sites were at least 15 m high and were at 100% site occupancy.

The FCS sites were in a fallow or cover crop (wheat or soybean) condition in preparation for a planting of *Taxus* or spruce seedlings. The seedlings were planted in 3-row beds with close plant spacing. The duration of each of these rotational periods (Table 2) was dependent on the nursery and product demand. Fertilization rates of the FCS fields varied, but all fields were fertilized once seedlings were present (Table 1) with a 20-0-10 ammonium nitrate based N fertilizer.

FCS and OPER fields received supplemental irrigation (~2.5 cm per week) by cooperators when needed; FOR and OTX did not receive fertilization or irrigation.

Table 2. Identification of the vegetation type present at the time of the sampling event is listed. The number of years the plant was in the field is represented in parentheses.

		Vegetation Present at Sampling Event											
		2001						**2002**					
Land Use	**Field**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**
FCS	**1**	Fallow			Taxus (1)			Taxus (2)					
	2	Not established						Fallow	Wheat	Spruce (1)			
	3	Fallow						Fallow				Spruce (1)	
	4	Fallow			Fallow*			Soybeans					
OPER	**1**	Taxus (4)						Taxus (5)					
	2	Taxus (3)						Taxus (4)					
	3	EAC (3)						EAC (4)					
	4	EAC (1)						EAC (2)					
OTX	**1,2**	Not established						Taxus (12)					
	3							Taxus (10)					
	4							Taxus (10)				Fallow**	
FOR	**1-4**	Forest (40+)						Forest (40+)					

*FCS field 4 received a manure application in September of 2001. The wells were destroyed during the application; sampling was discontinued until 2002.
**Plants in OTX field 4 were harvested in early October of 2002. Wells were destroyed in the harvest; therefore, sampling was discontinued.

Well Installation

In each land use category, groundwater was sampled from four different fields, with two wells per field. Wells were installed in three of the four OPER fields in 2000. In the fourth OPER field, two of the four FOR sites, and three of the four FCS fields, wells were established in 2001. The remaining wells were installed in June 2002. All of the OPER wells were in plots that were part of a broader plot study testing fertilizer treatments (See Chapter 3). The OPER wells were located in plots that were hand fertilized with the operational rate that the cooperating growers applied to the remainder of the field.

To install the wells, an installation pit 30 cm in diameter and 45-60 cm deep was dug (Figure 1). The installation pit was lined with a container to ensure topsoil would not fall into the pit contaminating the groundwater. The container had a 10 cm diameter hole at the base to allow a bucket auger to deepen the installation pit 1-1.5 m thru the subsoil and into the groundwater table. Average depth to the water table ranged between 1-3 m, varying with field location.

Wells were constructed with well points of either 3 cm or 5 cm (inside diameter) slotted (0.18 mm) well points (Big Foot Mfg., Cadillac, MI) 1.5 m in length. Non-perforated riser pipe (Big Foot Mfg., Cadillac, MI) was threaded (threaded joints used O-ring seals) to the well points to leave a riser 40-90 cm above ground. Points and risers were manufactured using schedule 40 PVC materials. The distance to the groundwater table determined the total length of the well. The well was closed with an adapter and threaded cap and the point was positioned 1-1.5 m into the groundwater table. The augured pit was backfilled to the installation pit with original subsurface material.

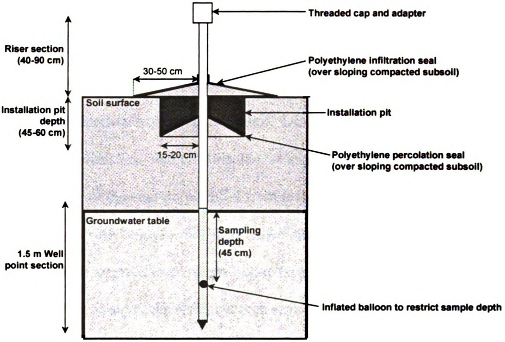

Figure 1. Well schematic showing installation procedure and sampling depth.

Compacted subsoil was sloped away from the well at the bottom of the pit and covered with a polyethylene percolation seal tightly taped to the well, prohibiting preferential flow. The installation pit was backfilled with original surface soil and a slightly larger infiltration seal was constructed, similarly to the percolation seal, at the soil surface.

After wells were installed, they were developed to restore hydraulic conductivity and water quality. To develop the wells, a heavy surger was rapidly dropped on the water surface, allowed to sink, and then forcefully raised in the well to dislodge fines around the well point. This process was repeated five times. A diaphragm pump (Teel® Model 3P739, Dayton Electric Mfg. Co., Miles, IL) was then used to draw water and fines out of the well. These steps were repeated 3-4 times until the water dispersed by the diaphragm pump was slightly opaque to clear.

Groundwater Sampling

Shallow groundwater was sampled monthly throughout the growing season (June-November) using a peristaltic pump (Masterflex® L/S™ portable sampling pump drives, Cole-Parmer Instrument Co., Vernon Hills, IL). A sampling tube and an air tube, both polyethylene (Dayco® Imperial Poly-Flo®, Flowline Components Inc., Baltimore, MD), was constructed for each well to avoid cross contamination of samples. The air tube had an inflatable balloon attached to allow the well to be sealed when sampling. The tubes were folded and stored above the water between sampling events throughout the study.

Sampling began by unfolding and inserting the tip of the sample tubing 45 cm into the groundwater table. The air tube was placed slightly lower than the sampling tube and the balloon was inflated to restrict the sample to the upper 45 cm of the groundwater table. The sampling tube was connected to the peristaltic pump to draw groundwater up from the well. Three well volumes of water were drawn out of the well and placed into eight containers (150 mL or 250 mL with respect to the well diameter) to ensure that the final sample was representative of the groundwater. pH (+/- 0.1 pH units), temperature (+/- 0.5°C), and conductivity (+/- 10 us/cm) were measured on the final two containers of each collection to ensure that the samples had reached equilibrium (Eckhardt, 1995; Wilson, 1994). The 2002 sampling repeated these steps for samples taken in June and determined that purging eight container volumes in these wells resulted in a representative groundwater sample. Under this assumption, groundwater well samples were randomly tested for pH, temperature, and conductivity for the remainder of the sampling events. Samples were filtered (47 mm Millipore™ glass fibre prefilters C, Millipore Corp., Billerica, MA) in the field in 2002 to remove any sediment, collected in 22 mL polyethylene scintillation vials, and frozen until analysis.

Analysis

Thawed samples were analyzed for nitrate+nitrite, nitrite, and ammonium at the Michigan State University Soil and Plant Nutrient Laboratory. All samples were analyzed on a Lachat flow injection analyzer (model Quik Chem IV system, 1988). Nitrate+nitrite was analyzed using the cadmium reduction method, which reduces nitrate to nitrite by running the sample through a copper-cadmium coil. Nitrite was determined colormetrically following the same procedure, but was not run through the copper-cadmium coil. Ammonium was colormetrically determined using the Salicylate method. We found that nitrite and ammonium were negligible (mean not significantly different from zero, α=0.05) in all the groundwater samples.

A small subset of samples (approximately 100) across treatments and dates was analyzed for dissolved organic N. Dissolved organic N was not a major component of the total N within the groundwater. By measuring the dissolved organic N on a small subset, and nitrite and ammonium on all samples, it is implied that little N is leaving the various systems through groundwater in any form other than nitrate. Because of this, we report all results as nitrate-N.

Data was statistically analyzed using SAS statistical software version 8e. Analysis of variance for repeated measures was used to determine the significant differences between land uses. Differences between uses were tested using a proc mixed model with a 0.05 level of significance. Spatial power according to day of year was used for the variance structure to adjust for uneven intervals between sampling events.

Results

Land Use and Year Effects

Shallow groundwater nitrate-N was first analyzed to determine relationships to the four land use categories (FOR, OTX, OPER, and FCS) over six dates in 2001 and 2002 (Figure 2). Land use significantly affected ($p \leq 0.0001$) nitrate-N concentrations in groundwater. Nitrate-N year effects across all uses were not significant ($p=0.216$); interaction was significant ($p=0.002$). Groundwater below FOR (unfertilized for at least 40 years) and OTX (older *Taxus* plants not fertilized in the last 4 years) had average nitrate-N concentrations less than 10 mg/L, while nitrate-N concentrations beneath OPER 2001 and FCS 2002 were statistically higher than the 10mg/L MCL. Nitrate-N under OPER was not statistically different between years ($p=0.055$), but was significantly higher under FCS in 2002 compared to 2001 ($p=0.001$). OPER and FCS data were analyzed further to determine if the differences in vegetation within each land use affected groundwater nitrate-N.

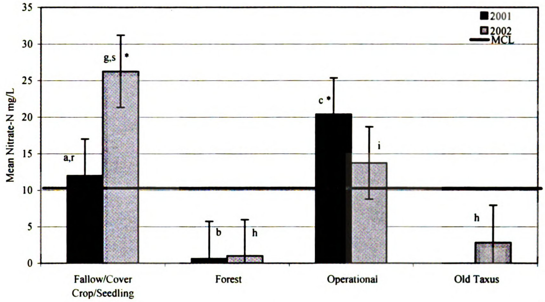

Figure 2. Mean (± SE) nitrate-N concentrations (8 wells per 6 sampling events) in the groundwater below the four land uses. Letters a,b,c, and g,h,i represent significant differences between treatments in 2001 and 2002, respectively (α=0.05). Letters r,s represent significant differences between years within treatment (α=0.05) and * signifies that the mean is significantly (α=0.05) above the MCL.

Species and Year Effects in Operational Land Use

Euonymus and *Taxus* fields within the OPER land use were analyzed to determine if species was related to groundwater nitrate-N concentrations and if the effects differed from 2001 to 2002 (Figure 3). Nitrate-N below the two species was statistically different (p=0.003); year effects were also significant (p=0.014); the interaction was not significant (p=0.344). Overall, nitrate-N below *Euonymus* was always higher than under *Taxus* (Figure 3). Nitrate-N concentrations were significantly different between years for *Euonymus* (p=0.018), but not for *Taxus* (p=0.14). Nitrate-N concentrations in shallow groundwater below *Euonymus* in both years were statistically higher than the MCL. OPER data was therefore divided into *Euonymus* and *Taxus* in all remaining analyses.

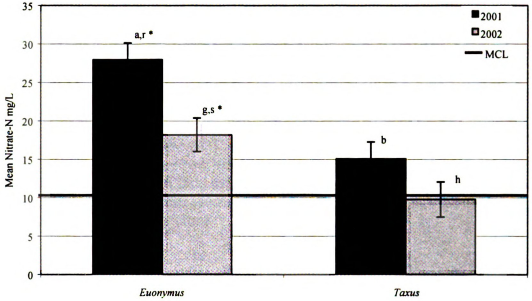

Figure 3. Mean (± SE) nitrate-N concentrations (4 wells over 6 sampling events) in groundwater below fertilized *Euonymus* or *Taxus* fields (previously combined as OPER land use). Letters a,b and g,h represent significant differences between treatments in 2001 and 2002, respectively (α=0.05). Letters r,s represent significant differences between years within treatment (α=0.05) and * signifies that the mean is significantly (α=0.05) above the MCL.

Effects in Fallow/ Cover Crop/ Seedling Land Use

FCS data were examined according to the vegetation of the various areas (Fallow, Cover Crop, or Seedlings) that initially had been grouped to designate land use (Figure 4). Vegetation factors were analyzed first to test for differences between species. Species differences within cover crops were not analyzed because wheat was only present for one sampling. The wheat data was eliminated from the data set and soybeans (SBN) became the only vegetation type within the cover crop area. Effects of spruce and *Taxus* seedlings were not significantly different (p=0.63); therefore, all seedling data points were combined for analysis.

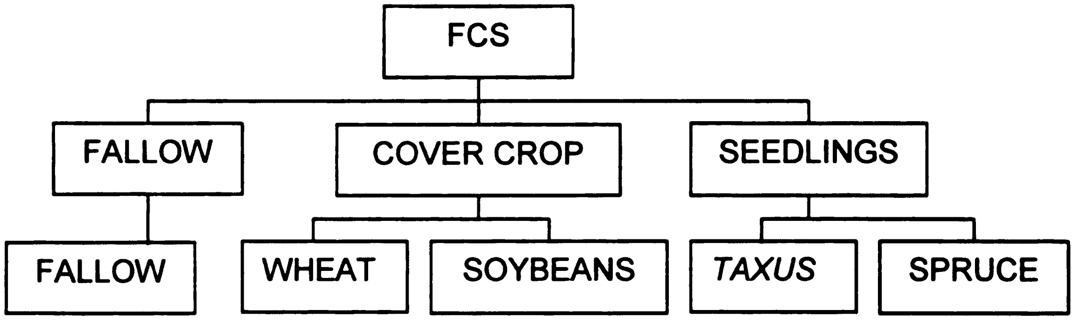

Figure 4. The breakdown of field use within FCS land use, which were being prepared for new plantings of coniferous seedlings. The vegetation was grouped into areas (Fallow, Seedlings, or Cover crop).

Once vegetation effects were found insignificant, area effects within FCS (Figure 4) could be analyzed. FCS data showed a significant day of year effect in both 2001 ($p \leq 0.0001$) and 2002 ($p=0.003$) and therefore are graphed as scatter plots in order to show seasonal trends that occurred. Nitrate-N below the soybean cover crop reached concentrations as high as 102 mg/L (Figure 5). This field (FCS 4) also received a manure application in 2001 and was believed to be fertilized while in the soybean cover crop. Nitrate-N concentrations under fallow and seedling areas were much lower (Figure 5) throughout the growing season in both 2001 and 2002. Nitrate-N beneath the soybean cover crop (SBN) was significantly greater than the fallow and seedling areas. Nitrate-N concentrations below the fallow and seedling areas were not significantly different and were grouped together for subsequent analyses. Nitrate-N concentrations in the shallow groundwater below the soybeans were significantly above the MCL for all sampling dates in 2002. Nitrate-N concentrations also significantly exceeded the MCL in 2001 under the fallow treatment on days 251, 275, and 303.

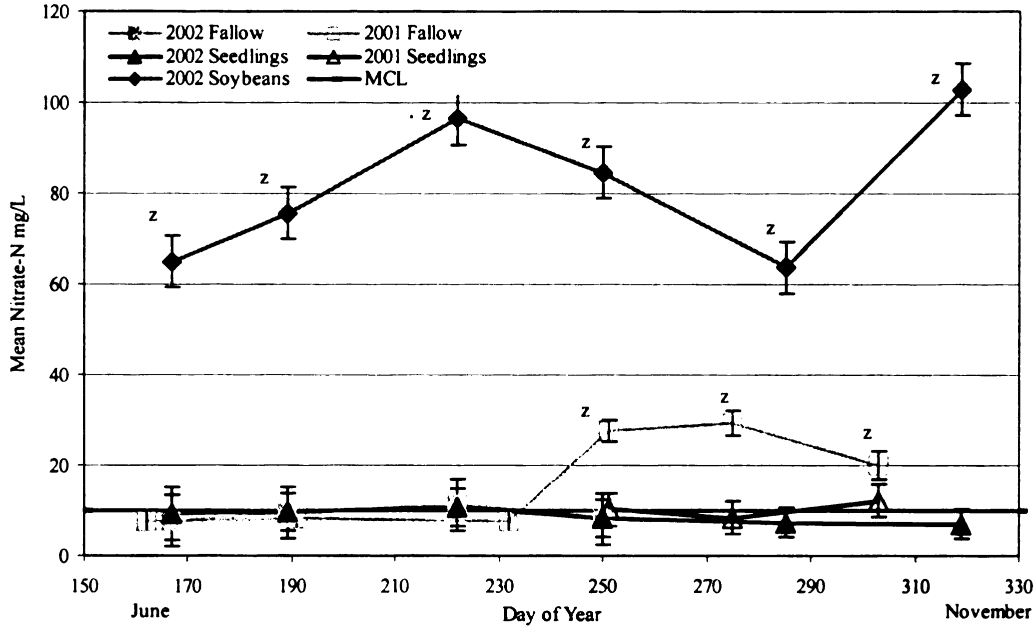

Figure 5. Mean (±SE) groundwater nitrate-N concentrations of the Fallow/Cover Crop/Seedling land use categorized into areas from sampling events June-November. The letter z signifies that the mean is significantly (α=0.05) above the MCL.

Additional Categorization of Land Use, Year, and Season Effects

Although sampled sites were originally categorized into four land uses (FOR, OTX, OPER, and FCS), subdividing the data obviously showed that more land use categories were needed because vegetation and species affect groundwater nitrate-N concentrations. Land use was reanalyzed (Figure 6) in view of the new use categories (FOR, OTX, *Euonymus*, *Taxus*, SBN, and Fallow or Seedling). Day of year was not significant in 2001 or 2002 once the land uses were further subdivided; therefore, data are shown in a bar graph by year (Figure 6).

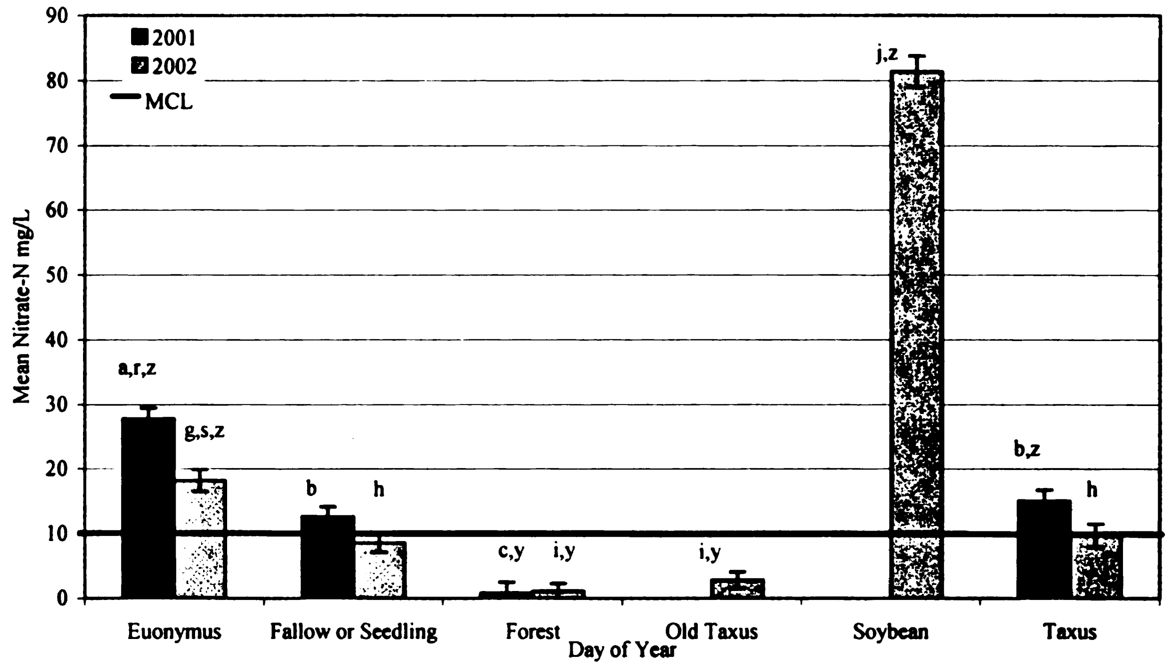

Figure 6. Mean (±SE) nitrate-N concentrations of 2001 and 2002 land use categories after dividing the Operational land use into *Euonymus* and *Taxus*, and the Fallow/Cover Crop/Seedling land use into Fallow or Seedling and Soybeans. Letters a,b,c, and g,h,i represent significant differences between treatments in 2001 and 2002, respectively ($\alpha=0.05$). Letters r,s represent significant differences between years within treatment ($\alpha=0.05$). Letter z,y signify that the mean is significantly above or below the MCL, respectively ($\alpha=0.05$).

Nitrate-N concentrations in shallow groundwater were significantly lower in 2002 beneath the *Euonymus* fields ($p=0.001$). Nitrate-N beneath the soybean cover crop in 2002 was significantly higher than all other land uses in both 2001 and 2002. Nitrate-N below FOR and OTX were significantly lower than the MCL. Nitrate-N below the soybean, *Euonymus* in 2001 and 2002, and *Taxus* in 2001 was significantly higher than the 10 mg nitrate-N/L MCL. Overall, the fertilized fields that contained smaller plants caused higher nitrate-N concentrations in the shallow groundwater. The unfertilized areas with large plants leached very low levels of nitrate-N into the shallow groundwater. Climatic changes from 2001 to 2002 could also have affected the amount of nitrate-N that percolated to the shallow groundwater. The 2002 season was a drought year and most of the fields were not irrigated. The lack of water leaching through the soil could have decreased the nitrate-N levels reaching the groundwater even though fertilizer applications were increased in 2002.

Discussion

Forest Land Use

Low levels of nitrate-N below FOR (not fertilized in at least 40 years) suggest that high biomass growth and no fertilization results in levels of nitrate-N in shallow groundwater far below the 10 mg/L MCL. Mueller (1995) and others have found nitrate-N concentrations in natural groundwater, such as under a forested area, to be less than 2 mg/L. Williams and Gresham (2001) noted that nitrate-N concentrations below a natural hardwood land use average < 0.5 mg/L. Jussy et al. (2002) determined that nitrate-N is only leached from a forested area if it is naturally produced in excess or added artificially. The low nitrate-N concentrations imply that any available inorganic N is quickly taken up due to the natural N-limited forest ecosystem. Although soil retains the largest pool of N in forests (Johnson, 1992), the dissolved organic N portion may not be readily available for plant uptake or leaching. Hedin et al. (1995) stated that total N hydrologic losses occurred as 95% dissolved organic N and as 0.2% inorganic nitrate-N. Our findings of low nitrate-N are consistent low inorganic levels; however, we also found low organic N portions in the shallow groundwater.

Older Taxus Land Use

Nitrate-N concentrations below OTX fields were all below the 10 mg nitrate-N/L MCL. This implies that if a moderately large biomass crop like older *Taxus* were left to grow in unfertilized conditions for four years, nitrate-N in shallow groundwater will be minimal. This may occur in less than 4 years. This indicates that contamination could be ameliorated in only a few years with increased plant demand and no or reduced fertilization, inorganic or manure.

Euonymus and Taxus Land Uses

Euonymus is a determinate grower with only one burst of growth early in the season; any fertilizer applied after the initial flush appears to be in excess, remains within the soil, and is thus susceptible to deep percolation when water is leached through the soil. Nitrate-N did decrease below *Euonymus* in 2002, which indicates that as the age of the plants increased, nitrate-N demand could have increased. Fertilization rate was higher in 2002 as well, but plant demand was also higher and compensated for the higher application rate. By 2002, any N additions from manure could have been reduced, accounting for the decrease in nitrate-N concentration. It appears that the *Euonymus* plants were operationally over-fertilized and this caused high seasonal leaching to occur.

Taxus, an indeterminate grower, takes up nitrate-N from the soil throughout the growing season, leaving less nitrate-N within the soil profile to leach to the groundwater. Average nitrate-N below *Taxus* decreased in 2002, to just below the 10 mg/L MCL, primarily due to an increase in plant size throughout the season. The decrease in nitrate-N groundwater concentrations suggests that an increase in plant size can begin to reduce nitrate-N leaching within one year. Although lower nitrate-N was measured beneath the *Taxus* plants, the nitrate-N entering the shallow groundwater was significantly higher than the older *Taxus* plants. The difference between *Taxus* plants suggests that the younger *Taxus* could receive reduced fertilization, which would economically save the nursery.

We speculate neither the *Euonymus* or *Taxus* plants are as N demanding as the larger plants present in the FOR or OTX areas, which can lead to higher nitrate-N concentrations in the groundwater. The *Euonymus* and *Taxus* fields also received fertilizer, which supplied more N than was needed to the plants in both 2001 and 2002. Higher nitrate-N below fertilized areas agrees with the results of Spalding and Exner (1993) who found that the level of nitrate-N is associated with the source availability along with regional environmental factors. Spalding and Exner (1993) studied nitrate-N concentrations throughout the U.S. and found that areas with well-drained soils dominated by irrigated agricultural land generally have concentrations above the 10 mg nitrate-N/L MCL.

Fallow or Seedling and Soybean Land Uses

In 2001, fields 1, 3, and 4 were fallow until sampling day 232, when two of the three fields changed in their land use. FCS field 1 was planted to tree seedlings, which did not increase nitrate-N because neither manure nor fertilizer was applied. In 2002, FCS field 1 received fertilization, and nitrate-N remained consistently close to the 10 mg/L MCL throughout the growing season, implying that the plants were taking up only a portion of the available applied N. These levels are significantly above nitrate-N concentrations seen below FOR, which suggests that the seedlings are not demanding the entire N source that is available, allowing leaching to occur. FCS field 4 was no longer sampled after day 232 because wells were destroyed during a manure application to the field in August. In 2002, field 4 was planted to soybeans and nitrate-N concentrations significantly increased to above 60 mg nitrate-N/L by May. Because groundwater was not sampled due to destroyed wells at the end of 2001, nitrate-N levels entering the groundwater due to the manure application are not known. However, nitrate-N concentrations were 40 mg/L greater in the spring than the previous fall. This increase could be due to 1) soluble nitrate-N or nitrified ammonium in the manure, 2) organic matter decomposing from the manure, or 3) from a suspected spring fertilization application of 84 kg N/ha. The large increase in nitrate-N from day 167 to day 222 could be from yet another fertilization application of 84 kg N/ha in July. Soybeans are supplied with N from biological N_2 fixation as well as from soil mineral N assimilation (Fabre and Planchon, 2000). For this reason, farmers in the United States do not normally apply inorganic N fertilizers or manure to soybean fields. Supplying FCS 4 with two N sources beyond the sources that legumes already fix, caused a large excess of N to build up in the soil and leach to the groundwater. Fabre and Planchon (2000) also state that in soils where the nitrate-N content is moderate, approximately 50% of N taken up by soybeans is derived from symbiotic fixation. In sandy loam soils, fixation can be as high as 75% of the N supply (Matheny and Hunt, 1983). After day 225, nitrate-N likely decreased because the inorganic fertilizer had been depleted and the soybeans were fixing less N leaving less to leach through the soil to the groundwater. By October, the soybeans began to die off and were plowed under causing a large disturbance in the soil. The decomposition of the root material would result in more organic matter present in the soil, which most likely caused the increase in groundwater nitrate-N on the last sampling day. Higher levels of precipitation at the time of low plant water use would also flush the excess nitrate-N out of the root zone and into the groundwater.

FCS field 3 was the only field to remain fallow through all of 2001. Nitrate-N concentrations increased from 7 mg N/L to 32 mg N/L in approximately 20 days and remained high for the rest of the growing season. The reason for this increase in nitrate-N is not known because no fertilizer was reportedly added to this field in 2001. Bauder et al. (1993) found that summer fallow practices often resulted in higher nitrate-N concentrations, especially when associated with organic matter mineralizing, which could explain the short increase in nitrate-N. Lateral flow could have also occurred from a nearby irrigation ditch to cause the increase. The field remained fallow in 2002 and levels returned to 7 mg N/L, implying that all excess nitrate-N might have been removed by runoff or penetrated deeper into the groundwater. The field was planted to seedlings in August 2002, but nitrate-N did not significantly change throughout either use. FCS field 2 was only sampled in 2002, and was planted to seedlings in July. The field was not fertilized and did not show any nitrate-N differences with the land use alteration.

Conclusions

We concluded that the fertilization history of an area does influence nitrate-N concentrations in shallow groundwater, but seasonal trends were not detected due to low replication. We found that areas that had high growth and had not received fertilizer in as little as 4 years had very low levels of nitrate-N reaching the groundwater. This suggests that nitrate-N contamination to the groundwater can be reduced in a short period of time if fertilization is completely eliminated. The continued success of the horticulture industry depends on fertilization, but we suggest that new fertilization practices that reduce application rates could help to alleviate potential nitrate-N problems within the industry. Eliminating manure applications can also help to alleviate potential contamination. As seen with the soybean field and *Euonymus* field 4, manure can add nitrate-N inputs for a long period of time. These additions matched with inorganic fertilizer inputs leads to a very large excess of nitrate-N that either has to be volatilized or leached to the groundwater. The soybean field is still problematic with the amended drinking water regulation of 20 mg nitrate-N/L in non-community water systems.

We concluded that nitrate-N concentrations in the groundwater are affected by plant age and size. Seasonal trends were not present in the larger, older plants that did not receive fertilization. We found that little nitrate-N was leached to the groundwater beneath larger, older plants such as FOR and OTX, which suggests that any available N was either taken up by the plants or volatilized. Seasonal trends were more apparent, but not significant, in the smaller, fertilized plants. Nitrate-N concentrations generally increased in the late summer, when deep percolation normally occurs, once plants were not taking up as much N as earlier in the season. This suggests that field nursery production within the horticulture industry has to be especially careful in fertilizing when stock is young and not as N demanding. Fertilizer applications can be reduced with the smaller age and size and the plant will still receive ample N throughout the growing season. Although nitrate-N below most of the fields was within the 20 mg nitrate-N/L amended drinking water standard, it would be an economical advantage to reduce fertilization within these crops. Once the plants are older and larger, they need more N and will be more likely to take up a majority of the fertilizer applied at the operational rate.

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CHAPTER THREE

FERTILIZATION IMPACTS ON NITRATE-N LEVELS IN FIELD NURSERY PRODUCTION

Abstract

Nitrate-N contamination to groundwater has become a major concern in nutrition management in agriculture and horticulture. In 2001 and 2002, we compared fertilization based on the RAR method to standard (operational) fertilizer practices of two nurseries in southwestern Michigan in *Taxus* (yew) and *Euonymus* (burning bush) fields. These practices were also compared to control plots that did not receive N fertilizer during the study. Soil water below the root zone and shallow groundwater were sampled beneath each of the treatments to determine if fertilization more closely matched to plant demand reduced the amount of nitrate-N that leached below the root zone and into the shallow groundwater. Nitrate-N in shallow groundwater did not differ between fertilization treatments. There was a significant decrease in nitrate-N between years, indicating that plant size and age reduced the amount of nitrate-N that percolated to the groundwater and N inputs from past manure applications had depleted. Species did influence nitrate-N in shallow groundwater. The RAR treatment reduced nitrate-N in soil water compared to the operational treatment, which suggests that reduced fertilization can reduce nitrate-N leaching. Nitrate-N concentrations in soil water decreased in 2002, suggesting that the larger plants demand more N, leaving less to leach below the root zone. *Euonymus* fields showed higher levels of nitrate-N than *Taxus*, but both species showed increases in nitrate-N at the end of the growing season. Further research should be conducted to determine fertilization practices for each species and age that would reduce nitrate-N concentrations late in the season.

Introduction

Background

Nitrogen (N) fertilizers are widely used in production agriculture and horticulture in order to meet the plant demand of these intensively managed systems. Since the introduction of synthetic fertilizers, N fertilizer use has increased twenty-fold in the United States (Nolan and Stoner, 2000). The increase in fertilizer use has caused increased awareness of the potential impact that fertilizers could have on groundwater quality. Nitrate-N is the most common nutrient in groundwater; nitrate-N contamination from agriculture production is the largest non-point source of pollution affecting groundwater quality (US EPA, 2000). In 2000, the United States Environmental Protection Agency (US EPA) determined that 135,000,000 people, including 99% of the rural population, in the United States obtain their drinking water from groundwater sources. High levels of nitrate-N in drinking water are known to cause methemoglobinemia in infants less than 6 months of age and have been speculated to be carcinogenic in adults. Because of human health concerns, the US EPA set a maximum contaminant level (MCL) of 10 mg nitrate-N/L in drinking water (US EPA, 2000).

Historically, drinking water wells were dug very shallow. Contamination of groundwater and newer technology has led to deeper installations where groundwater is less contaminated. This is only a temporary way to alleviate groundwater quality concerns; eventually, contaminants will reach drinking water depths. Improved fertilization practices that could be a permanent fix to excessive nitrate-N leaching need to be implemented in order to reduce groundwater contamination where it is occurring.

'Relative Addition Rate'

'Relative Addition Rate' (RAR) fertilization applications are an improved fertilization method proposed by Ingestad and Agren. Ingestad and Agren (1988, 1992) based the RAR method on the theory that relative growth rates of plants were equivalent to the relative uptake rates. If the relative uptake rate was determined, the same amount (RAR) could be replaced in the soil for uptake. With this method, additions are equal to uptake, which reduces the N loss to groundwater. Xu and Timmer (1998) further researched the RAR method and noted that in soil media, an additional nutrient supplement was needed at the beginning of the growing season for nursery seedlings. Alt (1998 a,b,c) and Goudling (2000) also stated that reduced fertilization applications matched to the plant demand will reduce nitrate-N leaching.

Research Goal

'Relative Addition Rate' (RAR) fertilization rates are compared to current fertilization practices (operational) as well as unfertilized areas (control) on two different woody ornamentals in four locations run by two cooperating growers located in the southwest portion of the Lower Peninsula of Michigan. Low nitrate-N leaching is important to this area because it constitutes 43% of Michigan's horticultural industry acreage (USDA, 2000). Michigan is also the fourth largest producer of landscape nursery ornamentals in the United States (USDA, 2002).

Varying fertilization practices were implemented in *Euonymus* (burning bush) and *Taxus* (yew), two of the dominant species in the industry. These two species also represent different growth habits. *Euonymus* is a determinate grower that produces one flush of growth early in the growing season. Determinate growing plants take up most of their N supply during this flush. *Taxus* however, is an indeterminate plant that grows and takes up N throughout much of the growing season.

Objectives and Hypotheses

By using varying fertilization practices, we will assess the following objectives.

Objective 1. Determine if fertilization rates affect nitrate-N concentrations in soil water and shallow groundwater.

We hypothesize that the RAR treatment will show reduced nitrate-N levels in soil water below the root zone as well as in shallow groundwater. Lowest levels of nitrate-N in both shallow groundwater and soil water should be observed below the control treatment and highest levels beneath the operational treatment.

Objective 2. Determine if there is an age effect in nitrate-N groundwater and soil water concentrations.

We hypothesize that nitrate-N concentrations beneath the RAR and control treatments should decrease in the 2002 samples compared to 2001 due to an extended decrease in fertilization rates as well as an increase in plant demand. We also hypothesize that the operational treatment should decrease nitrate-N slightly due to an increased plant N uptake.

Objective 3. Determine if the species variation affects nitrate-N concentrations and seasonal trends in shallow groundwater and soil water.

We hypothesize that less nitrate-N will leach through the soil to the shallow groundwater under the *Taxus* fields because of its indeterminate growth pattern. Seasonal trends of each species should determine the periods in a growing season that may be more susceptible to leaching events. In order for leaching to take place, excess nitrate-N must be present in the soil when precipitation and related deep percolation events occur. Because of these factors, it is hypothesized that leaching should occur in spring and fall of the growing seasons when precipitation is normally higher. Leaching should be less prevalent in the summer due to high evapotranspiration and a lack of water percolation below the root zone. It is also hypothesized that nitrate-N will be moderated throughout the growing season in *Taxus* due to its indeterminate growth pattern, while nitrate-N beneath the *Euonymus* fields will be more reflective of rainfall events.

Materials and Methods

Experimental Design

Experimental areas were located in Robinson or Holland Township in Michigan, in cooperation with two nurseries. Four fields composed of Granby loamy sand were selected to implement the study. Field 1 and 2 contained *Taxus cuspidate* 'Dark Green Spreader' (yew) and *Taxus x media* 'Runyan' (yew), respectively. Both fields 1 and 2 were planted in 1997. Fields 3 and 4 were both *Euonymus alatus* 'Compactus' (burning bush); however, field 3 was planted in 1997 and field 4 not until 2001. In 2001, the *Taxus* plants occupied 21.5% and 13.1% (canopy area x ground area / 100) of fields 1 and 2, respectively (Rios, 2002). *Taxus* plants were similar in size in both fields, averaging 22 cm in height. The *Euonymus* fields were not as similar as the *Taxus* fields in site occupancy in 2001. Plants in field 3 occupied 31.9% of the area, where plants in field 4 only occupied 6.7% of the field (Rios, 2002). Plants in fields 3 and 4 averaged 26 cm and 22 cm in height, respectively. All fields remained fully stocked with plants throughout the study, except for *Euonymus* field 3, which was 80% harvested in August of 2002.

Within the experimental areas, nine treatment plots (three treatments with three replicates) were established in a completely random design. The treatment plots averaged 20 m in length x one bed's width (1.5 m), which consisted of three rows of plants. Treatments were 1) operational, which imitated the cooperating nurseries fertilization applications, 2) 'Relative Addition Rate' (RAR), which received fertilization based on the uptake rate of the plant, and 3) control, which did not receive any N fertilizer throughout the study. Repeated measurements of nitrate-N were made on water collected just below the root zone and in shallow groundwater at 20 and 6 dates respectively, from early June thru mid November during 2001 and again in 2002. The 2001 soil water data was collected and originally reported by Rios (2002). These data were reanalyzed with the 2002 soil water data to determine year effects and draw more conclusions on the fertilization practices. The OPER well data were also used in another study we were conducting simultaneously (See Chapter 2).

Foliar N, Plant Crown Volume, and RAR calculations

Reconstruction of calculations to determine RAR fertilization rates was completed by reviewing calculations and figures developed by Rios (2002). In order to calculate the RAR application rate needed, monthly (June-October) foliar samples were taken. Foliage was harvested from random plants in the middle row of each treatment plot and analyzed to determine the N-content within the foliage. The foliar content was doubled to estimate the N-content in the stem and roots as well as the foliage.

Another factor in determining the RAR fertilization rate was plant crown volume, which was determined by measuring the height and two perpendicular diameters of a plant. Ten plants in the middle row of each treatment plot were tagged and measured monthly (June-October). The plant crown volume was inserted into a regression equation that predicted foliar biomass, which was multiplied by the determined foliar N concentration. The calculated foliar N content of the 30 day period could be compared to the previous 30 day period to estimate how much N the plant had taken up in that time. The difference in foliar content between the two dates was the fertilization rate that was added to the soil via inorganic fertilizer.

Fertilization

Fertilization Rates

A 20-0-10 ammonium nitrate based N fertilizer was used for all fertilization applications (Table 1). Operational plots were fertilized according to the nurseries current practice. In 2001, all operational plots were fertilized with 134 kg N/ha (120 lbs N/acre), split into two applications, one in May and one in June. In 2002, all operational plots received a higher rate of fertilizer, 84 kg N/ha with each application, totaling 168 kg N/ha (150 lbs N/acre) for the year (Table 1). This increase in fertilization was to account for larger plant demand with the increase in plant size.

Relative Addition Rate (RAR) plots were also fertilized with 20-0-10 ammonium nitrate based N fertilizer. These plots were fertilized on a monthly basis after sampling had determined how much N the plants had taken up in the previous 30 day interval (Table 1).

Fertilizer Applications

Regardless of the amount of the rate, fertilizer was applied uniformly to imitate a band application, which was the common application procedure followed by both nurseries. Weighed fertilizer amounts were subdivided into six equal portions. Shallow trenches (2-4 cm deep) were formed on each side of the three rows within the treatment plot and the fertilizer was evenly dispersed within each trench. Once the fertilizer was dispersed, the trenches were filled with soil to cover the fertilizer and minimize volatilization.

Table 1. 20-0-10 ammonium nitrate-N fertilization added to the operational and RAR treatments by field for 2001 (top) and 2002 (bottom).

	Operational Rate				RAR Rate			
Field	**1**	**2**	**3**	**4**	**1**	**2**	**3**	**4**
	(kg N/ha)				(kg N/ha)			
Day of Year								
129	67	67	67	67	34	34	34	34
164					61	44	8	2
183					28	58	2	2
213	67	67	67	67				
234					6	12	34	34
2001 Total	**134**	**134**	**134**	**134**	**128**	**148**	**78**	**72**
135	84	84	84	84	14	14	14	14
174					41	42	42	42
203	84	84	84	84	14	14	14	14
241					37	30	14	14
2002 Total	**168**	**168**	**168**	**168**	**106**	**100**	**84**	**84**

Shallow Groundwater Well Installation

Wells were placed in the treatment plot according to the directional flow of the groundwater. It was approximated that the shallow groundwater would move off of the plot in approximately 30 days. Groundwater samples were collected every 30 days in order to consistently collect water from the plot.

In each field, shallow groundwater wells were installed in two of the three replicates of each treatment. Installation began by establishing an installation pit (15-20 cm in diameter, 45-60 cm deep). A container, with a 10 cm diameter opening in the bottom, lined the installation pit to keep topsoil from contaminating the pit. The hole was extended to 1-1.5 m into the groundwater with a bucket auger. Wells, constructed of schedule 40 PVC with 1.5 m well point sections (5 cm inside diameter, 0.18 mm slot size, Big Foot Mfg., Cadillac, MI) and threaded to a riser section (Big Foot Mfg., Cadillac, MI) that protruded 40-90 cm out of the ground, were then inserted into the pit (Figure 1). Wells were closed with a threaded cap and adapter. The pit was backfilled with removed subsoil material to the base of the installation pit and a polyethylene percolation seal was tightly taped to the well over mounded subsoil. The installation pit was then backfilled with original topsoil and an infiltration seal was attached to the well. The seals were attached in order to keep preferential flow from occurring.

Wells were developed once they had been installed to dislodge fines from the well point. A surger was rapidly dropped into the groundwater and then forcefully pulled out; these steps were repeated five times. Once the wells had been surged, the water was drawn out of the well with a diaphragm pump (Teel® Model 3P739, Dayton Electric Mfg. Co., Miles, IL) to remove the fines. The surging and pumping procedures were alternately repeated until the water leaving the diaphragm pump was clear to slightly opaque.

Shallow Groundwater Sampling

Shallow groundwater was sampled using a peristaltic pump (Masterflex® L/S™ portable sampling pump drives, Cole-Parmer Instrument Co., Vernon Hills, IL) from June to November in 2001 and 2002. An air tube and a sampling tube, both polyethylene, (Dayco® Imperial Poly-Flo®, Flowline Components Inc., Baltimore, MD), were created for each well and stored within the well to avoid any cross contamination.

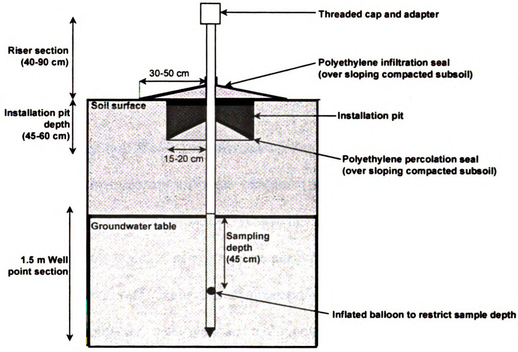

Figure 1. A shallow groundwater well schematic showing the installation design and sampling depth.

The air tube had an inflatable balloon on the end, which was inflated once the tube was placed 45 cm into the groundwater. Inflating the balloon restricted the sample to the upper 45 cm of the groundwater. The sample tube end was placed just above the air tube and was connected to the peristaltic pump. Three times the well water volume was displaced from the well prior to taking a sample. The water (~150 mL) was collected in a set of eight containers; the pH, conductivity, and temperature of the water in the final two containers was measured to ensure that the water to be sampled had reached equilibrium. A sample was then filtered (47 mm Millipore™ glass fibre prefilters C, Millipore Corp., Billerica, MA), stored in 22 mL scintillation vials, and frozen (-4°C) prior to analysis. This procedure was followed at each sampling event in 2001 and in the first sampling event (June) of 2002. After June of 2002, it was determined that purging 150 mL of water prior to sampling continuously produced samples with a similar pH (+/- 0.1 pH units), temperature (+/- 0.5°C), and conductivity (+/- 10 us/cm). These levels were monitored sporadically for the remainder of 2002 because of the accuracy found in sampling.

Porous Ceramic Cup Soil Water Sampler Installation

Two porous ceramic cup soil water samplers (model 1900, Soil Moisture Equipment Corporation, Santa Barbara, CA) were installed in the middle row, near the middle of each treatment plot. The porous ceramic cup soil water samplers, 61 cm in length, were installed at a 45° angle to place the ceramic cup directly below the root zone of the plant. A gas-powered auger was used to dig holes for the installation of the samplers. The porous ceramic cup of the sampler was coated with a silica flour slurry prior to the insertion to ensure that the cup would have good soil contact and successfully draw water out of the soil (Linden, 1977). Original soil material was used to refill the installation holes.

Soil Water Sampling

A tube opening within the cap of the sampler was connected to the peristaltic pump in order to apply a 3.76 bar (3.834 kg/cm^2) vacuum to the sampler in order to collect soil water for the next sampling event.

In 2001, sampling began by removing the cap of the sampler and inserting polyethylene tubing (Dayco® Imperial Poly-Flo®, Flowline Components Inc., Baltimore, MD) to the base of the sampler. The tubing was connected to a peristaltic pump (Masterflex® L/S™ portable sampling pump drives, Cole-Parmer Instrument Co., Vernon

Hills, IL), which drew the water up from the cup of the sampler. The soil water samples were collected in 22 mL scintillation vials. The sampler was emptied of any excess soil water and then resealed with the cap. A tube opening within the cap of the sampler was connected to the peristaltic pump in order to apply a 3.76 bar vacuum to the sampler in order to collect soil water for the next sampling event. Samples were collected 2-3 days after each significant rainfall event, resulting in 15 collections from May thru November.

In 2002, sampling techniques were altered slightly. In preparing for the 2002 season, we decided that it could be problematic to continue to remove the caps of the samplers because it affected the seal. If the caps would no longer hold a continuous tight seal, a vacuum would not be kept within the sampler, and soil water samples would not be available. We also believed that opening the tops of the samplers for each sampling event could introduce foreign objects into the cups. In May 2002, the inside of all of the samplers were rinsed thoroughly with double deionized water. Once the inside of the porous ceramic cup soil water samplers had been rinsed out, a piece of polyethylene tubing that was the length of the sampler was connected to the cap (Figure 2). The caps were then permanently attached to the samplers using silicone sealant. The tube opening within the cap was the only opening of the sampler, which was again used for applying the vacuum as well as drawing the sample.

Samples were taken weekly in 2002 in order to achieve a larger sample set to see more definitive seasonal and leaching event patterns. Samples were taken 2-3 days after each significant rainfall event in addition to the weekly sampling as necessary. Samples were filtered (47 mm Millipore™ glass fibre prefilters C, Millipore Corp., Billerica, MA) in the field directly into the 22 mL scintillation vials. Both 2001 and 2002 samples were frozen (-4° C) prior to analysis.

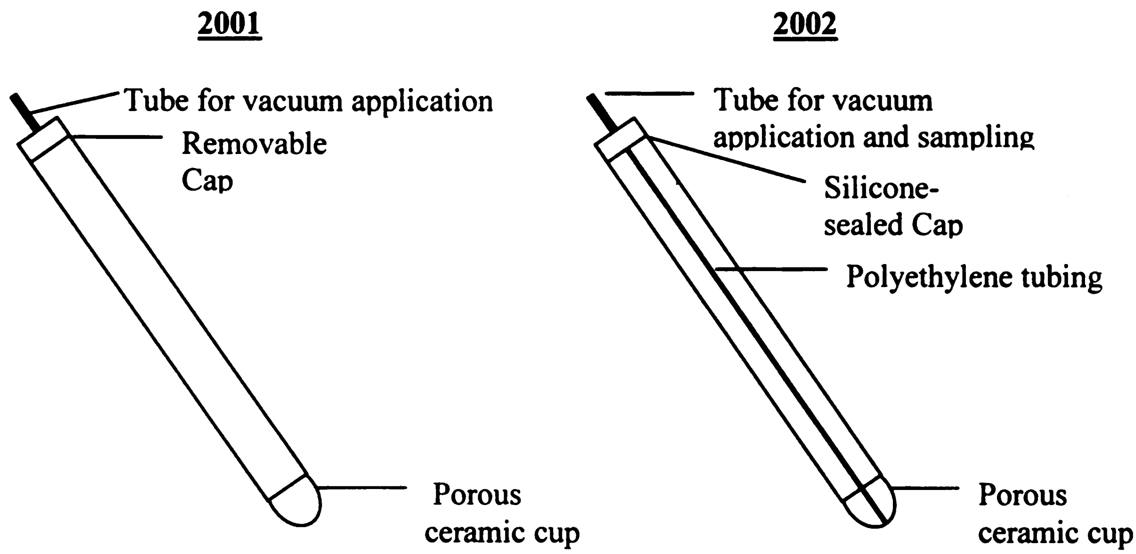

Figure 2. Porous ceramic cup soil water sampler schematic showing the construction of the samplers in 2001 and 2002.

Deep Percolation Estimation

Deep percolation was estimated using the Saxton et al. (1986) equation using the following assumptions: 75% sand, 20% clay, 3% soil organic matter and 0% coarse fragments by weight. A 30 cm thick root zone was calculated to have an available water capacity of 4.59 cm of water, with 2.64 cm of water in the soil being the wilting point and 7.23 cm being field capacity.

Hourly weather data from the MAWN (Michigan Automated Weather Network) system was downloaded (www.agweather.geo.msu.edu) for the West Olive site and used to compute daily data required to estimate FAO 56 reference evapotranspiration (REF-ET) according to Allen et al. (1998) for a grass reference. Sensitivity analysis with crop coefficient (Kc) varying from 0.82 to 1.00 indicated that the occurrence of DP was not sensitive to this range of coefficients; therefore, the daily crop PET was estimated by multiplying REF-ET by a Kc of 0.90. The resulting FAO 56 Penman-Montieth crop PET was then used in conjunction with precipitation and water balance methods adopted from Thornthwaite and Mather (1955) and Hewlett and Nutter (1969) to compute daily available water utilization, changes in soil water storage, actual evapotranspiration (AET), and estimated DP for each day of the growing season. Soils were assumed to be fully recharged at the beginning of the growing season and irrigation was incorporated into the balance as appropriate.

The reference PET was computed using REF-ET REFERENCE EVAPOTRANSPIRATION CALCULATOR Version 2.0 Windows. The REF-ET program supports reference ET computation guidelines and procedures that were by Jensen et al., (1990), Allen et al., (1998), and the ASCE, (2000). REF-ET was programmed at Utah State University and at the University of Idaho.

Analysis

In 2001, shallow groundwater and soil water samples were analyzed at the Michigan State University Soil and Plant Nutrient Laboratory using a Lachat flow injection analyzer (model Quik Chem IV system, 1988). Samples were analyzed for nitrate+nitrite using the cadmium reduction method. This method reduces nitrate-N to nitrite by running samples through a copper cadmium soil and then analyzes the nitrite colormetrically at 520 nanometers.

In 2002, shallow groundwater and soil water samples were analyzed for nitrate+nitrite as well as for nitrite and ammonium at the Michigan State University Soil and Plant Nutrient Laboratory using the flow injection analyzer. Nitrate+nitrite was analyzed the same as in 2001. Nitrite was analyzed colormetrically using samples that had not been run through the cadmium copper coil, and ammonium was analyzed colormetrically using the Salicylate method. Nitrite and ammonium were analyzed in 2002 to determine if other forms of inorganic nitrogen were present in the samples. Mean ammonium and nitrite concentrations were not significantly different from zero, leaving nitrate-N as the main source of inorganic N in the soil and groundwater. Because nitrite was negligible, nitrate+nitrite concentrations are reported as nitrate-N for the duration of the results.

Nitrate-N concentrations in shallow groundwater and soil water were analyzed statistically using SAS statistical software. Differences between treatments were determined by proc mixed with repeated measures using a 0.05 level of significance. Spatial power variance structure was used because sampling dates were not evenly spaced.

Results

Shallow Groundwater Nitrate-N Concentrations

Nitrate-N concentrations in shallow groundwater below different fertilization practices are presented and statistical inferences made for both *Euonymus* and *Taxus* on 2 fields each for years 2001 and 2002. Day of year effects were generally not significant for shallow groundwater samples; therefore, results are displayed as yearly averages and seasonal trends are not presented in graphs. The year mean results to be presented represent shallow groundwater samples from two wells over six monthly sampling events (June thru November). Each field was analyzed individually. Treatment differences within a year are generally reported first, followed by differences between years within treatment. Any significant differences in shallow groundwater nitrate-N concentrations from the 10 mg nitrate-N/L maximum contaminant level (MCL) are then reported.

Annual Mean Nitrate-N in *Taxus* Fields

In *Taxus* field 1 (Figure 3a), treatments were not significantly different from each other in 2001 or 2002 (p=0.33), year was significant (p=0.023), and the interaction was not significant (p=0.15). Nitrate-N below the RAR treatment in field 1 decreased significantly (p=0.022) between 2001 and 2002. The control and operational treatments did not significantly decrease in 2002. The nitrate-N concentrations beneath the RAR and operational treatments in 2001 were significantly above the 10 mg/L MCL. All others were within drinking water standards.

Nitrate-N concentrations beneath *Taxus* field 2 (Figure 3b) generally appeared to be less than nitrate-N under field 1 (Figure 3a). Treatments within each year of field 2 were not significantly different from each other (p=0.44). There was not a significant year effect (p=0.28), nor a significant interaction (p=0.42). Nitrate-N concentrations in the shallow groundwater beneath all treatments in both years of field 2 data were not significantly above the MCL.

Day of year was significant (p=0.03) only in samples beneath field 2 during 2002 although the data is shown in figure 3b as a bar graph. Nitrate-N beneath all treatments in 2002 field 2 decreased similarly throughout the growing season.

Annual Mean Nitrate-N in *Euonymus* Fields

Euonymus fields (Figure 4) generally showed higher nitrate-N in shallow groundwater than *Taxus* fields (Figure 3). Treatment in field 3 (Figure 4a) was significant (p=0.050), year was not significant (p=0.33), and the interaction was not

Figure 3a. *Taxus* field 1.

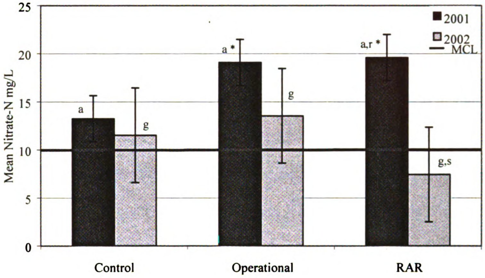

Figure 3b. *Taxus* field 2.

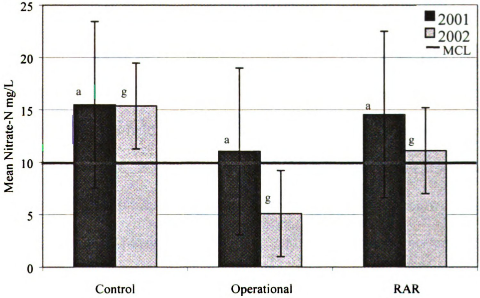

Figure 3. Mean nitrate-N mg/L (±SE) of shallow groundwater of *Taxus* field 1 and *Taxus* field 2. Letters a,b,c and g,h,i represent differences among treatments in 2001 and 2002 data, respectively (α=0.05). Letters r,s are present if there is a year effect (α=0.05) and * is present if the treatment is significantly different (α=0.05) from the maximum contaminant level (MCL).

significant (p=0.38). Treatments were not significantly different from one another in 2001, but in 2002, the control was significantly greater than the RAR (p=0.032). Nitrate-N concentrations in the operational and RAR treatments were not significantly different from 2001 to 2002. Nitrate-N concentrations in shallow groundwater beneath the control treatment in 2001 and 2002 and the operational treatment in 2001 were significantly higher than the MCL.

Nitrate-N concentrations in shallow groundwater beneath field 4 (Figure 4b) were similar to field 3 (Figure 4a). Treatment and year (Figure 4b) were not significant (p=0.47 and p=0.19, respectively); interaction was not significant as well (p=0.15). Treatments were not significantly different from one another in 2001 or 2002. The mean nitrate-N concentration was not significantly different beneath any of the treatments. Nitrate-N concentrations below the operational and control treatments in 2001 and the RAR treatment in 2002 were significantly higher than the 10 mg nitrate-N/L MCL.

<u>Comparison of Nitrate-N in Shallow Groundwater beneath *Taxus* and *Euonymus*</u>

Taxus fields 1 and 2 were not significantly different in 2001 (p=0.60) or 2002 (p=0.44); *Euonymus* field 3 and 4 were not significantly different in 2001 (p=0.97) or 2002 (p=0.90) either. Nitrate-N concentrations beneath the *Taxus* plots tended to slightly decrease in the autumn, where nitrate-N concentrations below *Euonymus* plots slightly increased at the end of the growing season. Nitrate-N concentrations beneath *Taxus* fields were significantly lower than below *Euonymus* fields in 2001 (p=0.038) and in 2002 (p=0.012).

Figure 4a. *Euonymus* field 3.

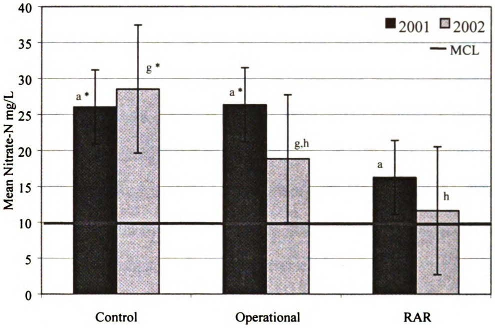

Figure 4b. *Euonymus* field 4.

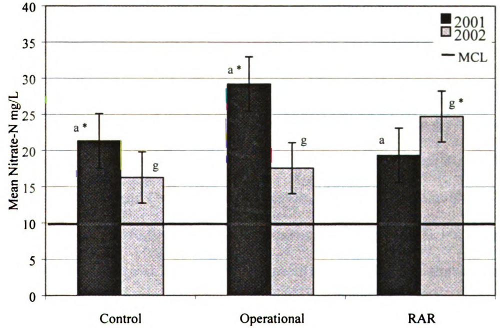

Figure 4. Mean nitrate-N mg/L (±SE) of shallow groundwater of *Euonymus* field 3 and *Euonymus* field 4. Letters a,b,c and g,h,i represent differences among treatments in 2001 and 2002 data, respectively (α=0.05). An * is present if the treatment is significantly different (α=0.05) from the maximum contaminant level (MCL). There were no significant year effects in *Euonymus*.

Soil Water Nitrate-N Concentrations

Because day of year is significant in much of the soil water nitrate-N data, soil water data are graphed by scatter plot, which display the day of year effects and seasonal trends. Each point in the graphs represents the average of up to six soil water samples (three replicates x two soil water samplers, less any missing values). Soil water was sampled 15 times in 2001 and 20 times in 2002. Soil water data from 2001 was originally reported by Rios (2002) and is further examined here with the 2002 data. For each year and field the treatment differences, day of year effect, and significance from the maximum contaminant level (MCL) are presented.

Nitrate-N in *Taxus* field 1

In both years, the soil water nitrate-N under the operational treatment in *Taxus* field 1 reached concentrations near 80 mg/L. The RAR and control treatments displayed much lower nitrate-N concentrations, only reaching peaks of 34-40 mg nitrate-N/L.

In 2001 (Figure 5a), soil water nitrate-N concentrations beneath *Taxus* field 1 increased and then decreased beneath all treatments throughout the growing season. They decreased in a similar pattern with nitrate-N concentrations greatest in the operational treatment. Over the growing season, treatments were significantly different from one another ($p=0.014$), day of year was significant ($p\leq0.0001$), but the interaction was not significant ($p=0.75$). Nitrate-N beneath the operational treatment was significantly higher than the RAR treatment from day 155 to day 200, and significantly above the control treatment on day 170. Nitrate-N under the operational treatment was significantly greater than the MCL from day 155 to day 200 (June and July), as well as on day 225.

In 2002 (Figure 5b), soil water nitrate-N greatly increased under the operational treatment after day 203, when the operational plots received 84 kg N/ha. The RAR and control nitrate-N concentrations showed smaller increases and all treatments showed highest various sized peaks on day 265. Nitrate-N concentrations in soil water beneath the treatments were significantly different over the growing season ($p=0.001$), day of year was significant ($p\leq0.0001$), and the interaction was significant ($p=0.003$). Nitrate-N in soil water under the operational treatment was significantly greater than the control treatment from day 225 to the end of the growing season (August thru November). The operational treatment was also significantly above the RAR treatment from day 252 to day 307 (September thru November). All treatments were significantly different from one another on day 307. Nitrate-N concentrations were significantly greater than the MCL under the operational treatment from day 225 to day 307 and beneath the RAR treatment from day 252 to day 307.

Nitrate-N in *Taxus* field 2

In *Taxus* field 2, 2001 data (Figure 6a) tended to have higher nitrate-N concentrations than field 1 data. Nitrate-N beneath field 2 reached concentrations as high as 100 mg/L, but greatly decreased in 2002, reaching a maximum concentration of approximately 40 mg nitrate-N/L. Soil water nitrate-N beneath field 2 in 2001 generally increased in concentration at the beginning of the season and tended to decrease throughout the sampling period. Treatments were significantly different ($p=0.019$). Day of year was also significant ($p=0.019$), but the interaction was not significant ($p=0.34$). Nitrate-N concentrations beneath the operational treatment were significantly greater than

Figure 5a. 2001

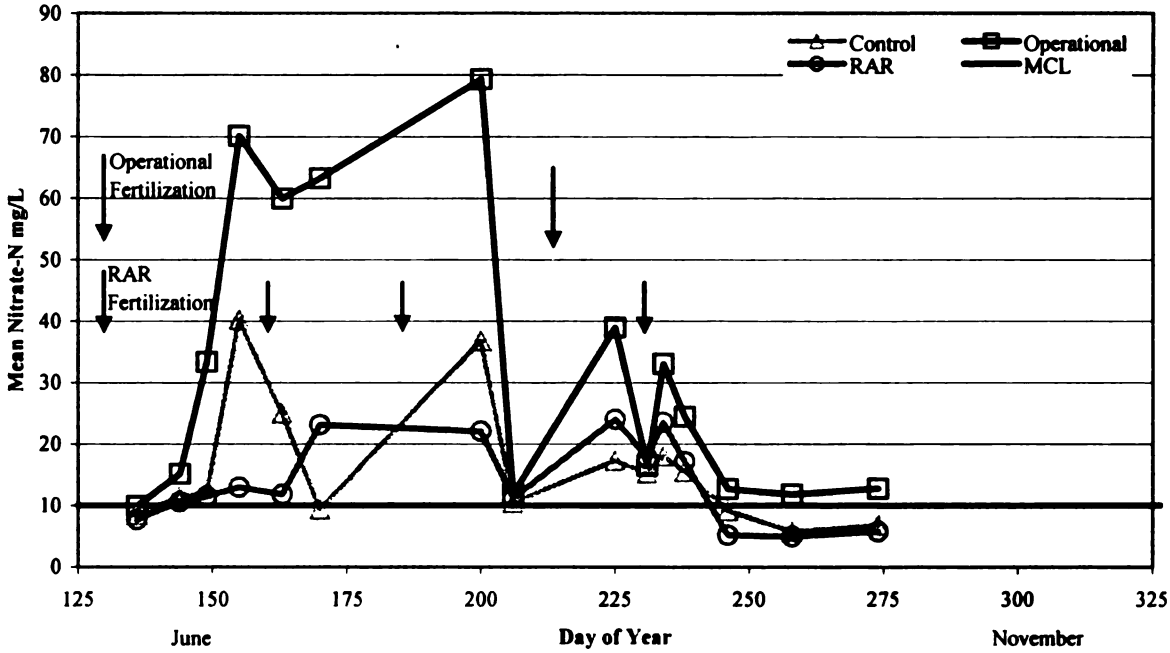

Figure 5b. 2002

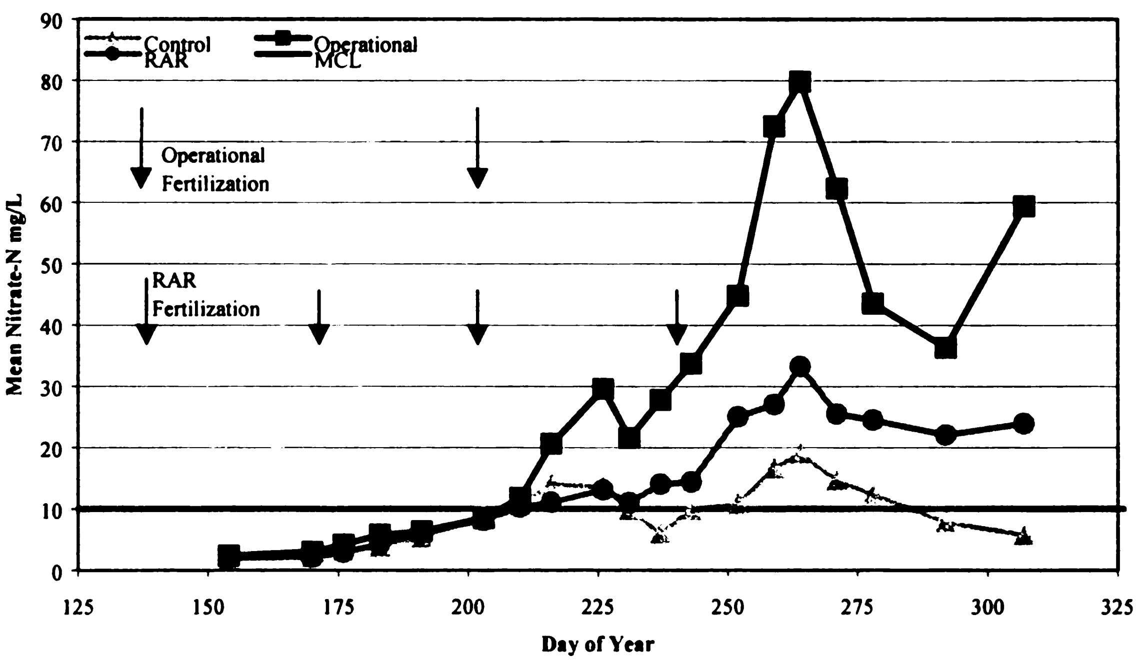

Figure 5. Soil water nitrate-N mg/L for *Taxus* field 1 in 2001 and 2002.

the RAR and control treatments on day 246. Control was significantly lower than the operational and RAR treatments on day 200. Soil water nitrate-N concentrations were significantly above the MCL under the operational and RAR treatments for a majority of the sampling events between July and October (day 200 to day 264).

In 2002 (Figure 6b), nitrate-N leaching was minimal at the beginning of the year, gradually increased reaching its maximum concentration at day 250, and then slowly decreased for the remainder of the season. Treatment and day of year in 2002 were significant ($p=0.008$ and $p\leq0.0001$, respectively), but the interaction was not significant ($p=0.18$). Nitrate-N beneath the control started at a low level and was much lower than the other treatments for most of the growing season. Nitrate-N under the control was significantly lower than the RAR on day 259 and 271 and the operational from day 252 to day 307. The RAR was significantly above the both the operational and control on day 243. Nitrate-N was significantly above the MCL beneath the RAR treatment from day 225 to day 278 (August thru October) and the operational treatment from day 259 to day 307 (September thru November).

Comparison of Nitrate-N in *Taxus* fields

The *Taxus* fields in 2001 were significantly different ($p=0.025$), implying that the species variation, spacing of the plants, or field characteristics of fields 1 and 2 caused differences in the soil water. The operational and RAR treatments were significantly different ($p=0.04$ and 0.02, respectively) in the two fields. In 2002, soil water nitrate-N concentrations beneath the *Taxus* fields were not significantly different ($p=0.13$).

Figure 6a. 2001

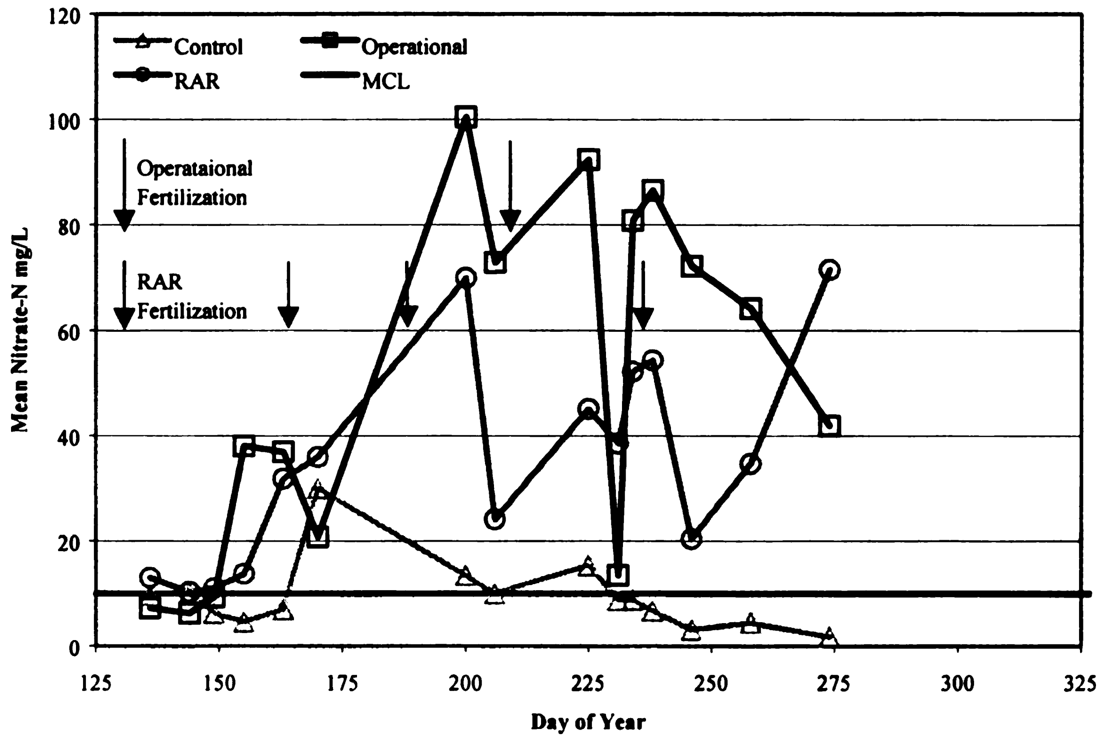

Figure 6b. 2002

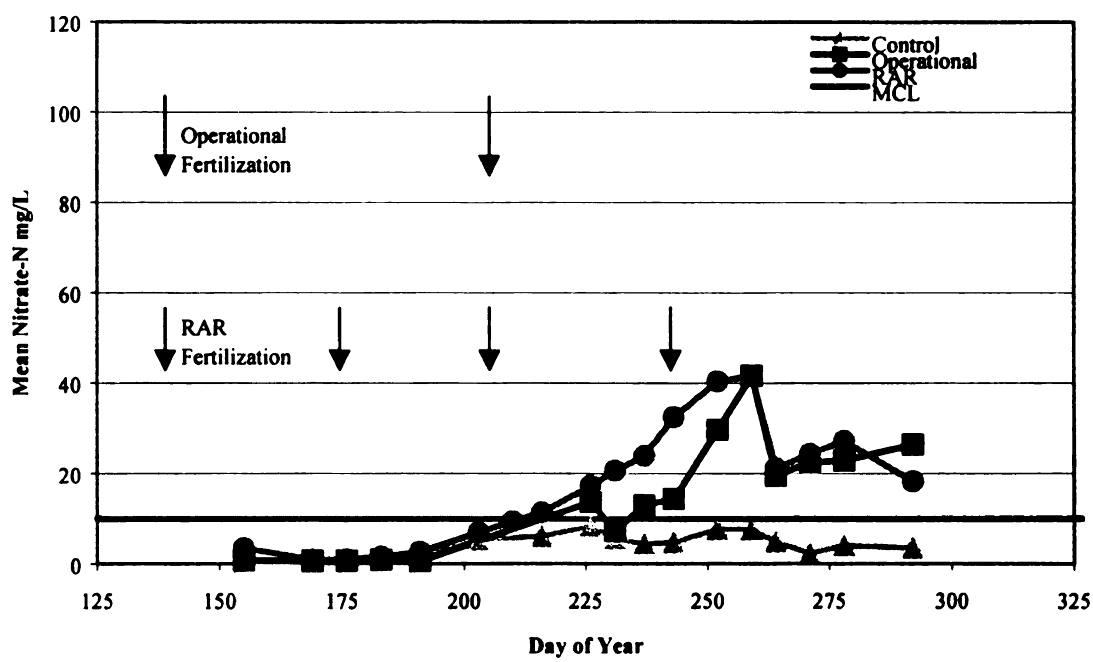

Figure 6. Soil water nitrate-N mg/L for *Taxus* field 2 in 2001 and 2002.

The change in significance could be due to increased plant size, climatic differences between years, reduction in N additions stemming from previous manure addition, or number of samples taken. The operational treatments in fields 1 and 2 were still statistically significant ($p=0.04$); however, the RAR and control treatments were not significantly different from one another.

Nitrate-N in *Euonymus* field 3

In 2001 (Figure 7a), nitrate-N in soil water beneath *Euonymus* in field 3 was not significantly different between treatments ($p=0.133$). Day of year was significant ($p=0.003$), and the interaction was not significant ($p=0.52$). The operational treatment tended to leach the highest concentration of nitrate-N, while the control tended to leach the least. All treatments start at low concentrations and gradually increase throughout the growing season. Nitrate-N concentrations in 2001 soil water samples were significantly greater than the MCL beneath the control, RAR, and operational treatments from day 258, 206, and 164, respectively, to the end of the sampling period.

In 2002 (Figure 7b), treatment was significant ($p=0.004$), day of year and interaction were also significant ($p\leq0.0001$ and $p=0.0002$, respectively). Nitrate-N started low in all treatments and then greatly increased beneath the operational treatment. Nitrate-N beneath the operational treatment was significantly higher than beneath the control and RAR treatments from day 226 to day 307 (August thru November). Nitrate-N beneath the RAR and control treatments was not significantly different from one another. Nitrate-N under the operational treatment was significantly above the MCL from day 226 to day 307.

Figure 7a. 2001

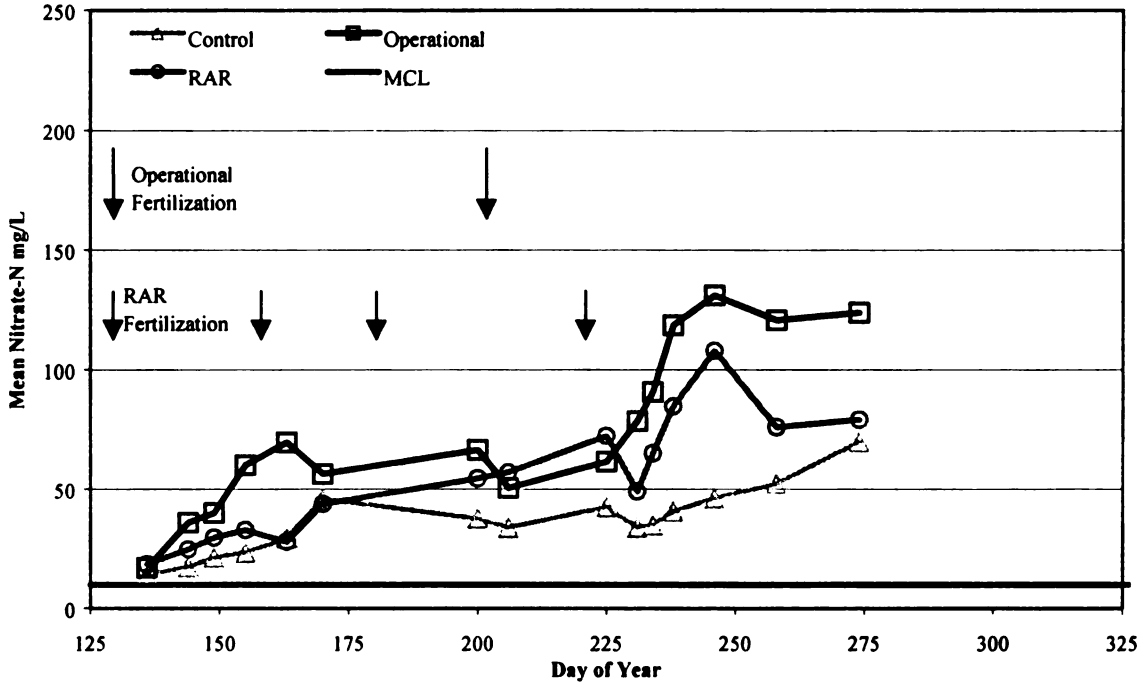

Figure 7b. 2002

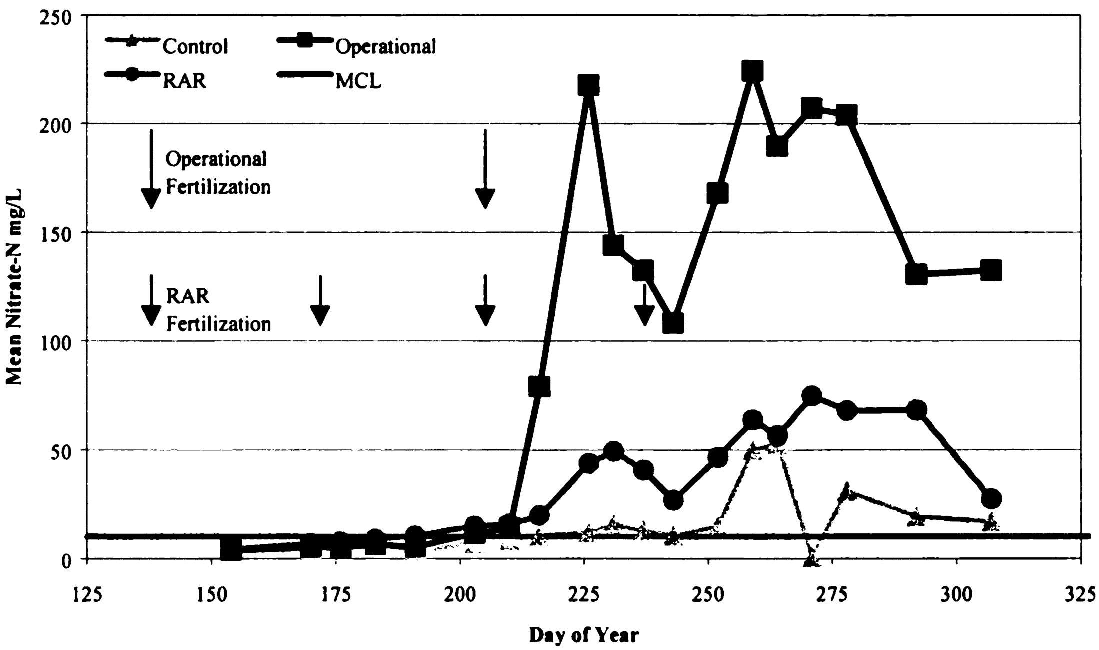

Figure 7. Soil water nitrate-N mg/L for *Euonymus* field 3 in 2001 and 2002.

Nitrate-N in *Euonymus* field 4

In *Euonymus* field 4, nitrate-N concentrations were slightly higher in 2001 (Figure 8a) compared to field 3, but in 2002 (Figure 8b) concentrations were much lower. In 2001 (Figure 8a), there were no significant differences (p=0.15) between treatments. Day of year was significant (p=0.0004), but the interaction was not (p=0.15). Tests indicated that the operational treatment did leach significantly higher concentrations of nitrate-N than the RAR and control treatments on day 200 and 238. Nitrate-N beneath the operational treatment was also significantly higher than the control on day 246 and 249. Nitrate-N beneath all treatments was significantly above the MCL on most dates from day 200 to the end of the growing season (July thru October).

In 2002 (Figure 8b), treatments were significant from one another (p=0.050). Day of year and the interaction were significant (p=0.0001 and p=0.0005, respectively). The 2002 nitrate-N concentrations in soil water below the operational treatment increased faster than the RAR and control treatments. The treatments especially separated by the autumn of 2002 (operational > RAR > control). Nitrate-N beneath the operational treatment was significantly above the control treatment from day 225 to day 307 (August thru November), excluding day 231 and greater than the RAR treatment on varying sampling days throughout August and September. Nitrate-N concentrations were significantly above the MCL beneath the operational treatment from day 200 to day 307 and beneath the RAR from day 264 to day 278.

Figure 8a. 2001

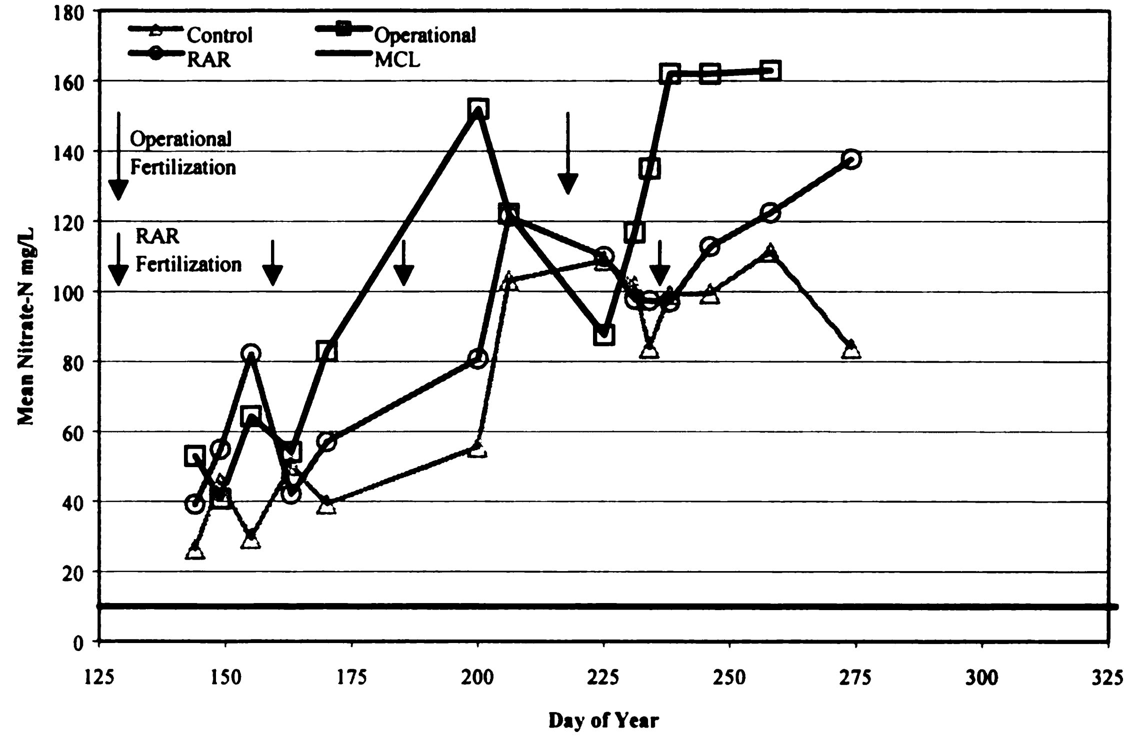

Figure 8b. 2002

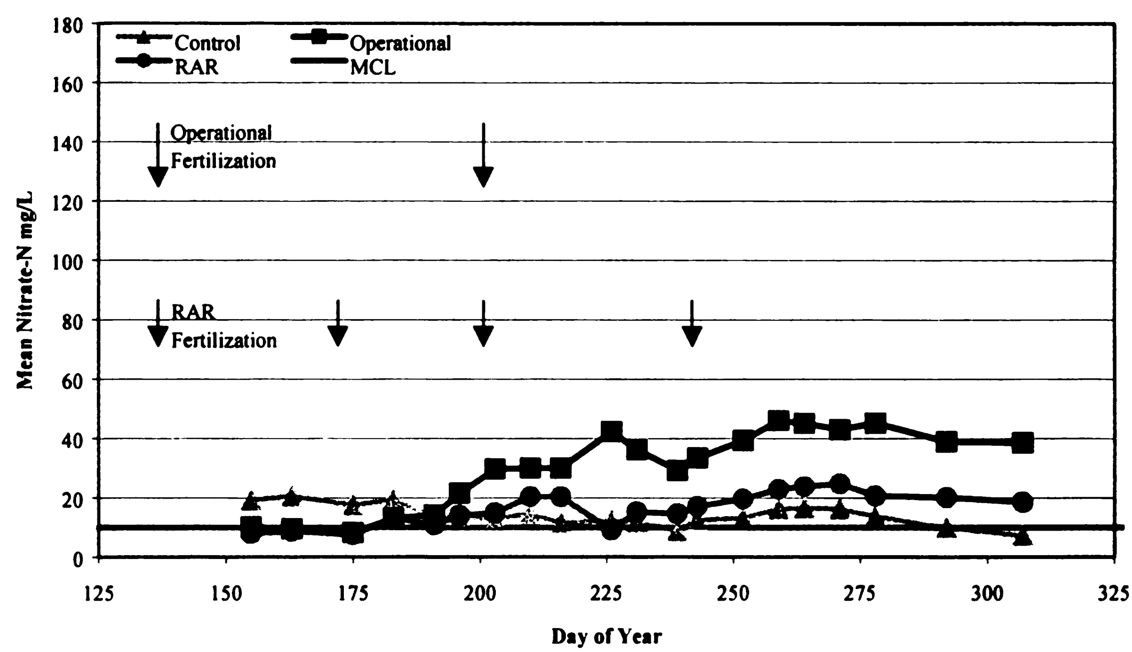

Figure 8. Soil water nitrate-N mg/L for *Euonymus* field 4 in 2001 and 2002.

Comparison of Nitrate-N in *Euonymus* fields

The *Euonymus* fields in 2001 were significantly different from one another ($p=0.035$). This difference could be caused by the age difference between fields and/or because manure was applied only to field 4. In 2002, nitrate-N in the soil water beneath the *Euonymus* fields was not significantly different ($p=0.094$). The manure application to field 4 was not a factor in the N amount in 2002 and plant size was more comparable. The treatment differences between fields were not significant in 2001 ($p=0.118$). The operational treatment differences between fields 3 and 4 were significant in 2002 ($p=0.019$), but the control and RAR treatments in the two fields were not different from one another.

Soil Water Nitrate-N Comparison Between Two Species

Species were significantly different ($p=0.008$) in 2001, but not in 2002 ($p=0.26$). This implies that as the plants increase in age and biomass, less nitrate-N percolates through the root zone to the soil water because there is larger plant demand for N in both species. The indifference between species in 2002 could also be related to the manure effects in part of the fields. These fields had not received manure for at least two years, which could indicate that the manure decomposition was completed and no more N could be mineralized from this additional source.

Discussion

Shallow Groundwater Nitrate-N

Taxus

Both fields of *Taxus* reflected lower concentrations of nitrate-N beneath the fertilized treatments in 2002, which suggests that there was more plant N uptake in 2002 or excess N from manure had mineralized, or both. Neither fertilization practice leached nitrate-N concentrations that were significantly above the 10 mg/L maximum contaminant level (MCL) on average, indicating that the *Taxus* took up a majority of the N supplied.

Nitrate-N beneath the RAR treatment in *Taxus* field 1 decreased significantly in 2002, which suggests that the RAR fertilization technique potentially limits the amount of nitrate-N reaching the groundwater.

Euonymus

The highest levels of nitrate-N in shallow groundwater were measured below *Euonymus* field 4. This field received a heavy manure application prior to planting; high levels in 2001 nitrate-N suggest that organic matter from the manure was decomposing and adding excess nitrate-N to the soil that was leached to the groundwater. An operational fertilization of 134 kg N/ha plus a manure application caused nitrate-N levels in shallow groundwater to be significantly above the maximum contaminant level. Nitrate-N beneath most treatments decreased in 2002, which suggests that the manure had less effect on nitrate-N concentration and that plant N uptake was higher.

Species Comparison

The difference in nitrate-N concentration in shallow groundwater between *Taxus* and *Euonymus* suggests that the different growth habits of the two species affects the timing and amount of nitrate-N that is taken up by the crop and that leaches to the groundwater. Because *Taxus* is an indeterminate grower, it will take up nitrate-N throughout much of the growing season, leaving less to leach to the groundwater. *Euonymus* takes up N for a much shorter period of time, taking up less N in midsummer to fall so more leaches with deep percolation to increase overall nitrate-N levels in the shallow groundwater. Most nitrate-N levels below the treatments in all fields decreased in 2002, which could be due to the increase in plant size or the elimination of mineralization and nitrification of manure N.

Implications

Although most of the shallow groundwater average nitrate-N concentrations are not over the legal drinking water limit, they are higher than naturally occurring nitrate-N concentrations that suggest that there is a potential problem. Nolan et al. (1998) states that nitrate-N can exist in groundwater for decades and increase in concentration with continued fertilizer application. Groundwater contamination can also be discovered long after it occurred because of the slow movement of groundwater (US EPA, 2000).

Conclusions

The results obtained in this study are similar to the water quality assessment conducted by the USGS from 1992-1995, which indicated that nitrate-N concentrations in shallow groundwater beneath agricultural land averaged 3.4 mg nitrate-N/L (Nolan and Stoner, 2000). They also found ammonium and nitrite concentrations were approximately 13 times less than nitrate (Nolan and Stoner, 2000). We found negligible concentrations of both implying that nitrification occurred very rapidly in these soils converting ammonium N to nitrate-N. The sandy soil makes conditions unfavorable for denitrification (i.e. aerobic environment) to occur, which could decrease nitrate-N concentrations in shallow groundwater (Stoner et al, 1998). These low concentrations in shallow groundwater also show the limited mobility of ammonium and nitrite.

The effectiveness of reduced N fertilization is suggested in the shallow groundwater data, but we could only detect large differences. The large amount of variability seen throughout the data could be due to the small plot size and limited replication. Increasing the number of replications in each field could increase the power of our tests, allowing us to draw more conclusions on the effect that fertilization practices have on nitrate-N concentrations in shallow groundwater. The inability to detect small differences could also indicate that the groundwater being collected was from off the plot. Soil water samples would alleviate this potential problem and give a better indication on the effectiveness of reduced fertilization practices.

Soil Water Nitrate-N

Taxus

Nitrate-N in soil water beneath *Taxus* fields reach peaks later in the growing season in 2002 compared to 2001. In 2002, both *Taxus* fields 1 and 2 reach peaks in mid-September, which implies that the plants were more actively taking up N prior to this point or that deep percolation was not occurring. The plants were more N demanding in 2002, and took up more of the available N until later in the season. Nitrate-N concentrations did not exceed the MCL in 2002 until later in the season as well, which implies that fall fertilization is not necessary in *Taxus* fields because the plants are not demanding as much N in that time period.

High precipitation and irrigation occurred in 2002 during the time of increase in nitrate-N concentration (Figure 9). Although our water balance data indicate that significant deep percolation does not occur during this time, some deep percolation must have occurred and caused available N to percolate quickly, resulting in the peaks in soil water nitrate-N concentration. Because deep percolation volumes were small, effects on groundwater concentrations were much less.

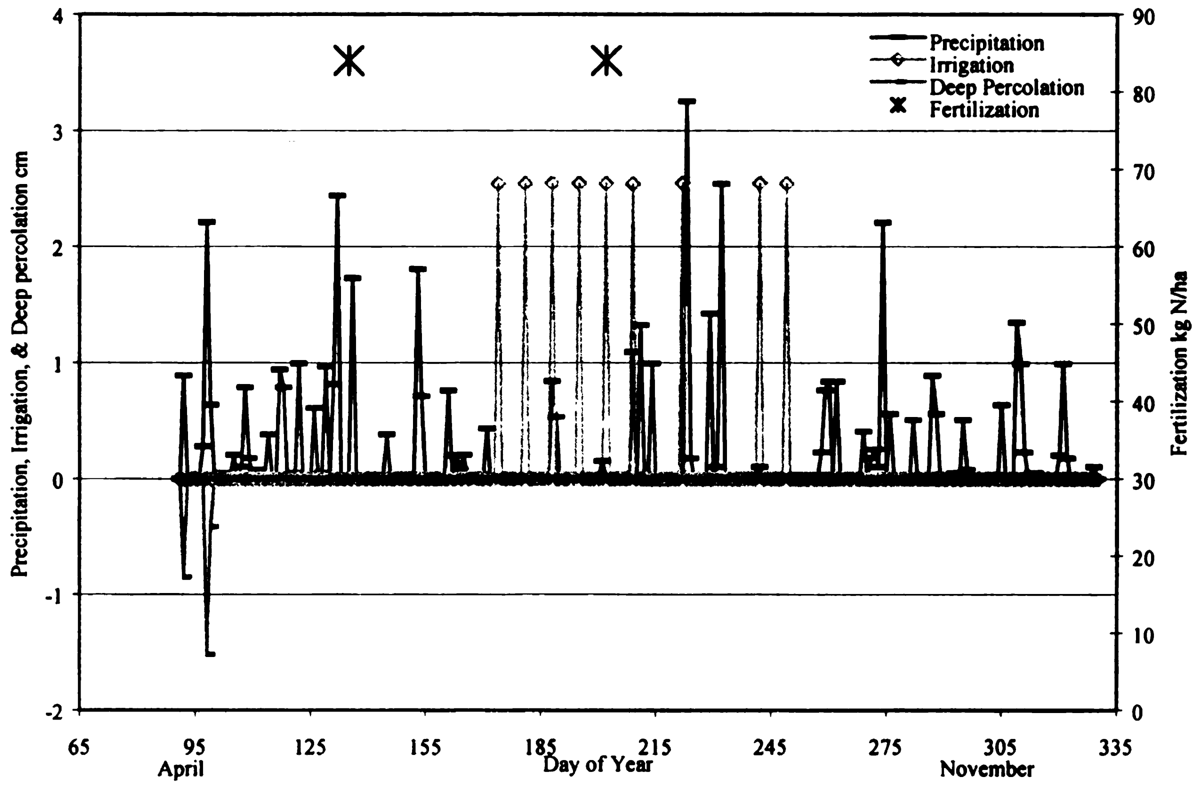

Figure 9. Precipitation, irrigation, deep percolation, and fertilization during 2002 for fields 1, 2, and 3 in Robinson Township in southwest Michigan.

Euonymus

In 2001, nitrate-N beneath the control and RAR treatments caused nitrate-N concentrations as high as 110 mg/L in field 3. In 2002, nitrate-N beneath these treatments rarely exceeded 50 mg/L. Nitrate-N concentrations under the operational treatment in 2001 reached 130 mg/L; in 2002, concentrations were nearly 230 mg/L at two different sampling events. The largest increase in nitrate-N concentration in soil water was seen soon after we applied 84 kg N/ha to the operational treatment on day 203. Also by August, approximately 80% of the plants in this field were lifted. This left a severely decreased biomass in the field to take up available N. Two large precipitation events also occurred at this time (Figure 9), which most likely flushed high concentrations of available nitrate-N below the root zone due to the lack of plants within the field.

Field 4 was located in Holland Township and had a different weather station than the other 3 fields. The 2002 water balance and fertilization can be seen in Figure 10. In 2002, all nitrate-N concentrations in field 4 treatments were below 50 mg/L throughout the growing season, which is significantly lower than 2001 concentrations that were approximately 160 mg nitrate-N/L at its maximum. This field received a manure application and cover cropping prior to the installation of the study in 2000, which could account for the dramatic decrease between years. In 2001, more N from the manure could have been mineralized, nitrified, and leached, while by 2002 much of the decomposable organic matter could have been mineralized. There was a large increase in nitrate-N late in the summer of 2002. The increase in nitrate-N concentrations is directly following two large precipitation events that led to significant leaching events in August, implying that available N was percolated with the leachate to below the root zone. These precipitation events likely leached high concentrations of nitrate-N to the shallow groundwater.

Species Comparison

Overall, soil water sampled under the *Euonymus* treatments displayed higher nitrate-N concentrations than under the *Taxus* treatments. All *Euonymus* treatments generally started at low nitrate-N concentrations and then increased throughout the growing season. Studies have shown that nitrate-N leaching is most susceptible in the spring when drainage is high and in the autumn after harvest (Di and Cameron, 2002). Di and Cameron (2002) state that 50-70% of the accumulated nitrate-N will leach during the autumn and winter. Nitrate-N is less likely to leach when plant demand is high as in late spring and summer unless fertilizer application rates are extremely high (Di and Cameron, 2002). This is also the period when deep percolation is usually low. White et al. (1983) reported similar results, finding 23-25% of leaching occurring in the autumn with the remaining in the winter; these levels would leave virtually no carryover into the spring. Duynisveld (1988) also found that excess N leaches out of sandy soils in the winter months.

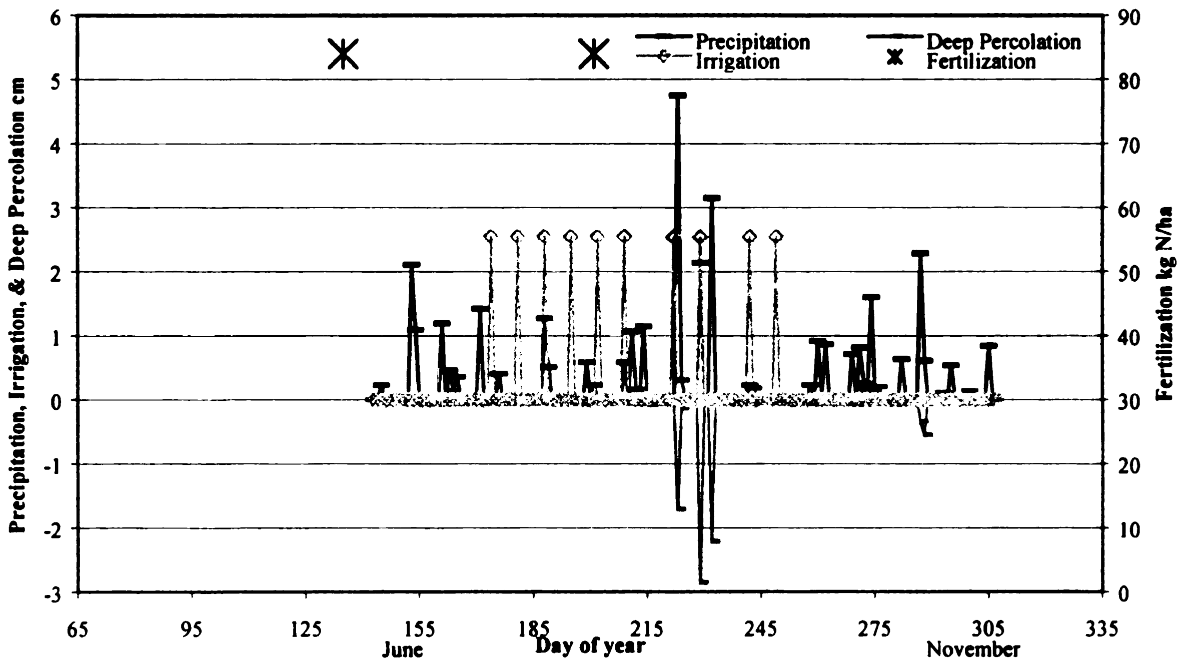

Figure 10. Precipitation, irrigation, deep percolation, and fertilization during 2002 for field 4 in Holland Township in southwest Michigan.

Implications and Conclusions

Williams and Gresham (2001) state that soil nitrate-N level in water show patterns much more clearly than the groundwater data. The soil water data in this research reflected this. The soil water data more clearly showed that the operationally fertilized plots did generally display higher nitrate-N concentrations than the RAR fertilization practice and the control treatment. Goulding (2000) and others found that splitting fertilizer applications in an approach similar to the RAR methodology was most effective in reducing leaching losses.

In 2002, the nitrate-N leaching decreased, which supports our hypothesis that the larger plant demand within the older plants will decrease nitrate-N leaching. The decrease could partially be due to the depletion of N from the previously applied manure. These data suggest the decreased fertilization practice using the RAR methodology will decrease the amount of nitrate-N that could eventually reach the groundwater. By more closely matching plant demand with N inputs, less nitrate-N was available to leach to the groundwater. Because Ingestad and Agren's work was done under steady-state nutrient conditions (1988), this methodology in the field may need to be further studied to obtain the least nitrate-N leaching possible. Alt (1998a) suggested that the N present within the soils should also be considered to avoid over-fertilization.

Foliar Nitrogen

Symptoms of a N deficiency were not seen in any treatment in 2001 or 2002. This implies that there was other N sources other than the inorganic N fertilizer additions that were available to the crops for at least a 2-year period. According to Marschner (1995), optimal foliar N is between 2 and 5% for woody ornamental crops. In 2001, Rios (2002) reported that foliar N was within this optimal range for all fields and all treatments. The conclusions made by Rios (2002) are consistent with 2002 data as well. This suggests that these fields had high nutrient status prior to fertilizer additions.

Conclusions

We conclude that fertilization rates affect nitrate-N concentrations in soil water. There were distinct reductions in nitrate-N in soil water in the autumn of 2002, which suggests that the RAR approach to reducing fertilization does reduce the amount of nitrate-N that percolates below the root zone. Although some of the data for the shallow groundwater suggested this, there was not a significant difference within the treatments to prove that the reduced fertilization was reducing nitrate-N entering the shallow groundwater. The data does strongly suggest that reduced fertilization practices are beneficial in reducing the amount of nitrate-N that reaches the groundwater, reducing the risk of future problems for nursery growers. Correct fertilizer additions are difficult to determine partially because of the large variety of crops as well as the age of the crops grown (Alt 1998c). Further research should be done to determine what ideal fertilization practices would be for these two species as well as others, developing fertilization guidelines for age and species specific practices for the field nursery industry to follow. It is also important to base nitrate-N leaching to deep percolation events and patterns.

We conclude that there is an age effect in nitrate-N groundwater and soil water concentrations. Year effects were more visible in the soil water, but the RAR treatment within *Taxus* field 1 did decrease significantly with increased age. The treatment year interaction within the soil water samples was significant, which implies that the increased age and size of the plants significantly decreased the amount of nitrate-N in the soil water. We also found that the fields had a high nutrient status that did not show N deficiencies throughout the study, including the control treatment that did not receive N fertilizer for 2 years.

We conclude that the species present affects nitrate-N concentrations in shallow groundwater and soil water, but only affects the seasonal trends in the soil water. Nitrate-N concentrations in shallow groundwater and soil water samples were significantly different between the *Taxus* and *Euonymus*, showing that the differing growth habits between the two species should be considered when fertilization recommendations are made. The *Taxus* took up more N because it naturally had a longer growth period, where as the *Euonymus* leached larger amounts of nitrate-N because it did not take up N throughout the growing season.

Soil water data more clearly showed seasonal trends that were occurring. The soil water data suggests that decreased fertilization can lead to less nitrate-N leaching to the soil water, which would eventually reach the groundwater. The shallow groundwater data did not as clearly define these relationships, although it did show a general trend that with increased age and plant size, less nitrate-N would leach into the groundwater. The groundwater results did prove there is a need for new management strategies to control nitrate-N contamination. Increased replication within the shallow groundwater wells probably would have more clearly defined the patterns that are occurring with nitrate-N concentrations in the groundwater.

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CHAPTER FOUR

SUMMARY AND RECOMMENDATIONS

Land Use Study

We concluded that the fertilization history of an area as well as the plant's age and size do influence nitrate-N concentrations in shallow groundwater. We found that older plants (40+ year old forests and 10-12 year old *Taxus*) that had moderate to large biomasses and did not receive fertilizer or manure for an extended period of time, leached very low amounts of nitrate-N into the shallow groundwater and nitrate-N concentrations were low.

Fields being prepared for tree seedlings generally leached low levels of nitrate-N during fallow periods and unfertilized seedling periods. These fields received varied fertilization, but overall did not receive fertilizer in the year that the field was planted to seedlings. The fields that were planted to seedlings had also not received manure since the mid-1990s. These fields indicate that little leaching occurs when fertilizer or manure is not applied. Soybean cover crop periods within these fields were fertilized with inorganic additions as well as manure, which resulted in very high concentrations of nitrate-N in the shallow groundwater.

Fertilized woody ornamental fields did show higher nitrate-N concentrations in shallow groundwater. Manure applied to one of the *Euonymus* fields in 2000 was most likely still undergoing mineralization and nitrification in 2001. The large decrease between years, suggests that manure has an extended effect on the nitrate-N that is present and susceptible to leaching. This is further supported by significantly higher nitrate-N concentrations in shallow groundwater obtained from beneath the soybean field that received manure and inorganic N fertilizers.

The *Euonymus* and *Taxus* plants were much smaller than the moderately large older *Taxus* and large forest trees, which could imply that they are not as N demanding. These levels were significantly higher than the 10 mg nitrate-N/L MCL below *Euonymus* fields, but not beneath *Taxus* fields. This suggests that fertilizer applications need to be altered according to the age of the plant and the species present. Regardless of the species, nitrate-N levels were significantly higher than the unmanaged, mature forested area, which implies that more nitrate-N is leaching to the groundwater than occurs naturally, and there is an economical as well as environmental advantage in reducing fertilizer applications in the woody ornamental fields.

Fertilizer Plot Study

We concluded that fertilization rates, plant age and size, and species affect nitrate-N concentrations in soil water, but not shallow groundwater nitrate-N concentrations. Nitrate-N concentrations in the shallow groundwater were not significantly lower with reduced fertilization, but in general the concentrations were decreasing. Nitrate-N also decreased in 2002, which further supports that older, larger crops leach less nitrate-N because they demand more N. It is difficult to separate this age/size effect from residual manure effects.

Soil water reflected significantly reduced nitrate-N in the RAR and control treatments, especially in 2002. The reduction between years could also be due to residual N inputs from manure. Nitrate-N in soil water below the RAR and control treatments generally remained lower in the autumn compared to the operational treatment. These results suggest that less leachable nitrate-N is present in the soil in the reduced fertilizer treatments. This also suggests that the reduced RAR fertilization practice is more closely matching plant demand and over-fertilization is less likely to occur. There were smaller increases in nitrate-N in soil water beneath the RAR treatment late in the season in both species, which suggests that fertilization applications in the autumn are not needed. N present in the soil at the beginning of the growing season and atmospheric deposition may also need to be considered to more closely match demand with uptake. The plants did not experience N deficiency symptoms in either year suggesting that there were other N inputs available to the plants in the 2-year period. Considering all N inputs and outputs appears necessary to more accurately apply N fertilizer to avoid peaks of nitrate-N later in the season.

Significance for Nursery Management

Overall, plant size and fertilization largely affect nitrate-N inputs into the groundwater. Reduced fertilization strategies for all field nursery species need to be developed to avoid large levels of nitrate-N entering the groundwater. We found that fertilization practices within the tree seedlings and *Taxus* areas are not problematic environmentally, but fertilization can be reduced to be more economical. *Euonymus* and soybean fields are being over-fertilized and new fertilization practices need to be implemented to reduce nitrate-N losses.

If the amended drinking water regulations of a 20 mg nitrate-N/L MCL for non-community water systems were established in these areas, all fields except the soybeans would be satisfactory; however there is still an economical advantage to reducing fertilization in all of the various land uses. Implementing the drinking water regulation also requires site-specific posting and notification.

Nursery managers should be aware of the following conclusions.

- Increased plant demand with age and size results in decreased groundwater nitrate-N concentrations.
- Determinate plants have been operationally over-fertilized, while indeterminate plants have not. Fertilization rates need to be decreased in determinate plants, but can be reduced in both to save in fertilization costs.
- Soybean cover crops do not need to be fertilized with manure or N fertilizers.
- Manure applications release N into the soil for several years.
- Manure applications are not needed to grow a successful crop.
- High nitrate-N concentrations in shallow groundwater can be ameliorated within 1-4 years using reduced to no fertilization.