

Impact of Common Landscaping Plants on Nitrate Leaching

Principles Investigators

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Introduction

Aesthetically pleasing, managed landscapes contribute to the quality of life in urban, suburban, and rural settings. These landscapes may include large open spaces like parks, ornamental gardens and golf courses, or other communal sports facilities, as well as smaller planting assemblies, such as typical backyard gardens. Ornamental plantings may cover relatively large areas, contiguously or as the multi-yard mosaics typical of residential subdivisions. Despite their prevalence, little is known about NO₃ leaching under managed landscapes.

Because of the predominance of lawn coverage in ornamental landscapes, water quality research has focused on NO₃ leaching from the turf-soil ecosystem. In a review article on the fate of nitrogen applied to turf, Petrovic (1990) concluded that only a small amount of fertilizer nitrogen (<10%) normally leaches from established turf to groundwater, a finding mirrored by other studies (Gold et al., 1990). More recently Jiang et al. (2000) have shown that even when the grass is killed, turf sites retain 90% of their accumulated nitrogen during the ensuing year even if no vegetation is replanted. If turf is re-established soon after death, a normal nitrogen retention pattern is restored within three months of reseeded (Bushoven et al., 2000).

To assess the environmental impact of residential, institutional or municipal landscaping fully, all components of the landscape must be evaluated for their ability to retain nitrogen. Erickson et al. (2001) reported in a plot study of nitrogen mobility in landscape plantings that mixed species plantings leached ten times more NO₃ than did the St. Augustinegrass [*Stenotaphrum secundatum* (Walt.) Kuntze] turf (48.3 vs. 4.1 kg NO₃-N ha⁻¹). The study was conducted on recently established plots (<1 year old) that were fertilized at 300 and 150 kg N ha⁻¹yr⁻¹ for the grass and mixed-species, respectively. While instructive, this study likely does not reflect the NO₃ mobility maintained under minimum fertility in more northern climates.

Little is known about the pools of carbon and nitrogen in landscape plantings, both factors that likely contribute to the cycling and retention of nitrogen. In their studies of carbon sequestration in the turf-soil ecosystem of Colorado golf courses, based on an analysis of historic soil-testing data, Qian and Follett (2002) found that organic matter accumulated rapidly for 25 to 30 years at rates approaching one ton per hectare per year. Soil organic matter content reached 4 to 5% of dry soil mass within that period. This would be equivalent to approximately 3,000 kg organic N ha⁻¹. In a follow-up study using a grassland ecosystem model, Qian et al. (2003) determined that if clippings were retained on turf after 30 years and fertilizer rates were not reduced, significant NO₃-leaching would occur. Similar results were reported by Porter et al. (1980) in a study of

variously aged lawns in New York. We currently have no data on the nitrogen mobility of other landscape plant communities. For turf, the evidence to date suggests that nitrogen retention may be linked to the maturity of the turf-soil ecosystem, as has been observed in forest ecosystems (Emmett et al., 1994)

The research reported here addresses the issue of N retention in fully established landscape plantings utilizing a reasonably mature, complex landscape managed according to a minimum maintenance schedule.

Methodology

Study Area

The study was conducted in the Horticultural Display Garden and the Learning Landscape, both on the Kingston Campus of the University of Rhode Island. Both areas were established between 1994 and 1995 on land that had been a landscaped site for at least 50 years. The soil in areas covered with turfgrass were limed (1,952 kg ha⁻¹) once, prior to sodding with Chewings fescue (*Festuca rubra* spp. *commutate*) in 1994. Turfgrass areas were fertilized with ~ 48.4 kg ha⁻¹ approximately once a year in the spring. Shredded bark mulch (2 - 3") was applied to shrub, tree and perennial flower beds annually.

Locations for soil and soil water sampling were chosen to represent a range of landscape vegetation types. These included annual flowers (AF, n=3), perennial flowers (PF, n=4), deciduous trees (DT, n=3), deciduous shrubs (DS, n=4), evergreen trees (ET, n=4), evergreen shrubs (ES, n=6), ground covers (GC, n=5), turf (T, n=4), native woodland (W, n=5), and unplanted-mulched areas (BL, n=5). Distance from the Learning Landscape to the woodland area sampled was approximately 500 m. The scientific and common names of plants included in each group are shown in Table 1.

Sampling

Ceramic suction cup lysimeters (2.25-cm o.d., 7-cm long) were installed vertically at 50 or 60 cm depth, and at approximately half the distance from the center to the edge of a planting (for AF, PF, DS, ES, and GC) or the trunk to the edge of the drip line of a tree (for ET, DT, and W). Lysimeters were placed in the center of the area planted to turf (T) or covered by mulch only (BL). Suction (-80 kPa) was applied for 1 h using a hand vacuum pump (SoilMoisture Equipment Corp., Santa Barbara, CA) one or two days after rainfall events exceeding 25 mm. The water samples were passed through a

Whatman No. 42 filter, and the filtrate stored in 20-mL plastic vials at 4°C. Nitrate in soil water was determined colorimetrically as described below.

Soil samples were collected monthly from the top 10 cm with a 2.5-cm dia. Steel core sampler while the ground was not frozen within 30 cm of the lysimeters. Mulch and leaf litter were removed from the surface before sampling. Soil samples were stored in sealable plastic bags at 4°C.

Principle Findings and Significance

Soil NO₃ and NH₄ were extracted according to the method of Keeney and Nelson (1982). Soil (1 g fresh weight) was extracted with 10 mL 2 N KCl solution for 30 min and the extract passed through a Whatman #42 filter. The filtrate and lysimeter water samples were analyzed for NO₃ and NH₄ colorimetrically using an automated nutrient analyzer (Alpkem Flow Solution IV, OI Analytical, College Station, TX).

Soil moisture was determined gravimetrically by drying soil (5 g) at 105°C for 24 h. Soil pH was determined by adding 10 mL deionized distilled water to 1 g soil. The mixture was allowed to equilibrate for 1 h and the pH of the solution determined using a pH meter (Denver Instrument, Denver, CO) (Hendershot et al., 1993). The organic matter content of the soil was determined by mass loss-on-ignition at 550°C for 4 h (Karam, 1993).

Statistical Analyses

Pooled data were not normally distributed, so differences in soil NO₃ and NH₄ and soil water NO₃ concentrations among vegetation types were evaluated using a one-way analysis of variance on ranks. Dunn's Multiple Range Method was used to identify statistically significant differences among vegetation types ($P < 0.05$).

Soil Organic Matter and pH

The pH and organic matter content of soils under different vegetation types are shown in Table 2. Soil organic matter ranged from 99 g kg⁻¹ in turf to 242 g kg⁻¹ in the woodlands. Woodland soil had the lowest pH value (5.2), with soil from other vegetation types ranging in pH from 5.9 to 6.4.

Soil Water Nitrate

Median NO₃ concentrations in soil water as a function of sampling date are shown in Fig. 1. Soil water was sampled on 23 separate dates during the 20-month study period. A particularly dry summer made it difficult to obtain soil water samples in 2002. We report median values because the data were not normally distributed. The range of median NO₃ concentrations was greater in June of 2002 than in 2003, with the reverse being true in November of these two years. Median soil water NO₃ levels were higher than the drinking water regulatory limit of 10 mg NO₃-N L⁻¹ in three of the 10 vegetation types evaluated, with frequency of exceedence following the order: GC (39%) > T (20%) > BL (10%). The high median soil water NO₃- concentrations recorded during June 2002 for GC and BL were probably due to soil disturbance during resetting of lysimeters, which were raised to avoid a silt layer at 60 cm.

Values of NO₃ concentration in soil water were pooled for the entire sampling period and are shown in Table 3. Median NO₃ levels spanned over two orders of magnitude. No statistically significant differences were observed among GC, BL, T, DT, and ET, with these vegetation types representing the highest median soil water NO₃ concentrations (1.4 to 7.8 mg NO₃-N L⁻¹). The middle range of soil water NO₃ concentrations (0.2 to 0.3 mg NO₃-N L⁻¹) included PF, AF, DS, and ES, with no statistically significant differences among the vegetation types within this group. The woodlands had the lowest soil water NO₃ level (0.01 mg NO₃-N L⁻¹). Statistically significant differences were observed among the vegetation types in the low, medium and high soil water NO₃ concentration groups.

Soil Extractable Nitrate and Ammonium

Extractable soil NO₃ levels followed opposite temporal trends in 2002 and 2003 (Fig. 2). Nitrate concentrations declined steadily by an order of magnitude from June to December of 2002, whereas an increase of almost two orders of magnitude was observed over the same period in 2003. Soil NO₃ levels were in the range of 1 to 10 μg NO₃-N g⁻¹ on most of sampling dates. The woodlands constituted the exception, with NO₃ values consistently lower than 1 μg NO₃-N g⁻¹ throughout the sampling period.

Pooled median extractable soil NO₃ levels in the woodland soil were 0.5 μg NO₃- N g⁻¹, about an order of magnitude lower than for all other vegetation types, and were significantly different from them (Table 3). No statistically significant differences were observed among all other vegetation types, with soil NO₃ concentrations ranging from 3.1 μg NO₃-N g⁻¹ for annual flowers to 7.8 μg NO₃-N g⁻¹ for turf.

Temporal trends in extractable soil NH₄ levels were similar to those observed for

NO₃ (Fig. 3), with values declining about an order of magnitude from June to December 2002, and steadily increasing over two orders of magnitude from June to December 2003. As with extractable soil NO₃, NH₄ concentrations were within the range of 1 to 10 µg NH₄-N g⁻¹ for most of the sampling period.

Analyses of pooled data indicated that levels of extractable soil NH₄ ranged from 3.6 µg NH₄-N g⁻¹ for perennial flowers and evergreen trees to 10.1 µg NH₄-N g⁻¹ for annual flowers (Table 3). Statistically significant differences were observed between those vegetation types with low NH₄ levels (PF, ET, GC) and those with high levels (W, DT, AF).

Relationship of Soil Water Nitrate to Surface Soil Properties

Correlation analyses using the Pearson Product Moment method revealed a statistically significant negative correlation between the log₁₀ of soil water NO₃ and soil organic matter ($r = -0.713$, $P = 0.0206$) and a positive correlation between log₁₀ soil water NO₃ and extractable soil NO₃ ($r = 0.779$, $P = 0.0079$), whereas there was no correlation when untransformed values of soil water NO₃ were used (Fig. 4). In contrast, no statistically significant correlation was found between log₁₀ water NO₃ and either soil pH ($r = 0.514$, $P = 0.129$) or extractable soil NH₄ ($r = -0.301$, $P = 0.398$). Multiple linear regression analysis using a best subset approach indicated that the log₁₀ soil water NO₃-N could be predicted based on soil OM and extractable nitrate levels ($r^2 = 0.644$) using the equation:

$$\log_{10} \text{ soil water NO}_3 = -0.362 + (0.223 * \text{soil extractable NO}_3) - (0.0496 * \text{soil OM})$$

Discussion

Our results show that landscaping vegetation types differ considerably in terms of soil water NO₃ concentrations found 50-60 cm below the soil surface. At one end of the spectrum woodlands exhibited the lowest NO₃ concentrations, whereas trees, turf, ground covers, and unplanted areas are at the other extreme, with flowers and shrubs occupying the middle ground. Of these, ground cover, unplanted areas, and turf had median concentrations of NO₃ that were equal to or higher than the 10 mg NO₃-N L⁻¹ regulatory limit for drinking water (Hallberg, 1989) at some point during the year. Examination of pooled data for extractable NO₃ concentration in surface (0 - 10 cm) soil revealed statistically significant differences between the woodlands and all other vegetation types, but no differences among the remaining vegetation types (Table 3). The acidic pH of woodland soil (5.2) could have slowed nitrification rates, resulting in higher NH₄ levels (Table 3).

There was a statistically significant correlation between extractable soil NO₃ concentration in the upper 10 cm and the log₁₀ of NO₃ concentration in soil water at a depth of 50-60 cm, but not when the untransformed soil water NO₃ concentration was used. A correlation between extractable soil NO₃ and soil water NO₃ would have suggested that the changes in the concentration of nitrate in soil water was the result of the same processes, likely dilution occurring as a result of leaching, across all vegetation types. The fact that soil water NO₃ concentration increases disproportionately with surface soil extractable NO₃ concentration suggests that the relative importance of processes controlling NO₃ levels (e.g. microbial immobilization, nitrification, denitrification) differs under different types of vegetation.

In the case of turf, fertilizer inputs are a likely explanation for higher NO₃- levels, as is the large amount of N₂-fixing clover intermixed with the grass. This is the first report of elevated soil NO₃ leaching from clover-invaded turf. The elevated extractable soil NO₃ during late summer, when turf roots are inhibited by high temperature (Jiang and Huang, 2000) but clover roots may remain healthy, indicate the importance of the N contribution by clover. Turf was irrigated and prevented from entering a drought-induced summer dormancy, but high temperatures could not be avoided.

Differences in NO₃ sinks likely also contribute to the effects of vegetation on NO₃ concentration in soil water. Assuming that the microbial biomass is at steady state with respect to N, the two main sinks for NO₃ in soil are plant uptake and denitrification. The effects of vegetation type may be due to differences in root architecture. Mature trees generally have relatively shallow nutrient-absorbing root systems, aside from the deep roots used for anchoring, that may result in less opportunity for interception of nitrate deeper into the soil profile than in vegetation with a greater concentration of fine roots at greater depths. For example, more than 90% of the small, nutrient-absorbing roots were in the top 12.5 cm of soil in a pine forest on clay soils of North Carolina (Coile, 1937). Furthermore, the roots most actively involved in nutrient uptake are often found outside the drip line, whereas we took soil and water samples within the area under the tree canopy, in part to avoid encroaching on other vegetation types. Leaf fall appears unlikely to be an important factor. Hardwood and conifer stands contribute only 19 and 26 kg N ha⁻¹, respectively (Kozłowski et al., 1991). This is a modest amount of N and its mineralization can occur over a 5-18 year period. Thus leaf fall in autumn is unlikely to contribute significantly to N leaching.

We speculate that differences in denitrification rates - higher in vegetation types with low soil water nitrate and lower in those with high nitrate levels - may also contribute to the effects of vegetation on soil water NO₃ levels. Such differences may arise from

different inputs of biodegradable organic C that can be used by denitrifying bacteria, and/or the establishment of anaerobic conditions that support denitrification. Our data show that the concentration of NO₃ in soil water decreases with higher soil organic matter, suggesting that differences in bioavailable C may affect soil water nitrate by controlling rates of denitrification. Since OM contributes to water holding capacity, it may also affect NO₃ dynamics via establishment of conditions conducive to denitrification. A high level of mulch-derived organic matter may thus contribute to reduction of NO₃ leaching in landscaped areas.

Our results have implications for the design and management of sustainable landscaping to maintain groundwater quality. Woodlands clearly are the most benign type of vegetation with respect to potential for NO₃ leaching into groundwater. As such, their incorporation in an undisturbed state into landscape designs should be given serious consideration. Annual and perennial flowers and deciduous and evergreen shrubs also contribute minimally to soil water NO₃, and thus should be given priority in terms of area covered by plantings. By contrast, trees, turf, ground cover plants, and unplanted areas are most likely to contribute higher levels of NO₃ to ground water, and thus should be used sparingly. In the case of turf, the combined effects of long-term establishment, fertilizer additions, and clover invasion may have contributed to NO₃-beyond what has been observed by others (e.g. Petrovic, 1990; Cohen et al., 1999; Jiang et al., 2000).

Aesthetically pleasing landscaping and protection of groundwater quality may be achieved by minimizing disturbance of existing natural woodlands, reducing the unplanted areas and areas covered by vegetation types that are associated with high levels of soil water NO₃, and making more extensive use of those landscaping plants that show minimal soil water NO₃ levels. Those areas most likely to leach NO₃- were monoculture or sparsely vegetated areas (e.g. under trees, unplanted-mulched areas), whereas densely planted and diversified landscapes are better able to capture mineralized N and less likely to permit NO₃- leaching.

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Table 1. Scientific and common names of plants in different vegetation types studied.

Vegetation type	Scientific name	Common name
Annual flowers	<i>Dahlia</i> spp.	Annual dwarf dahlia
	<i>Impatiens valleriana</i>	Dwarf impatiens
	<i>Zinnia elegans</i>	Zinnia
	<i>Portulaca grandiflora</i>	Rose moss
	<i>Lobelia erinus</i>	Blue annual lobelia
Deciduous shrubs	<i>Corylopsis spicata</i>	Spike winter-hazel
	<i>Clethra alnifolia</i>	Summersweet
	<i>Syringa reticulata</i>	Japanese tree-lilac
	<i>Syringa meyeri</i>	Garden lilac
	<i>Fothergilla gardena</i>	Dwarf fothergilla
Deciduous trees	<i>Betula papyrifera</i>	Paper birch
	<i>Syringa reticulata</i>	Japanese tree-lilac
	<i>Metasequoia glyptostroboides</i>	Dawn redwood
Evergreen shrubs	<i>Taxus baccata</i>	English yew
	<i>Ilex glabra</i>	Inkberry
	<i>Rhododendron 'Catawbiense'</i>	Rhododendron
	<i>Microbiota decussata</i>	Siberian carpet grass
	<i>Kalmia latifolia</i>	Mountain laurel
	<i>Rhododendron chinoides</i>	Rhododendron
Evergreen trees	<i>Pinus strobus</i>	Eastern white pine
	<i>Thuja occidentalis</i>	American arborvitae
	<i>Sciadopitys verticillata</i>	Japanese umbrella pine
	<i>Pinus mugo</i>	Dwarf pine
	<i>Sarcococca hookeriana</i>	Sweet box
	<i>Picea glauca</i> var. <i>albertiana</i>	Alberta spruce
	<i>Vinca minor</i>	Myrtle
Ground cover	<i>Arctostaphylos uva-uris</i>	Bearberry
	<i>Ajuga reptans</i>	Carpet bugle
	<i>Pachysandra terminalis</i>	Pachysandra
	<i>Veronica alpina</i>	Spiked speedwell
Perennial flowers	<i>Cimicifuga racemosa</i>	Black cohosh
	<i>Hemerocallis</i> spp.	Daylily
	<i>Hosta-X "Krossa regal"</i>	Hosta
	<i>Coreopsis verticillata</i>	Threadleaf coreopsis
Turf	<i>Festuca rubra</i> ssp. <i>commutata</i>	Chewings fescue
	<i>Trifolium repens</i>	White clover
Native woodland	<i>Dennstaedtia punctiloba</i>	Hay-scented fern
	<i>Similax</i> spp.	Green brier
	<i>Fagus grandifolia</i>	American beech
	<i>Quercus velutina</i>	Black oak
	<i>Betula populifolia</i>	Gray birch
	<i>Osmunda cinnamomea</i>	Cinnamon fern
	<i>Lycopodium</i> spp.	Club-moss

Table 2. Organic matter content and pH of soil under different vegetation types.

Vegetation type	O.M. content (g kg ⁻¹)	pH
Native woodland	242 ± 49	5.24
Perennial flowers	123 ± 6	6.09
Annual flowers	139 ± 20	6.38
Deciduous shrubs	129 ± 26	6.02
Evergreen shrubs	166 ± 75	6.00
Evergreen trees	169 ± 61	6.02
Deciduous trees	165 ± 63	5.86
Turf	99 ± 16	6.07
Unplanted - mulched	107 ± 25	6.13
Ground cover	105 ± 24	6.05

Table 3. Concentration of NO₃ in soil water and of extractable soil NO₃ and NH₄ under different vegetation types. Data were pooled for the June 2002 to November 2003 sampling period.

Type of vegetation	Soil water NO ₃ conc. (mg N L ⁻¹)				Extractable soil NO ₃ conc. (µg N g ⁻¹)				Extractable soil NH ₄ conc. (µg N g ⁻¹)			
	n	Median ¹	25%	75%	n	Median	25%	75%	n	Median	25%	75%
Native woodland	95	0.0 a	0.0	0.1	77	0.5 a	0.4	0.8	70	6.7 b	4.6	23.0
Perennial flowers	45	0.2 b	0.1	0.8	60	3.4 b	2.0	6.3	60	3.6 a	2.3	8.8
Annual flowers	30	0.3 b	0.1	1.1	42	3.1 b	2.2	3.9	42	10.1 b	4.9	20.3
Deciduous shrubs	47	0.3 b	0.1	1.4	63	4.8 b	2.8	9.3	61	4.8 ab	2.9	11.2
Evergreen shrubs	63	0.3 b	0.1	1.2	76	4.0 b	2.8	6.0	76	4.8 ab	2.7	10.8
Evergreen trees	52	1.4 c	0.4	4.1	68	4.3 b	2.7	7.4	68	3.6 a	2.4	7.5
Deciduous trees	40	1.8 c	0.4	4.1	45	5.0 b	2.5	10.1	46	6.8 b	3.6	13.4
Turf	34	3.0 c	0.6	10.8	70	7.8 b	3.6	16.8	65	4.7 ab	2.9	14.0
Unplanted - mulched	73	3.7 c	0.8	8.6	67	4.2 b	2.6	7.5	64	5.4 ab	2.9	12.7
Ground cover	63	7.8 c	1.7	15.4	70	5.2 b	3.2	8.8	72	4.0 a	2.4	11.4

¹Values followed by the same letter within a column were not significantly different ($P < 0.05$).

Figure Legends

Fig. 1. Soil water NO₃ concentration under different landscaping vegetation types as a function of sampling date from June 2002 to November 2003. Values are medians (n ≥ 3). Bold horizontal line represents regulatory limit for NO₃-N in drinking water (Hallberg, 1989). AF = annual flowers; BL = unplanted-mulched; DS = deciduous shrubs; DT = deciduous trees; ES = evergreen shrubs; ET = evergreen trees; GC = ground cover; PF = perennial flowers; T = turf; W = native woodland.

Fig. 2. Concentration of extractable NO₃ in soil under different landscaping vegetation types as a function of sampling date from June 2002 to November 2003. Values are medians (n ≥ 3). Abbreviations as in Fig. 1.

Fig. 3. Concentration of extractable NH₄ in soil under different types of landscaping vegetation types as a function of sampling date from June 2002 to November 2003. Values are medians (n ≥ 3). Abbreviations as in Fig. 1.

Fig. 4. Scatter plots of median soil water NO₃ vs. soil organic matter content (A), median extractable soil NO₃ (B), median extractable soil NH₄ (C), and soil pH (D). Abbreviations as in Fig. 1.

Fig. 1

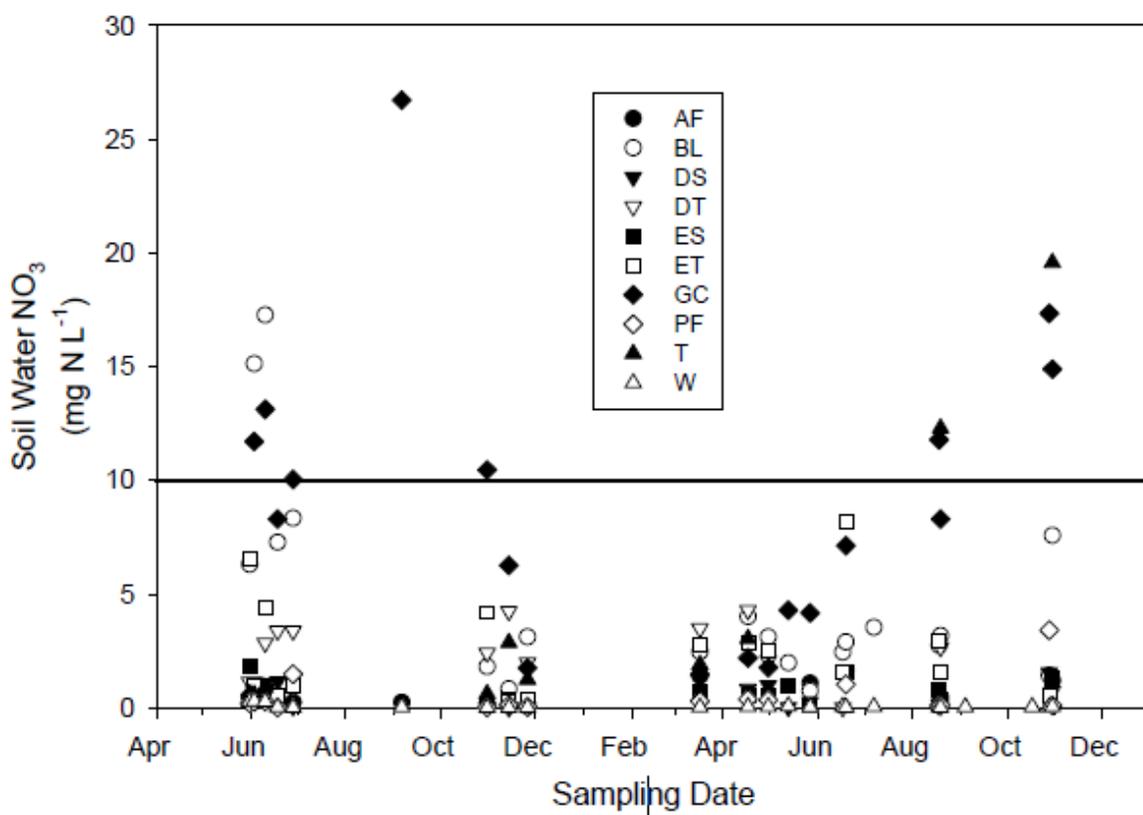


Fig. 4

