Report for 2003RI18B: Impact of Common Landscaping Plants on Nitrate Leaching

- Articles in Refereed Scientific Journals:
    - Amador, J. A., R. J. Hull, E. L. Nicosia, and J. T. Bushoven. 2004. Fate of nitrate under common landscaping plants. Journal of Environmental Quality (In review)

Report Follows

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 NO_3 leaching under managed landscapes.

Because of the predominance of lawn coverage in ornamental landscapes, water quality research has focused on NO_3 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 reseeding (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 NO_3 than did the St. Augustinegrass [*Stenotaphrum secundatum* (Walt.) Kuntze] turf (48.3 vs. 4.1 kg NO_3-N ha^{-1}). The study was conducted on recently established plots (<1 year old) that were fertilized at 300 and 150 kg N $ha^{-1}yr^{-1}$ for the grass and mixed-species, respectively. . While instructive, this study likely does not reflect the NO_3 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 NO_3^- 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.

MATERIALS AND METHODS

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 $4^{o}C$. 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 $4^{o}C$.

Analyses

Soil NO_3 and NH_4 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 NO_3 and NH_4 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 $105^{o}C$ 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 $550^{o}C$ for 4 h (Karam, 1993).

Statistical Analyses

Pooled data were not normally distributed, so differences in soil NO_3 and NH_4 and soil water NO_3 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).

RESULTS

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 NO_3 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 NO_3 concentrations was greater in June of 2002 than in 2003, with the reverse being true in November of these two years. Median soil water NO_3 levels were higher than the drinking water regulatory limit of 10 mg NO_3-N L^{-1} in three of the 10 vegetation types evaluated, with frequency of excedence following the order: GC (39%) > T (20%) > BL (10%). The high median soil water NO_3^- 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 NO_3 concentration in soil water were pooled for the entire sampling period and are shown in Table 3. Median NO_3 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 NO_3 concentrations (1.4 to 7.8 mg NO_3-N L^{-1}). The middle range of soil water NO_3 concentrations (0.2 to 0.3 mg NO_3-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 NO_3 level (0.01 mg NO_3-N L^{-1}). Statistically significant differences were observed among the vegetation types in the low, medium and high soil water NO_3 concentration groups.

Soil Extractable Nitrate and Ammonium

Extractable soil NO_3 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 NO_3 levels were in the range of 1 to 10μg NO_3-N g^{-1} on most of sampling dates. The woodlands constituted the exception, with NO_3 values consistently lower than 1 μg NO_3-N g^{-1} throughout the sampling period.

Pooled median extractable soil NO_3 levels in the woodland soil were 0.5 μg NO_3-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 NO_3 concentrations ranging from 3.1 μg NO_3-N g^{-1} for annual flowers to 7.8μg NO_3-N g^{-1} for turf.

Temporal trends in extractable soil NH_4 levels were similar to those observed for NO_3 (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 NO_3, NH_4 concentrations were within the range of 1 to 10 μg NH_4-N g^{-1} for most of the sampling period.

Analyses of pooled data indicated that levels of extractable soil NH_4 ranged from 3.6 μg NH_4-N g^{-1} for perennial flowers and evergreen trees to 10.1μg NH_4-N g^{-1} for annual flowers (Table 3). Statistically significant differences were observed between those vegetation types with low NH_4 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 $\log_{10}$ of soil water NO_3 and soil organic matter (r = - 0.713, P = 0.0206) and a positive correlation between $\log_{10}$ soil water NO_3 and extractable soil NO_3 (r = 0.779, P = 0.0079), whereas there was no correlation when untransformed values of soil water NO_3 were used (Fig. 4). In contrast, no statistically significant correlation was found between $\log_{10}$ water NO_3 and either soil pH (r = 0.514, P = 0.129) or extractable soil NH_4 (r = -0.301, P = 0.398). Multiple linear regression analysis using a best subset approach indicated that the $\log_{10}$ soil water NO_3-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 NO_3 concentrations found 50-60 cm below the soil surface. At one end of the spectrum woodlands exhibited the lowest NO_3 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 NO_3 that were equal to or higher than the 10 mg NO_3-N L^{-1} regulatory limit for drinking water (Hallberg, 1989) at some point during the year. Examination of pooled data for extractable NO_3 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 NH_4 levels (Table 3).

There was a statistically significant correlation between extractable soil NO_3 concentration in the upper 10 cm and the $\log_{10}$ of NO_3 concentration in soil water at a depth of 50-60 cm, but not when the untransformed soil water NO_3 concentration was used. A correlation between extractable soil NO_3 and soil water NO_3 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 NO_3 concentration increases disproportionately with surface soil extractable NO_3 concentration suggests that the relative importance of processes controlling NO_3 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 NO_3^- levels, as is the large amount of N_2-fixing clover intermixed with the grass. This is the first report of elevated soil NO_3 leaching from clover-invaded turf. The elevated extractable soil NO_3 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 NO_3 sinks likely also contribute to the effects of vegetation on NO_3 concentration in soil water. Assuming that the microbial biomass is at steady state with respect to N, the two main sinks for NO_3 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 (Kozlowski 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 NO_3 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 NO_3 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 NO_3 dynamics via establishment of conditions conducive to denitrification. A high level of mulch-derived organic matter may thus contribute to reduction of NO_3 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 NO_3 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 NO_3, 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 NO_3 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 NO_3^- 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 NO_3, and making more extensive use of those landscaping plants that show minimal soil water NO_3 levels. Those areas most likely to leach NO_3^- 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 NO_3^- leaching.

ACKNOWLEDGEMENTS

We thank Cherryl Tefft, Nicole Schwarz, Tracey Daly, Andrea Bixby, Maricruz Merino, Jack Barry, and Charles Gilbert for their help with different aspects of this study.

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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	*Dahlia* spp.	Annual dwarf dahlia
	Impatiens valleriana	Dwarf impatiens
	Zinnia elegans	Zinnia
	Portulaca grandiflora	Rose moss
	Lobelia erinus	Blue annual lobelia
Deciduous shrubs	*Corylopsis spicata*	Spike winter-hazel
	Clethra alnifolia	Summersweet
	Syringa reticulata	Japanese tree-lilac
	Syringa meyeri	Garden lilac
	Fothergilla gardena	Dwarf fothergilla
Deciduous trees	*Betula papyrifera*	Paper birch
	Syringa reticulate	Japanese tree-lilac
	Metasequoia glyptostroboides	Dawn redwood
Evergreen shrubs	*Taxus baccata*	English yew
	Ilex glabra	Inkberry
	Rhododendron 'Catawbiense'	Rhododendron
	Microbiota decussata	Siberian carpet grass
	Kalmia latifolia	Mountain laurel
	Rhododendron chinoides	Rhododendron
Evergreen trees	*Pinus strobus*	Eastern white pine
	Thuja occidentalis	American arborvitae
	Sciadopitys verticillata	Japanese umbrella pine
	Pinus mugo	Dwarf pine
	Sarcococca hookeriana	Sweet box
	Picea glauca var. *albertiana*	Alberta spruce
Ground cover	*Vinca minor*	Myrtle
	Arctostaphylos uva-uris	Bearberry
	Ajuga reptans	Carpet bugle
	Pachysandra terminalis	Pachysandra
Perennial flowers	*Veronica alpina*	Spiked speedwell
	Cimcifuga racemosa	Black cohesh
	Hemerocallis spp.	Daylily
	Hosta-X "Krossa regal"	Hosta
	Coreopsis verticillata	Threadleaf coreopsis
Turf	*Festuca rubra* ssp. *commutata*	Chewings fescue
	Trifolum repens	White clover
Native woodland	*Dennstaedtia punctiloba*	Hay-scented fern
	Similax spp.	Green brier
	Fagus grandifolia	American beech
	Quercus velutina	Black oak
	Betula populifolia	Gray birch
	Osmunda cinnamomea	Cinnamon fern
	Lycopodium 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 NO_3 in soil water and of extractable soil NO_3 and NH_4 under different vegetation types. Data were pooled for the June 2002 to November 2003 sampling period.

	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})**			
Type of vegetation	**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

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

FIGURE LEGENDS

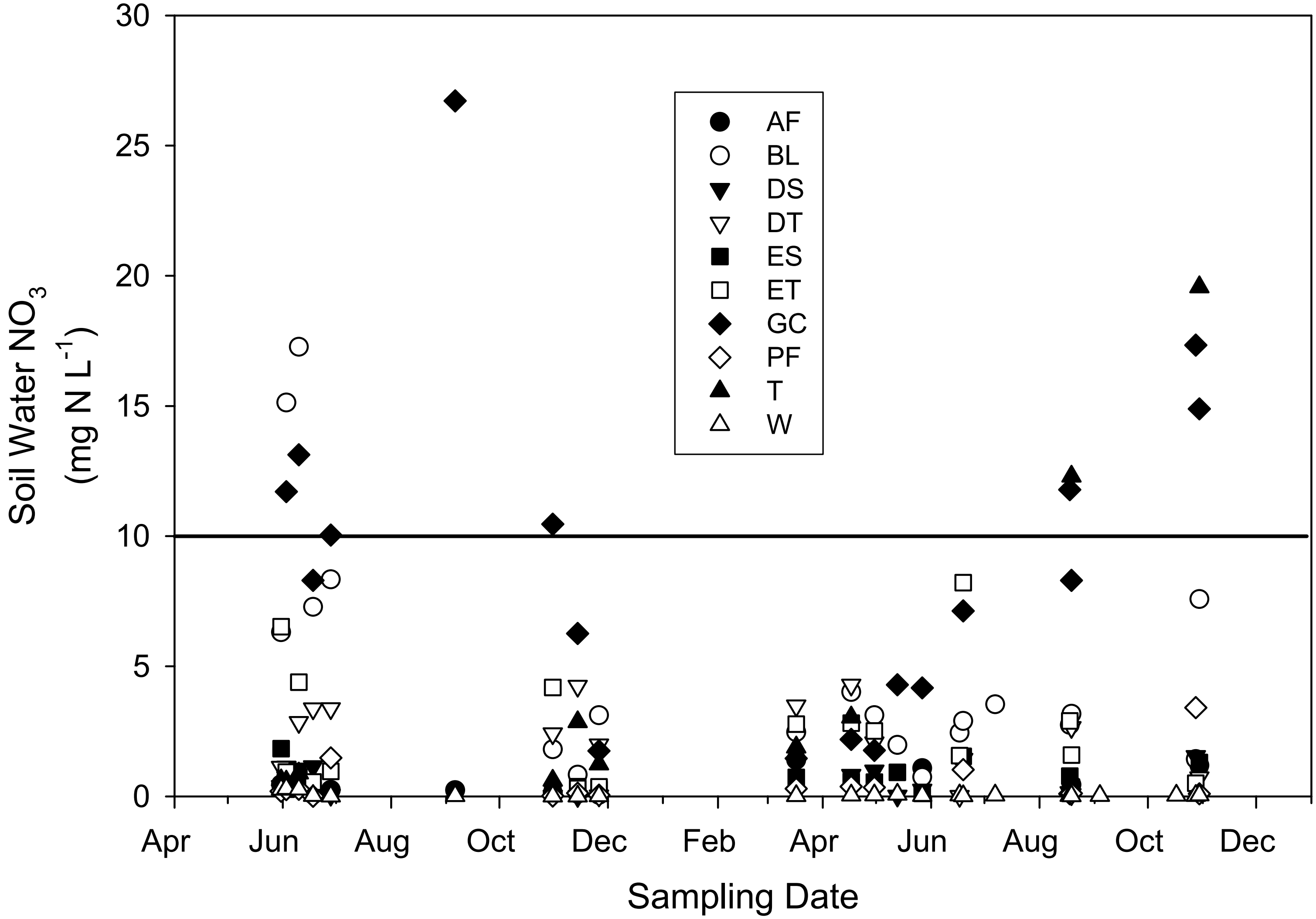
Fig. 1. Soil water NO_3 concentration under different landscaping vegetation types as a function of sampling date from June 2002 to November 2003. Values are medians ($n \geq 3$). Bold horizontal line represents regulatory limit for NO_3-N in drinking water (Hallberg, 1989). AF = annual flowers; BL = 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 NO_3 in soil under different landscaping vegetation types as a function of sampling date from June 2002 to November 2003. Values are medians ($n \geq 3$). Abbreviations as in Fig. 1.

Fig. 3. Concentration of extractable NH_4 in soil under different types of landscaping vegetation types as a function of sampling date from June 2002 to November 2003. Values are medians ($n \geq 3$). Abbreviations as in Fig. 1.

Fig. 4. Scatter plots of median soil water NO_3 vs. soil organic matter content (A), median extractable soil NO_3 (B), median extractable soil NH_4 (C), and soil pH (D). Abbreviations as in Fig. 1.

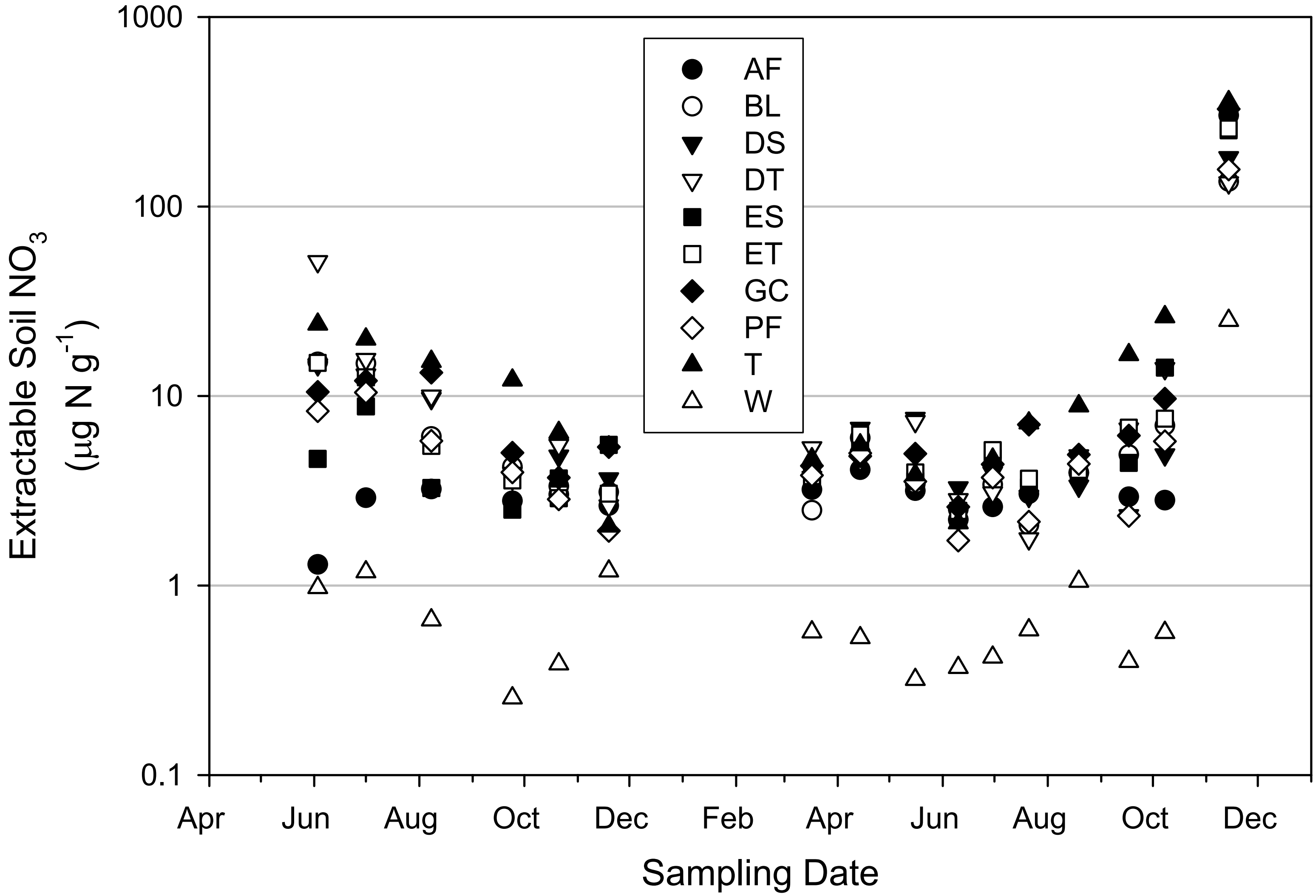
Fig. 1



AF
BL
DS
DT
ES
ET
GC
PF
T
W
Soil Water NO_3
(mg N L^{-1})
30
25
20
15
10
5
0
Apr
Jun
Aug
Oct
Dec
Feb
Apr
Jun
Aug
Oct
Dec
Sampling Date

1

Fig. 2

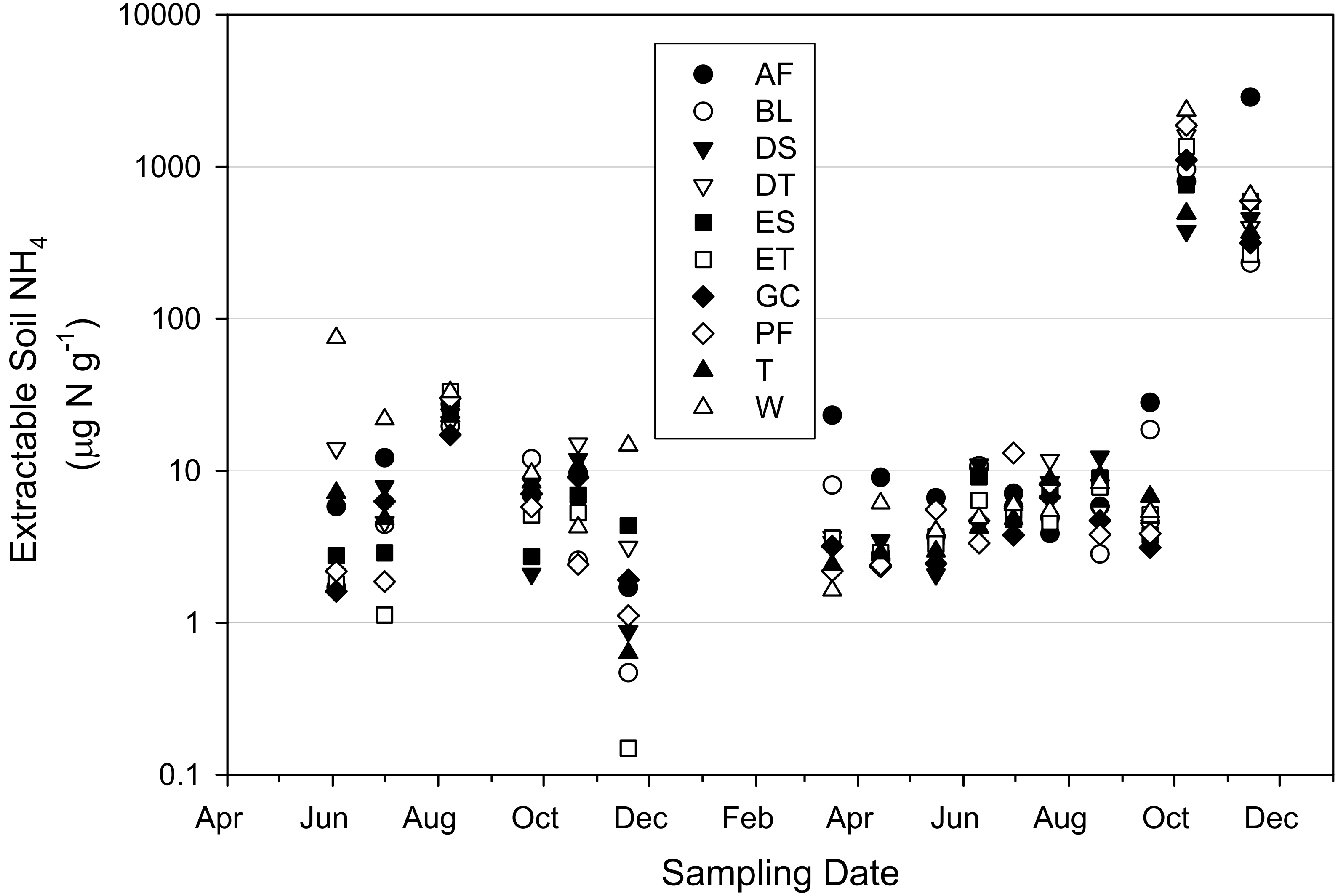


1000
100
10
1
0.1
Extractable Soil NO3
(µg N g-1)
AF
BL
DS
DT
ES
ET
GC
PF
T
W
Apr
Jun
Aug
Oct
Dec
Feb
Apr
Jun
Aug
Oct
Dec
Sampling Date

1

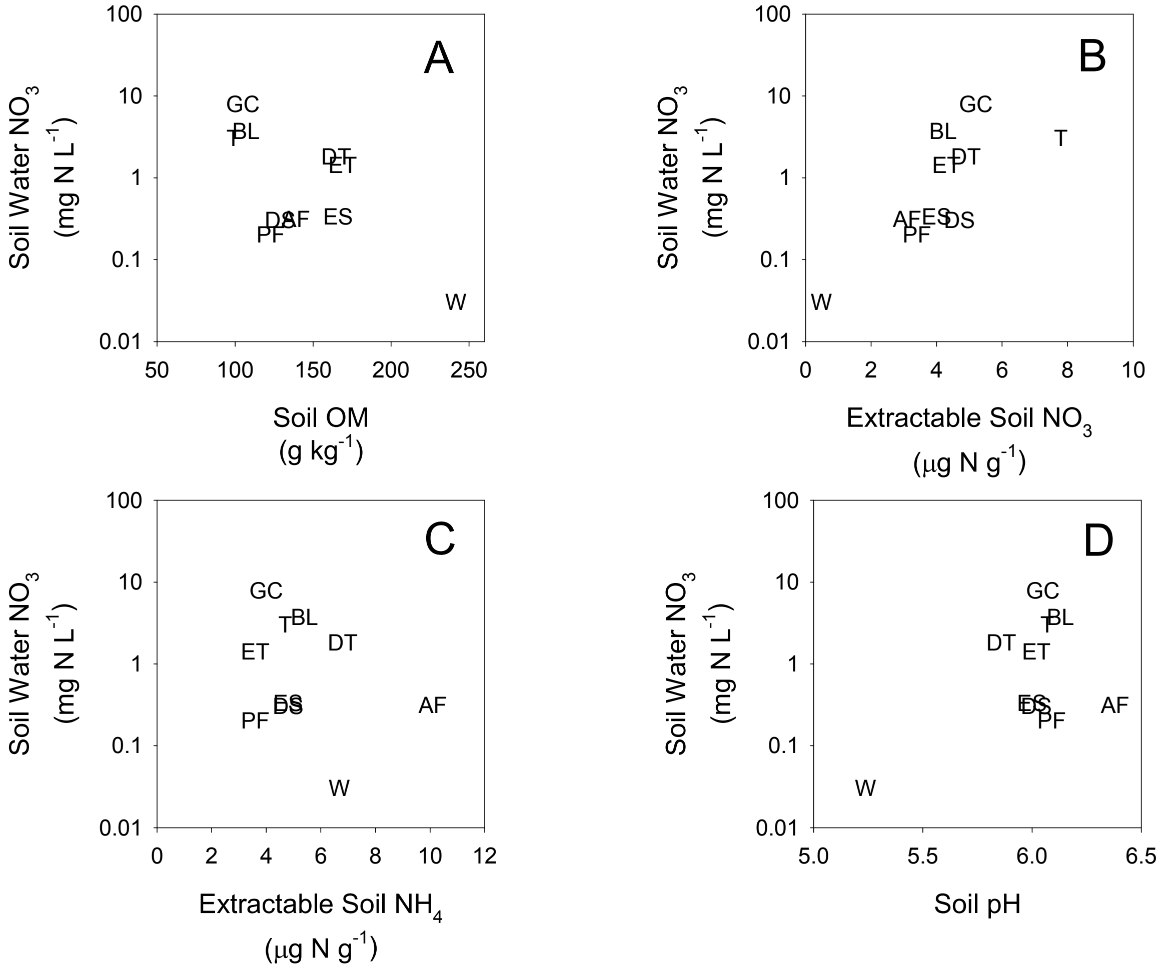
1

Fig. 3



Extractable Soil NH4
(µg N g-1)
10000
1000
100
10
1
0.1
AF
BL
DS
DT
ES
ET
GC
PF
T
W
Apr
Jun
Aug
Oct
Dec
Feb
Apr
Jun
Aug
Oct
Dec
Sampling Date

Fig. 4


A
B
C
D
Soil Water NO3 (mg N L-1)
Soil OM (g kg-1)
Extractable Soil NO3 (μg N g-1)
Extractable Soil NH4 (μg N g-1)
Soil pH
GC
BL
T
DT
ET
DS
AF
ES
PF
W

1