NITROGEN LEACHING BELOW RIPARIAN AUTUMN OLIVE STANDS IN THE DORMANT SEASON

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ABSTRACT.—Our research objective was to determine if excess nitrate (NO_3^-) and ammonium (NH_4+) were leaching below the rooting zones of autumn olive stands during the dormant season. Autumn olive is a nitrogen fixer, through a symbiotic relationship with actinomycetes of the genus *Frankia*. It is an exotic woody shrub that was promoted for wildlife habitat but has become naturalized and is difficult to eradicate. Suction lysimeters were installed in plots of autumn olive and adjacent open field plots in three southern Illinois riparian sites. Soil water samples were collected every two weeks from January 2003 to March 2003 and analyzed for nitrate and ammonium. Results showed significantly greater nitrate leaching during the dormant season under autumn olive than in open fields representative of early successional species composition. Mean nitrate-N concentrations were 16.84 mg L^{-1} under autumn olive compared to 1.01 mg L^{-1} under open field conditions. Ammonium was not significantly different between the two plot types. In watersheds where autumn olive is a common riparian plant, the observed significant nitrate leaching could have important water quality and site productivity implications, suggesting the need for vegetation management.

Autumn olive (*Elaeagnus umbellata* Thunb.) is a nitrogen fixing woody shrub native to Japan, China and Korea (Rehder 1940). As a nitrogen fixer, it reduces atmospheric nitrogen (N_2) to ammonia (NH_3) for use by plants, through a symbiotic relationship with the actinomycete (a filamentous bacteria) *Frankia*. This symbiotic relationship provides a source of energy to the microorganism and a supply of nitrogen to the autumn olive plant.

Autumn olive was first cultivated in the United States in the 1830s (Redher 1940). It is an open-growing woody shrub that can reach a height of ~6 meters and a spread of ~7 meters and has been promoted for a wide range of uses including food and cover for wildlife, nectar for bees, and erosion control (Allen and Steiner 1972, Hayes 1976). Interplanted autumn olive was also found to increase height and volume of the hardwood species black walnut (*Juglans nigra*) (Funk et al. 1979, Geyer and Rink 1998). Autumn olive was planted extensively in Illinois in the 1960s and 1970s and has become naturalized across much of the eastern United States. This exotic species has spread from its original planting sites, with old-field and disturbed sites as optimal habitat for reproduction (Nestleroad et al. 1987). Its rapid spread is attributed in part to seed dispersal by birds that are attracted to the fruit (Nestleroad et al. 1987). Attempts to control the plant by herbicide have been made with limited success (Edgin and Ebinger 2001).

In Ontario, Canada, Catling et al. (1997) found the plant went from unknown as a wild plant, to a rapidly spreading weed within 10 years. The shrub has the potential to establish on natural sandy openings such as prairie, savanna, barren, dune and shore communities, which are in need of protection in Canada (Catling et al. 1997).

Based on our knowledge of the literature, N fixation rates by autumn olive have not been quantified. However, autumn olive is an actinorhizal nitrogen fixer like red alder (*Alnus rubra* Borg.). Red alder has been planted in the Pacific Northwest in conifer stands, especially Douglas-fir (*Pseudotsuga menziesii*) and shown to increase biomass and root systems of the Douglas-fir (Brozek 1990). Red alder N fixation rates have been found to range from 50 to 200 kg ha^{-1} y^{-1} (Cole et al. 1978, Binkley et al. 1992).

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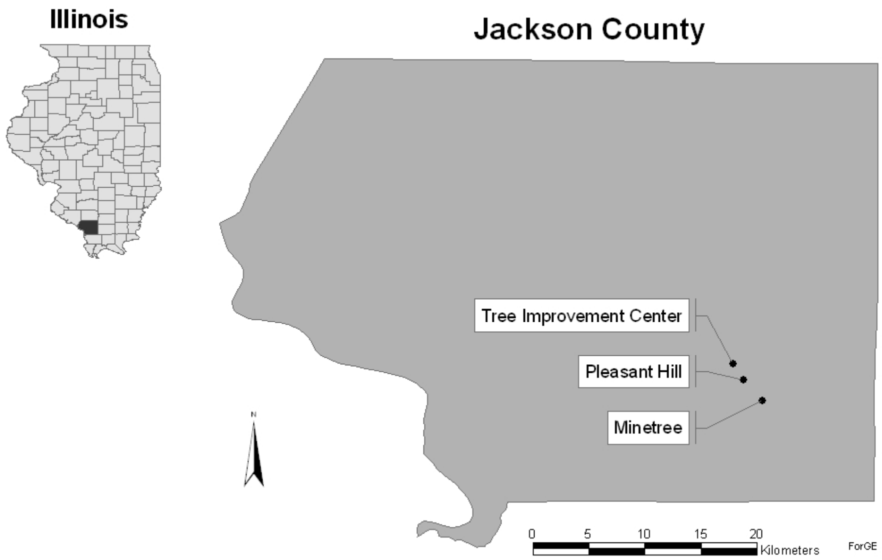

Figure 1.—Study location in Jackson County, Illinois.

Nitrogen fixing species can influence soil acidity and leaching of nutrients. Van Miegroet and Cole (1984) found increased nitrification that occurred under a red alder stand was a source of soil acidification, even more so than atmospheric deposition. Base cations can leach through the system with mobile NO_3^- as their companion ion. The release of cations from the soil decreases the nutrient availability of the site and may have implications for long-term site productivity. The proton generation generally results in increased acidification in the upper most soil horizons (Van Miegroet et al. 1988).

Studies have found that N-fixing plants like red alder can contribute excess NO_3^- to the soil and ground water. These excess nutrients can leach into streams (Van Miegroet and Cole 1984). Nutrient pollution negatively impacts water quality and biota in the stream and is the cause of major environmental problems like hypoxia in the Gulf of Mexico (Rabalais 2002). The rapid spread of autumn olive and its ability to fix nitrogen may have important downstream water quality implications.

This research compared the amount of nitrogen in soil water under autumn olive and old-field sites. The objective was to investigate whether autumn olive, as a nitrogen-fixing plant, was producing excess nitrogen that was leaching below the rooting zone.

Study Sites

The study was conducted on three riparian sites on land owned by Southern Illinois University at Carbondale in Jackson Co., IL. (fig. 1). The sites were chosen due to their high density of autumn olive shrubs and the occurrence of old field habitats. Soil properties differed among, but not within, sites (table 1).

The Minetree Road (MT) riparian site was a pasture until 1990, and is not currently in agricultural use. It was dominated by autumn olive, black locust (*Robinia pseudoacacia*), briars (*Rubus spp*.) and various grasses. The plots were located upslope from an intermittent stream and did not experience any flooding during the study period.

The Pleasant Hill Road (PH) riparian site contained autumn olive and mixed hardwood species and was once grazed. It is presently fenced from an adjoining pasture. The riparian plots were adjacent to a stream that was disconnected from its floodplain through severe downcutting; no riparian flooding occurred during the study period.

The Tree Improvement Center (TIC) riparian site was originally owned by the U.S. Forest Service and contains experimental stands of black walnut and numerous other hardwood species. The plots were located upslope from an intermittent stream and were not flooded during the study period.

Table 1.—Study site characteristics.

	Site		
Location	Minetree Rd (MT) Lat. 37° 41' N Long. 89° 14' W	Pleasant Hill (PH) Lat. 37° 41' N Long. 89° 15' W	Tree Improvement Center (TIC) Lat. 37° 42' N Long. 89° 16' W
Soil Classification	*Oxyaquic Fragiudalf*	*Typic Fluvaquent*	*Oxyaquic Fragiudalf*
Soil Texture Class	Loam	Silt loam	Silt loam
Soil Organic Matter	3.0%	2.1%	2.2%
Autumn Olive Plots			
Biomass	11.22 kg m^{-2}±(2.64)	10.01 kg m^{-2}±(4.46)	5.67 kg m^{-2}±(0.50)
Average Age (yrs)	13	11	7

Each site contained two plots in the same landscape position, one dominated by autumn olive and the comparison plot in an open field condition. The open field condition was defined as no autumn olive plants present, and dominated by herbaceous vegetation, primarily grasses. Autumn olive biomass (table 1) was predicted from stem diameter at 5 cm above ground level (Thakur et al. 1993). The plots measured 8.4 meters by 4.8 meters. A buffer width of 0.61 meters was incorporated on the inside of the plot boundary, and the remaining area was divided into 18 equal subplots (1.2 meters by 1.2 meters), 6 of which were randomly chosen for lysimeter installation.

Methods

The lysimeters were composed of PVC pipe with a porous ceramic cup and measured 61 centimeters in length. They were installed at a soil depth above the permanent water table, as indicated by the occurrence of mottling (Mitch and Gosselink 1993). The lysimeters were capped with rubber stoppers and put under 60 centibars of tension to draw soil water in through the porous cup.

In October 2002, the lysimeters were installed following the procedure given by Soil Moisture Equipment Company (Santa Monica, CA). Great caution was used to ensure no surface organic matter was in the backfill and that the backfill was of the same horizon in the soil profile. A 2-3 cm layer of Bentonite clay was placed in the bottom of the wells at the TIC and MT sites to prevent groundwater upwelling. It was not used at the PH site because no mottling was observed at that site. Bentonite clay was also placed around the lysimeter at the surface at all sites to prevent direct infiltration of surface water around the sides of the lysimeter.

When the lysimeters were installed, they were capped and immediately put under tension at 60 centibars. They were flushed three times in November and December 2002, since nitrification generally increases following soil disturbance (Paul and Clark 1996). Flushing consisted of evacuating and discarding the soil water and restoring tension. Tree shelters were placed around the lysimeters at the three sites in January and February 2003, to prevent deer damage.

Bi-monthly samples were collected from January 2003 until March 2003 for a total of six sample dates and 182 samples. The soil water samples were transferred from the lysimeters via suction into a flask and then poured into acid washed 125 ml plastic sample bottles, which were kept on ice during transport to the laboratory for analysis. The flask was washed in the field with de-ionized water between samples. All lysimeters were returned to 60 centibars of tension.

In the laboratory, samples were analyzed for ammonium (NH_4^+) (mg L^{-1}) on a Hach 4000v Spectrophotometer (Loveland, CO) using the Nesslerization method (APHA 1992). The samples were analyzed for nitrate (NO_3^-) (mg L^{-1}) on a Dionex Ion Chromatograph (Sunnyvale, CA).

The soil water concentrations from the subplots within each plot were averaged prior to analysis. Nitrate-N concentrations were analyzed as randomized complete block design with repeated measures

Table 2.—Mean soil water nitrate-N and ammonium concentrations for each site by date.

Date	Mean Nitrate-N (mg L^{-1})		Mean Ammonium-N (mg L^{-1})	
	Autumn Olive	Field	Autumn Olive	Field
		Minetree Site		
January 4	*[1]	*	*	*
January 21	12.80	0.22	0.09	0.19
February 4	14.68	1.93	0.25	1.66
February 18	12.07	0.00	0.14	2.17
March 4	34.35	0.10	0.17	2.13
March 20	13.04	0.05	0.10	1.47
		Pleasant Hill Site		
January 4	32.62	2.62	0.34	0.14
January 21	18.57	*	0.19	*
February 4	36.24	1.17	0.24	0.09
February 18	31.95	0.86	0.15	0.15
March 4	27.28	4.17	0.26	0.17
March 20	30.71	1.72	0.09	0.07
		Tree Improvement Center Site		
January 4	2.14	0.10	0.23	0.09
January 21	4.40	0.12	0.11	0.17
February 4	2.47	0.08	0.07	0.03
February 18	1.26	0.08	0.14	0.05
March 4	8.32	0.07	0.14	0.19
March 20	5.17	0.04	0.13	0.03

[1]No samples taken due to deer damage

over time within each experimental unit. The data were analyzed using the mixed model procedure in SAS (SAS Institute 1999). Nitrate data were log transformed to obtain normality. Ammonium data were not examined statistically due to the large number of zero values.

Results and Discussion

The mean soil water nitrate-N concentration was significantly (16.7 times) greater in the autumn olive plots than the open field plots (fig. 2). The results are consistent with studies of red alder stands, where excess nitrogen leaching was observed via soil water collection (Cole et al. 1978, Van Miegroet and Cole 1984). Cole et al. (1978) found 2.2 kg ha^{-1} yr^{-1} of nitrogen lost through leaching in red alder stands compared to 0.6 kg ha^{-1} of nitrogen lost through leaching in Douglas-fir ecosystems. Van Miegroet and Cole (1984) found that there was approximately 50 kg ha^{-1} $yr^{-1}$of nitrate-N leached beyond the 40 cm soil depth in red alder stands.

Soil water nitrate-N concentrations in the autumn olive plots at the MT and PH sites were consistently above the 10 mg L^{-1} drinking water standard set by the USEPA. Nitrate-N values at MT ranged from 12.07 to 34.35 mg L^{-1} and the values at PH ranged from 18.57 to 36.24 mg L^{-1}. The TIC site autumn olive plot values were always lower than 10 mg L^{1} (table 2).

At the PH field plots, soil water nitrate-N concentrations were generally higher than the MT and TIC field plots. Currently, the PH site contains a livestock-grazed pasture. Significant nitrate leaching can occur from urine and fecal spots in grazed pastures in the humid United States (Stout et al. 1997). The MT site has not been used for livestock pasture in at least 13 years, and the TIC site has not been cultivated or pastured for at least 40 years, when the center was established.

Date of sampling was not a significant effect in our model ($p = 0.09$). There was a strong main effect of vegetation type on nitrate-N concentrations below autumn olive stands across all sampling dates (fig. 3). There is evidence that nitrogen fixation varies seasonally, with the highest rates occurring when soil temperatures reach 25°C, normally during the growing season (Zitzer et al. 1989). The nitrate-N that leached during the dormant season may have originated from residual nitrogen fixed during the previous growing season or reduced, but still active, N fixation during the dormant season.

On average, ammonium-N concentrations were lower than nitrate-N concentrations in both vegetation types (table 1). Much of the ammonium generated by N fixation was likely immobilized by heterotrophic microbes and plants or converted to nitrate by nitrifying bacteria (Paul and Clark 1996). Also, ammonium does not readily leach due to its positive charge and incorporation into clay lattices (Paul and Clark 1996).

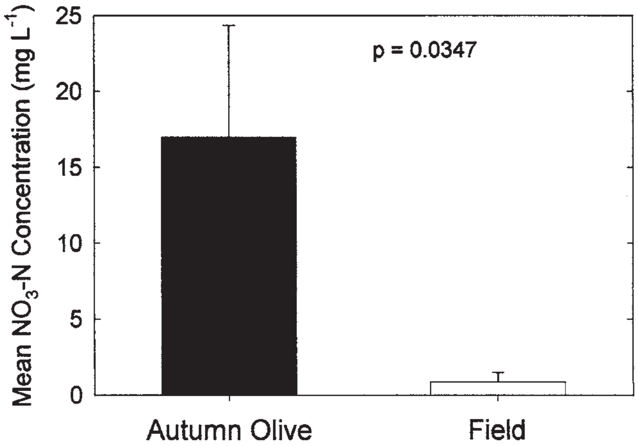

Figure 2.—Mean soil water nitrate-N concentration in autumn olive and open field plots across three riparian sites in southern Illinois (January 4, 2003-March 20, 2003). (Error bars represent ± 1 standard error)

Conclusions

Invasive plants are known to degrade ecosystems throughout the United States by excluding native vegetation. Our results demonstrate an additional negative ecosystem consequence of invasive species, excess nitrate leaching, and should provide further justification for the institution of policies to address this issue. Nitrate export from autumn olive infested sites could contribute to eutrophication of downstream water bodies especially in saline environments (estuaries) (Rabalais et al. 2002). Eutrophication and subsequent hypoxia in the Gulf of Mexico is a critical issue facing the agricultural and marine fisheries communities in the eastern and southern United States.

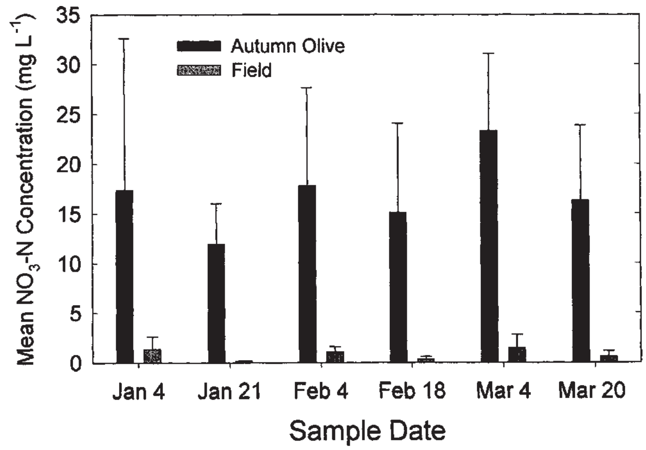

Figure 3.—Temporal variability of mean soil water nitrate-N concentrations in autumn olive and open field plots across three riparian sites in southern Illinois. (Error bars represent ± 1 standard error)

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Literature Cited

Allan, P.F.; Steiner, W.W. 1972. **Autumn olive for wildlife and other conservation uses.** U.S. Department of Agriculture Leaflet No. 458:1-8.

American Public Health Association (APHA). 1992. **Standard methods for the examination of water and wastewater.** 18^{th} Edition. Method 4500-NH_3 C. 1325 p.

Binkley, D.; Lousier, J.D.; Cromack, Jr., K. 1992. **Ecosystem effects of sitka alder in a douglas-fir plantation.** Forest Science 30:26-35.

Brozek, S. 1990. **Effect of soil changes caused by red alder (*Alnus rubra*) on biomass and nutrient status of Douglas-fir (*Pseudotsuga menziesii*) seedlings.** Canadian Journal of Forest Resources 20:1320-1325.

Catling, P.M.; Oldham, M.J.; Sutherland D.A.; Brownell V.R.; Larson B.M.H. 1997. **The recent spread of autumn olive, *Elaeagnus umbellata*, into southern Ontario and its current status.** Canadian Field-Naturalist 111(3):376-380.

Cole, D.W.; Gessel, S.P.; Turner, J. 1978. **Comparative mineral cycling in red alder and douglas-fir.** In D.G. Briggs et al (Ed) Utilization and management of alder. U.S. Forest Service Pacific Northwest Experiment Station. p 327-336.

Edgin, B.; Ebinger, J. 2001. **Control of autumn olive (*Elaeagnus umbellata* Thunb.) at Beall Woods Nature Preserve, Illinois, USA.** Natural Areas Journal 21:386-388.

Funk, D.T; Schlesinger R.C.; Ponder, Jr. F. 1979. **Autumn olive as a nurse plant for black walnut.** Botanical Gazette 140(Suppl.):S110-S114.

Geyer, W.A.; Rink, G. 1998. **Interaction effects of seed source, culture, and pest management on growth of *Juglans nigra* in plantations.** Silvae Genetica 47:51-58.

Hayes, B. 1976. **Planting the *Elaeagnus* Russian and autumn olive for nectar.** American Bee Journal 116:74 and 82.

Mitsch, W.J.; Gosselink, J.G. 1993. **Wetlands.** New York, NY: Van Nostrand Reinhold. 722 p.

Nestleroad, J., Zimmerman, D.; Ebinger, J. 1987. **Autumn olive reproduction in three Illinois state parks.** Transactions of the Illinois State Academy of Science 80:33-39.

Paul, E.A.; Clark, F.E. 1996. **Soil Microbiology and Biochemistry.** San Diego, CA: Academic Press. 340 p.

Rabalais, N.N.; Turner, R.E.; Wiseman, W.J. 2002. **Gulf of Mexico hypoxia, aka "The dead zone".** Annual Review Of Ecology And Systematics 33:235-263.

Rehder, A. 1940. **Manual of cultivated trees and shrubs. 2nd Edition.** Macmillan Publishing, New York. 996 p.

SAS Institute Inc. 1999. **SAS Version 8 for Windows**. Cary, NC.

Stout, W.L., Fales, S.A., Muller, L.D., Schnabel, R.R., Priddy, W.E., Elwinger, G.F. 1997. **Nitrate leaching from cattle urine and feces in northeast USA.** Soil Science Society of America Journal 61:1787-1794.

Thakur, I.K.; Kaushal, A.N.; Dhall, S.P. 1993. **Biomass prediction of some shrubs.** Indian Journal of Forestry 16(4):378-381.

Van Miegroet, H.; Cole, D.W. 1984. **The impact of nitrification on soil acidification and cation leaching in a red alder ecosystem.** Journal of Environmental Quality 13(4):586-590.

Van Miegroet, H.; Homann, P.S.; Cole, D.W. 1988. **Soil nitrogen dynamics following harvesting and conversion of red alder and douglas fir stands.** Soil Science Society of America Journal 56:1311-1318.

Zitzer, S. F.; Dawson J.O.; Gertner G.Z. 1989. **Seasonal changes in nitrogen fixation activity of European black alder and Russian olive.** In: Rink G., and C.A. Budelsky, eds. Proceedings, 7th Central Hardwoods Forest Conference; 1989 March 5-8; Carbondale, IL. Gen. Tech. Rep. NC-132. St.Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station: 134-139.