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NITRATE AND FECAL COLIFORM CONCENTRATIONS IN SILVOPASTURE AND PASTURE LEACHATES

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Abstract: A major limitation to efficient forage-based livestock production in Appalachia is asynchrony of forage availability and quality with nutritional requirements of the grazer. Silvopasture is being studied to improve the seasonal distribution and persistence of high quality herbage, sustainability and environmental integrity of the agricultural landscape. Fundamental knowledge of the impacts of agricultural practices on water quality is needed to address producer goals and societal concerns. Water quality was monitored at the soil/bedrock interface under conventional pasture (CP), silvopasture (SP), and hardwood forest (HF) on a central Appalachian landscape. The pasture and silvopasture were rotationally grazed by sheep during the spring to fall grazing season (2004-2008). Geometric mean fecal coliform bacteria concentrations were greatest in SP (18.0 cfu 100 ml^{-1}) with no difference between CP (7.5 cfu 100 ml^{-1}) and HF (5.6 cfu 100 ml^{-1}). Mean NO_3-N concentration was lowest in SP (2.2 mg L^{-1}) and greatest in CP (4.4 mg L^{-1}) and HW (4.1 mg L^{-1}). Mean NH_4-N concentrations showed different trends with the lowest mean concentration in CP (0.7 mg L^{-1}) and the greatest in SP and HW (2.6 mg L^{-1}). The observations will be important information for the development of decision support tools for maximizing forage and livestock productivity, through silvopastoral management on sloping land of central Appalachia, while protecting surface and groundwater quality.

Key Words: percolation, macropores, water quality, groundwater, Appalachian hardwoods

INTRODUCTION

Efficient forage-based livestock production in Appalachia is limited by asynchrony of forage availability and quality with nutritional requirements of the grazer. Producers require dependable plant resources and management practices that improve the seasonal distribution and persistence of high quality herbage, sustainability, and environmental integrity of agricultural landscapes. Silvopastoral agroforestry systems are being investigated for potential production and environmental benefits on complicated landscapes common to the Appalachian region (Feldhake and Schumann 2005).

High infiltration rates, macropores (Holden 2009), thin soils and fractured bedrock (Levison and Novakowski 2009) are common on central Appalachian landscapes and contribute to rapid recharge of shallow groundwater (Kipp and Dinger 1987). Deciduous forest sites of the region are characterized by thick surface organic layers and extensive systems of macropores (Carmean 1957). Staley et al. (2008) found that conversion of deciduous forest to silvopasture resulted in soil chemistry changes indicative of rapid transition to improved pasture. Boyer and Neel (2007) found that surface litter changes and remnant macropores in silvopasture recently established from deciduous forest resulted in changes organic carbon transport to the soil/bedrock interface. Grazing land management system effects on nutrient cycling and the fate and transport of pathogens require careful study in order to develop environmentally effective systems that protect public health.

Numerous field and model studies have shown the intimate linkage between hillslope hydrology and N-cycling and fecal coliform bacteria (FC) transport (e.g., Cirmo and McDonnell 1997; Dorner et al. 2006). The purpose of this study was to determine if the delivery of inorganic nitrogen (NO_2-N, NO_3-N, and NH4-N) and fecal coliform bacteria with water leaching to the soil/bedrock interface differs between pasture (CP), forest (HF), and silvopasture (SP) systems.

MATERIALS AND METHODS

The study site is located in southern West Virginia at 37° 47’ 39” N, 80° 58’ 22” W (Fig. 1). The conventional pasture is composed primarily of orchard grass (*Dactylis glomerata* L.), Kentucky bluegrass (*Poa pratensis*), and white clover (*Trifolium alba*) and has been maintained as pasture for many years. The conventional pasture is surrounded by mixed hardwood forest, part of which was converted to silvopasture by thinning the primarily red oaks (*Quercus sp.*) and planting orchard grass, rye grass (*Lolium perenne* L.), and white clover. Four 1.9 cm diameter piezometers (Solinst, Georgetown, Ontario, Canada) were installed to the soil/bedrock interface in each land use category (pasture, silvopasture, and forest). The lowest 30 cm of each piezometer was stainless steel and screened. The pasture and silvopasture areas were rotationally grazed by sheep during the growing season.

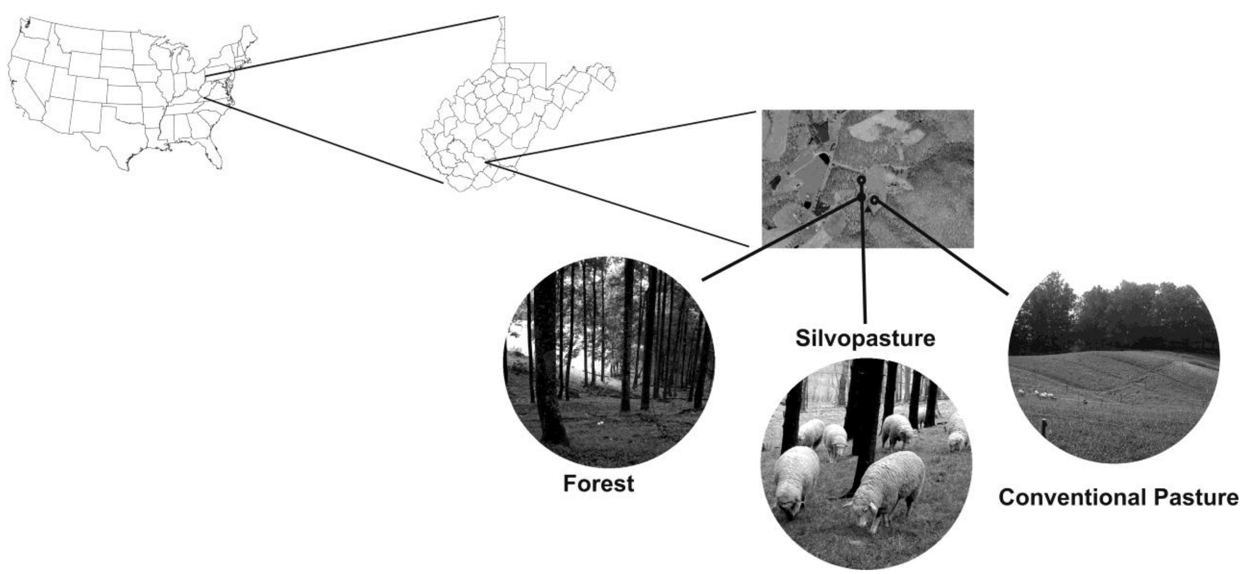

Figure 1. Study location.

Shortly after storms water samples were retrieved from the piezometers with a peristaltic pump (Geotech Environmental Equipment, Inc., Denver, CO) and 4.8 mm diameter silicone tubing. Water samples were transported back to the laboratory in sterile plastic bottles on ice. The water samples were quickly filtered through 0.45 µm filters which were placed on mFC nutrient agar media in Petri plates. FC were counted on the filter media following incubation at 44.5° C for 22 to 24 hours and recorded as colony forming units (CFU) per 100 ml. The sample water that passed through the filters was analyzed by suppressed ion chromatography (Dionex Corp., Sunnyvale, CA) for major anions and cations and recorded as mg L^{-1}.

The period of record is September 2004 through December 2008. In seasonal analyses spring is March – May, summer is June – August, fall is September – November, and winter is December – February. Sheep usually grazed the SP and CP sites April – October. FC counts were normalized by adding one to all FC counts and transforming to logarithms (base 10) for all statistical analyses. Statistical tests were done with the Statistical Analysis System (SAS Institute, Inc., Cary, NC). All statistical tests are significant at the P ≥95 percent level unless stated otherwise.

RESULTS

Water appeared at the soil/bedrock interface more frequently in silvopasture site than the pasture or forest sites. The total number of storm samples collected at the silvopasture, pasture, and forest sites was 296, 179, and 71, respectively. Table 1 shows the summary statistics for inorganic N and FC concentrations in each of the land use treatments.

Table 1. Summary statistics for inorganic N and fecal coliform concentrations in silvopasture (SP), pasture (CP), and hardwood forest (HF). Means with the same letter are not significantly different within rows.

	SP		CP		HF	
	mean[1]	s.e.[2]	mean	s.e.	mean	s.e.
Number of samples	296		179		71	
Inorganic N (mg L^{-1})	4.9[a]	0.62	5.0[a]	0.38	6.3[a]	1.52
$NO_2 + NO_3$-N	2.2[a]	0.26	4.4[b]	0.34	4.1[b]	0.78
NH_4-N	2.6[a]	0.49	0.7[b]	0.10	2.6[a]	1.36
Fecal coliforms (CFU 100 ml^{-1})	18.0[a]	1.21	7.5[b]	1.28	5.6[b]	1.45

[1]Geometric mean (mean of the logarithms transformed back to a real number) for fecal coliforms.
[2]Standard error for fecal coliforms is the anti-log of the standard error of log concentration.

Seasonal means of NO_3-N concentrations are shown in Figure 2. NO_3-N concentrations in the SP leachates are lower than the concentrations in CP or HW leachates in all seasons, but spring. NO_3-N concentrations were greatest in fall with CP and HW NO_3-N concentrations averaging

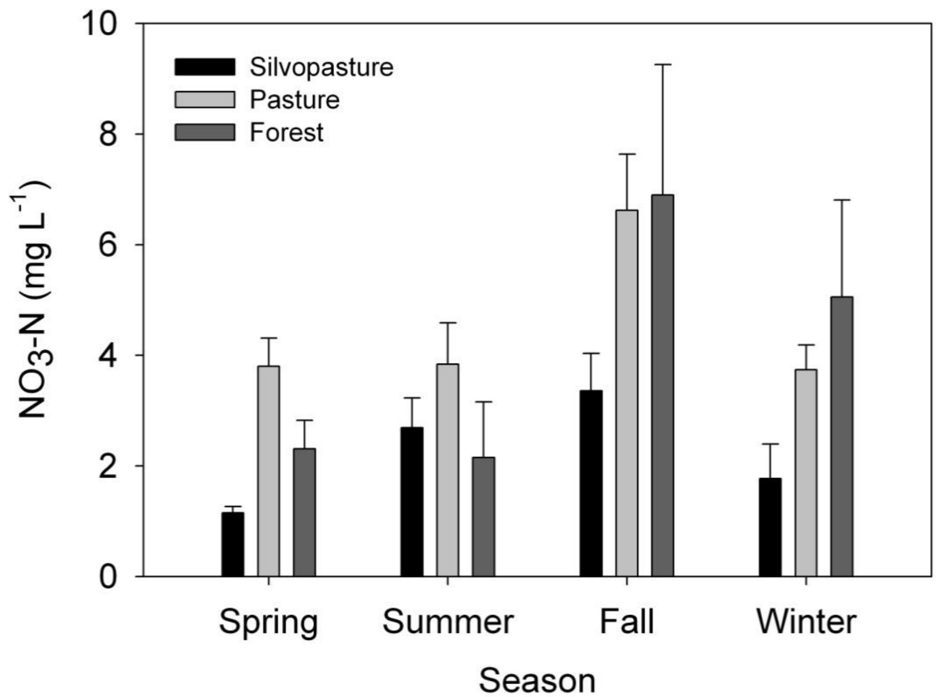

Figure 2. Mean seasonal NO3-N concentrations at the soil/bedrock interface in silvopasture, pasture, and hardwood forest land uses. Spring = Mar – May, Summer = June – Aug., Fall = Sept. – Nov., Winter = Dec. – Feb.

6.6 and 6.9 mg L^{-1}, respectively. The fall NO_3-N concentration in SP averaged 3.4 mg L^{-1}. Linear regression analysis of NO_3-N concentration versus days since start of study failed to indicate any significant trend during the study. Linear regression trend analysis of NH_4-N concentrations did indicate significantly decreasing concentrations. NH_4-N concentrations decreased about 2 mg L^{-1} yr^{-1} in SP and HW land uses and about 0.15 mg L^{-1} yr^{-1} in CP.

Geometric mean FC concentrations at the soil/bedrock interface were highest in summer in all three land use treatments (Fig. 3) and FC concentrations were next highest in fall and gradually decreased through winter to their lowest concentrations in spring. The highest geometric mean FC concentrations during the growing season occurred in the forest site, which was not grazed by sheep. Trend analysis using linear regression failed to show any significant trend in log FC concentrations in the CP or HW land uses, but a highly significant ($P \geq 99.9$) decreasing trend (0.23 log CFU 100 ml^{-1} yr^{-1}) in the SP land use.

Cumulative frequency analyses of the occurrence of NO_3-N concentrations show similar results up to about 30 percent of the samples (see Fig. 4). At the 30 percent level nitrate concentrations increase more rapidly in CP and least rapidly in SP. The CP and HW cumulative frequency curves converge at about 80 percent of the samples and the SP samples remain lower until about 95 percent of the samples where all three curves are similar. Higher FC concentrations are shown

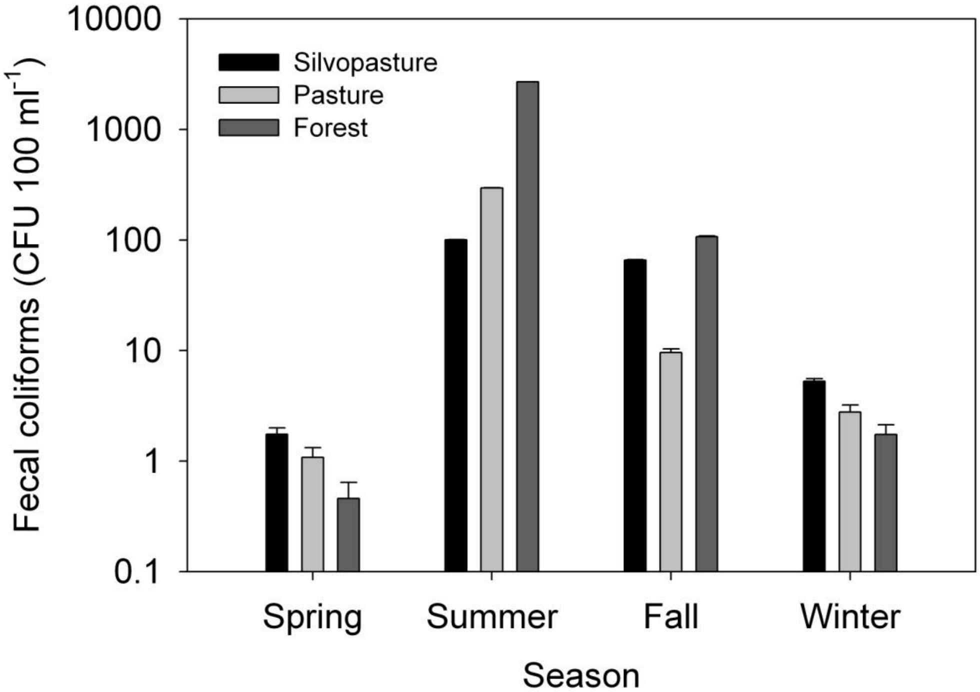

Figure 3. Geometric mean seasonal FC concentrations at the soil/bedrock interface in silvopasture, pasture, and hardwood forest land uses. Spring = Mar – May, Summer = June – Aug., Fall = Sept. – Nov., Winter = Dec. – Feb.

for SP in Figure 5. Forty percent of the samples from SP had FC concentrations ≤ 1 CFU 100 ml^{-1}. More than sixty percent of the CP and HW samples had FC concentrations ≤ 1 CFU 100 ml^{-1}.

DISCUSSION

The low NO_3-N concentrations at the soil/bedrock interface in SP relative to those in CP and HF are encouraging from a water quality standpoint. NO_3-N concentration in SP might have been expected to be similar to those in HF, but the forage plants in SP were probably using much of the NO_3-N that might have been expected to leach. Staley et al. (2008) found that soil chemical characteristics of these same silvopasture sites were rapidly approaching pasture-like conditions, but they did not look at NO_3-N. Over time, SP NO_3-N might be expected to approach the concentrations found in CP, but the trend analysis failed to show any movement in that direction. The high NO_3-N concentrations in fall in CP and HW might be related to leaf fall in HF and senescing of white clover in CP. There was much less leaf fall and little white clover in the SP plots and the C3 grasses in the SP plots were likely able to use much of the NO_3-N that did result from those sources.

There is a constant shift in soil systems between NH_4-N and NO_3-N as oxidizing and reducing conditions occur. The lack of differences in total inorganic N concentrations between the three land uses, but shifted emphasis of NH_4-N and NO_3-N between the systems indicates that the land uses were having differential effects on the oxidizing and reducing conditions.

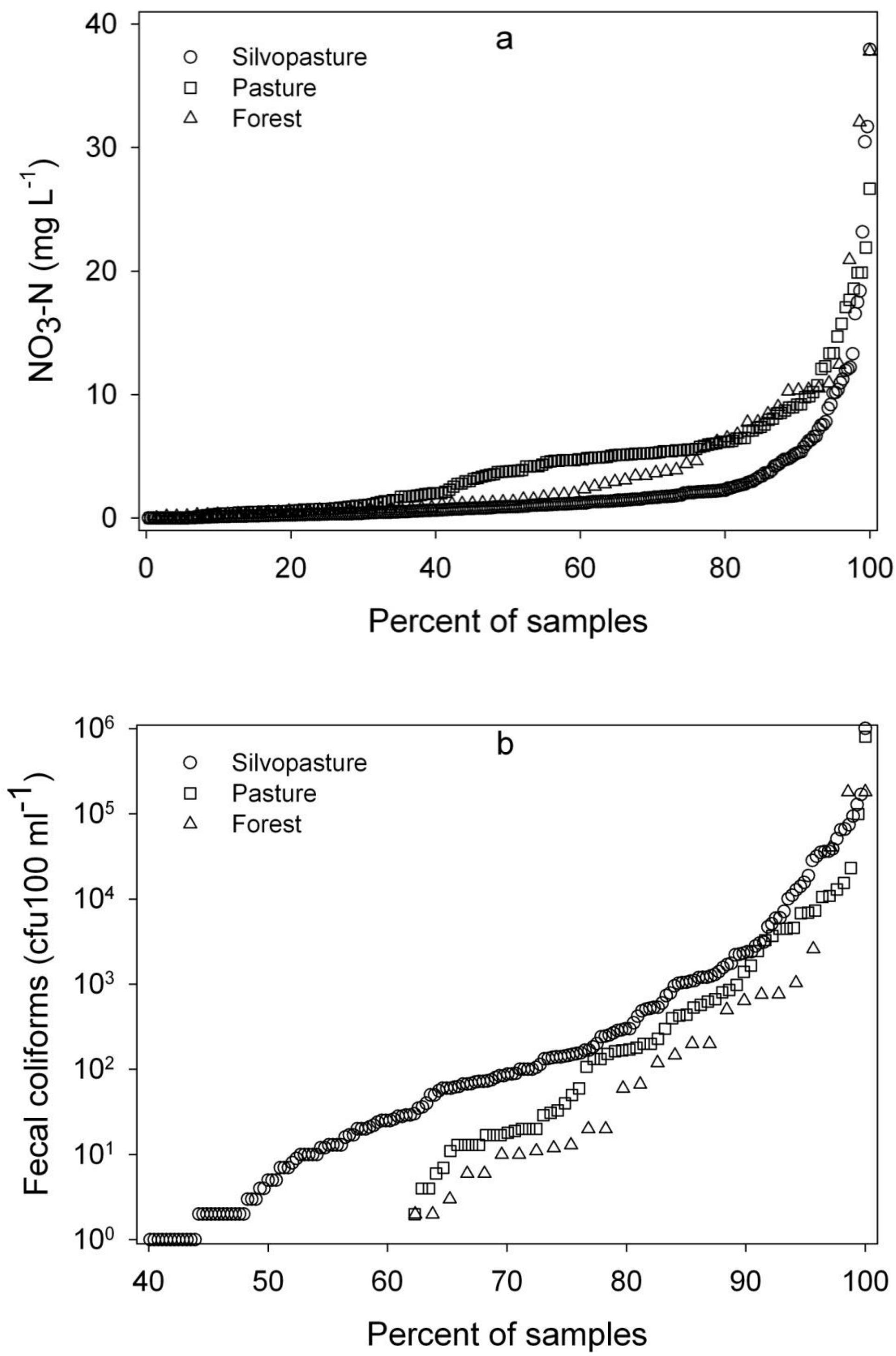

Figure 4. Cumulative distributions of a.) NO_3-N and b.) FC concentrations at the soil/bedrock interface in silvopasture, pasture, and hardwood forest.

The high geometric mean FC concentrations in SP are troubling and might have resulted from a well-organized system of macropores and disturbance of the surface litter layer. Removal of some of the organic litter layer diminishes the sites ability to intercept water before it reaches mineral soil and the macropores provide a fairly direct route to deeper soil layers bypassing much of the filtration provided by the soil matrix. Boyer et al. (2009) found that macropores readily transmitted *Cryptosporidium* oocysts, which are two to four times greater in size than FC, through soil. The high FC concentrations at the soil/bedrock interface in HW were a surprise since livestock were not grazed in the vicinity of the piezometers. Results shown in Figure 4b indicate that FC were not transported to the soil/bedrock interface on a regular basis (more than 60 percent of the HW samples did not test positive for FC). The intermittent high FC counts in HW water samples were probably a result of FC transported from wild animal burrows through intersecting macropores. Wild animals cannot be excluded as sources of FC in the SP samples, but a much higher percentage of samples in SP tested positive for FC indicating that sheep manure was a source of bacteria.

Geometric mean FC concentrations in SP would be expected to equal the geometric mean concentration in CP after five to six years if the current trend continues. However, the SP sites should retain some of the macropore features and FC concentrations might still be somewhat greater than those in pasture at the soil/bedrock interface. FC bacteria reaching the soil/bedrock interface are expected to experience a tortuous route through bedrock fractures, often in-filled with sediment, and never reach surface water. A higher portion of flow in CP might be overland flow providing fecal coliform bacteria a more direct route to surface water.

Results from this study show that NO_3-N contributions to shallow groundwater are less under silvopasture than conventional pasture. Macropores in silvopasture systems seem to lend easier transport of fecal organisms to shallow groundwater, but the tortuous route flow route through fractured bedrock to surface water should minimize impacts on surface water quality. Ungrazed buffers along surface streams might provide effective barriers to fecal bacterial contamination from silvopasture areas where overland flow is minimized. The observations from this study will be important information for the development of decision support tools for maximizing forage and livestock productivity, through silvopastoral management on sloping land of central Appalachia, while protecting surface and groundwater quality.

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