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Spatial Heterogeneity of Soil Nutrients, Nitrogen Dynamics, and Vegetation in a 3rd Order Stream Floodplain in Southwestern West Virginia

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SPATIAL HETEROGENEITY OF SOIL NUTRIENTS, NITROGEN DYNAMICS, AND VEGETATION IN A 3RD ORDER STREAM FLOODPLAIN IN SOUTHWESTERN WEST VIRGINIA

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ABSTRACT

Spatial Heterogeneity of Soil Nutrients, Nitrogen Dynamics, and Vegetation in a 3rd Order Stream Floodplain in Southwestern West Virginia

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Soil processes often exhibit spatial heterogeneity within ecosystems and this heterogeneity may influence community structure. This study was conducted to determine spatial patterns and variability of soil nutrients and plant communities within different vegetation types in a stream floodplain in southwestern West Virginia. One 5-m × 5-m site was established in each of three vegetation/drainage types: pasture (PA), old field (OF), and wetland scar (SC). Pasture and SC sites were located ~25 m apart on flat bottomland; the OF site was located on a moderate slope 6.3 m above bottomland, ~200 m from PA and SC. A 10-m × 1-m transect was also established perpendicular to the visible boundary between PA and SC drainage types, but not within the PA and SC sites. Each site was divided into 1-m^2 plots (n = 25) and the transect was divided into 0.25-m^2 plots (n = 40). For sites, mineral soil was taken to a 5-cm depth with a 2-cm diameter soil corer centrally from each 0.25-m^2 quadrant of and combined into a single composite sample per plot (n = 25 per site). For transect, mineral soil was taken to ~5-cm depth using a hand trowel and samples for each plot were kept separate (n = 40). Soil organic matter was measured as loss-on-ignition. Extractable NH_4^+ and NO_3^- were determined before and after laboratory incubation (28 days at 27 C) to determine net N mineralization and nitrification. Cations were analyzed using inductively coupled plasma emission spectrometry. Vegetation was assessed using estimated percent cover (sites) and aboveground harvested biomass (transect). Mean organic matter was significantly higher (P <0.05) in SC than in OF and PA (10.6, 8.1, and 8.3%, respectively). Nitrification was nearly 100% of mineralization in all soils, and was significantly lower (P <0.05) in PA than in OF and SC (0.7, 1.6, and 1.8 µg NO_3^--N/g soil/d, respectively). Aluminum was significantly higher (P <0.05) in SC than in OF and PA (202.1, 4.8, and 0.5 µg Al^{3+}/g soil, respectively). Calcium, magnesium, and pH were all significantly higher (P <0.05) in OF (1035.7 and 334.8 µg/g soil, and 4.6, respectively). Transect results were similar to PA and SC sites and an abrupt transition was found between PA and SC site types. Vegetation analysis revealed three distinct communities with SC dominated by wetland species, OF dominated by upland species, and PA dominated by a mixture with slightly more upland species. Transect vegetation also consisted of largely wetland species within wetland and a mixture in pasture, however *Arthraxon hispidus* dominated for ~1 m at the boundary. Spatial variability of organic matter was much lower than spatial variability of nitrification, which was higher in PA than in OF and SC. Thus, availability of organic substrates to N-processing microbes is less variable than N processing itself, underlining the complexity of biotic factors responsible for regulating soil N processes.

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I would like to thank my wife, Kelly, for dealing with my stress (and mess of papers) over the past two years and convincing me that I would in fact survive graduate school. I would also like to mention my Siberian Huskies (Titus, Katia, Gypsy, and Arlo) who helped me relax by demanding long walks in the park and play breaks ever hour. (We'll be sledding/carting as soon as I finish!) I need to thank my parents, Sue and Golden, for letting me make my own choices, convincing me that school was a good thing, and taking Kelly and me to many a "free" movie and dinner when funds were in short supply and we needed a break from everything. I would also like to mention my in-laws, Nikki and David Stiltner, for more "free" movies and dinners and pestering me to finish my school work. Hey, every now and then we all need some motivation.

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CHAPTER I

INTRODUCTION

The West Virginia Department of Highways (WVDOH) has proposed construction of a wetland within the Mill Creek area of southwestern West Virginia, near Saltpetre in Wayne County. In accordance with Section 404 of the Clean Water Act, this action is being considered to compensate for loses of natural wetland habitat due to widening and rerouting portions of U.S. Route 52 through the area. Although there is debate over mitigation effectiveness (Malakoff 1998; Race and Fonseca 1996), continued research might improve mitigation efforts (Mitsch and Gosselink 2000; Mitsch and Wilson 1996). A soil nutrient analysis was requested as part of site selection. Since the proposed site already had poorly drained areas with characteristic wetland vegetation, this provided an opportunity to study fine-scale spatial heterogeneity of soil processes within a floodplain and to examine possible pre/post inundation scenarios.

Heterogeneity – defined by Li and Reynolds (1995) as “the complexity and/or variability of a system property in space and/or time” – can be an important component controlling ecosystem structure and function. For example, soil heterogeneity is considered to play an important role in maintaining biodiversity (Bell *et al*. 2000; Vivian-Smith 1997) and has been linked with structural establishment of plant communities (Robertson *et al*. 1988; Cross and Schlesinger 1999). A better understanding of spatial variability at many scales is necessary for efficient and effective management of natural resources (Gosz 1992). Understanding spatial heterogeneity may help determine the response of ecosystems to disturbance, such as forest harvesting or excess inputs of nitrogen (N) to forests via atmospheric deposition. For example, spatially discrete areas of high N mineralization rates ("hot spots") may serve as a source of N loss following disturbance, whereas similar areas of low net N mineralization due to high N immobilization may serve as an N sink, thereby mitigating ecosystem-level N loss (Gilliam *et al.* 2001b). Similarly, Walley *et al*. (1996) found that landscape variability in N mineralization and nitrification was closely related to patterns of disturbance responses in a Canadian boreal forest. Finally, quantification of heterogeneity will result in improved statistical estimates (Parkin 1993).

Processes controlling the cycling of N and other soil nutrients in terrestrial ecosystem are often spatially heterogeneous (Gilliam *et al*. 2001b). Morris and Boerner (1998, 1999) found substantial landscape-scale variability in patterns of nitrification and microbial biomass in eastern hardwood forest soils, and concluded that moisture was a major factor in determining such variability. Some studies (e.g., Ferrari 1999) have found spatial variability of N processing in forest soils to be related to gap formation and leaf litter chemistry of contrasting tree species, whereas other studies have stressed hydrologic regime as a source of spatial patterns in soil N dynamics (Ohrui *et al*. 1999). Devito *et al*. (1999) reported spatial patterns in net N mineralization to be controlled by soil organic matter, vegetation composition, and drainage. Stevenson (1986) reported that temperature, moisture, pH, ammonium (NH_4^+), oxygen (O_2) and carbon dioxide (CO_2) control nitrification while carbon-to-nitrogen ratios (C/N) control net N mineralization and immobilization. Van der Krift and Berendse (2001) determined that temperature fluctuations associated with seasonal changes significantly influenced N mineralization. It has also been suggested that vegetation, not climate, is a main factor controlling N mineralization along vegetation and elevation gradients (Knoepp and Swank 1998; van der Krift and Berendse 2001). However, N availability may also influence, as well as be influenced by, vegetation (Wedin and Tilman 1990).

Spatial variability of soil cations, particularly magnesium (Mg^{2+}), calcium (Ca^{2+}), and aluminum (Al^{3+}), has received little attention in ecological studies. Typically, Mg^{2+} and Ca^{2+} are more soluble at higher pH while Al^{3+}, which is toxic to most plants because it competes with Ca^{2+} and other cations for binding sites in fine roots (Shortle and Smith 1988), is more soluble at lower pH (Barbour *et al.* 1999; Postek *et al*. 1995). Cross and Schlesinger (1999) and Schlesinger *et al*. (1996) determined that spatial variability of Ca^{2+}, Mg^{2+}, and sulfate sulfur (SO_4-S) was due to geophysical forces while shrubs maintained N, phosphorus (P), potassium (K^+), and organic carbon (C) distribution. Pellerin *et al*. (2002) highlighted a negative correlation between Al^{3+} and Ca^{2+}-Mg^{2+} concentrations in soils and showed higher Al^{3+} concentrations in hydric soils near streams. The ratio of Ca^{2+}/Al^{3+}, sometimes used as an indicator of forest health, has been shown to strongly influence net nitrification at Fernow Experimental Forest in West Virginia (Gilliam *et al*. 2001b).

Although spatial variability of soil N dynamics has been studied more often in the context of ecosystem response to disturbances such as forest harvesting (Gilliam and Adams 1999; Gilliam *et al*. 2001a), it also has important implications for terrestrial ecosystem responses to inundation, whether from periodic flooding or from the process of wetland creation. Previous work at Greenbottom Wildlife Management Area, West Virginia has shown that processing of N in terrestrial soil changes rapidly following inundation during wetland construction (Gilliam *et al*. 1999). These changes largely take the form of reduced nitrification, but continued net N mineralization. In the absence of plants adapted to waterlogged conditions brought on by inundation, mineral N (both NH_4^+ and NO_3^-) can accumulate in the available pool. The eventual fate of NH_4^+ is not clear, but, in the presence of adequate organic matter, accumulated NO_3^- can be denitrified to N_2O (Mitsch and Gosselink 2000), a serious greenhouse gas. Thus, it is critical to know how spatially variable soil N processes are prior to inundation to predict or understand the response of these processes during wetland construction.

Accordingly, the purpose of this study was to assess fine-scale spatial variability of soil properties related to soil N dynamics at a site that is to undergo wetland creation. Thus, this study will provide baseline (pre-inundation) data for mitigation efforts at Mill Creek, allowing future monitoring of changes and study of wetland soil development. This study will also provide predictions of soil chemistry for the mitigated wetland by selecting plots that are both inside and outside of poorly drained areas within the study site. Specific objectives of the study are as follows:

1. Characterize soil nutrients/properties (mineral N pools, N mineralization, nitrification, pH, moisture, organic matter, Ca^{2+}, Mg^{2+}, and Al^{3+}) and diversity of plant species within a low-order floodplain.
2. Compare soil nutrients/properties, species diversity, and spatial variability of soil nutrients/properties among different drainage patterns and plant communities within a low-order floodplain.
3. Determine relationship between soil heterogeneity and species diversity.
4. Determine spatial patterns of soil nutrients/properties along a wetland boundary gradient and their relationship to species diversity.

CHAPTER II
MATERIALS AND METHODS

Site description

Mill Creek mitigation area is an abandoned pasture located in the floodplain of a third-order stream in Wayne County, West Virginia, near the town of Saltpetre (Figure 1). Mixed deciduous forest surrounds the site. Total rainfall, taken as an average from four nearby monitoring stations (Dewey Lake, Yatesville Lake, Beech Fork Lake, and East Lynn Lake), was 605 mm between 1 January 2001 and 14 October 2001 (Figure 2). Study site exhibits a temperate climate.

Rapid flooding occurs during heavy rains (Dewey Sanderson, personal communication), and standing water can be found after such events (personal observation) in drainage ditches and, particularly important for this study, in a crescent-shaped depression that exhibits several wetland vegetation characteristics. This site has been referred to as a "scar" (Dan Evans, personal communication) and may be the remnants of a cattle wallow (Frank Gilliam, personal communication). There is a noticeable drop in elevation of approximately 5 cm within the scar compared to surrounding pasture (personal observation). Bottomland slopes up toward a forested hilltop, the lower slopes of which are dominated by old-field vegetation. This site will soon become a constructed wetland to offset losses incurred in rerouting U.S. Route 52.

Field sampling

Three 5-m × 5-m sites were established within the study area, one each in three visually distinct patches of vegetation with varying drainage patterns. Two sites were located on the floodplain: one (UTM center 364,867.3 × 4,216,283.1) inside the wetland scar, dominated by *Juncus effusus* L. (common rush) and *Carex* spp. (sedge), and one (UTM center 364,877.8 × 4,216,308.1) approximately 25 m away in the pasture, dominated by species of *Festuca elatior* L. (meadow fescue) and *Aster pilosus* Willd. (white heath aster). Another site (UTM center 365,051.9 × 4,216,381.6) was located on a moderate slope dominated by *Ambrosia artemisifolia* L. (common ragweed) and *Andropogon virginicus* L. (broomsedge) approximately 200 m away. Hereafter, these sites will be referred to as SC (wetland scar), PA (pasture), and OF (old field), respectively.

Figure 1. Map of proposed mitigation area with study sites marked (solid circles). Cells A-E are areas that will be flooded due to mitigation efforts. Saltpeter is located near the southwest corner of the map, but is outside the map boundary and cannot be seen. OF, PA, and SC represent approximately locations of old field, pasture, and wetland scar plots, respectively.

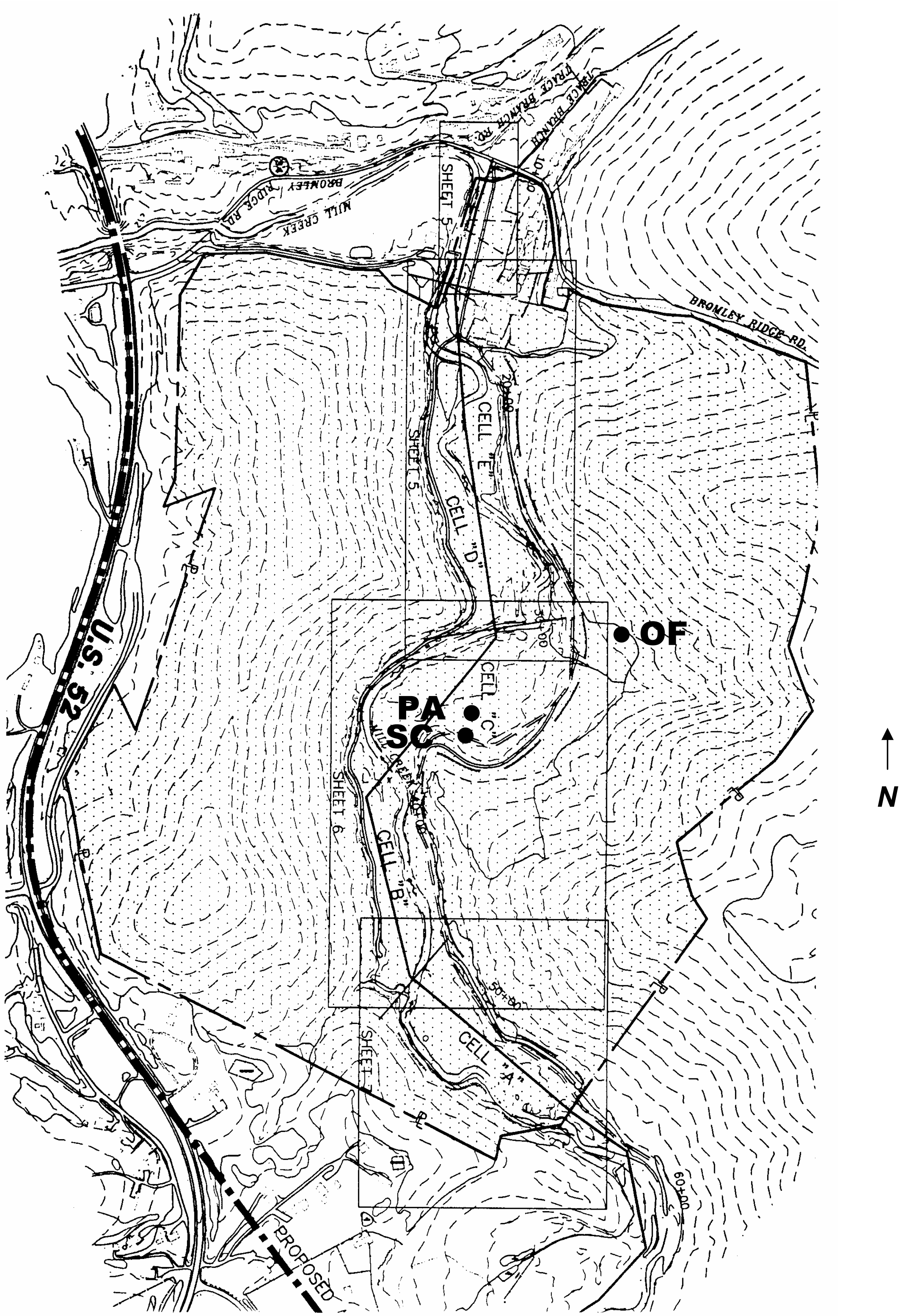
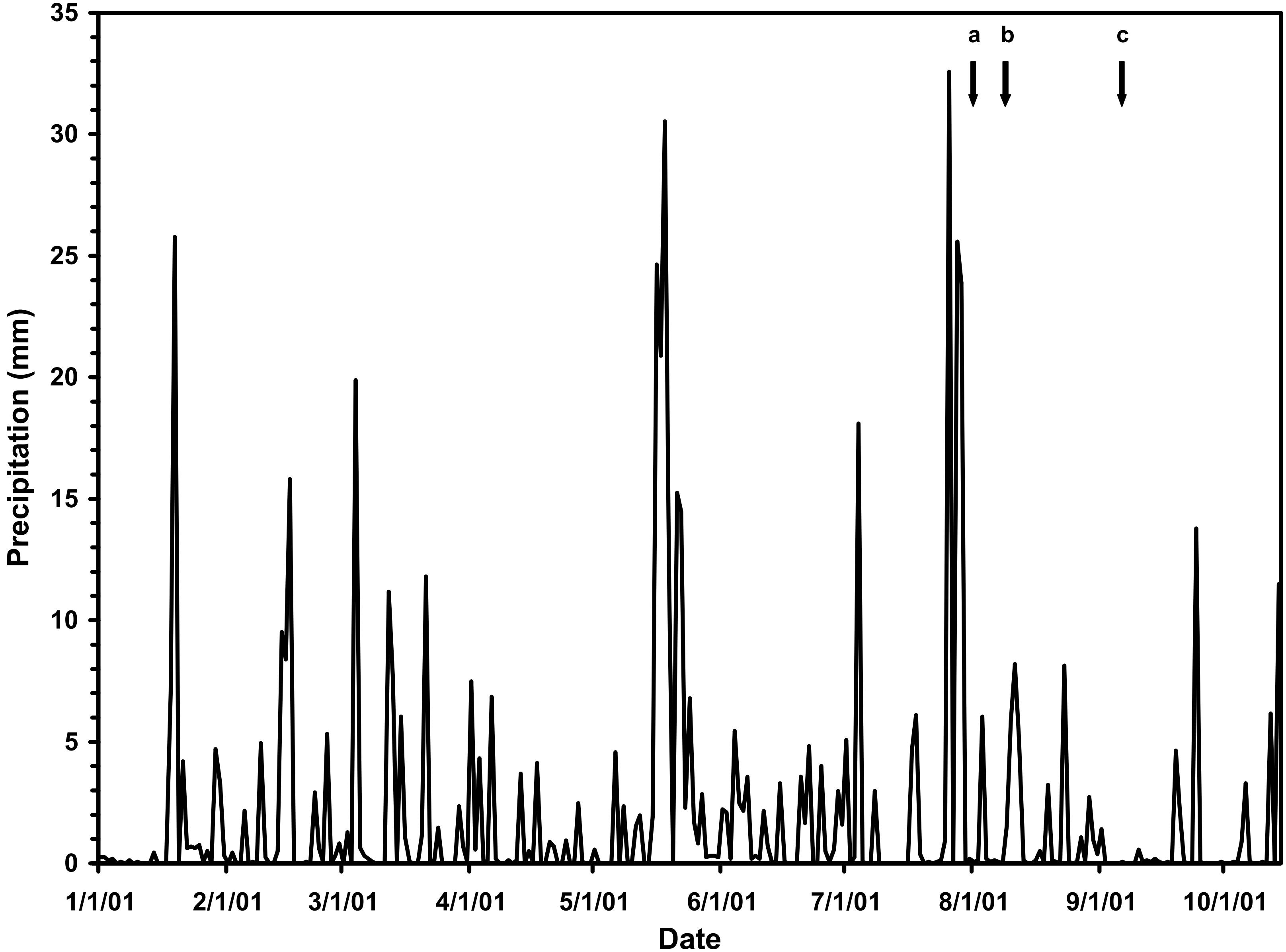

U.S. 52
PA
SC
OF
N
CELL "A"
CELL "B"
CELL "C"
CELL "D"
CELL "E"
SHEET 5
SHEET 6
BROMLEY RIDGE RD.
TRACE BRANCH RD.
MILL CREEK
PROPOSED
20+00
50+00
60+00

Figure 2. Daily precipitation (mm) for 1 January 2001 through 14 October 2001 averaged from four monitoring stations located near the study site including Yatesville Lake, Dewey Lake, Beech Fork Lake, and East Lynn Lake. Data collected by Dewey Sanderson as part of hydrologic study. Arrows denote soil-sampling dates as follows: a) OF and PA, b) SC, and c) transect.



35
30
25
20
15
10
5
0
Precipitation (mm)
a
b
c
1/1/01
2/1/01
3/1/01
4/1/01
5/1/01
6/1/01
7/1/01
8/1/01
9/1/01
10/1/01
Date

Each 5-m × 5-m site was divided into 25 1-m^2 plots and each plot was quartered using a 1-m^2 PVC frame with center cross (Figure 3). One mineral soil sample (O horizon removed) was taken from near the center of each quadrant of 1-m^2 plots to a depth of 5 cm using a 2-cm diameter punch tube. Four samples (one from each quadrant) were combined to create a composite sample for each 1-m^2 plot. This created a total of 25 soil samples per vegetation/drainage type spaced at approximately 1-m intervals. Soil samples were immediately placed on ice for transport to Marshall University. PA and OF samples were collected 1 August 2001 (Figure 2a) and SC samples were collected 10 August 2001 (Figure 2b) due to flooding at SC on the previous sample date.

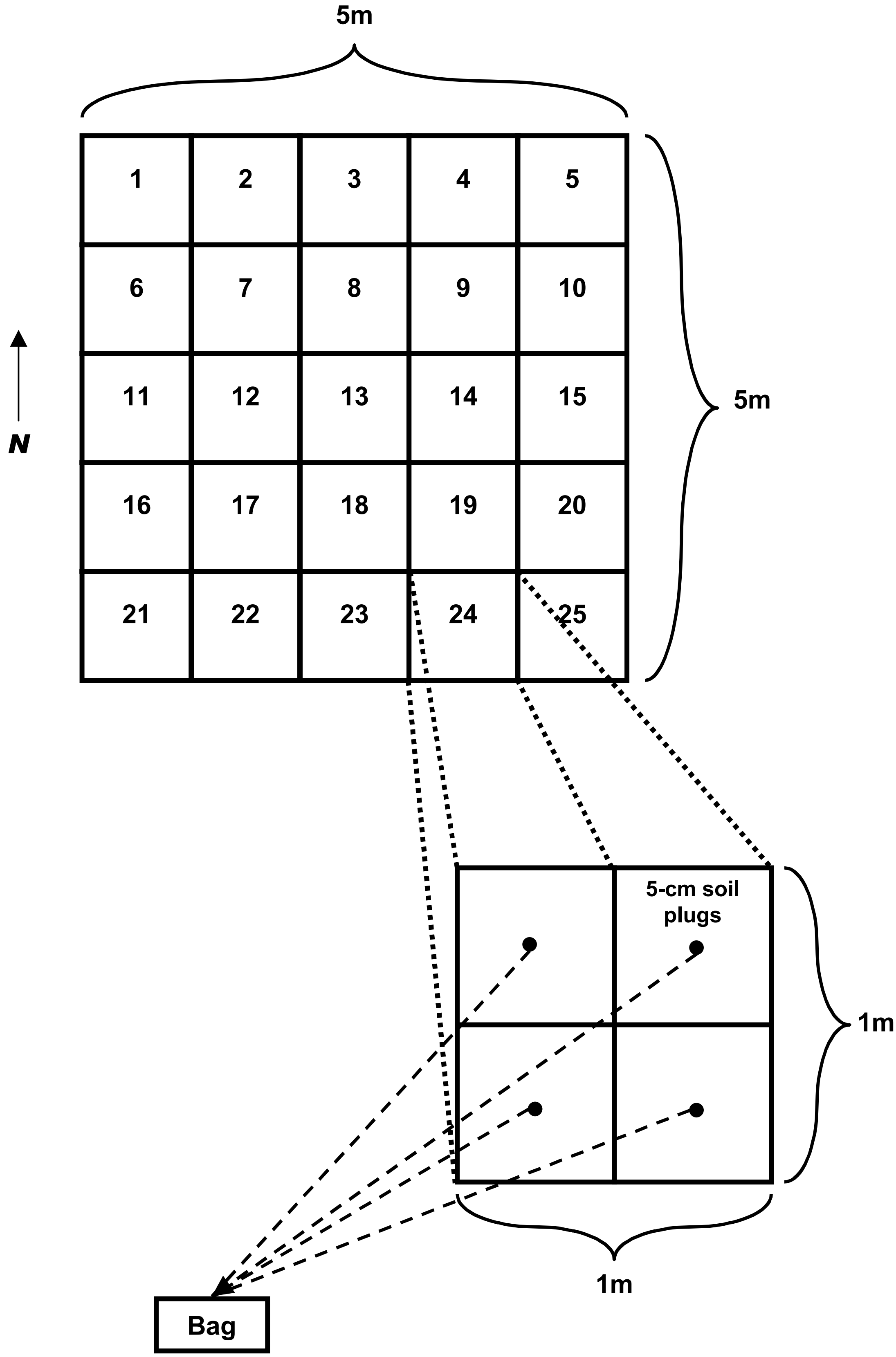
A 10-m transect was established perpendicular to the scar boundary and centered with 5 m extending into both scar and pasture areas, but not into PA and SC sites. Using this transect as a centerline, a quartered 1-m^2 PVC frame (used in plot sampling) was used to define 40 0.25-m^2 plots along the transect (paired plots at 0.5-m intervals). Soil samples were collected on 5 September 2001 (Figure 2c) using a hand trowel to a depth of approximately 5 cm and O horizon was removed. Soil samples were immediately placed on ice for transport to Marshall University laboratory.

Vegetation cover was estimated within 1-m^2 plots at OF, PA, and SC sites using percent cover estimation in October 2002. Aboveground vegetation was harvested within each 0.25-m^2 transect plot on 3 October 2001 using gardening shears to cut stems at ground level. Vegetation from each transect plot was placed in a labeled plastic trash bag for transport back to laboratory for sorting, drying, and weighing. Botanical nomenclature follows Strasbaugh and Core (1977). Species will hereafter be referred to by a four-letter code (Appendix A). Additionally, wetland indicator status (Appendix B) for each species is presented to assess community structure.

Laboratory analyses

Soil moisture was measured gravimetrically and determined as mass lost over 24 h at 100 C. Organic matter was determined from dried soil samples using a loss-on-ignition method (mass lost over 7 h at 500 C). Soil samples were extracted (see below) for pre-incubation analysis of extractable NO_3^-, NH_4^+, Al^{3+}, Ca^{2+}, and Mg^{2+} and pH was recorded from the extracts. Soil samples were then incubated at 27 C for 28 d and extracted for post-incubation analysis. Extraction and analysis for NH_4^+ and NO_3^- were done for mineral soil only, following methods

Figure 3. Schematic for sampling design used for site studies. Box labeled 1-25 represents study site and numbering scheme. Enlarged 1- × 1-m box represents one plot quartered with PVC frame. Soil plugs were 5-cm deep and 2-cm in diameter.


5m
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
5m
N
5-cm soil plugs
1m
1m
Bag

described in Gilliam and Adams (1999). Briefly, moist soils were extracted with 1N KCl at an extract:soil ratio of 10:1 (v:w). Extracts were analyzed colorimetrically for NH_4^+ and NO_3^- with a Bran+Luebbe TrAAcs 2000 automatic analysis system. Aluminum, Ca^{2+}, and Mg^{2+} ions were analyzed via inductively coupled plasma emission spectrometry (ICP) with a Varian Liberty 110 ICP Emission Spectrometer. Extractable N pools were determined as the pre-incubation levels of NH_4^+ and NO_3^-. Net N mineralization was calculated as post-incubation N (NH_4^+ plus NO_3^-) minus pre-incubation N pools (NH_4^+ plus NO_3^-); net nitrification was calculated as post-incubation NO_3^- minus pre-incubation NO_3^-.

Transect vegetation was sorted by species, where possible. Two species, *Poa* sp. and another grass-like species, could not be identified or separated and were combined as graminoids. Species were placed in paper bags and dried in an oven at 55 C for >24 h before weighing. Botanical nomenclature follows Strausbaugh and Core (1977).

Data analysis

Prior to statistical analysis the cumulative data sets (site study and transect study) were each tested for normality using Shapiro-Wilk test in Statistix 7.0 (Analytical Software 2000). All site study variables conformed to a normal distribution and were therefore used as untransformed data. All transect variables except soil moisture and Mg^{2+} conformed to normality. Transect moisture data were log transformed for analysis, however they were decoded for presentation within this thesis. Magnesium data departed only slightly for normality ($W = 0.95$; $P < 0.10$) and any attempts to transform them resulted in further departures. Therefore, transect Mg^{2+} data were used untransformed.

Means were compared across all three site types using one-way analysis of variance (ANOVA) and least significant difference (LSD) multiple range tests in Statistix 7.0 (Analytical Software 2000). Degree of spatial variability within sites was assessed by calculating variance and coefficient of variance (CV) for soil variables at each site. Spatial variability between sites was assessed using Bartlett's test and a Tukey-type test was employed to compare variances when differences were found (Zar 1984). Although autocorrelation is preferred as a test for spatial variability and spatial dependence (Li and Reynolds 1995; Palmer 1990; Dutilleul 1993; Issaks and Srivasta 1989; Schlesinger *et al*. 1996; Robertson 1987), lack of sufficient data pairs made such analysis impossible (MW Palmer, personal communication). CV (Schlesinger *et al*.

1996) and variance (Guo *et al*. 2002) are both considered good alternate measures of spatial variability. Variability was also assessed visually by plotting "bubble maps" in which circles of sizes proportional to sample values were arrayed in a grid similar to field sites (Appendix C). Vegetation data were analyzed for richness (whole site and mean per 1-m^2 plot) using Microsoft Excel 97 and diversity (Shannon index, base *e*), evenness, and percent similarity between sites using Ecological Quantitative Analysis Software (Brower *et al*. 1998). Relationships between variables were assessed with correlation analysis using Statistix 7.0 (Analytical Software 2000) and direct gradient analysis using canonical correspondence analysis (CCA) was performed with PC-ORD 4 (McCune and Mefford 1999). Plot scores in CCA are reported as Linear Combination (LC) scores (Palmer 1993) and environmental variables were plotted using intraset biplot scores (McCune and Mefford 1999).

Transect samples were assigned an "inside" or "outside" of scar status based on their position along the transect (n = 20 per class). Means were compared between status groups using one-way ANOVA and LSD multiple range tests in Statistix 7.0 (Analytical Software 2000). Trends were determined by regression analysis for variables exhibiting significant differences. Differences in variability were assessed using sample variance and Bartlett's test (Zar 1984). Direct gradient analysis of plant-environment relationships using CCA was performed with PC-ORD 4 (McCune and Mefford 1999). Plot scores in CCA are reported as Linear Combination (LC) scores (Palmer 1993) and environmental variables were plotted using intraset biplot scores (McCune and Mefford 1999).

Interpretation of CCA diagrams has been described in detail elsewhere (Palmer 1993; Ter Braak 1986), and will not be discussed here at length. In short, a properly scaled CCA diagram describes five main aspects of a data set. These are importance of environmental variables (arrow lengths), correlation of environmental variables (angle between arrows), environmental characteristics of sites (location of site scores in relation to arrows), environmental preference of species (location of species scores in relation to arrows), and relationship of environmental variables to species composition axes (Palmer 1993). It should also be noted that CCA analysis should not account for 100% of total variance since part of that variance is due to noise (Ter Braak 1986).

CHAPTER III

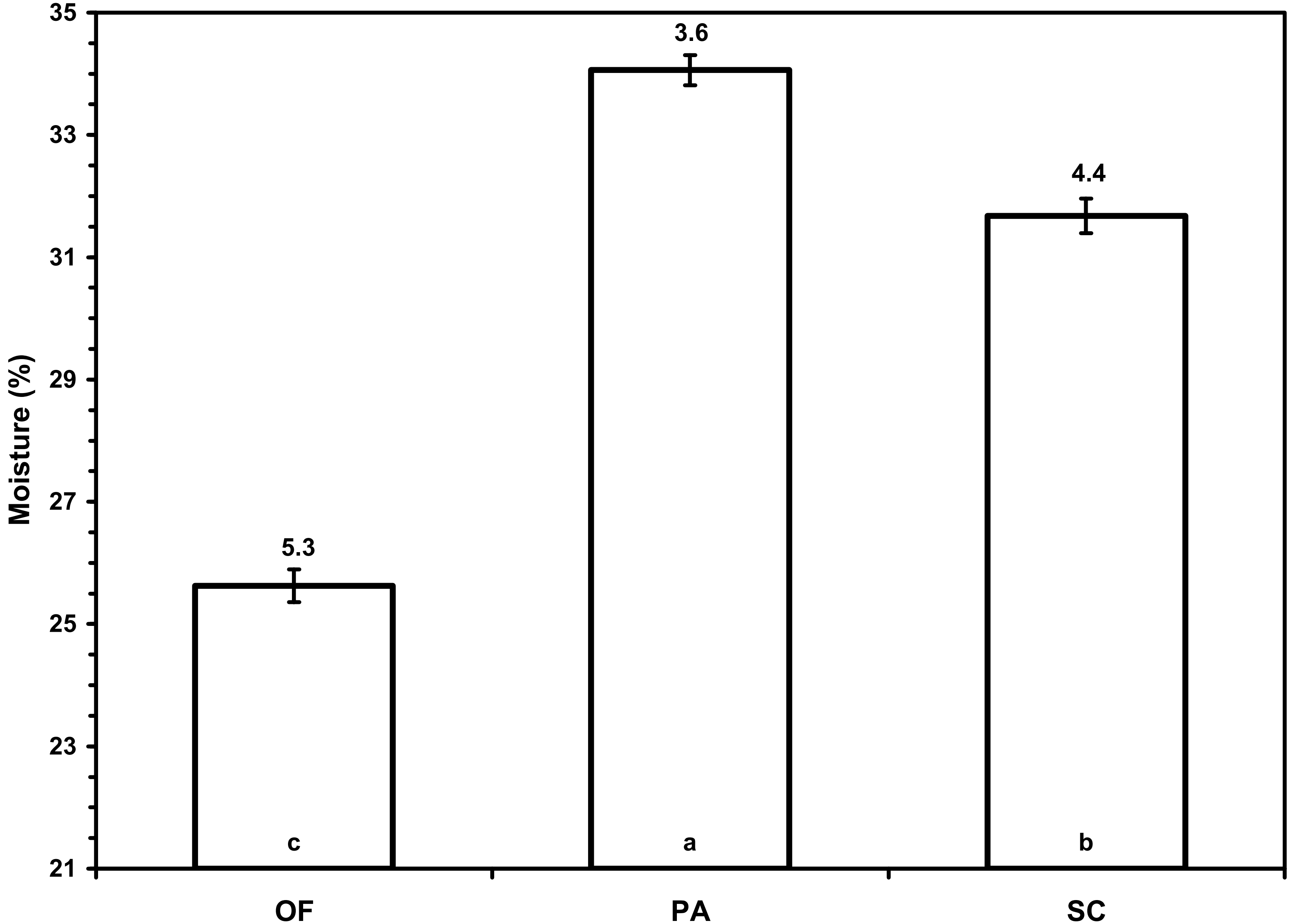
SPATIAL VARIABILITY WITHIN AND AMONG PASTURE, OLD FIELD, AND WETLAND SCAR

Spatial patterns of soil moisture, organic matter, and pH

Soil moisture was significantly different ($P < 0.05$) among sites, being highest for PA, intermediate for SC, and lowest for OF (Figure 4). Although it was expected that moisture would be highest for SC, the data do not show this, likely a result of sampling on different dates. Samples from SC were collected approximately one week after PA and OF samples due to flooding (i.e., standing water) at SC at the time of initial sample collection (Figure 2). Therefore, SC plots had saturated soils when PA and OF samples were collected. Also note that CV's are within the same range, with OF being highest (Figure 4). This is likely due to OF being located on a slope, which would create an internal moisture gradient. These CV values are slightly lower than those reported by Kelly and Canham (CV = 7-13%; 1992) in old fields of Hudson Valley, New York. It should be noted that these CVs do not indicate any significant difference in variance between any of the sites (Table 1).

Organic matter was approximately 23% higher ($P < 0.05$) for SC (Figure 5) with no significant difference between OF and PA. This is consistent with wetland vegetation and periodic standing water found at SC. Periodic flooding slows decomposition rates by creating an anaerobic environment (Mitsch and Gosselink 2000). It is also possible that higher organic matter at SC is a result of higher above- and belowground plant biomass at this site, a consequence of continued plant growth at times of low rainfall, when such growth at the other sites may be limited by water stress. CV's were similar with a range of 8–12, with SC being highest. Further analysis with Bartlett's test revealed a higher degree of variance for SC (Table 1). Higher variance for SC indicates greater spatial variability of organic matter. This is likely due to greater microtopographic variability observed at SC. Small mounds of soil would be flooded less frequently (i.e., last to submerge, first to emerge) creating islands where decomposition could occur longer, forming patches of soil with lower organic matter (Jones *et al*. 1996). Organic matter had a low positive correlation (R = 0.38) with moisture ($P < 0.01$) over all 3 sites combined (Table 2). However, high positive correlations (R = 0.72-0.84; $P < 0.01$) were found at each site when examined independently (Table 2). Lower overall correlation resulted from similarity of organic matter but differences in moisture between OF and PA

Figure 4. Summary (mean ± SE; n = 25 per site) of soil moisture (%) for old field (OF), pasture (PA), and wetland scar (SC) sites at Mill Creek mitigation area in Wayne County, West Virginia. Bars with the same lowercase letters are not significantly different (P <0.05; LSD multiple range test). Numbers presented over bars are coefficients of variance (CV) for each site.



Moisture (%)
35
33
31
29
27
25
23
21
3.6
4.4
5.3
c
a
b
OF
PA
SC

Table 1. Comparison of within-site and overall variance of soil nutrients and processes for three site types in an abandoned pasture in Wayne County, WV. Variances with the same lowercase superscript are not significantly different. Statistical significance was determined using Bartlett's test and a Tukey-style test for multiple comparisons among variances (Zar 1984).

	OF	**PA**	**SC**	**Bartlett's *P***	**Overall**
Aluminum	62.79 ^{b}	1.99 ^{c}	$1.70\times10^{3\ a}$	<0.0001	9.54×10^{3}
Calcium	$4.57\times10^{4\ b}$	$4.16\times10^{5\ a}$	$1.12\times10^{4\ c}$	<0.0001	2.47×10^{5}
Magnesium	$3.19\times10^{3\ b}$	$1.44\times10^{4\ a}$	$1.08\times10^{3\ c}$	<0.0001	1.44×10^{4}
Moisture	1.81	1.51	1.98	ns	14.48
Net nitrification rate	1.32	0.85	1.59	ns	1.47
Net N-mineralization rate	1.30	0.64	1.04	ns	1.19
NH_4^+-N	22.38 ^{b}	42.24 ^{ab}	104.47 ^{a}	<0.001	57.07
NO_3^--N	6.69	10.99	6.02	ns	10.63
Organic matter	0.60 ^{b}	0.41 ^{b}	1.71 ^{a}	<0.01	2.15
pH	$1.79\times10^{-2\ b}$	$6.28\times10^{-2\ a}$	$1.972\times10^{-3\ c}$	<0.0001	1.04×10^{-1}

Figure 5. Summary (mean ± SE; n = 25 per site) of soil organic matter (%) for old field (OF), pasture (PA), and wetland scar (SC) sites at Mill Creek mitigation area in Wayne County, West Virginia. Bars with the same lowercase letters are not significantly different (*P* <0.05; LSD multiple range test). Numbers presented over bars are coefficients of variance (CV) for each site.

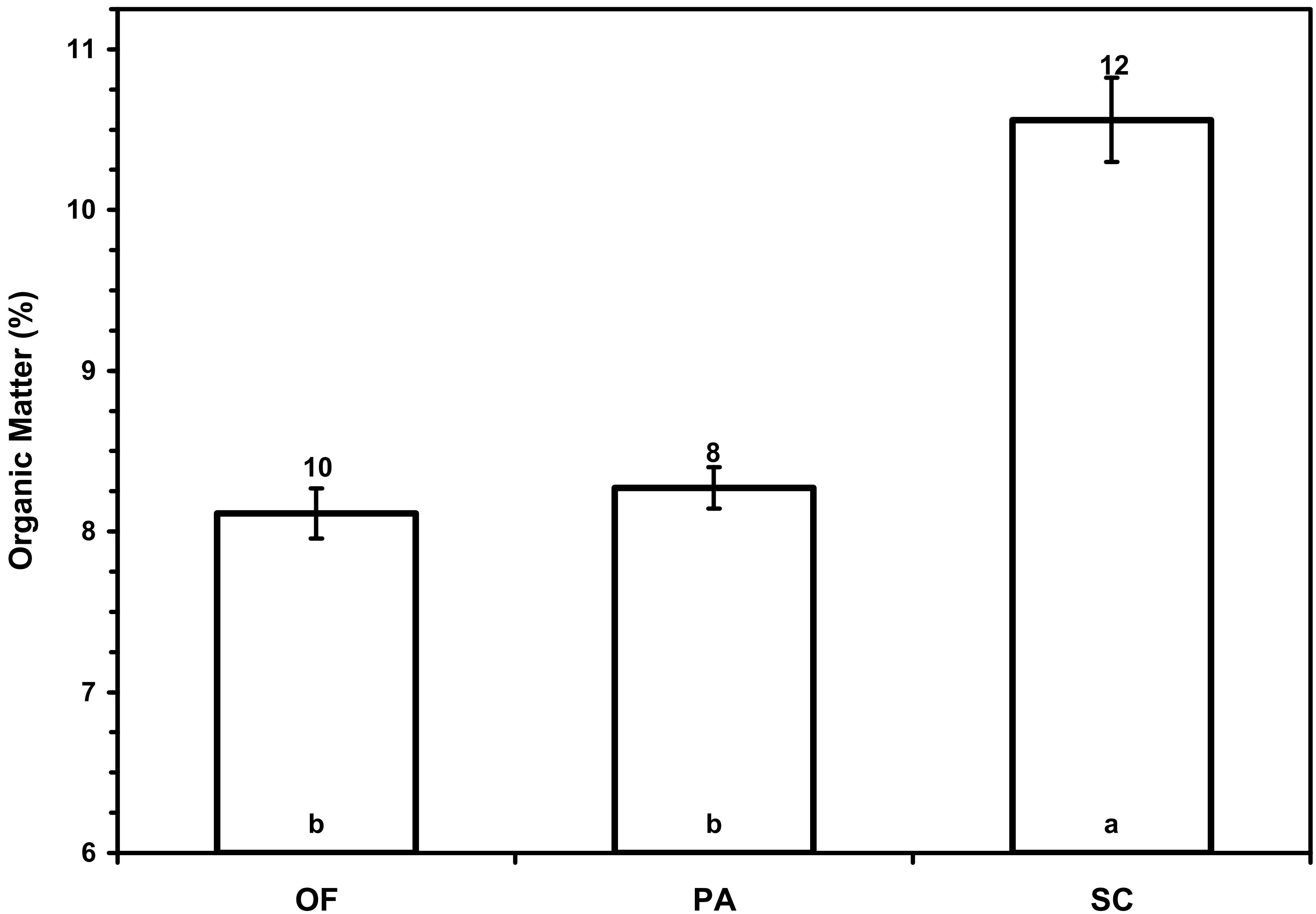

Organic Matter (%)
11
10
9
8
7
6
12
10
8
b
b
a
OF
PA
SC

Table 2. Correlation matrix for aluminum (Al), magnesium (Mg), calcium (Ca), soil moisture (moist), NH_4^+ and NO_3^- pools, net nitrification and N-mineralization rates (Nit and N-min, respectively), organic matter (OM) and pH at OF, PA, and SC sites of Mill Creek study area Wayne County, West Virginia. Dashes (-) indicate no significant correlation.

	Al	Ca	Mg	Moist	NH_4^+	Nit	N-min	NO_3^-	OM
All plots combined (*n* = 75)									
Ca	-0.56‡								
Mg	-0.19*	0.70†							
Moist	0.21*	-0.34‡	-0.69‡						
NH_4^+	-	-	-	-					
Nit	0.26†	-	-	-0.20*	0.65‡				
N-min	0.28†	-	0.20*	-0.21*	0.49‡	0.98‡			
NO_3^-	-0.37‡	-	-0.22*	0.34‡	0.42‡	0.20*	-		
O.M.	0.75‡	-0.39‡	-	0.38‡	-	-	0.19*	-0.23*	
pH	-0.83‡	0.68‡	0.45‡	-0.33‡	-	-	-	0.30‡	-0.60‡
OF (*n* = 25)									
Ca	-0.54‡								
Mg	-	-							
Moist	-	0.36*	0.51‡						
NH_4^+	-	-	-	-					
Nit	-	-	-	-	0.35*				
N-min	-	-	-	-	-	0.99‡			
NO_3^-	-	-	-	-	-	0.36*	0.34*		
OM	-	-	0.58‡	0.84‡	-	-	-	0.34*	
pH	-0.39*	0.62‡	-	0.63‡	-	-	-	-	0.64‡
PA (*n* = 25)									
Ca	0.39*								
Mg	0.41†	0.95‡							
Moisture	-	-	-						
NH_4^+	-	-	-	-					
Nit	-	-	-	-	0.62‡				
N-min	-	-	-	-	0.43†	0.97‡			
NO_3^-	-	-	-	-	0.84‡	0.64‡	0.50†		
OM	-	-	-	0.72‡	-0.37*	-	-	-	
pH	-	0.36*	0.50†	-	-	0.35*	0.39*	-	-
SC (*n* = 25)									
Ca	-								
Mg	-	0.60‡							
Moisture	-	-	0.58‡						
NH_4^+	-0.42†	-	-	-					
Nit	-	-	-	-	0.81‡				
N-min	-	-	-	-	0.67‡	0.98‡			
NO_3^-	-	-	-	-	0.79‡	0.67‡	0.57‡		
OM	-	0.51‡	0.72‡	0.77‡	-	-	-	-	
pH	-0.51‡	-	-	-	-	-	-	-	-

*, $P < 0.10$; †, $P < 0.05$; ‡, $P < 0.01$

(Figure 6). This shows that correlations between organic matter and moisture are scale dependent, at least with single date sampling. This may be a result of different soil types (i.e. hydric vs. non-hydric), however no soil identifications were made in this study.

Soil pH was significantly different (P <0.05) at all three sites, with a low of approximately 3.9 for SC while PA and OF had pH values between 4.4 - 4.6 (Figure 7). These findings are similar to other studies that found lower pH in swamp versus old-field soils (Gilliam *et al*. 1999). However, some studies have found lower pH in xeric versus mesic forest soils (Morris and Boerner 1999). Again, these differences may be due to soil type rather than one variable, such as moisture. Often, organic soils are more acidic while mineral soils can be neutral or alkaline (Mitsch and Gosselink 2000). PA showed the greatest spatial variability (P <0.05) with regard to pH, while SC was more homogeneous (Table 1). This may be a result of H^+ mobility through water during flooded conditions, allowing a more even distribution of protons in soil. Overall, there was a negative correlation (R = -0.60; P <0.01) between pH and organic matter, however, only OF has a significant in-site correlation (R = 0.64; P <0.01) between pH and organic matter (Table 2). A similar pattern occurred between pH and moisture with an overall negative correlation (R = -0.33; P <0.01) and positive correlation (R = 0.63; P <0.01) in OF (Table 2). These reversals of correlation between overall floodplain and individual sites further highlight the scale dependence of soil properties.

Nitrogen dynamics and spatial patterns

Whereas NH_4^+ pools were similar for all sites (Figure 8), NO_3^- pools were significantly higher (P <0.05) for PA (Figure 9). This is due to two factors. First, flooded soils usually experience anaerobic conditions, limiting NO_3^- production (Corre *et al*. 2002; Dubey and Singh 2001). This results in lower NO_3^- pools at SC. Second, excess NO_3^- is highly mobile and easily leached from soils (Fenn *et al*. 1998; Barbour *et al*. 1999), possibly resulting in removal of NO_3^- from OF due to runoff. This leaching may have resulted in NO_3^- accumulation at PA, which is located down slope from OF. Ammonium variability (CV) in PA and SC was nearly double OF (Figure 8). However, comparison of variances only shows a significant difference between OF and SC (P <0.05) with PA intermediate, but similar to both OF and SC, and NH_4^+ variability at SC was nearly double overall variability (Table 1). Nitrate variability was similar at all sites (Table 1). Higher variability at SC might have resulted in a manner similar to organic matter

Figure 6. Comparison of soil moisture (%) and soil organic matter (%) for old field (OF), pasture (PA), and wetland scar (SC) sites at Mill Creek mitigation area in Wayne County, West Virginia. Equation for regression line is $y = 0.15x + 4.49$ with $R^2 = 0.15$.

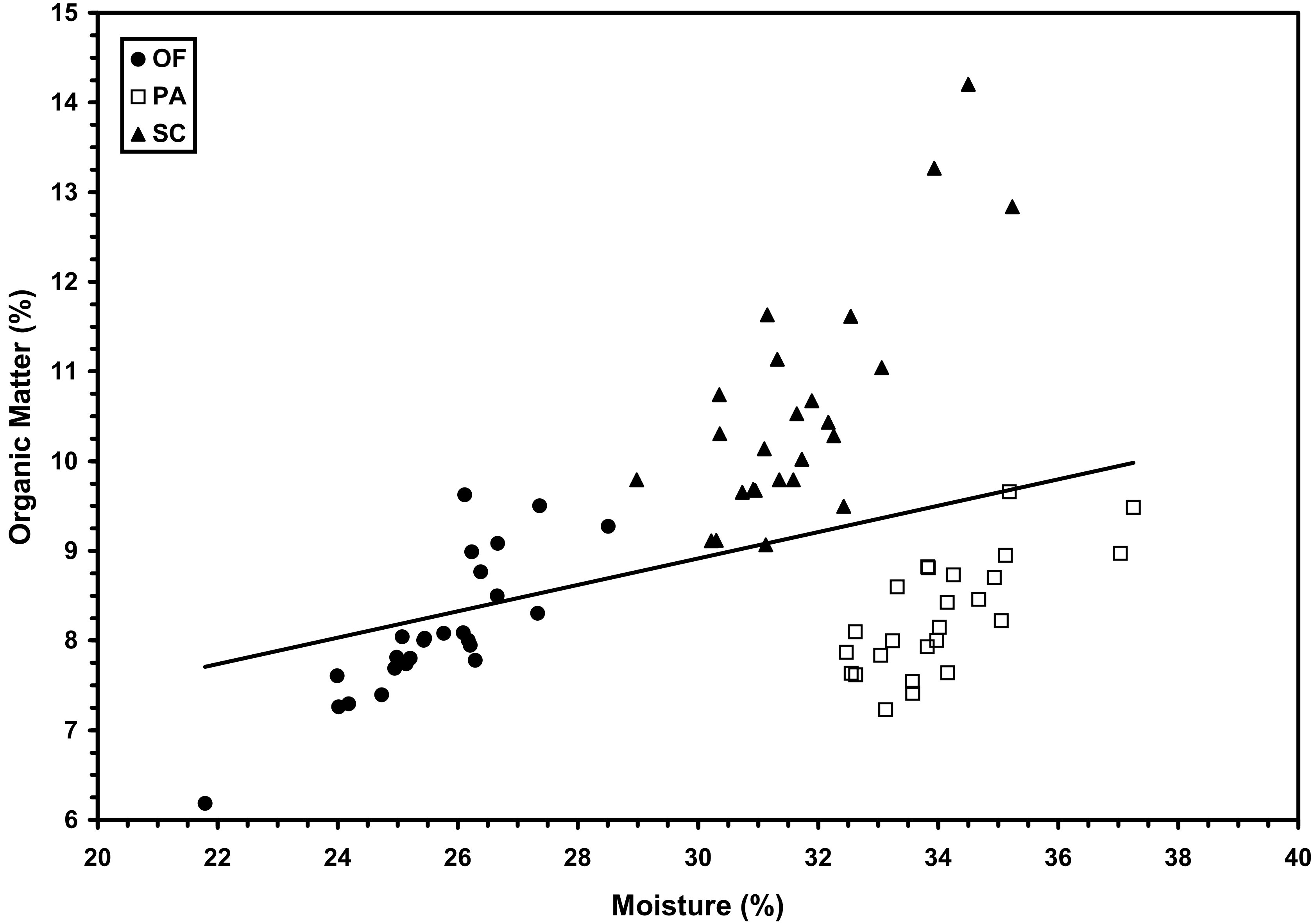

OF
PA
SC
Organic Matter (%)
Moisture (%)
15
14
13
12
11
10
9
8
7
6
20
22
24
26
28
30
32
34
36
38
40

Figure 7. Summary (mean ± SE; n = 25 per site) of soil pH for old field (OF), pasture (PA), and wetland scar (SC) sites at Mill Creek mitigation area in Wayne County, West Virginia. Bars with the same lowercase letters are not significantly different (P <0.05; LSD multiple range test). Numbers presented over bars are coefficients of variance (CV) for each site.

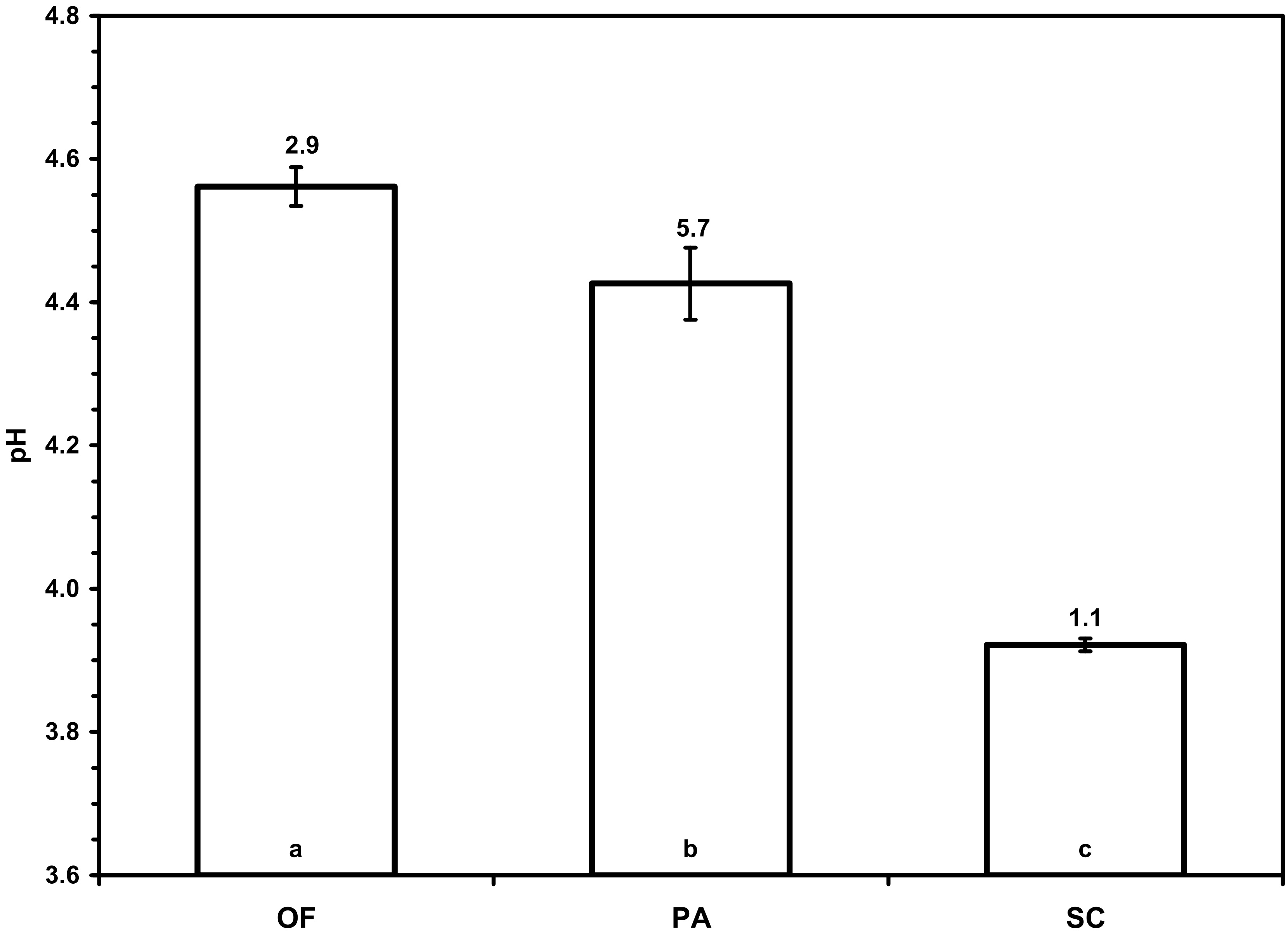
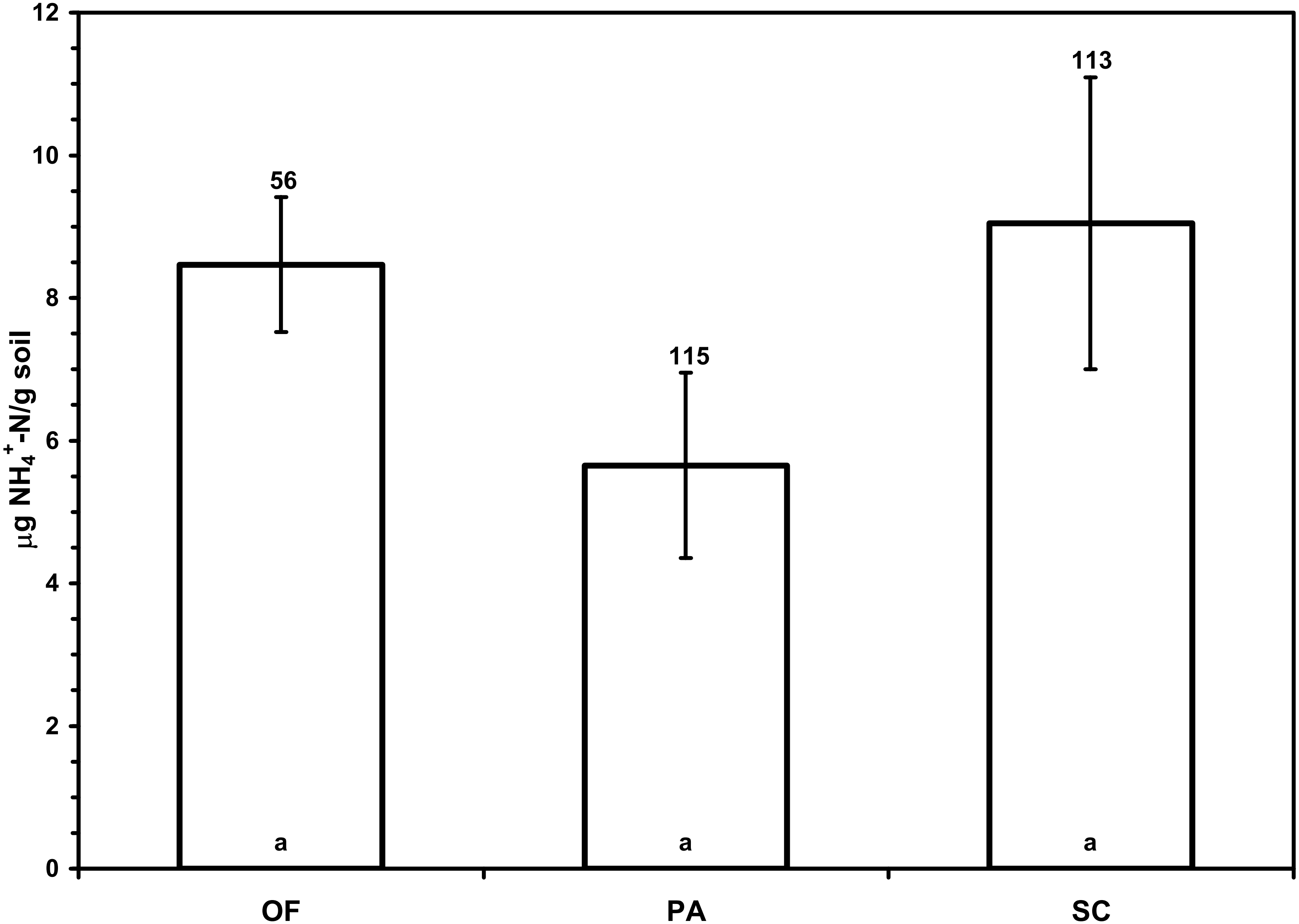
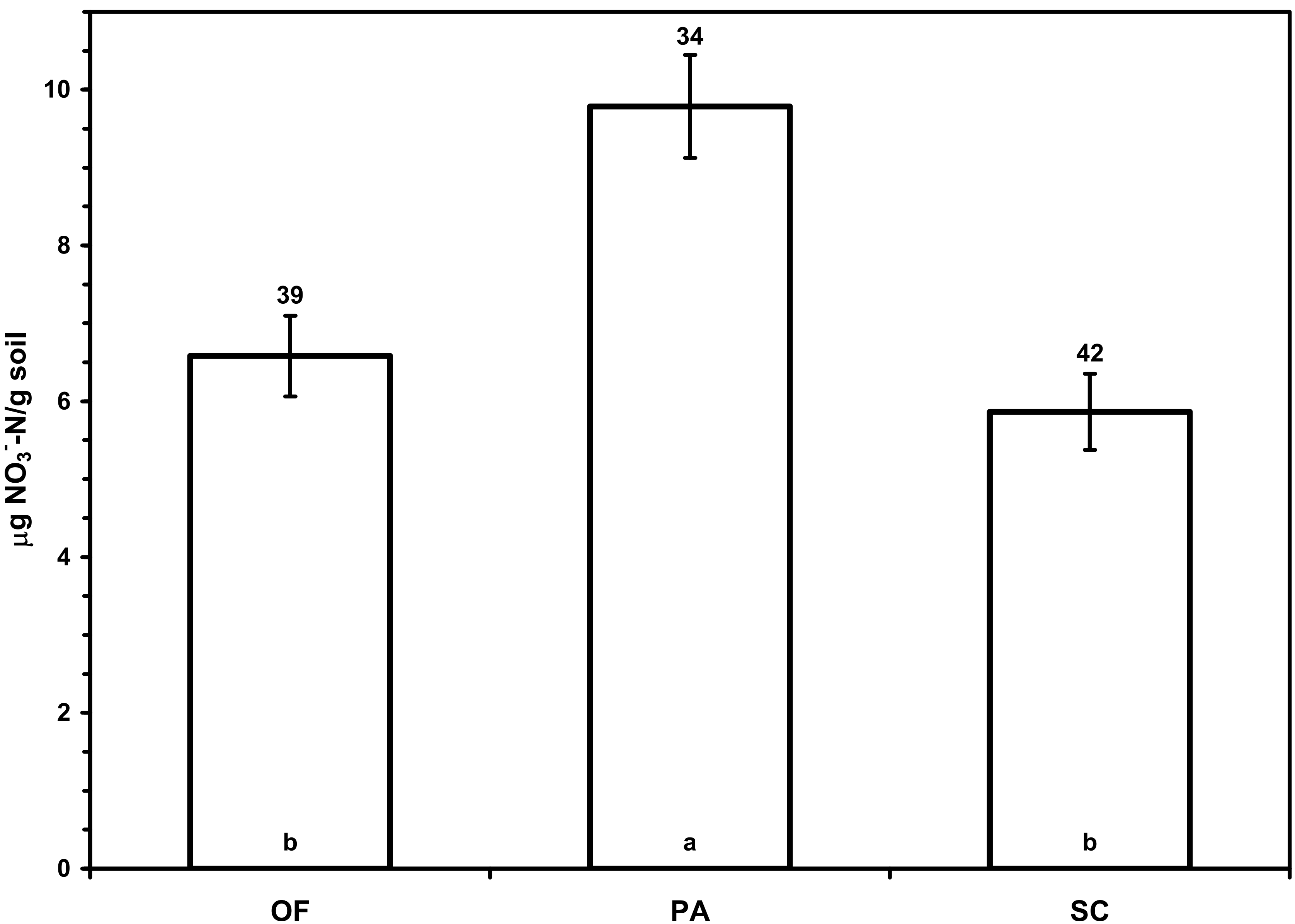

4.8
4.6
4.4
4.2
4.0
3.8
3.6
pH
2.9
5.7
1.1
a
b
c
OF
PA
SC

Figure 8. Summary (mean ± SE; n = 25 per site) of NH_4^+ pools (µg NH_4^+-N/g soil) for old field (OF), pasture (PA), and wetland scar (SC) sites at Mill Creek mitigation area in Wayne County, West Virginia. Bars with the same lowercase letters are not significantly different (P <0.05; LSD multiple range test). Numbers presented over bars are coefficients of variance (CV) for each site.



12
10
8
6
4
2
0
μg NH_4^+-N/g soil
56
115
113
a
a
a
OF
PA
SC

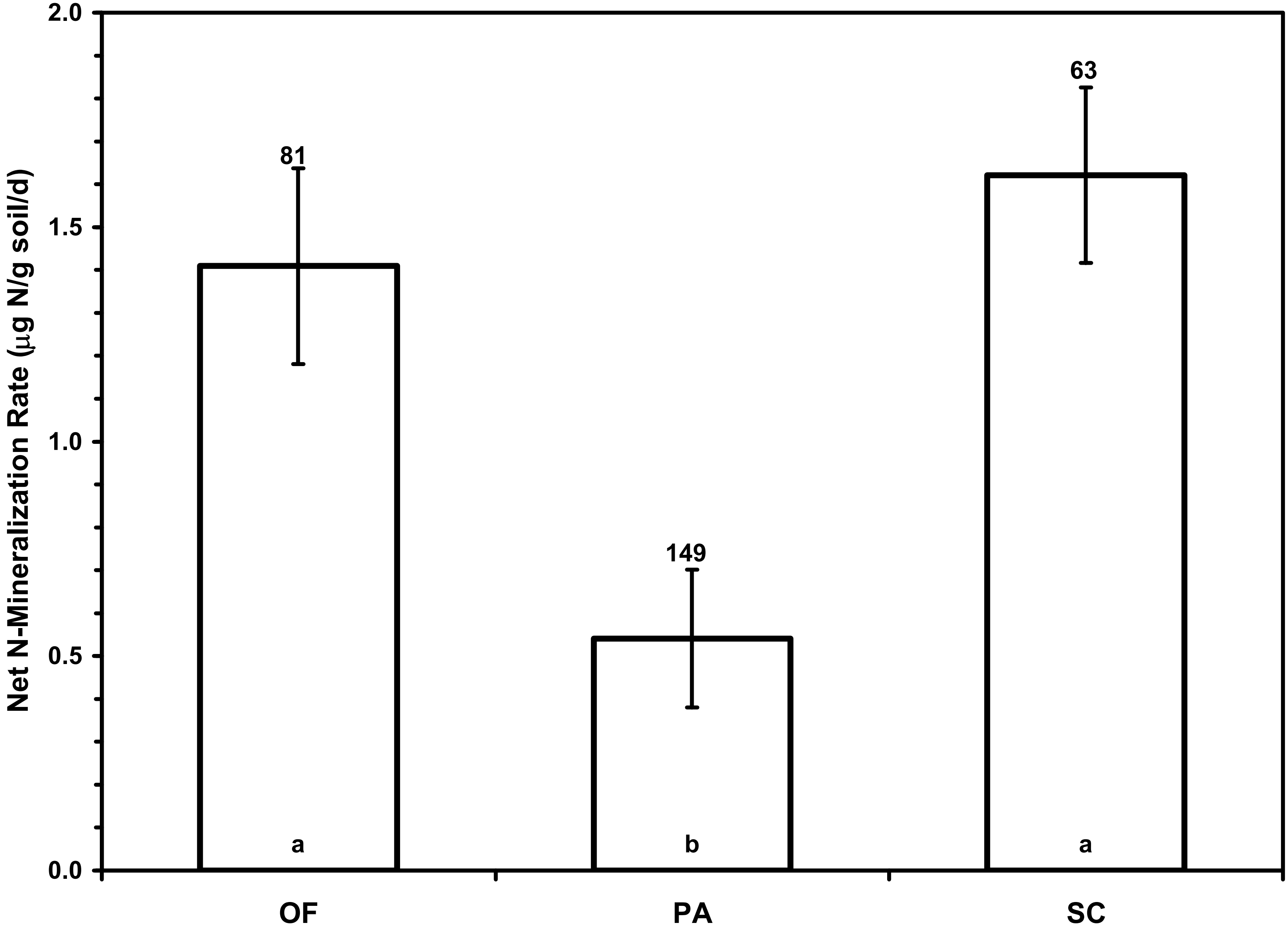
Figure 9. Summary (mean ± SE; n = 25 per site) of NO_3^- pools (µg NO_3^--N/g soil) for old field (OF), pasture (PA), and wetland scar (SC) sites at Mill Creek mitigation area in Wayne County, West Virginia. Bars with the same lowercase letters are not significantly different (*P* <0.05; LSD multiple range test). Numbers presented over bars are coefficients of variance (CV) for each site.


μg NO_3^--N/g soil
0
2
4
6
8
10
39
34
42
b
a
b
OF
PA
SC

variability: small mounds produce areas where nitrification can occur, decreasing NH_4^+ concentrations and effectively creating a patchy distribution. Moderate variability at PA is likely the result of a legacy of grazing history. Overall, NH_4^+ pools were positively correlated with NO_3^- pools (R = 0.42; P <0.01), but there was no correlation in OF (Table 2). Similar correlations were found in PA and SC (0.84 and 0.79, respectively; P <0.01 for both). There was also a weak negative correlation (R = -0.37; P <0.10) between NH_4^+ and soil organic matter in PA (Table 2). There were no correlations between NH_4^+ and pH overall or at any one site. Although NO_3^- pools were positively correlated (R = 0.34; P <0.01) with moisture (Table 2), this may simply be an artifact since there was no correlation at individual sites. However, this may also be due to scaling factors in that correlations are only found at landscape scale, not plot scale. Nitrate pools and soil organic matter are negatively correlated (R = -0.23; P <0.10) over all sites and positively correlated (R=0.34; P<0.10) in OF. Overall, there was a slight correlation (R = 0.30; P <0.01) between NO_3^- and pH, but no correlation was found at individual sites (Table 2).

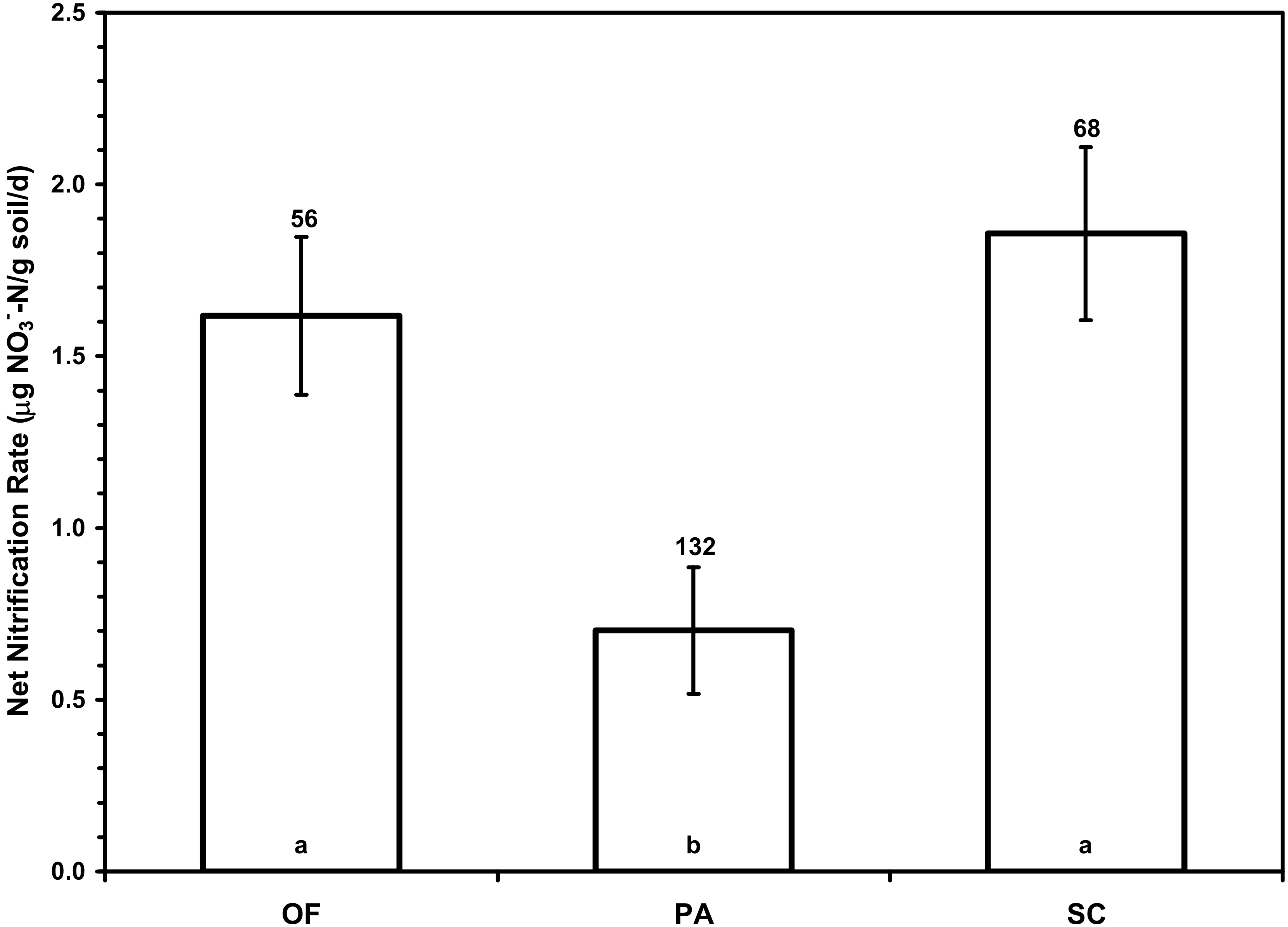
Mean net N-mineralization and net nitrification rates for PA were approximately 40% and 36%, respectively, of values recorded for OF and SC (Figures 10 & 11). These low rates of net N mineralization and net nitrification lend some evidence to leaching as a source of NO_3^- at PA. The data also show that SC soils can be highly nitrifying under aerobic conditions. PA had the highest CV for both net N mineralization and net nitrification (149 and 132, respectively). These results are within the range of CVs noted by Kelly and Canham (1992) for N mineralization (CV = 28-135%) in old fields of Hudson Valley, New York. Further analysis with Bartlett's test indicated, however, that there was no significant difference in variance among sites (Table 1). Therefore, spatial variability within these sites was similar for net N-mineralization and net nitrification rates. More importantly, virtually all N mineralization occurs in the form of nitrification (Figure 12), indicating highly nitrifying soils. Scatter plot analysis showed all points close to or above unity (slope = 1) for all plot samples (Figure 12). All points above the 1:1 line indicate conversion of NH_4^+ pools to NO_3^-. This relationship between net N mineralization and net nitrification was further reinforced by a high correlation (R = 0.98; P <0.01) for all 3 sites combined and high correlations (R = 0.97-0.99; P <0.01) for all sites individually (Table 2). Also, positive correlations between net nitrification and NH_4^+ pools (Table 2) may also indicate oxidation of NH_4^+ pools as well as newly mineralized NH_4^+. Positive correlations between net nitrification and NO_3^- pools indicate that NO_3^- is being

Figure 10. Summary (mean ± SE; n = 25 per site) of net N-mineralization rate (μg N/g soil/d) for old field (OF), pasture (PA), and wetland scar (SC) sites at Mill Creek mitigation area in Wayne County, West Virginia. Bars with the same lowercase letters are not significantly different (*P* <0.05; LSD multiple range test). Numbers presented over bars are coefficients of variance (CV) for each site.



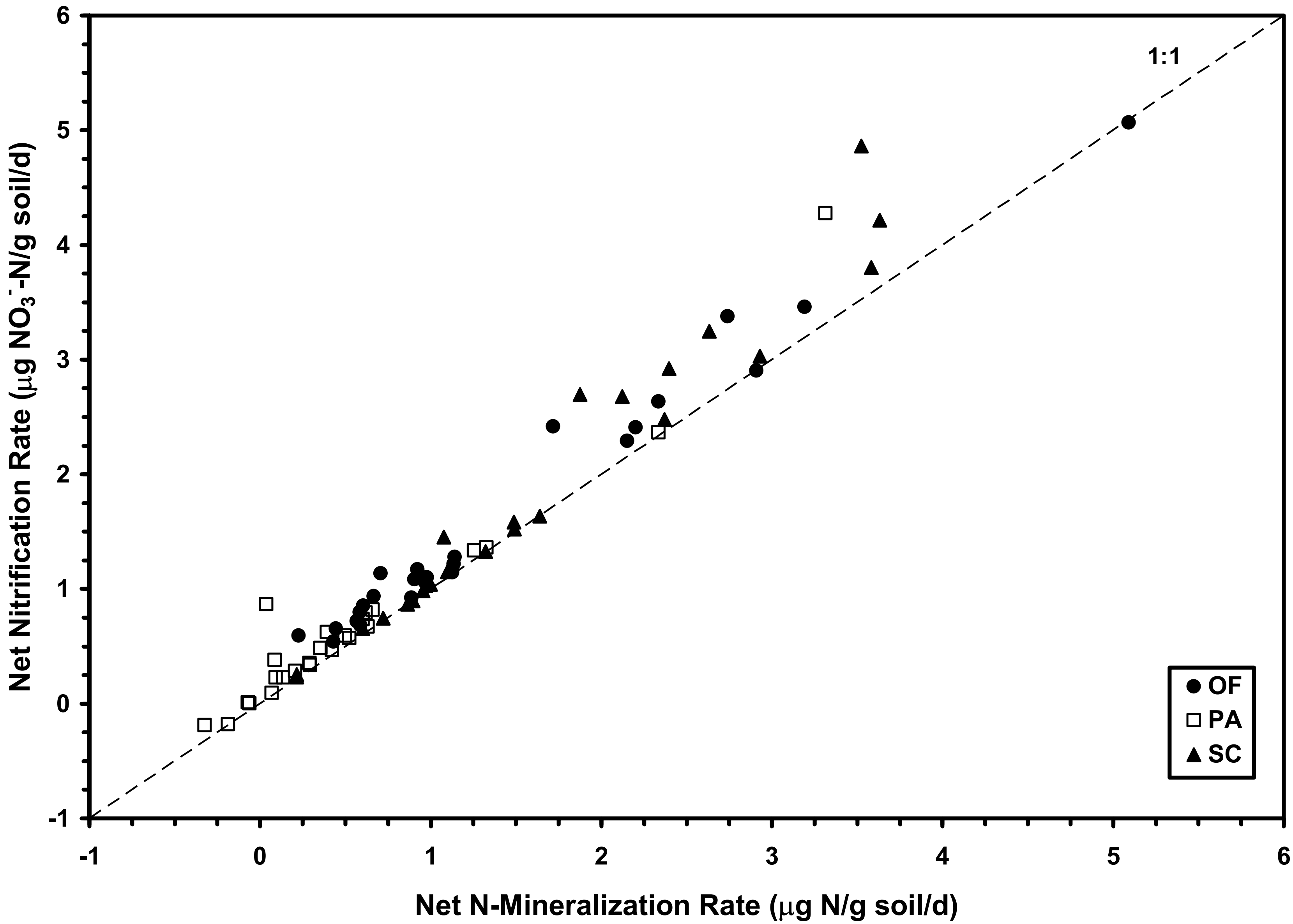
Net N-Mineralization Rate (μg N/g soil/d)
2.0
1.5
1.0
0.5
0.0
81
149
63
a
b
a
OF
PA
SC

Figure 11. Summary (mean ± SE; n = 25 per site) of net nitrification rate (µg NO_3^--N/g soil/d) for old field (OF), pasture (PA), and wetland scar (SC) sites at Mill Creek mitigation area in Wayne County, West Virginia. Bars with the same lowercase letters are not significantly different (*P* <0.05; LSD multiple range test). Numbers presented over bars are coefficients of variance (CV) for each site.



Net Nitrification Rate (μg NO3- -N/g soil/d)
2.5
2.0
1.5
1.0
0.5
0.0
56
132
68
a
b
a
OF
PA
SC

Figure 12. Comparison of net N-mineralization rate (µg N/g soil/d) and net nitrification rate (µg NO_3^--N/g soil/d) for old field (OF), pasture (PA), and wetland scar (SC) sites at Mill Creek mitigation area in Wayne County, West Virginia. 1:1 line indicates 100% nitrification of mineralized N.


Net Nitrification Rate (μg NO_3^--N/g soil/d)
Net N-Mineralization Rate (μg N/g soil/d)
1:1
OF
PA
SC
-1
0
1
2
3
4
5
6

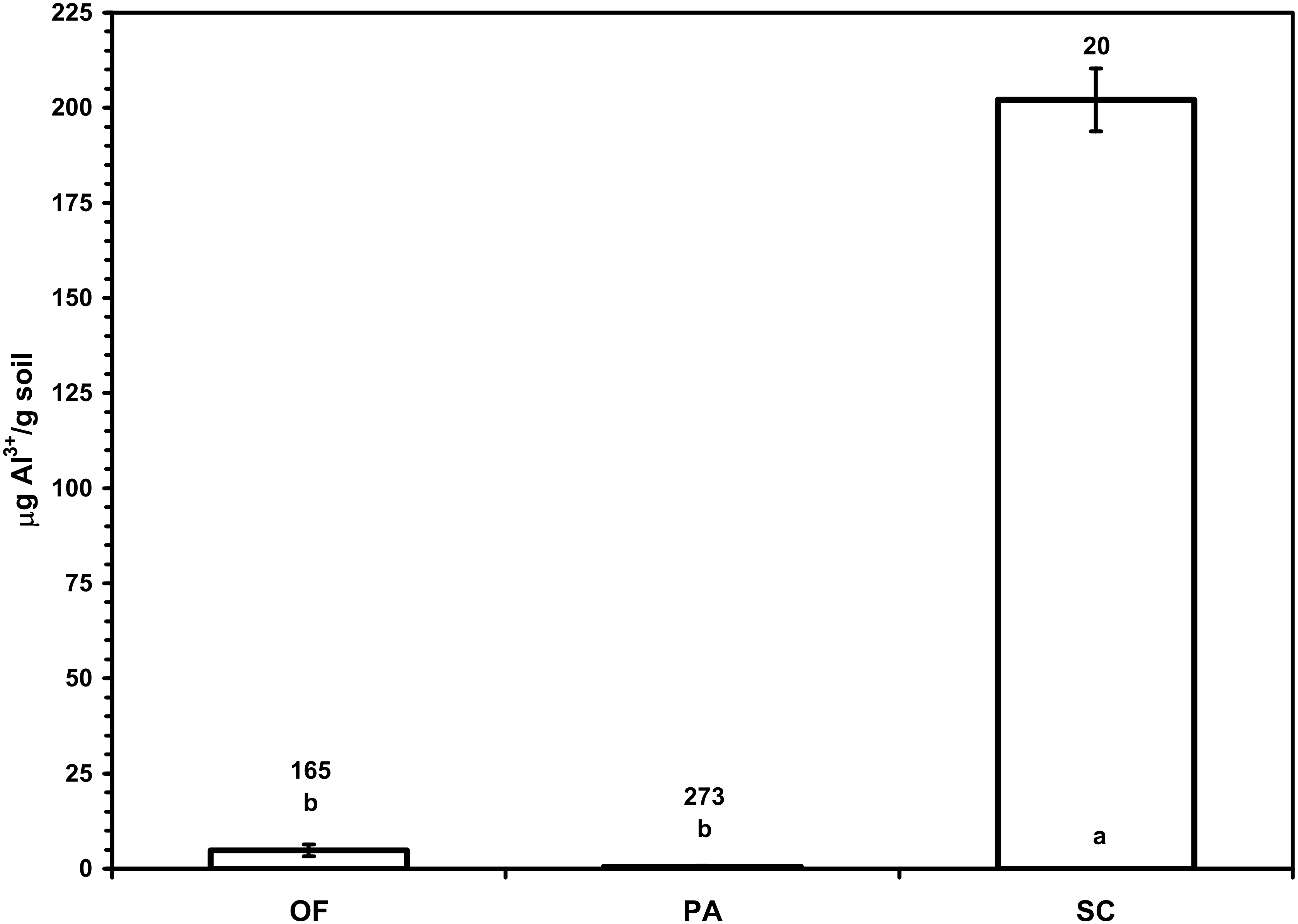
produced in the soils regularly and is not necessarily leaching into PA. Low correlations between net N mineralization and organic matter and moisture cause these results to disagree with other studies showing moisture or organic matter as a driving force for N mineralization (Stevenson 1986; Knoepp and Swank 1998; Zak and Grigal 1991). There was also no evident pattern of correlation between net nitrification and pH as found by Morris and Boerner (1998). There is also some disagreement with Sumner *et al.* (1991), who stated that nitrification is virtually non-existent below pH 4.5. Here, all soil pH is <4.5 and nitrification occurs quite readily. This discrepancy may be related to differences in measurement techniques or it may be a result of nitrogen saturation at this site.

The extremely high relative nitrification is quite notable and has important implications for the potential response of these soils to inundation during the process of wetland creation. Rates of nitrification that are essentially 100% of rates of N mineralization indicate that virtually all NH_4^+ released via ammonification is converted to NO_3^-, a highly mobile and reactive form of inorganic N (Barbour *et al*. 1999). In forest soils, high relative nitrification is rare and, when it occurs, is indicative of N saturation (Gilliam *et al*. 2001a), a condition that develops when N availability (usually from atmospheric deposition of N–"acid rain") exceeds N demand by plants and microbes (Barbour *et al* 1999). Atmospheric N deposition is a likely cause of excess inputs since the eastern and northeastern regions of the U.S. are the greatest recipients in North America (Fenn *et al.* 1998). In N saturated systems, NO_3^-, along with Ca^{2+}, K^+, and Mg^{2+} (Currie *et al*. 1999), can be leached out of soils and into streams or other bodies of water that lie downslope. This excess input of nutrients can lead to eutrophication of lakes, ponds, and slow-moving streams, creating highly productive, low diversity ecosystems dominated by algae (Smith and Smith 1998).

Spatial patterns of Al^{3+}, Ca^{2+}, and Mg^{2+} cations

High Al^{3+} concentrations (202 µg Al^{3+}/g soil) were found in SC soils, while very little Al^{3+} was found in OF or PA sites (Figure 13). These results are consistent with Pellerin *et al.* (2002) who found higher concentrations of Al in hydric soils within 0.5m of a stream in Bear Brooke, Maine. Sample variance is significantly different (P <0.05) among sites, with SC being most variable (Table 1). However, based on CV, SC appears to be the most homogeneous (Figure 13). This is likely due to large differences in mean Al^{3+} concentration within these sites

Figure 13. Summary (mean ± SE; n = 25 per site) of Al^{3+} (µg Al^{3+}/g soil) for old field (OF), pasture (PA), and wetland scar (SC) sites at Mill Creek mitigation area in Wayne County, West Virginia. Bars with the same lowercase letters are not significantly different ($P < 0.05$; LSD multiple range test). Numbers presented over bars are coefficients of variance (CV) for each site.



225
200
175
150
125
100
75
50
25
0
μg Al3+/g soil
20
165
b
273
b
a
OF
PA
SC

as well as several plots within PA and OF that had no detectable Al^{3+} (Appendix C-8). Since Al^{3+} is more soluble as pH decreases (Barbour *et al*. 1999), this is consistent with the lower pH recorded for SC (Figure 7) and is reinforced by a high negative correlation (R = -0.83; P <0.01) between Al^{3+} and pH with all plots combined (Table 2). However, this pattern did not hold in PA, and the correlation was less significant (P <0.10) in OF. Aluminum was highly correlated (R = 0.75; P <0.01) with organic matter overall, but not at any individual site (Table 2). This was likely due to low variability of organic matter within sites (Table 1; Figure 5). Aluminum also had a highly significant negative correlation (R = -0.37; P <0.01) with NO_3^- pools when all plots are combined. Again, this correlation did not appear in any individual site. There were similar correlations between Al and both N-mineralization (R = 0.28; P <0.05) and nitrification (R = 0.26; P <0.05) when all plots were combined, but not within any one site (Table 2). These similarities are the result of nearly 100% nitrification at all sites (Figure 12).

Calcium, which is more soluble at higher pH, followed a trend similar to pH with significantly higher (P <0.05) values in OF, lower values in SC, and intermediate values in PA (Figure 14). This agrees with results from Gilliam *et al*. (1999) where lower amounts of Ca^{2+} were found in swamp soils compared to old-field soils. Sample variance for Ca^{2+} was significantly different (P <0.05) among sites, with PA being most variable and exceeding overall sample variance (Table 1). A similar pattern of variability was detected with CV comparisons (Figure 14). Calcium was significantly correlated with pH (R = 0.68, P <0.01) with all sites combined, but no correlation was found at SC (Table 2). Calcium had an overall high negative correlation with Al^{3+} (R = -0.56; P <0.01), which was similar to correlation found in OF and in Bear Brook, Maine (Pellerin *et al*. 2002). This is also consistent with liming experiments in which addition of lime increased Ca^{2+} and decreased Al^{3+} (Nadeau *et al*. 1998/1999). However, Ca^{2+} was positively correlated with Al^{3+} at PA and there was no correlation at SC (Table 2). Relationships of calcium with moisture and organic matter were vague at best. Overall, there were negative correlations with both moisture (R = -0.34; P <0.01) and organic matter (R = -0.39; P <0.01). However, at individual sites Ca^{2+} and moisture only had a significant correlation at OF (R = 0.36; P <0.10) while Ca^{2+} and organic matter only had a significant correlation at SC (R = 0.51; P <0.01).

Magnesium was highest in OF, and lowest in PA (P<0.05) with SC approximately half values recorded at OF (Figure 15). This tends to agree with Gilliam *et al.* (1999) who found

Figure 14. Summary (mean ± SE; n = 25 per site) of Ca^{2+} (µg Ca^{2+}/g soil) for old field (OF), pasture (PA), and wetland scar (SC) sites at Mill Creek mitigation area in Wayne County, West Virginia. Bars with the same lowercase letters are not significantly different (*P* <0.05; LSD multiple range test). Numbers presented over bars are coefficients of variance (CV) for each site.

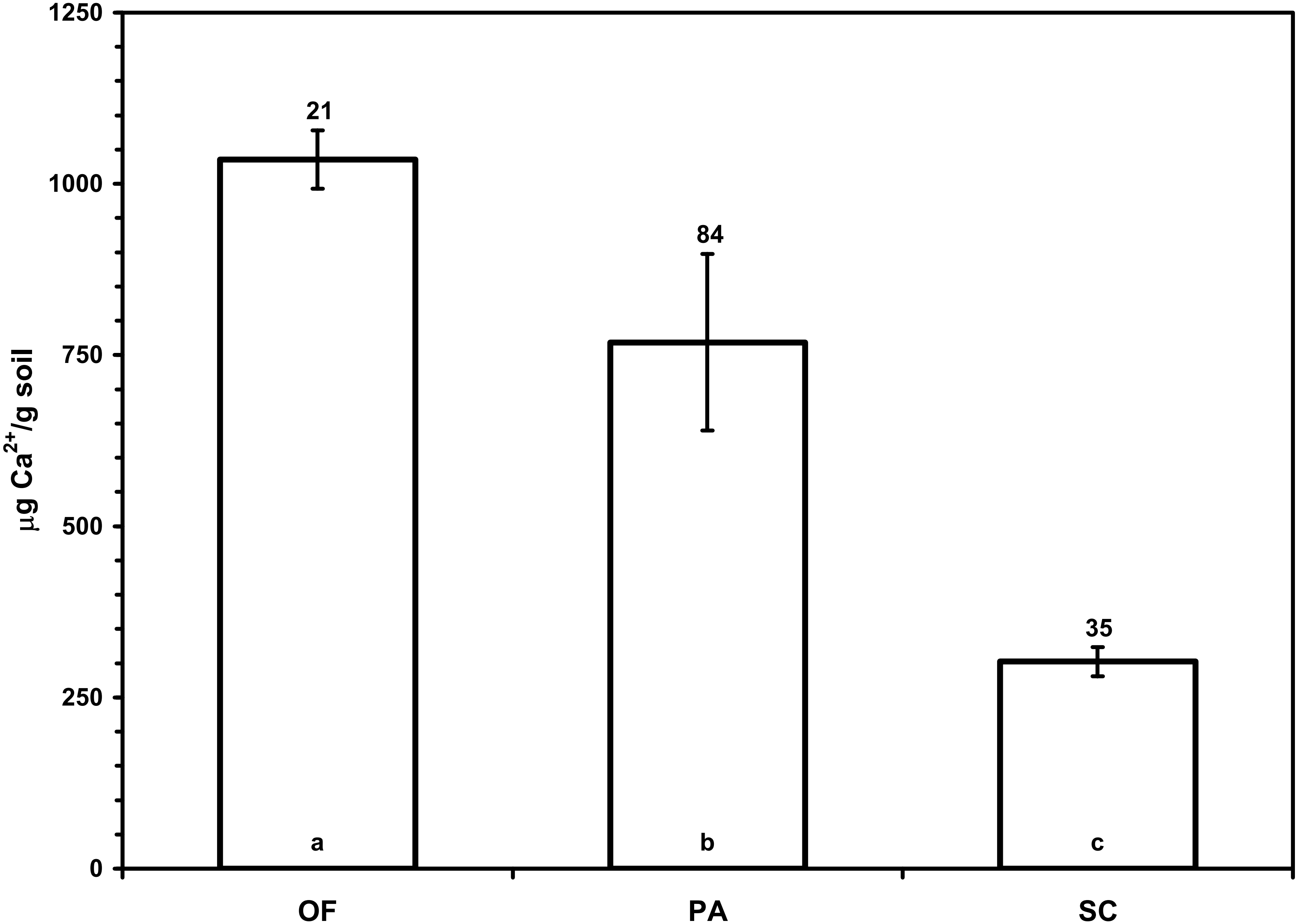
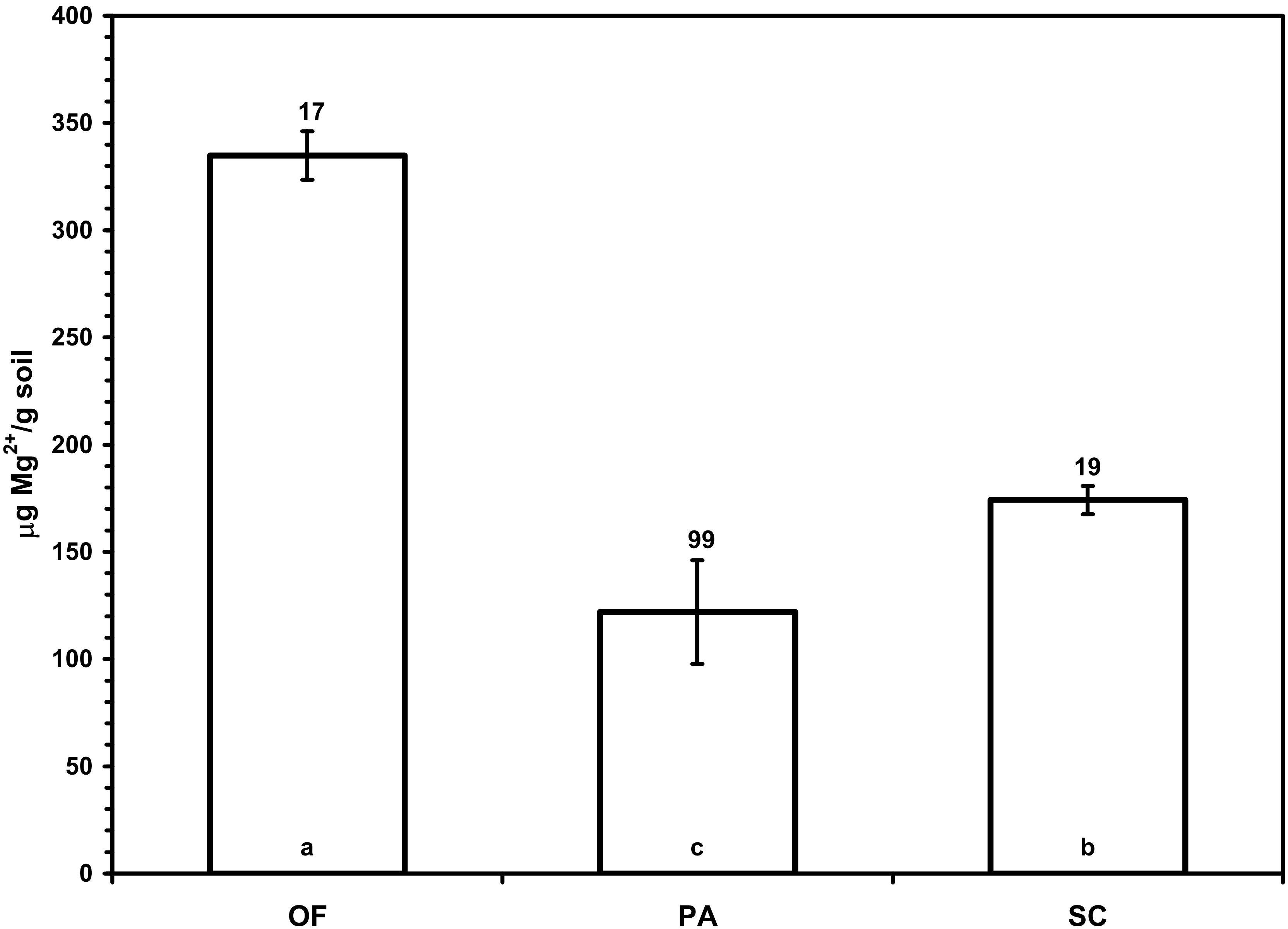

1250
1000
750
500
250
0
µg Ca2+/g soil
21
84
35
a
b
c
OF
PA
SC

Figure 15. Summary (mean ± SE; n = 25 per site) of Mg^{2+} (µg Mg^{2+}/g soil) for old field (OF), pasture (PA), and wetland scar (SC) sites at Mill Creek mitigation area in Wayne County, West Virginia. Bars with the same lowercase letters are not significantly different (*P* <0.05; LSD multiple range test). Numbers presented over bars are coefficients of variance (CV) for each site.



μg Mg2+/g soil
0
50
100
150
200
250
300
350
400
17
99
19
a
c
b
OF
PA
SC

lower Mg^{2+} in swamp soils compared with old-field soils. However, there is no readily apparent explanation for low values recorded at PA. Variance was significantly different among sites with PA being most variable and having variance similar to all plots combined (Table 1). Zak and Grigal (1991) noted similar results in which differences in N-cycling rates comparable to those observed among ecosystems from diverse geographic regions were noted in ecosystems separated by only a few meters. Overall, Mg^{2+} was highly correlated (R = 0.70; P <0.01) with Ca^{2+} and had similar correlations at PA and SC (Table 2). These results agree will Pellerin *et al*. (2002), however an overall low correlation between Mg^{2+} and Al^{3+} (R = -0.19; P <0.10) with a positive correlation in PA does not agree with their results. Overall, Mg^{2+} is negatively correlated (R = -0.69; P <0.01) with moisture, however these variables are positively correlated at OF and SC (Table 2). Magnesium also had a positive correlation with pH overall and at PA. A high positive correlation was also found between Mg^{2+} and organic matter at OF and SC sites (Table 2).

Vegetation composition and patterns

Old-field vegetation was dominated by species typically found in upland areas (UPL and FACU; see Appendix B for full description of classifications) including AMAR, ELCA, GLHE, POSI, and ASPI (Table 3). No wetland species occurred in OF due to its well-drained soils and sloping topography. Pasture vegetation is also dominated by upland species, but a few wetland species (OBL and FACW), such as CIAR and JUEF, occurred there sporadically (Table 4). Scar vegetation was dominated by species typically found in wetlands including JUEF, LYNU, POPE, POHY, CATR, and ASLA (Table 5). High incidence of upland species, such as ASPI, ECCR, and COCO may be a result of length of flooding in combination with growth habits (i.e. after spring/summer flooding is over, non-wetland species that mature quickly may become established in drier areas).

Overall species richness (species/25m^2) was highest in OF, which was more than two times greater than SC (Table 6). Plot species richness (species/m^2) was also highest in OF and significantly different (P <0.05) among all sites (Figure 16). Pasture exhibited the lowest plot richness primarily due to an abundance of FEEL, which formed dense mats of vegetation. As a result of this, diversity and evenness were also low in PA (Table 6). Diversity was highest in OF, however evenness was highest in SC. Magnesium and moisture appear to have the greatest

Table 3. Species encountered within a 5-m x 5-m site located within an old field (OF) in Wayne County, WV. Order based on mean percent cover for n = 25 1-m^2 plots. Species codes are defined in Appendix A. Wetland indicator status indicates probability of finding species in wetland areas (Appendix B).

Species	Mean Cover (%)	Wetland Indicator Status
POSP	64.6	–
AMAR	29.4	FACU
VALT	24.0	FAC
PAAN	16.8	FAC
SEVI	12.4	NI
ELCA	12.2	FACU
LECU	12.0	NI
GLHE	10.0	FACU
POSI	8.8	FACU-
ASPI	8.0	UPL
PASP	7.8	–
OXST	7.4	UPL
EUCO	6.2	FAC
RUCA	6	NI
TRFL	4.8	NI
ANVI	4	FACU
FEEL	3.4	FACU-
PALA	2.2	FAC+
CIVU	2.2	FACU-
HOLA	1.8	FACU
LESP	1.8	–
ERSP	1.6	UPL
PACL	1.2	FAC+
ACRH	1.2	FACU-
JUTE	1	FAC-
MUSP	1	–
TRPR	0.8	FACU-
ERCA	0.8	NI
DACA	0.6	NI
PLSP	0.4	–
VEAL	0.4	NI
TAOF	0.4	FACU-
MESP	0.2	–
EUSE	0.2	FAC-

Table 4. Species encountered within a 5-m x 5-m site located within an abandoned pasture (PA) in Wayne County, WV. Order based on mean percent cover for n = 25 1-m^2 plots. Species codes are defined in Appendix A. Wetland indicator status indicates probability of finding species in wetland areas (Appendix B).

Species	Mean Cover (%)	Wetland Indicator Status
FEEL	71.0	FACU-
ASPI	58.4	UPL
POSP	23.0	–
SOCA	7.2	UPL
CIAR	7.0	FACW+
VEAL	5.8	FAC
SEGL	3.2	FAC
DISA	2.8	FACU-
ARHI	2.6	NI
JUEF	1.8	FACW+
ELCA	1.8	FACU
PHPO	1.2	NI
JUTE	1.2	FAC-
CAVU	1.2	OBL
GLHE	0.6	FACU
PAAN	0.6	FAC
OXST	0.6	UPL
TAOF	0.2	FACU-
CYST	0.2	FACW

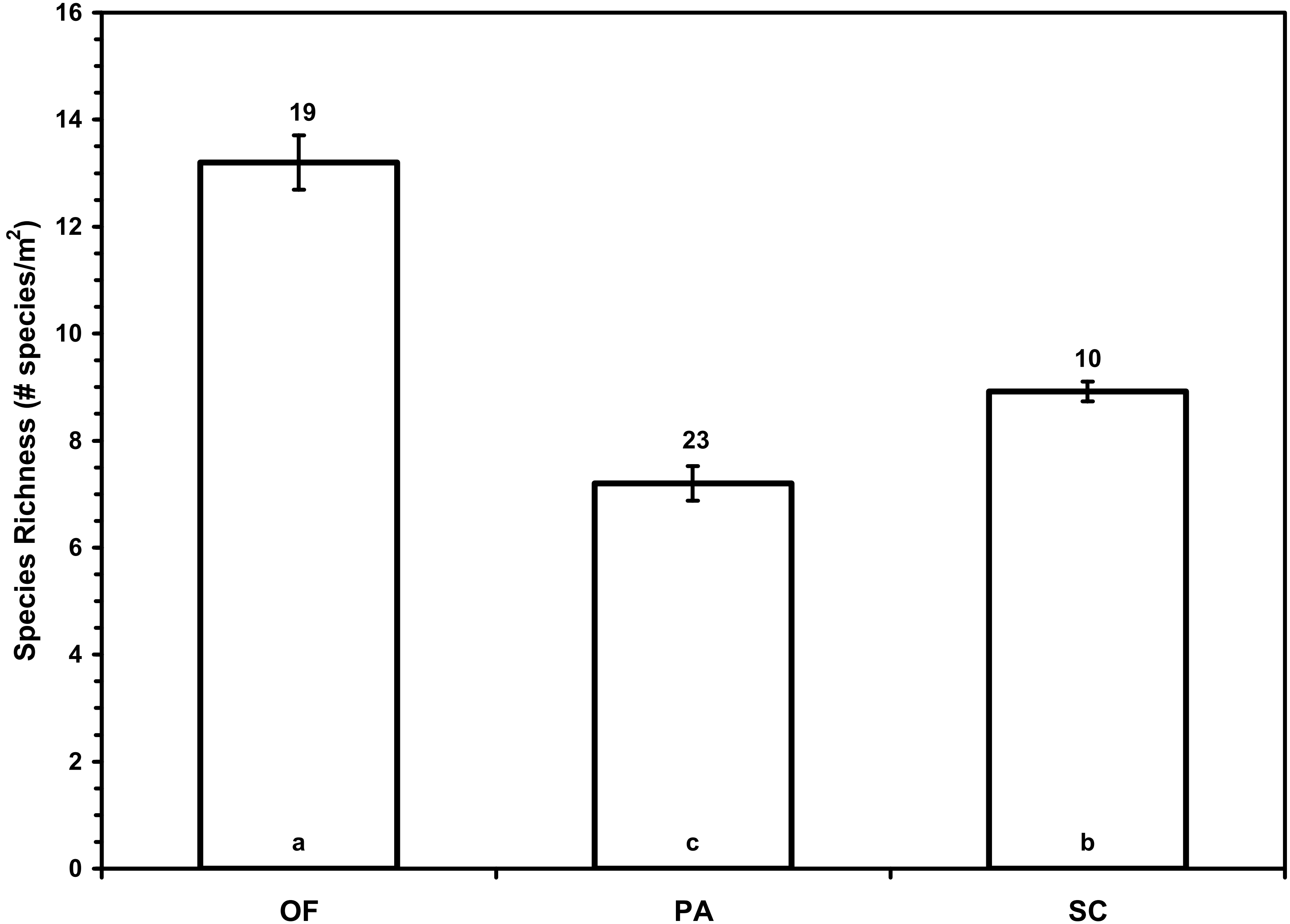
Table 5. Species encountered within a 5-m x 5-m site located within a wetland scar (SC) in Wayne County, WV. Order based on mean percent cover for n = 25 1-m^2 plots. Species codes are defined in Appendix A. Wetland indicator status indicates probability of finding species in wetland areas (Appendix B).

Species	Mean Cover (%)	Wetland Indicator Status
JUEF	60.8	FACW+
LYNU	54.6	OBL
POPE	27.0	FACW
ASPI	26.4	UPL
POHY	25.8	OBL
ECCR	18.6	FACU
CATR	14.2	FACW+
ASLA	13.0	FACW-
COCO	9.0	FAC-
SOCA	7.0	UPL
SEGL	1.6	FAC
CAVU	1.2	OBL
XAPE	0.6	NI
FEEL	0.4	FACU-
ACRH	0.4	FACU-

Table 6. Species richness, evenness, and Shannon diversity for OF, PA, and SC sites in Wayne County, WV.

	Species Richness	Diversity	Evenness
OF	34	2.68	0.759
PA	19	1.78	0.604
SC	15	2.16	0.799

Figure 16. Summary (mean ± SE; n = 25 per site) of plot species richness (# species/m^2) for old field (OF), pasture (PA), and wetland scar (SC) sites at Mill Creek mitigation area in Wayne County, West Virginia. Bars with the same lowercase letters are not significantly different ($P < 0.05$; LSD multiple range test). Numbers presented over bars are coefficients of variance (CV) for each site.



Species Richness (# species/m²)
16
14
12
10
8
6
4
2
0
19
23
10
a
c
b
OF
PA
SC

impact on species richness (Table 7). Other contributing factors might include Ca^{2+}, NO_3^-, and pH. These results are consistent with Palmer (1990) who found that calcium, or a correlated variable (i.e. Mg^{2+}), was responsible for plant-environment relationships at larger scales and among plots.

Old-field vegetation is most similar to PA vegetation and vice versa based on percent similarity indices (Table 8). This is likely a result of hydrologic conditions and proximity of sites (i.e. within the same floodplain). Scar vegetation is most similar to PA vegetation. This makes sense considering proximity of PA to SC and may be a result of spatial mass effects in which species migrate to areas where they are less likely to survive and increase diversity even though they may not thrive in the new environment (Kunin 1998). Old field and SC are least similar because they have drastically different hydrologic regimes and are further apart.

Multivariate analysis

Direct gradient analysis (CCA) revealed clear separation between all three sites based on vegetation and environmental data (Figure 17). Axes 1 and 2 described 23.8 and 16.9% of overall variance, respectively. Adding axis 3 (not shown) only described an additional 1.7% of variance. Overall correlations noted earlier (Table 2) appear as environmental gradient indicators either pointing in the same or opposite directions. Calcium, pH, Al^{3+}, and organic matter appear to form a major axis along which all three sites are separated. Magnesium is most closely related to moisture and is negatively correlated. Together, Mg^{2+} and moisture create an axis along which separates OF from PA with PA being wetter and containing less Mg^{2+}. Oddly, N pools and mineralization processes appear to have little influence in separating sites, with the possible exception of SC and PA. Nitrate pools appear to be negatively correlated to NH_4^+, N mineralization, and nitrification. Clearly, POPE, LYNU, JUEF, and POHY are more closely associated with SC, even though they are present in PA. ASPI is a rather ubiquitous species that occurred at all sites to varying extents and therefore plots near the middle of the figure. Other species, such as AMAR, VALT, and POSP were definitely associated with upland OF plots while FEEL was located predominantly in PA plots.

CCA performed on individual site data revealed varying degrees of total variation within sites. Logically, plots that are closer together should exhibit similar characteristics and sites with lower variability should have closely spaced plot scores. However, high variability in nutrient

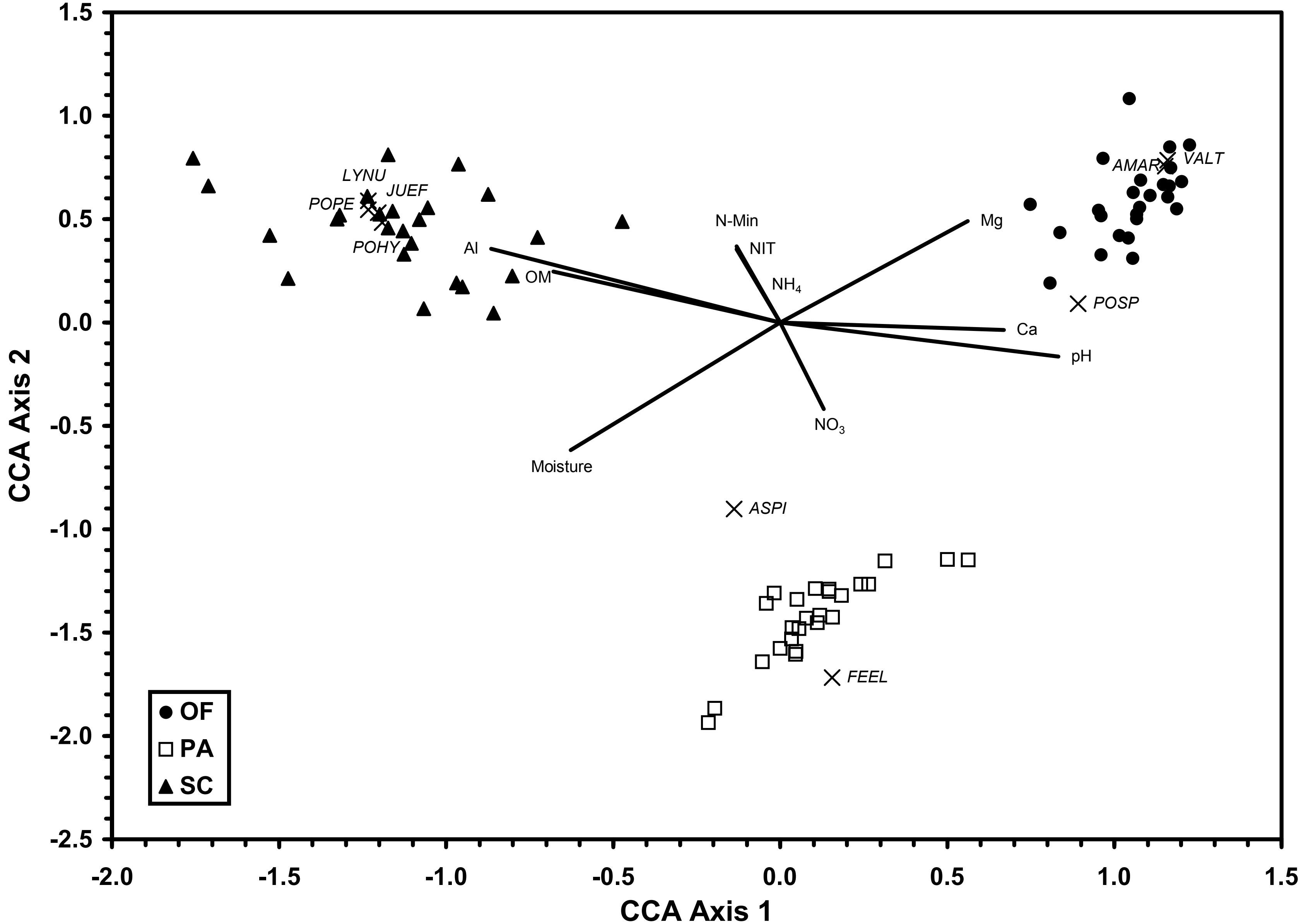
Table 7. Correlation of species richness per m^2 plot with soil variables combined from three site types (OF, PA and SC).

	Species Richness	***P***
Aluminum	-0.18	ns
Calcium	0.28	<0.05
Magnesium	0.60	<0.001
Moisture	-0.73	<0.001
NH_4^+-N	0.10	ns
Net nitrification rate	0.16	ns
Net N-mineralization rate	0.17	ns
NO_3^--N	-0.29	<0.05
Organic matter	-0.16	ns
pH	0.29	<0.05

Table 8. Similarity of plant communities (% similarity) among OF, PA, and SC sites in Wayne County, WV.

	OF	**PA**	**SC**
OF	1		
PA	0.192	1	
SC	0.004	0.062	1

Figure 17. CCA ordination plot for old field (OF), pasture (PA), and wetland scar (SC) sites at Mill Creek mitigation area in Wayne County, West Virginia. Lines radiating from origin represent environmental gradients. The nine most abundant species overall were included and their positions are marked with X's. Including more than nine species made the figure too cluttered to be useful.



1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-2.5
CCA Axis 2
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
CCA Axis 1
LYNU
JUEF
POPE
POHY
Al
OM
N-Min
NIT
NH4
Mg
Ca
pH
NO3
Moisture
AMAR
VALT
POSP
ASPI
FEEL
OF
PA
SC

availability causes a scattering of plots within the ordination space. OF plots vary mostly with respect to Al^{3+} and soil organic matter (Figure 18). Axes 1 and 2 described 12.8 and 6.2% of site variance, respectively. Adding axis 3 (not shown) described an additional 4.7% of variance. Also note the high degree of separation between plots which should be similar (e.g. plots 2 and 3) and clumping of other plots which are in close proximity (e.g. plots 6, 11, 16, 17, and 22; 19 and 24; 20 and 25). Most plot similarities within OF seem to occur in a north-south configuration (see Figure 3). This may be due to a southwesterly slope aspect (Figure 1) creating rows of similar plots that occur at similar elevations. Three plant species (POSP, AMAR, and PAAN) were common in all plots, as indicated by their location near the ordination origin. Other species, such as SEVI, ASPI, and GLHE are less common and add to site complexity.

PA plots vary mostly with respect to soil organic matter and possibly Ca^{2+} (Figure 19). Axes 1 and 2 described 17.9 and 10.0% of site variance, respectively. Adding axis 3 (not shown) described an additional 7.7% of variance. Several adjacent plots in PA appear in ordination as clusters (e.g. 11 and 12; 19 and 24; 20 and 21). Some plots (e.g. 8 and 15; 25 and 4; 14 and 24) that are spatially more separated appear as very similar clusters. Based on CCA analysis, there is no directional pattern to plot similarity within PA. This may be a result of relatively flat topography. Several species, including POSP, SOCA, VEAL, and ASPI are common to all PA plots as indicated by their location near the ordination origin. Other species, such as DISA, CIAR, SEGL and ARHI occur sporadically and increase site complexity.

SC plots vary with respect to many of the measured environmental variables, including Ca^{2+}, soil organic matter, Mg^{2+}, NO_3^-, N mineralization, nitrification, and Al^{3+} (Figure 20). Axes 1 and 2 described 15.3 and 7.0% of site variance, respectively. Adding axis 3 (not shown) described an additional 5.3% of variance. Almost all plots are scattered equally throughout the ordination space. However, a few neighboring plots are clustered together (e.g. 1 and 2; 3 and 4). Note the partial separation of lower numbered (northern) plots from higher numbered (southern) plots. LYNU and JUEF are common to all plots while ASPI occurs in plots with higher Ca^{2+}, which is consistent with its designation as an upland species, while ECCR, SOCA, and CATR occur in plots with higher Al^{3+}.

Figure 18. CCA ordination plot for old field (OF) site at Mill Creek mitigation area in Wayne County, West Virginia. Lines radiating from origin represent environmental gradients. The ten most abundant species were included and their positions are marked with X's. Numbers beside plots indicate plot number as assigned during study and can be used to determine approximate distance between plots (see Figure 3).

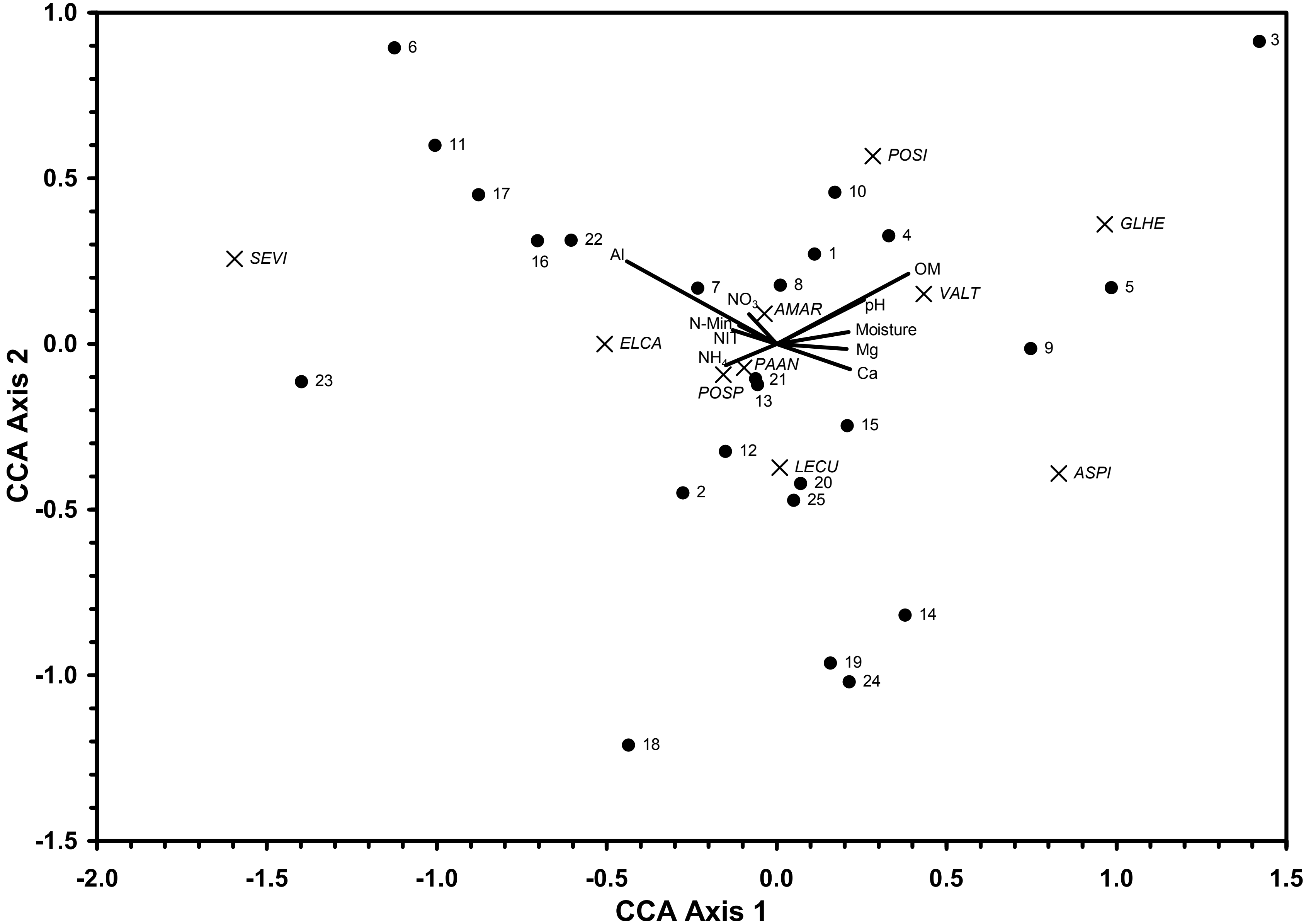

1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
CCA Axis 1
CCA Axis 2
SEVI
ELCA
AMAR
POSI
GLHE
VALT
PAAN
POSP
LECU
ASPI
Al
NO_3
N-Min
NIT
NH_4
OM
pH
Moisture
Mg
Ca
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25

Figure 19. CCA ordination plot for pasture (PA) site at Mill Creek mitigation area in Wayne County, West Virginia. Lines radiating from origin represent environmental gradients. The nine most abundant species were included and their positions are marked with X's. Numbers beside plots indicate plot number as assigned during study and can be used to determine approximate distance between plots (see Figure 3).

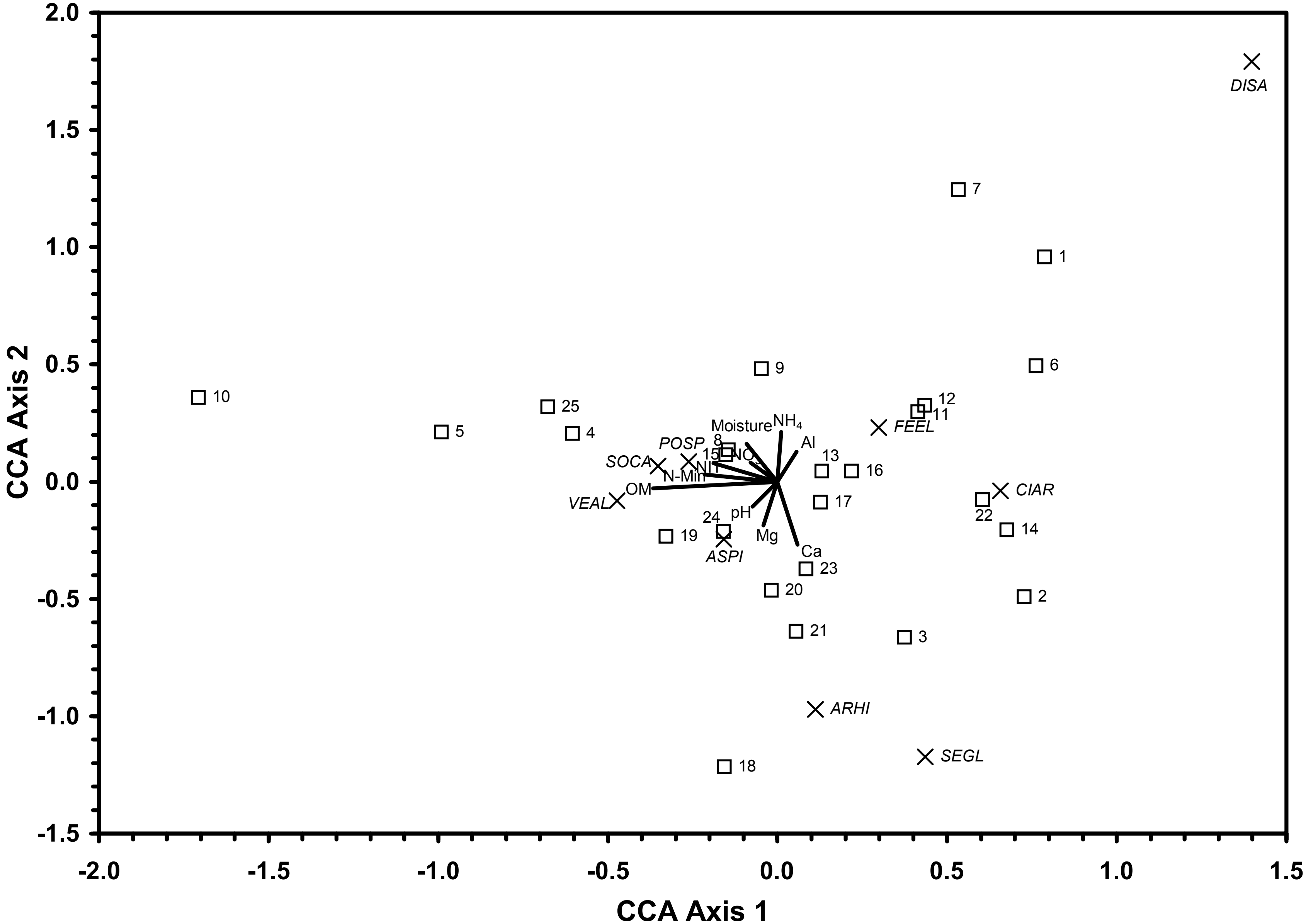
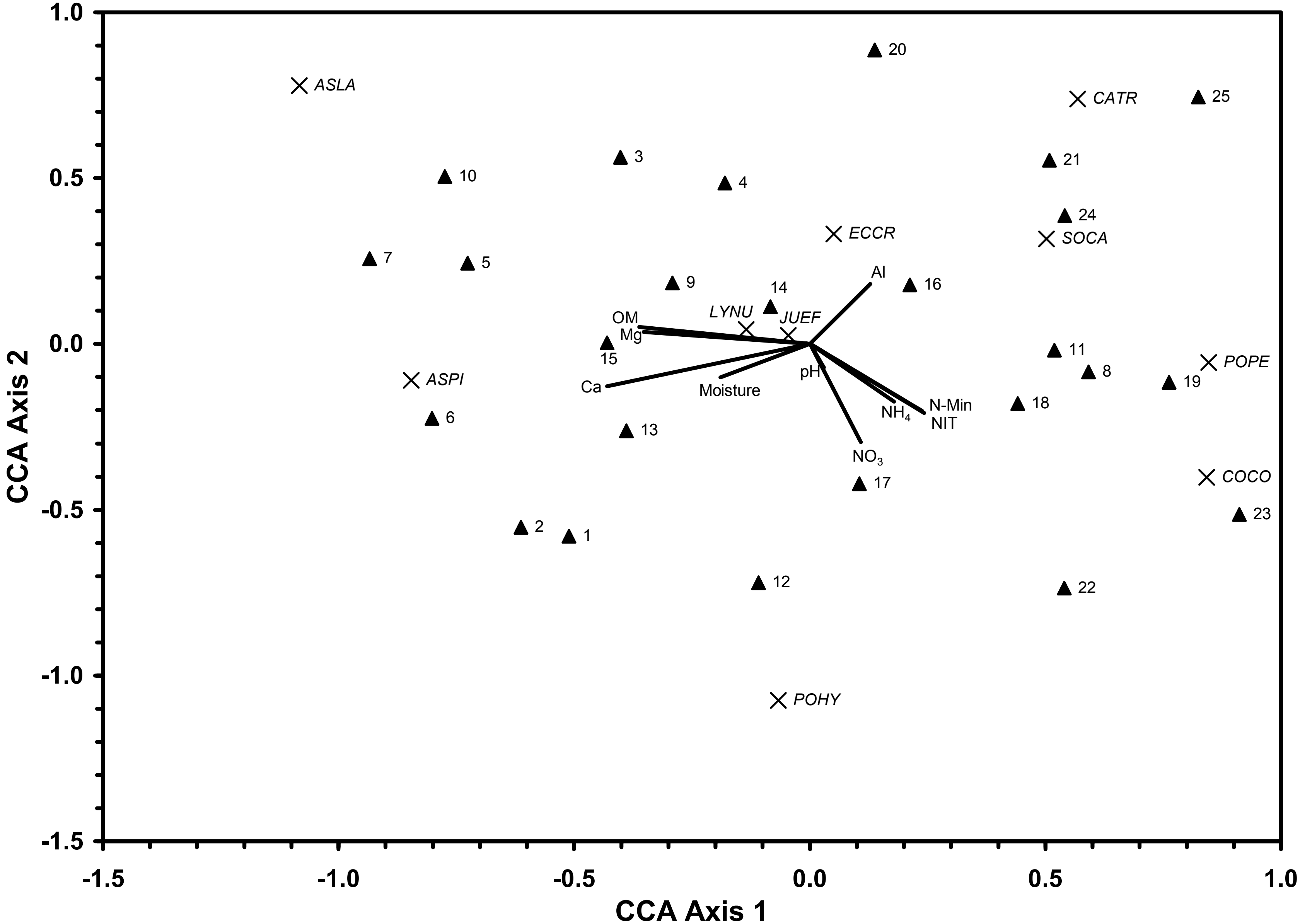

CCA Axis 2
CCA Axis 1
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-2.0
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
DISA
7
1
6
9
10
25
5
4
12
11
FEEL
Moisture
NH4
Al
POSP
8
15
NO
13
16
SOCA
N-Min
NIT
CIAR
OM
VEAL
17
22
24
pH
14
19
Mg
ASPI
Ca
23
20
2
21
3
ARHI
SEGL
18

Figure 20. CCA ordination plot for wetland scar (SC) site at Mill Creek mitigation area in Wayne County, West Virginia. Lines radiating from origin represent environmental gradients. The ten most abundant species were included and their positions are marked with X's. Numbers beside plots indicate plot number as assigned during study and can be used to determine approximate distance between plots (see Figure 3).


CCA Axis 2
CCA Axis 1
1.0
0.5
0.0
-0.5
-1.0
-1.5
-1.5
-1.0
-0.5
0.0
0.5
1.0
ASLA
CATR
ECCR
SOCA
LYNU
JUEF
ASPI
POPE
COCO
POHY
Al
OM
Mg
Ca
Moisture
pH
NH_4
N-Min
NIT
NO_3
1
2
3
4
5
6
7
8
9
10
11
12
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22
23
24
25

Predictions

Based on comparisons of OF and PA sites with SC, the following predictions can be made. First and intuitively, soil moisture should increase as a result of inundation. Soon afterward organic matter will begin to accumulate as a result of anoxic conditions and slowed decomposition, thereby increasing soil organic matter. Soil acidity will also increase following inundation, leading to typically acidic wetland soils. Aluminum solubility will likely increase as a result of lower pH while at the same time Mg^{2+} and Ca^{2+} will be less available. Increased soil moisture, aluminum toxicity, and decreased availability of macronutrients will result in the death of current vegetation and lower species richness and diversity in the short term. Depending on wetland construction parameters, species diversity might recover to levels similar to those present in PA and SC combined, but may not occur for several decades.

Ammonium pools and will probably experience little change while N-mineralization is likely to increase. Nitrification will likely remain high at the PA and SC sites until after inundation. After this time, NO_3^- should accumulate in the soil, increasing the size of the NO_3^- pool. In the absence of uptake of NO_3^- by plants (which will be under water and dead), this excess NO_3^- may be lost to the atmosphere via denitrification as N_2O, one of the greenhouse gases contributing to global warming. Further work will be necessary to quantify this response.

CHAPTER IV

SPATIAL VARIABILITY ACROSS A PASTURE/WETLAND SCAR BOUNDARY

Spatial patterns of soil moisture, organic matter, pH, and litter

Soil moisture was approximately 3% higher (P <0.01) within the scar (Table 9). Regression analysis indicated a trend of increasing moisture from 5 m outside scar to 5 m inside scar (Figure 21). This is encouraging since higher soil moisture is one criterion for determining wetland status (Mitsch and Gosselink 2000). A trend of increasing moisture indicates that the visible boundary has an underlying hydrologic component. Soil moisture is slightly less variable (P <0.10) within the scar (Table 10).

Organic matter did not differ significantly between plots inside and outside scar (Table 9). Consequently, regression analysis did not find a significant trend for organic matter along transect (Figure 22). This was unexpected since periodically flooded areas tend to have higher organic matter (Mitsch and Gosselink 2000). Also, site studies found approximately 2% more organic matter in wetland scar soils (Figure 6). Organic matter inside scar had similar variance to organic matter outside scar (Table 10) and was not significantly correlated with moisture (Table 11).

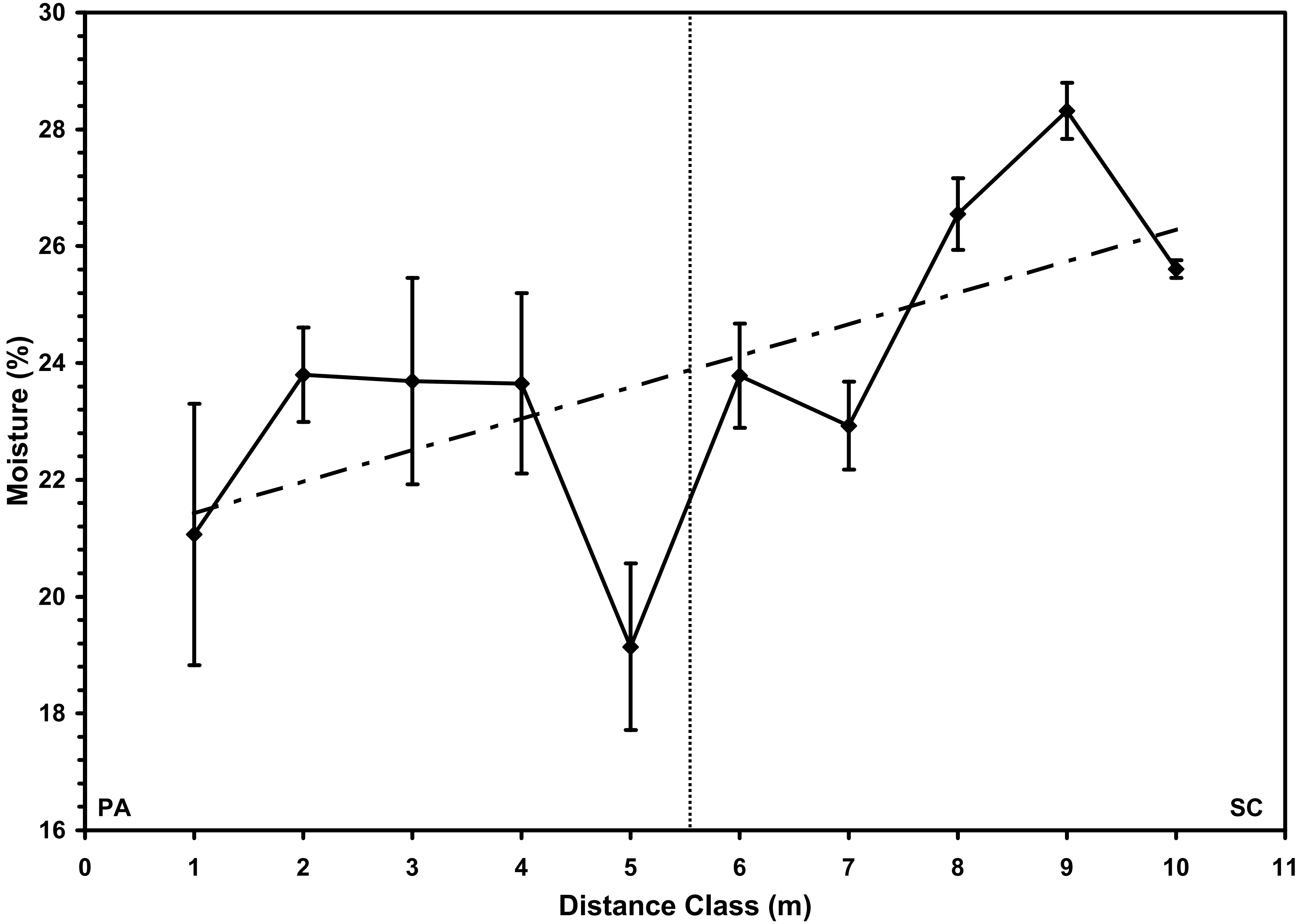
Soil pH was slightly, although significantly (P <0.0001), higher outside wetland scar (Table 9). Regression analysis revealed a similar trend for decreasing pH along the transect from pasture to wetland scar (Figure 23). Again, these results are similar to those reported by Gilliam *et al.* (1999) for old-field and swamp soils. These results are also similar to results reported earlier in this thesis for site studies (Figure 7) in which SC plots exhibited lower soil pH than PA plots. Soil pH was less variable inside wetland area as demonstrated by a variance nearly two orders of magnitude lower within the scar (P <0.0001; Table 10). The boundary between pasture and wetland occurs abruptly with respect to pH. Between distance classes 5 and 6 (visible border of wetland) soil pH drops 0.2 units and remains stable at approximately 3.9 (Figure 23). Soil pH is not correlated with organic matter, but shows a highly significant negative correlation (R = -0.41; P <0.01) to soil moisture (Table 11). This is similar to overall correlations found in site studies (Table 2).

Litter outside scar was twice the mass (P < 0.001) of litter inside scar (Table 9) resulting in a negative linear regression with respect to distance along transect (Figure 24). This was

Table 9. Summary of soil properties (mean ± SE) in 0.25-m^2 plots (n = 40) along a 10-m transect in an abandoned pasture in Wayne County, WV. Transect was centered (5 m outside and 5 m inside) and perpendicular to visible boundary of a wetland scar. Samples assigned as inside or outside scar based on position (n = 20 outside; n = 20 inside). Significance determined by ANOVA and LSD comparison of means.

	Outside Scar	**Inside Scar**	***P***
Aluminum (µg/g soil)	1.1 ± 1.0	59.2 ± 3.2	<0.0001
Calcium (µg/g soil)	1464.4 ± 47.7	991.1 ± 23.6	<0.0001
Litter (g)	72.3 ± 7.6	36.0 ± 3.8	<0.001
Magnesium (µg/g soil)	168.9 ± 6.3	110.2 ± 3.6	<0.0001
Moisture (%)	22.3 ± 0.8	25.4 ± 0.5	<0.01
Net nitrification rate (µg NO_3^- -N /g soil/d)	1.2 ± 0.2	1.1 ± 0.2	ns
Net N-mineralization rate (µg N/g soil/d)	1.2 ± 0.2	1.3 ± 0.3	ns
NH_4^+ -N (µg/g soil)	2.4 ± 0.3	2.0 ± 0.1	ns
NO_3^- -N (µg/g soil)	4.4 ± 0.5	2.3 ± 0.3	<0.001
Organic matter (%)	8.5 ± 0.1	8.5 ± 0.2	ns
pH	4.2 ± 0.03	4.0 ± 0.006	<0.0001

Figure 21. Summary (mean ± SE; n = 4 per distance class) of soil moisture (%) along a 10-m transect centered on a visible wetland boundary at Mill Creek mitigation area in Wayne county, West Virginia. PA and SC indicate site types and the vertical dotted line indicates visible boundary. Equation for regression line is $y = 0.54x + 20.88$ with $R^2 = 0.39$.



30
28
26
24
22
20
18
16
Moisture (%)
0
1
2
3
4
5
6
7
8
9
10
11
Distance Class (m)
PA
SC

Table 10. Comparison of variance for soil nutrients and processes along a 10-m transect in an abandoned pasture in Wayne County, WV. Transect was centered on and perpendicular to visible boundary of wetland scar. Sample grouping based on position along transect (outside = 1-5m and inside = 6-10 m). Statistical significance was determined using Bartlett's test (Zar 1984).

	Outside Scar	**Inside Scar**	**Bartlett's *P***	**Overall**
Aluminum	19.03	205.02	<0.0001	975.10
Calcium	4.56×10^{4}	1.11×10^{4}	<0.01	8.51×10^{4}
Litter	1.16×10^{3}	2.91×10^{2}	<0.01	1.04×10^{3}
Magnesium	786.74	257.67	<0.05	1391.3
Moisture	12.02	5.18	<0.05	10.95
Net nitrification rate	0.45	0.54	ns	0.48
Net N-mineralization rate	0.62	1.57	<0.05	1.07
NH_4^+	2.01	0.37	<0.001	1.20
NO_3^-	4.25	1.52	<0.05	4.01
Organic matter	0.41	0.75	ns	0.57
pH	1.96×10^{-2}	7.08×10^{-4}	<0.0001	2.66×10^{-2}

Figure 22. Summary (mean ± SE; n = 4 per distance class) of soil organic matter (%) along a 10-m transect centered on a visible wetland boundary at Mill Creek mitigation area in Wayne county, West Virginia. PA and SC indicate site types and the vertical dotted line indicates visible boundary. No significant trend was found.

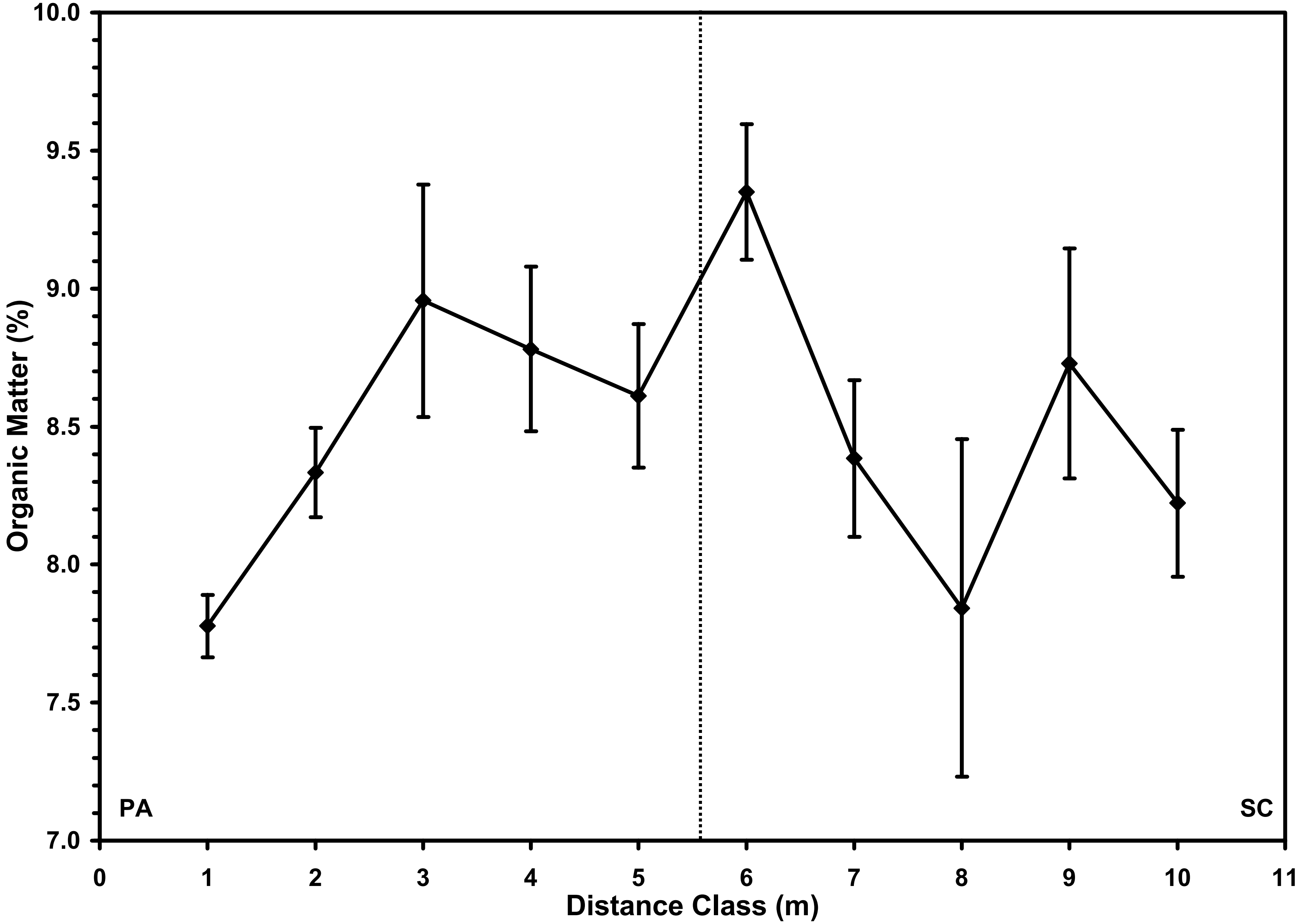

10.0
9.5
9.0
8.5
8.0
7.5
7.0
Organic Matter (%)
PA
SC
0
1
2
3
4
5
6
7
8
9
10
11
Distance Class (m)

Table 11. Correlation matrix for aluminum (Al), magnesium (Mg), calcium (Ca), soil moisture (moist), NH_4^+ and NO_3^- pools, net nitrification and N-mineralization rates (Nit and N-min, respectively), organic matter (OM), pH, and litter for a 10-m transect at Mill Creek study area Wayne County, West Virginia. Dashes (-) indicate no significant correlation.

	Al	Ca	Mg	N-min	Moisture	NH_4^+	Nit	NO_3^-	O.M.	pH
Ca	-0.80‡									
Mg	-0.83‡	0.87‡								
N-min	-	-	-							
Moisture	0.53‡	-0.29*	-0.44‡	-						
NH_4^+	-	-	-	0.32†	-0.47‡					
Nit	-	-	-	0.92‡	-	0.27*				
NO_3^-	-0.54‡	0.60‡	0.55‡	0.36†	-	-	0.50‡			
OM	-	0.31*	0.31†	-	-	-	-	-		
pH	-0.77‡	0.73‡	0.66‡	-	-0.41‡	0.26*	-	0.53‡	-	
Litter	-0.56‡	0.59‡	0.61‡	-	-	0.38†	-	0.57‡	-	0.48‡

*, $P < 0.10$; †, $P < 0.05$; ‡, $P < 0.01$

Figure 23. Summary (mean ± SE; n = 4 per distance class) of pH along a 10-m transect centered on a visible wetland boundary at Mill Creek mitigation area in Wayne county, West Virginia. PA and SC indicate site types and the vertical dotted line indicates visible boundary. Equation for regression line is $y = -0.04x + 4.33$ with $R^2 = 0.82$.

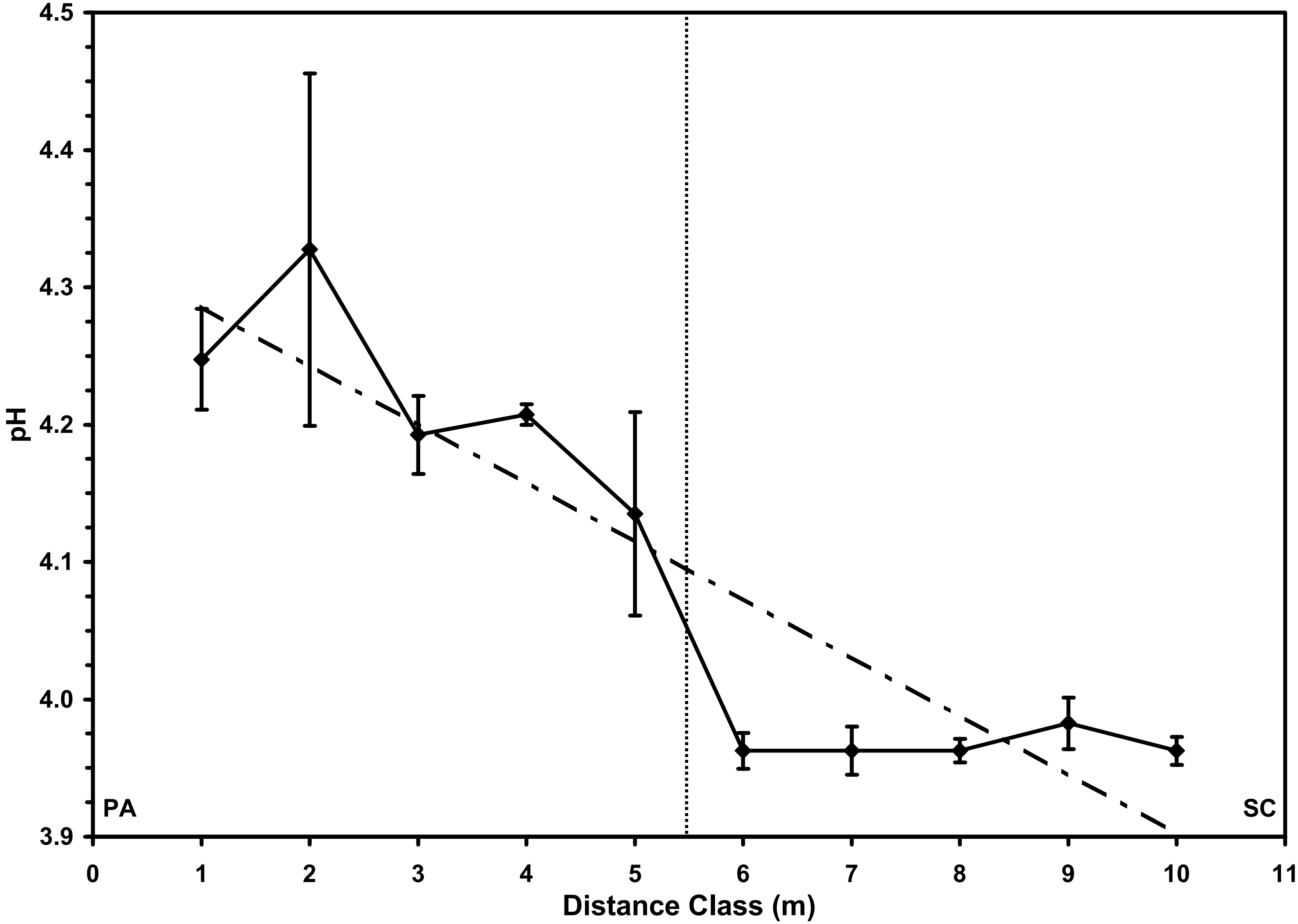
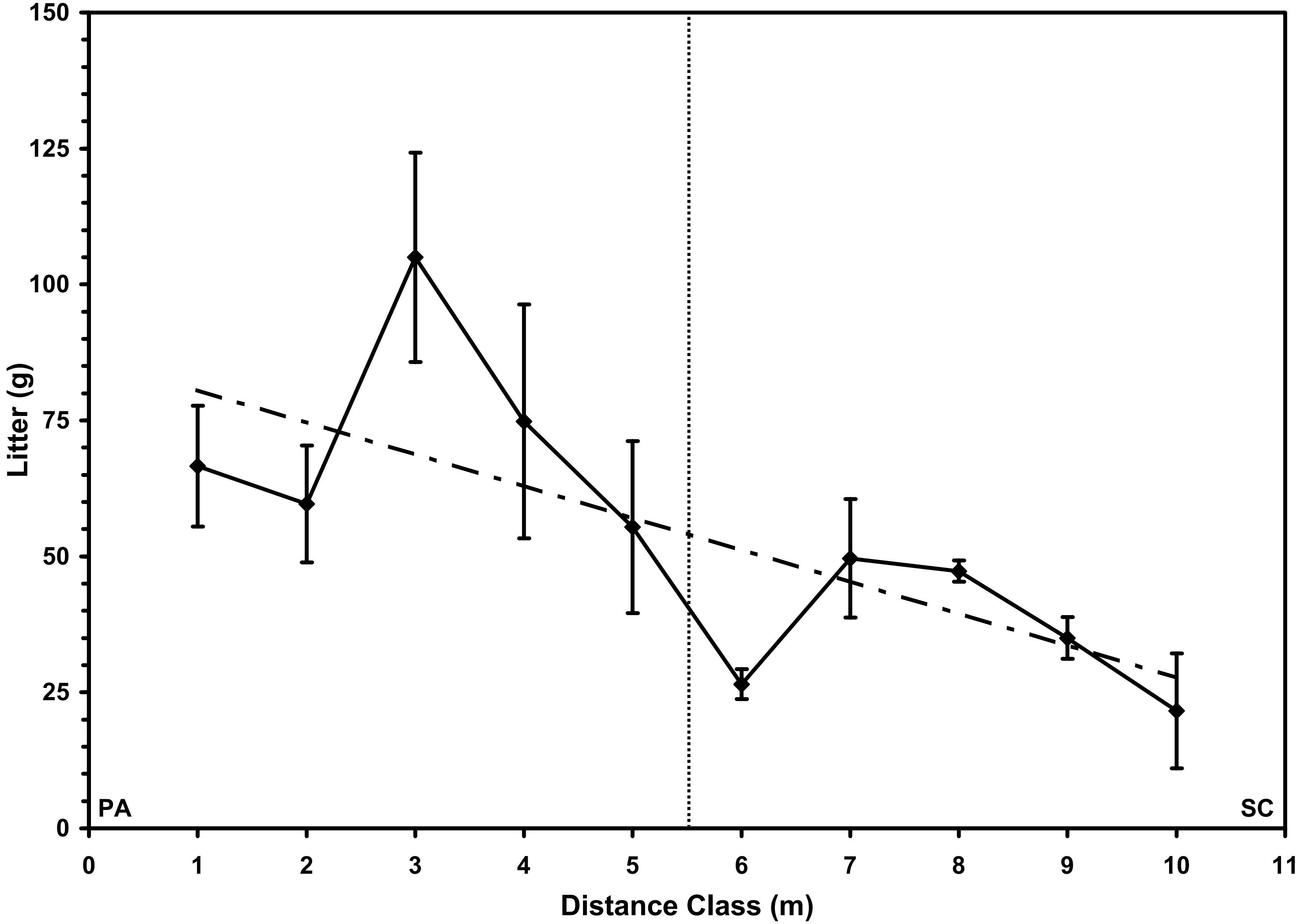

4.5
4.4
4.3
4.2
4.1
4.0
3.9
pH
PA
SC
0
1
2
3
4
5
6
7
8
9
10
11
Distance Class (m)

Figure 24. Summary (mean ± SE; n = 4 per distance class) of litter (g) along a 10-m transect centered on a visible wetland boundary at Mill Creek mitigation area in Wayne county, West Virginia. PA and SC indicate site types and the vertical dotted line indicates visible boundary. Equation for regression line is $y = -5.88x + 86.49$ with $R^2 = 0.52$.


150
125
100
75
50
25
0
Litter (g)
PA
SC
0
1
2
3
4
5
6
7
8
9
10
11
Distance Class (m)

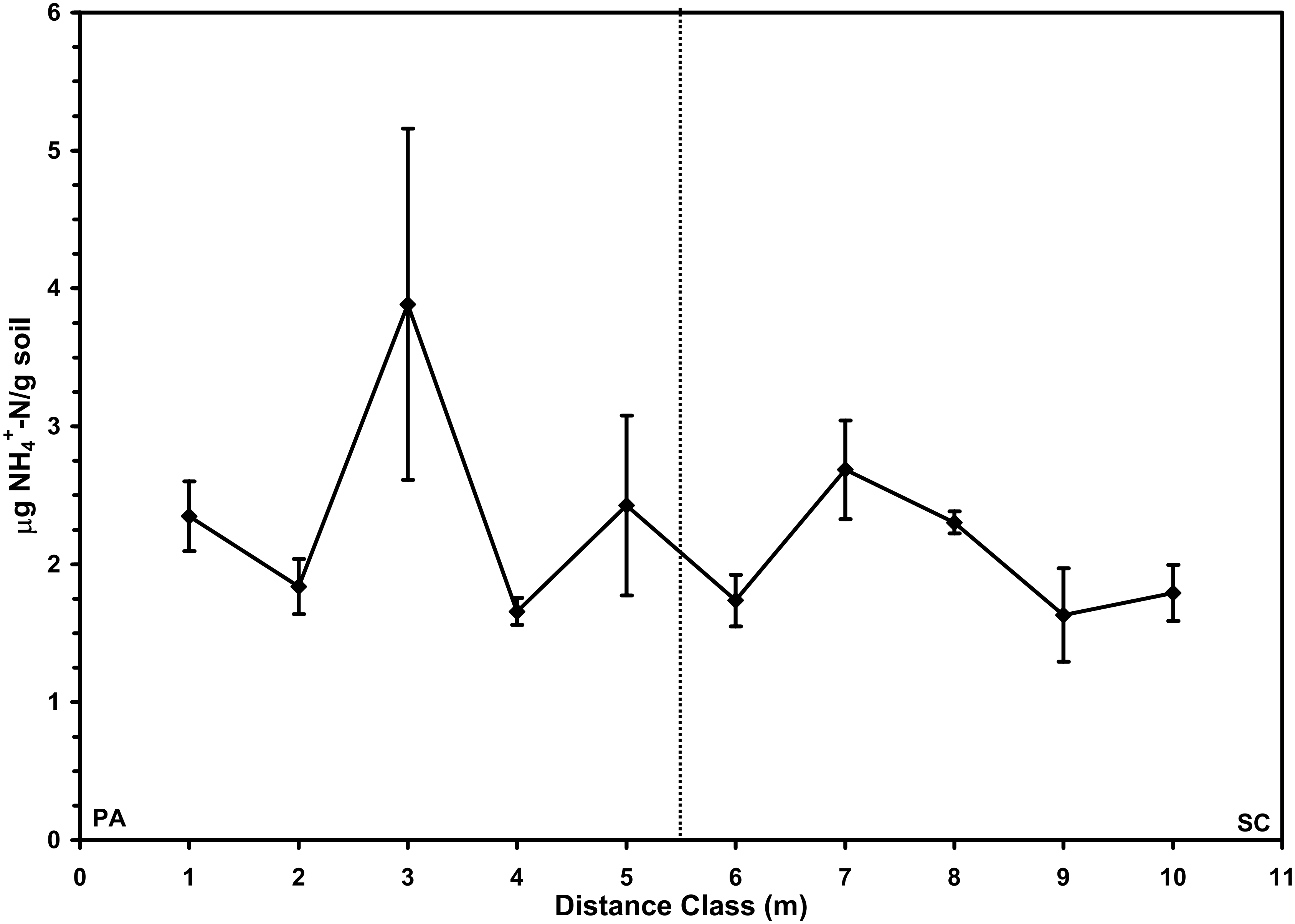
probably due to large quantities of standing dead FEEL and POSP outside wetland boundary. Transition from pasture to wetland scar appears to be gradual for litter, demonstrated by 7 of 10 points being very near the regression line in Figure 24. Variability of litter was also higher outside scar ($P < 0.01$; Table 10), which may be a result of species growth patterns (i.e. FEEL and POSP tend to grow in clumps, so if a large dead clump is present in one plot the overall average will increase along with variance). Litter is correlated with neither soil moisture nor organic matter. There is, however, a highly significant positive correlation ($R = 0.48$; $P < 0.01$) between litter and pH. This may indicate greater productivity at higher pH, however this is a risky assumption considering the differences in species composition between PA and SC sites that was noted earlier (Tables 4 & 5).

Nitrogen dynamics and spatial patterns

Ammonium concentration did not differ significantly between plots inside and outside scar (Table 9). Regression analysis also found no significant trend for NH_4^+ along transect (Figure 25). This is similar to results obtained from the site study above (Figure 9). Accordingly, there is no transition zone for NH_4^+. However, NH_4^+ concentrations within the scar are significantly less variable ($P < 0.001$) with variance in pasture being five times variance noted in wetland area (Table 10). This is likely due to high variability noted in distance classes 3 and 5 (Figure 25). Ammonium was not correlated with organic matter, but had a highly significant negative correlation ($R = -0.47$; $P < 0.01$) with moisture (Table 11). This correlation was not found in site studies (Table 2). There were also positive correlations with pH ($R = 0.26$; $P < 0.10$) and litter ($R = 0.38$; $P < 0.05$). The correlation with litter probably results from increased productivity in areas with more available NH_4^+.

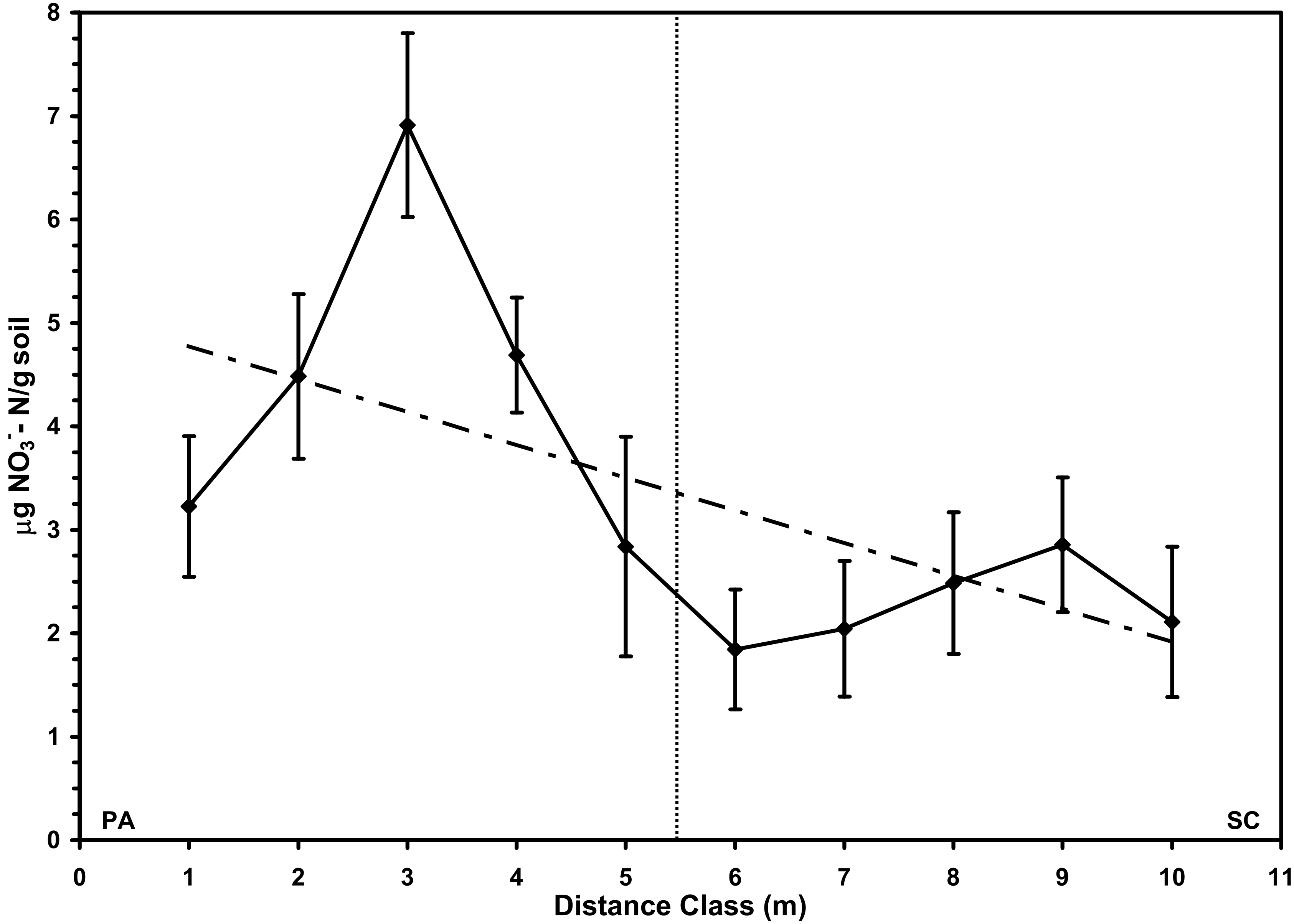
Nitrate concentration outside scar was nearly double concentration inside scar ($P < 0.001$; Table 9). Therefore, regression analysis revealed a negative trend for NO_3^- with respect to distance (Figure 26). Similar patterns were found in site study above (Figure 9). This pattern is likely related to long term soil moisture and hydrologic patterns because periodically flooded soils do not usually accumulate large NO_3^- pools (Gilliam *et al*. 1999; Mitsch and Gosselink 2000). However, there was no correlation between NO_3^- pools and moisture (Table 11), most likely due to sampling time. Nitrate variability is nearly 3 times higher outside scar ($P < 0.05$; Table 10). Nitrate pools are not correlated with either NH_4^+ pools or organic matter (Table 11).

Figure 25. Summary (mean ± SE; n = 4 per distance class) of NH_4^+ pools (μg NH_4^+-N/g soil) along a 10-m transect centered on a visible wetland boundary at Mill Creek mitigation area in Wayne county, West Virginia. PA and SC indicate site types and the vertical dotted line indicates visible boundary. No significant trend was found.



6
5
4
3
2
1
0
μg NH4+-N/g soil
PA
SC
0
1
2
3
4
5
6
7
8
9
10
11
Distance Class (m)

Figure 26. Summary (mean ± SE; n = 4 per distance class) of NO_3^- pools (µg NO_3^--N/g soil) along a 10-m transect centered on a visible wetland boundary at Mill Creek mitigation area in Wayne county, West Virginia. PA and SC indicate site types and the vertical dotted line indicates visible boundary. Equation for regression line is y = -0.32x + 5.10 with R^2 = 0.37.



8
7
6
5
4
3
2
1
0
μg NO_3^- - N/g soil
PA
SC
0
1
2
3
4
5
6
7
8
9
10
11
Distance Class (m)

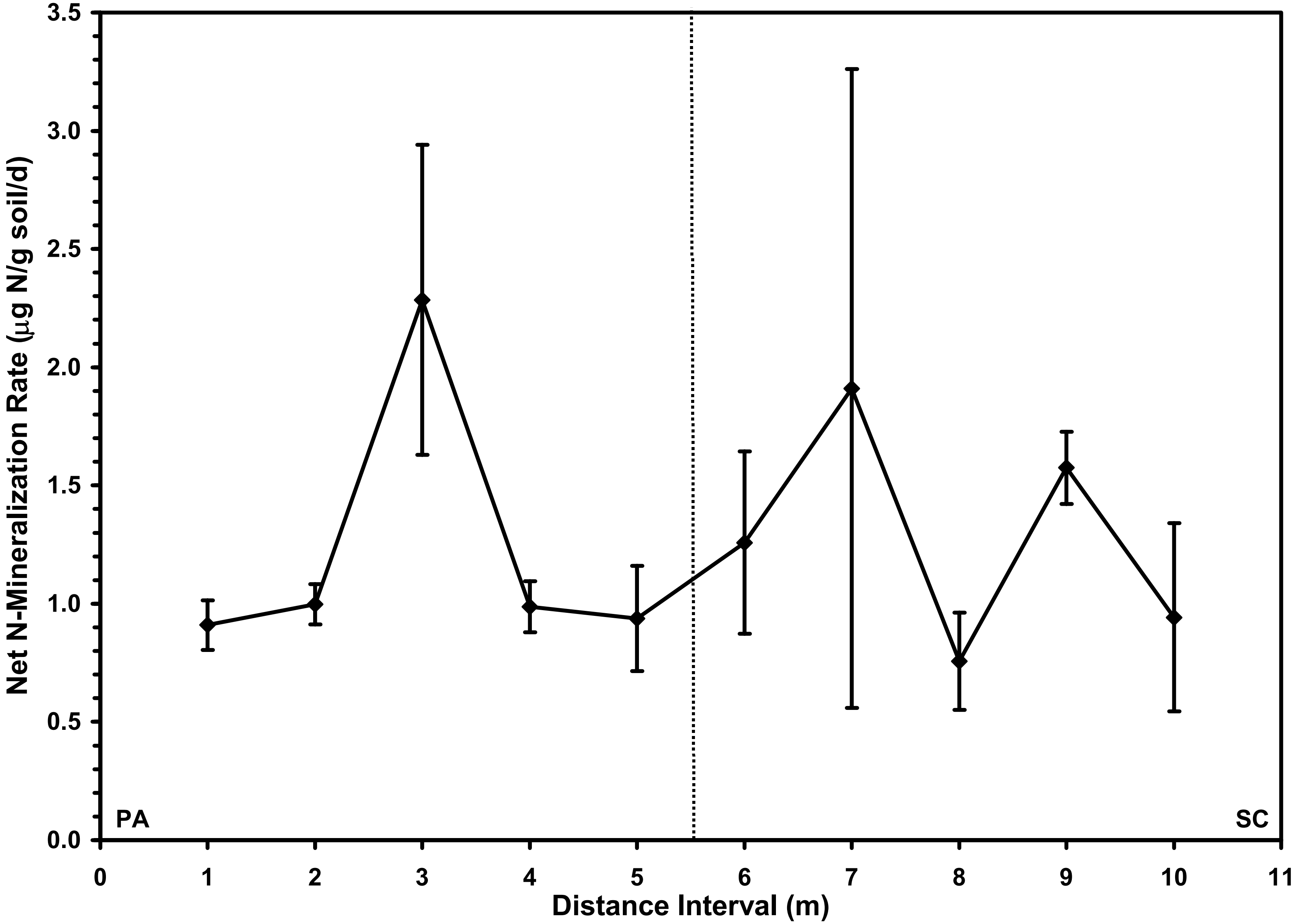
The strong positive correlation (R = 0.53; P <0.01; Table 11) between NO_3^- and pH was not expected since nitrate production is an acidifying process (Sumner *et al*. 1991). This may indicate that these NO_3^- pools were not derived from nitrification at this site, but from some other source such as acid deposition or leaching from areas upslope. A high degree of correlation (R = 0.57; P <0.01) between NO_3^- and litter may be a result of increased production in areas with higher NO_3^- availability.

Net N-mineralization and nitrification rates were similar in wetland and pasture segments of the transect (Table 9) and presented similar patterns as evidenced by their high degree of correlation (R = 0.92; P <0.01; Table 11). No significant linear regressions were found and there is no apparent boundary between pasture and wetland with regards to net N-mineralization and nitrification rates (Figures 27 & 28). This is not consistent with site study data, which found much lower net N-mineralization and nitrification rates in PA compared with SC (Figure 10 & 11). There is no readily available explanation for this, except that time between sampling dates may have allowed drying out of wetland soils and N dynamics may have shifted. This idea is consistent with other reports of changing spatial variability through time (Guo *et al*. 2002). Ehrenfeld *et al*. (1997) found that spatial patterns can appear, disappear, and even become reversed over time. They also noted that these temporal changes might prove to be very important in development of plant communities. Net N-mineralization is correlated with both NH_4^+ (R = 0.32; P <0.05) and NO_3^- pools (R = 0.36; P <0.05; Table 11). Net nitrification produced similar correlations to both NH_4^+ (R = 0.27; P <0.10) and NO_3^- pools (R = 0.50; P <0.01; Table 11). The extremely high degree of correlation between net N-mineralization and nitrification rates indicates highly nitrifying soils and may be a sign of environmental problems, such as acid deposition and N saturation (Gilliam *et al* 2001a). Implications of such a situation are dealt with in Chapter III, since the plot study produced similar results (Table 2).

Spatial patterns of Al^{3+}, Ca^{2+}, and Mg^{2+} cations

Aluminum concentration inside the wetland area was approximately 53 times higher (P <0.0001) than in pasture (Table 9) leading to a highly significant positive correlation with respect to distance (Figure 29). This result is similar to site study results where only SC site had any appreciable KCl extractable Al^{3+} (Figure 13). This is also in agreement with Pellerin *et al.*

Figure 27. Summary (mean ± SE; n = 4 per distance class) of net N-mineralization rate (µg N/g soil/d) along a 10-m transect centered on a visible wetland boundary at Mill Creek mitigation area in Wayne county, West Virginia. PA and SC indicate site types and the vertical dotted line indicates visible boundary. No significant trend was found.



Net N-Mineralization Rate (μg N/g soil/d)
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
PA
SC
0
1
2
3
4
5
6
7
8
9
10
11
Distance Interval (m)

Figure 28. Summary (mean ± SE; n = 4 per distance class) of net nitrification rate (µg NO_3^--N/g soil/d) along a 10-m transect centered on a visible wetland boundary at Mill Creek mitigation area in Wayne county, West Virginia. PA and SC indicate site types and the vertical dotted line indicates visible boundary. No significant trend was found.

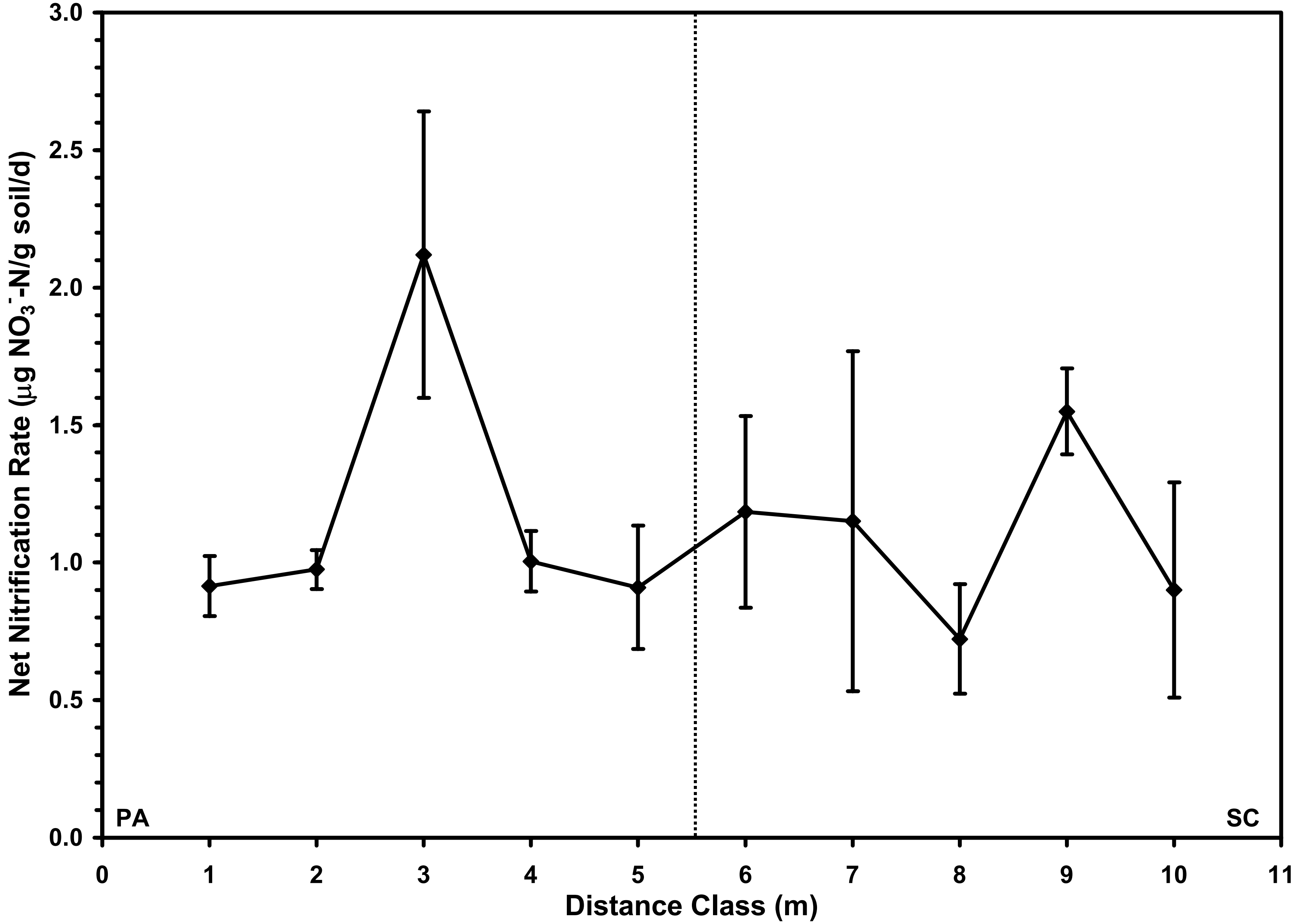
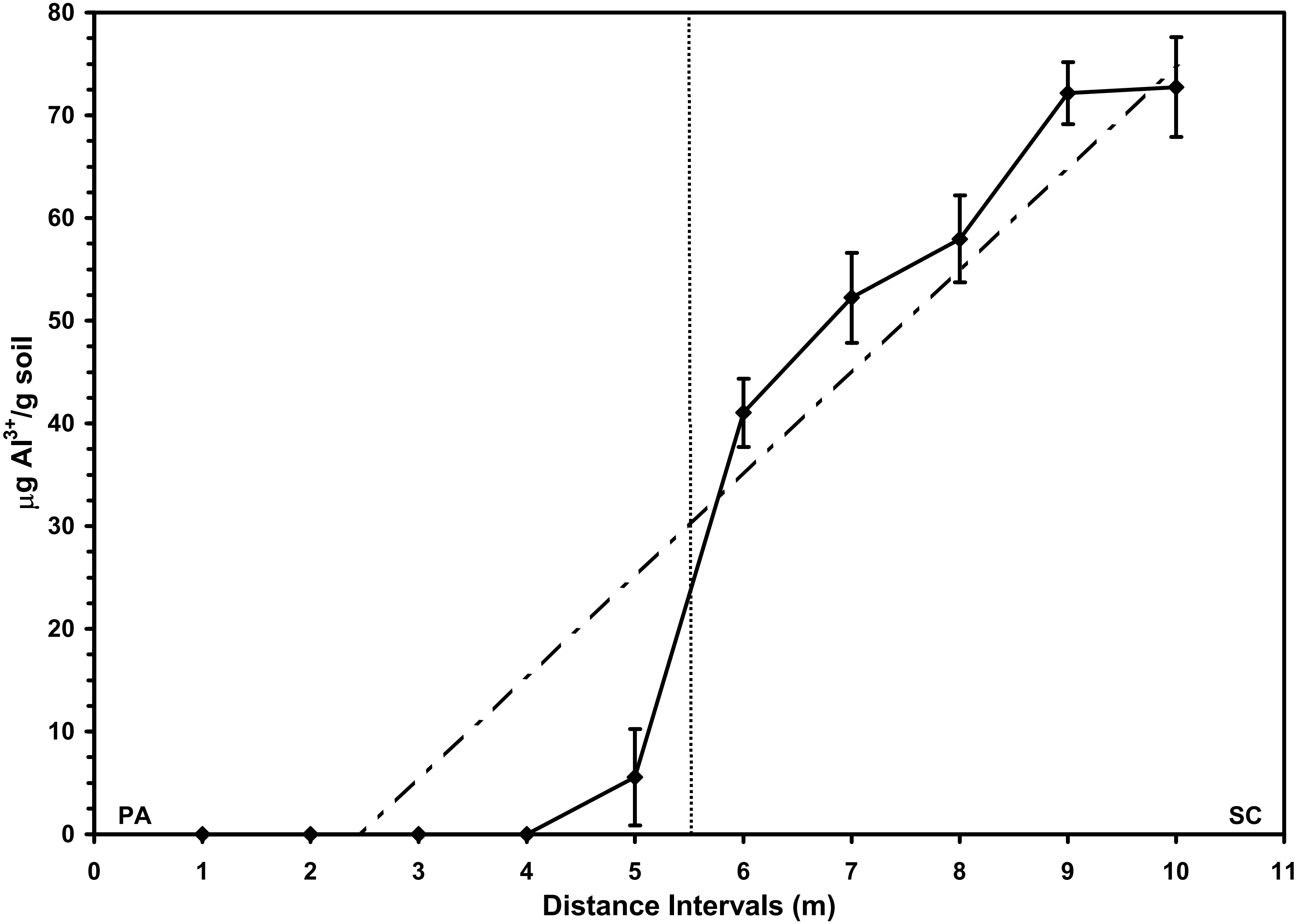

Net Nitrification Rate (μg NO_3^--N/g soil/d)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
PA
SC
0
1
2
3
4
5
6
7
8
9
10
11
Distance Class (m)

Figure 29. Summary (mean ± SE; n = 4 per distance class) of Al^{3+} (µg Al^{3+}/g soil) along a 10-m transect centered on a visible wetland boundary at Mill Creek mitigation area in Wayne county, West Virginia. PA and SC indicate site types and the vertical dotted line indicates visible boundary. Equation for regression line is y = 9.95x - 24.56 with R^2 = 0.89.

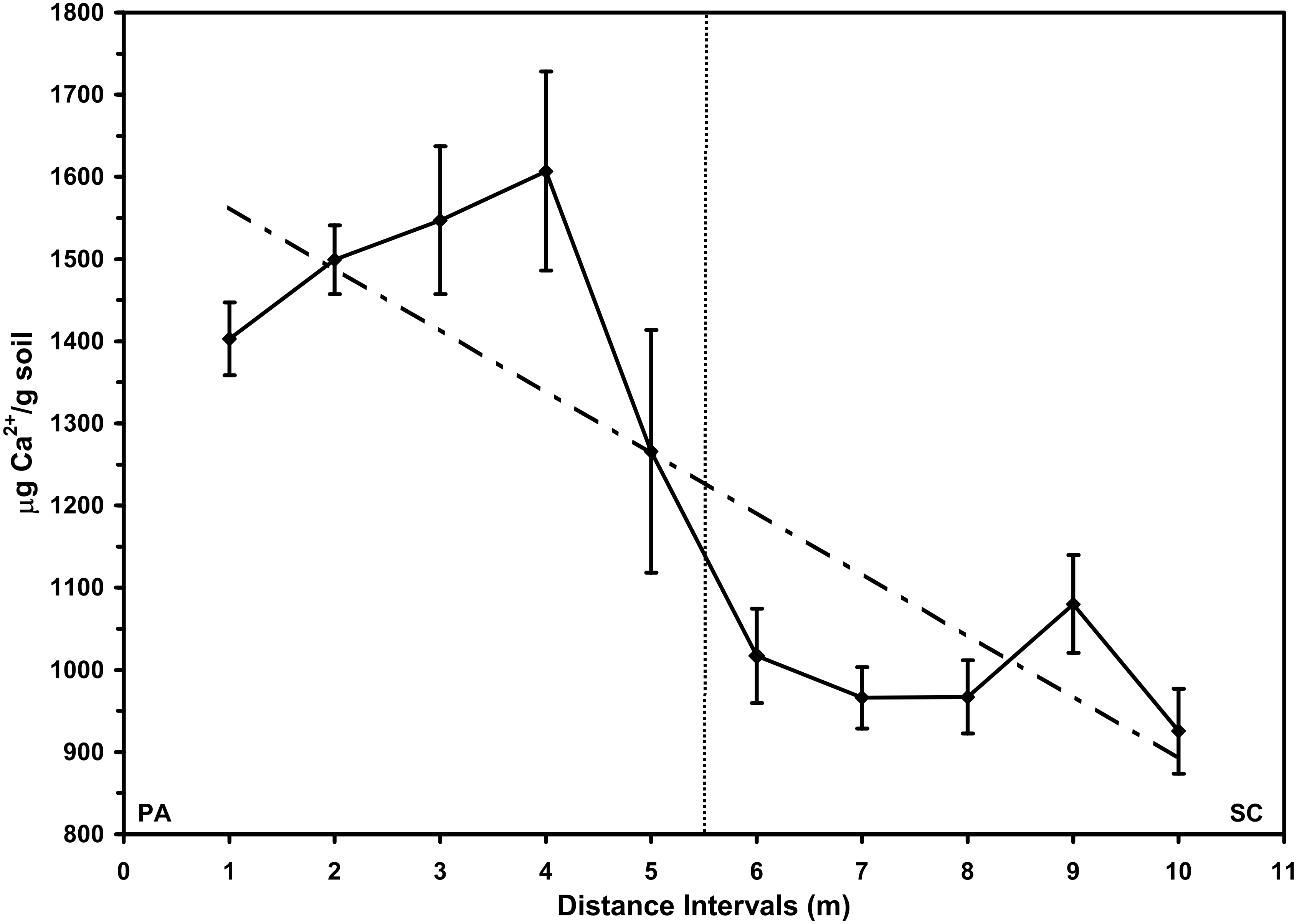


80
70
60
50
40
30
20
10
0
μg Al3+/g soil
PA
SC
0
1
2
3
4
5
6
7
8
9
10
11
Distance Intervals (m)

(2002) who found higher Al^{3+} concentrations in hydric soils near streams. Variability within the wetland area was >10 times higher (*P* <0.0001) than in pasture portion of transect (Table 10). This difference was likely due to large differences in means recorded for pasture and wetland areas. There were a significant number (18 of 20) of pasture plots that did not have any KCl extractable Al^{3+}. The 2 plots in pasture that had a measurable amount of KCl extractable Al^{3+} were adjacent to the wetland boundary (Figure 29). Aluminum presented a highly significant positive correlation (R = 0.53; *P* <0.01) with soil moisture (Table 11). The high negative correlation (R = -0.77; *P* <0.01) between Al^{3+} and pH was expected based on high solubility of Al^{3+} at low pH (Barbour *et al*. 1999). However, according to these results a change of 0.2 pH units can cause aluminum to be 53 times more soluble. There was a highly significant negative correlation (R = -0.56; *P* <0.01) between Al^{3+} and litter as well (Table 11), indicating the detrimental effects of aluminum on plant productivity. Aluminum was negatively correlated (R = -0.54; *P* <0.01) with NO_3^-. No correlation was found with N minerlaization, NH_4^+ pools, nitrification, or organic matter. The lack of correlation with N mineralization and nitrification is important because it shows that although Al^{3+} is toxic to some plants, it does not affect microorganisms responsible for N mineralization and nitrification.

Calcium concentration was significantly higher (*P* <0.0001) in pasture area (Table 9) resulting in a negative regression line with respect to distance along transect (Figure 30). Again, these results mirror those of the site study (Figure 14) and agree with Pellerin *et al*. (2002). Variability in pasture was approximately 4 times higher (*P* <0.01) than that found in wetland area (Table 10). High negative correlations between Al^{3+} and Ca^{2+}, such as those found here (R = -0.80; *P* <0.01; Table 11), were expected based on differences in solubility related to pH. While Al^{3+} is soluble at lower pH, Ca^{2+} is more soluble at higher pH (Barbour *et al.* 1999). This results in a negative correlation between the two as found here and by Pellerin *et al*. (2002). Evidence of this relationship is also seen in the high positive correlation (R = 0.73; *P* <0.01) between Ca^{2+} and pH (Table 11). Weak correlations were found with moisture (R = -0.29; *P* <0.10) and organic matter (R = 0.31; *P* <0.10) while no correlation was found with N mineralization, NH_4^+ pools, or nitrification. A high correlation (R = 0.59; *P* <0.01) between Ca^{2+} and litter is indicative of calcium's status as a macronutrient. Patches with higher levels of available Ca^{2+} should tend to have higher primary productivity, and therefore more litter and

Figure 30. Summary (mean ± SE; n = 4 per distance class) of Ca^{2+} (µg Ca^{2+}/g soil) along a 10-m transect centered on a visible wetland boundary at Mill Creek mitigation area in Wayne county, West Virginia. PA and SC indicate site types and the vertical dotted line indicates visible boundary. Equation for regression line is y = -74.57x + 1637.90 with R^2 = 0.71.



1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
μg Ca2+/g soil
PA
SC
0
1
2
3
4
5
6
7
8
9
10
11
Distance Intervals (m)

standing dead biomass. Calcium is also significantly correlated (R = 0.60; *P* <0.01) with NO_3^- pools (Table 11).

Magnesium concentration followed a similar pattern as Ca^{2+}, which is reflected in the high positive correlation (R = 0.87; *P* <0.01) between these two variables. Extractable Mg^{2+} was significantly higher (*P* <0.0001) in pasture area (Table 9) resulting in a negative regression line with respect to distance along transect (Figure 31). These results are similar to those noted in site study (Figure 15) and agree with Pellerin *et al*. (2002). Variability in pasture was approximately 3 times higher (*P* <0.05) than that found in wetland area (Table 10). Again, a high negative correlation (R = -0.83; *P* <0.01) with Al^{3+} and a high positive correlation (R = 0.66; *P* <0.01) pH were expected based on high solubility of Mg^{2+} at higher pH (Barbour *et al*. 1999). A high correlation (R = 0.61; *P* <0.01) between Mg^{2+} and litter is also indicative of magnesium's status as a macronutrient; this correlation occurs due to reasons mentioned for calcium. Magnesium has a higher correlation (R = -0.44; *P* <0.01) with moisture than Ca^{2+} (Table 11). Also similar to Ca^{2+}, Mg^{2+} is weakly correlated (R = 0.31; *P* <0.05) with organic matter and is not correlated with N mineralization, NH_4^+ pools, or nitrification. Magnesium is highly correlated (R = 0.55; *P* <0.01) with NO_3^- pools (Table 11).

Vegetation composition and patterns

Plots inside the wetland scar had dissimilar plant communities compared to plots outside wetland scar. This is due to dominance of DISA and graminoids in pasture area with ASPI, CAFR, and CATR dominating wetland area (Table 12). The only species shared equally is ARHI (Table 12), which coincidentally occurred in the border plots. This species appears to be well adapted to wetland edges. These results are similar to those of Reader and Best (1989) who found different dominant species associated with rim versus trough of shallow depressions (<0.25 m deep, approximately 2 m in diameter) within a pasture in Ontario, Canada. The dissimilarity between pasture and wetland areas is also demonstrated by a percent similarity of 0.119. However, this percent similarity is nearly double the similarity index obtained for PA and SC sites (Table 7). This may be a result of taking closely spaced samples through the transition zone instead of separating them by several meters as was done in site studies. Sites that are in close proximity often share some species whether or not those species are well adapted to both sites (Kunin 1998). Also consider the similarity index in that these plots were arranged in a

Figure 31. Summary (mean ± SE; n = 4 per distance class) of Mg^{2+} (µg Mg^{2+}/g soil) along a 10-m transect centered on a visible wetland boundary at Mill Creek mitigation area in Wayne county, West Virginia. PA and SC indicate site types and the vertical dotted line indicates visible boundary. Equation for regression line is $y = -9.50x + 191.82$ with $R^2 = 0.72$.

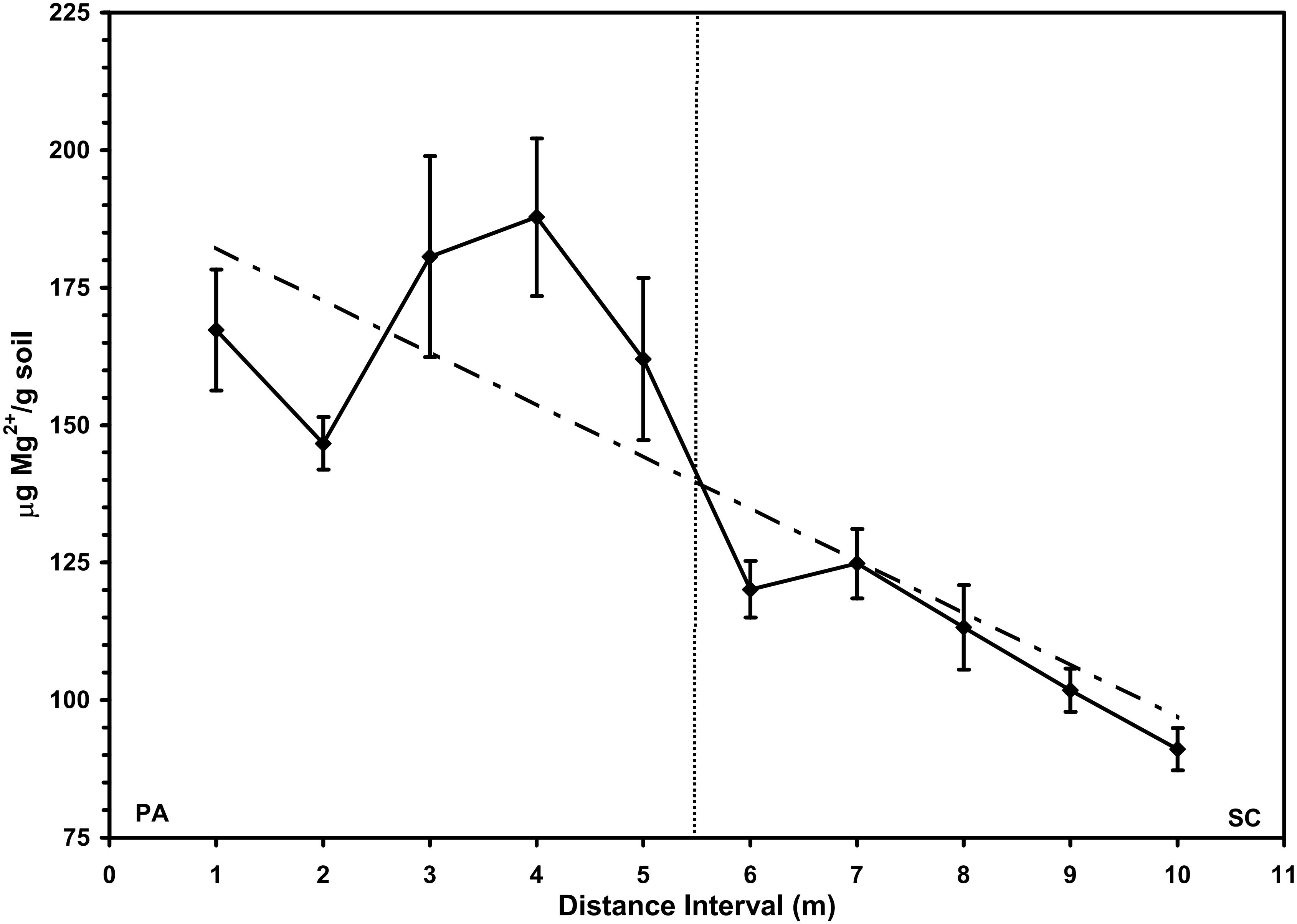

225
200
175
150
125
100
75
μg Mg2+/g soil
0
1
2
3
4
5
6
7
8
9
10
11
Distance Interval (m)
PA
SC

Table 12. Species encountered along a 10-m transect in Wayne County, WV. Order based on mean dry weight of aboveground biomass for 0.25-m^2 plots (n = 40). Transect was centered (5 m outside and 5 m inside) and perpendicular to visible boundary of a wetland scar. Plots assigned as inside or outside scar based on position (n = 20 outside; n = 20 inside). An asterisk (*) between values indicates significant difference (*P* <0.05). Species codes are defined in Appendix A. Wetland indicator status indicates probability of finding species in wetland areas (Appendix B). Graminoids contains POSP and another unidentifiable grass-like species, which were impossible to accurately separate.

Species	Mean Biomass (g/0.25-m^2) Outside Scar		Inside Scar	Wetland Indicator Status
ASPI	0.9	*	54.3	UPL
DISA	21.9	*	0.2	FACU-
ARHI	8.0		7.4	NI
CAFR	0.0	*	13.2	OBL
Graminoids	9.1	*	1.1	–
CATR	0.0	*	5.8	FACW+
JUEF	0.0	*	3.7	FACW+
LYNU	0.0	*	3.6	OBL
SOCA	2.1	*	0.2	UPL
AGSP	0.0	*	0.8	–
VEAL	0.5	*	0.0	NI
XAPE	0.5	*	0.0	NI
OXCO	0.1	*	0.0	FACU
DIVI	0.0	*	0.1	FACW
SEGL	<0.1	*	0.0	FAC
POPE	<0.1		<0.1	FACW

continuous line and divided at an arbitrary boundary. From this perspective, there is a distinct discontinuity along the chosen boundary.

Species richness was similar for plots inside and outside wetland scar (5.1 species/0.25 m^2 and 4.4 species/0.25 m^2, respectively; Figure 32). Species diversity was also similar both inside and outside the wetland area (0.61 and 0.68, respectively) as was evenness (0.54 and 0.56, respectively). The low diversity and evenness are probably related to this areas use as a pasture. As in many situations, species diversity is highest at the boundary between these habitats (Figure 32). Mean total biomass (measured as total of average species biomass per plot) in wetland area was nearly double that in pasture (90.2 g/0.25 m^2 and 43.2 g/0.25 m^2, respectively). This might indicate greater primary productivity within the wetland area, however there was significantly more dead biomass in the pasture area (Figure 24). This difference in mean average biomass may also be a result of vegetation types. ASPI, which dominated the wetland scar segment, has very stout, heavy stems that contributed significantly to total weight.

Multivariate analysis

Direct gradient analysis (CCA) solidified the idea of discontinuity along the transect (Figure 33). Aluminum and Mg^{2+} form appear as opposing gradient axes and are a driving force behind axis 1, which explains 39.6% of transect variance. Axis 2 explains 21.5% of variance and axis 3 (not shown) explained only 6.5% of variance. Calcium and pH are also closely related to Mg^{2+}. Net nitrification, N mineralization, and NH_4^+ pools explained little of the variation among plots. Of the 20 distance classes (0.5-10 m, 0.5-m increments), 9 form a cluster defined as pasture (0.5-4.5 m). Another 9 classes form a cluster defined a wetland scar (6-10 m). Only two distance classes (5 and 5.5 m) can possibly be classified as a transition, or ecotone, region. However, based on the environmental axes, these distance classes are environmentally similar to pasture and wetland scar, respectively. The only real explanations for the separation of these transition distance classes are the presence of ARHI within these plots and higher soil organic matter, particularly at 5 m. Again, these plots are on the visible boundary between wetland and pasture and ARHI appears to be specialized for this location, owing to its not being found elsewhere to any great extent.

Although it is typically thought that transition zones are gradual (Gosz 1992), this particular one appears to be defined by a rather distinct boundary. This may be an isolated or

Figure 32. Summary (mean ± SE; n = 4 per distance class) of plot species richness (# species/m^2) along a 10-m transect centered on a visible wetland boundary at Mill Creek mitigation area in Wayne county, West Virginia. PA and SC indicate site types and the vertical dotted line indicates visible boundary. No significant trend was found.

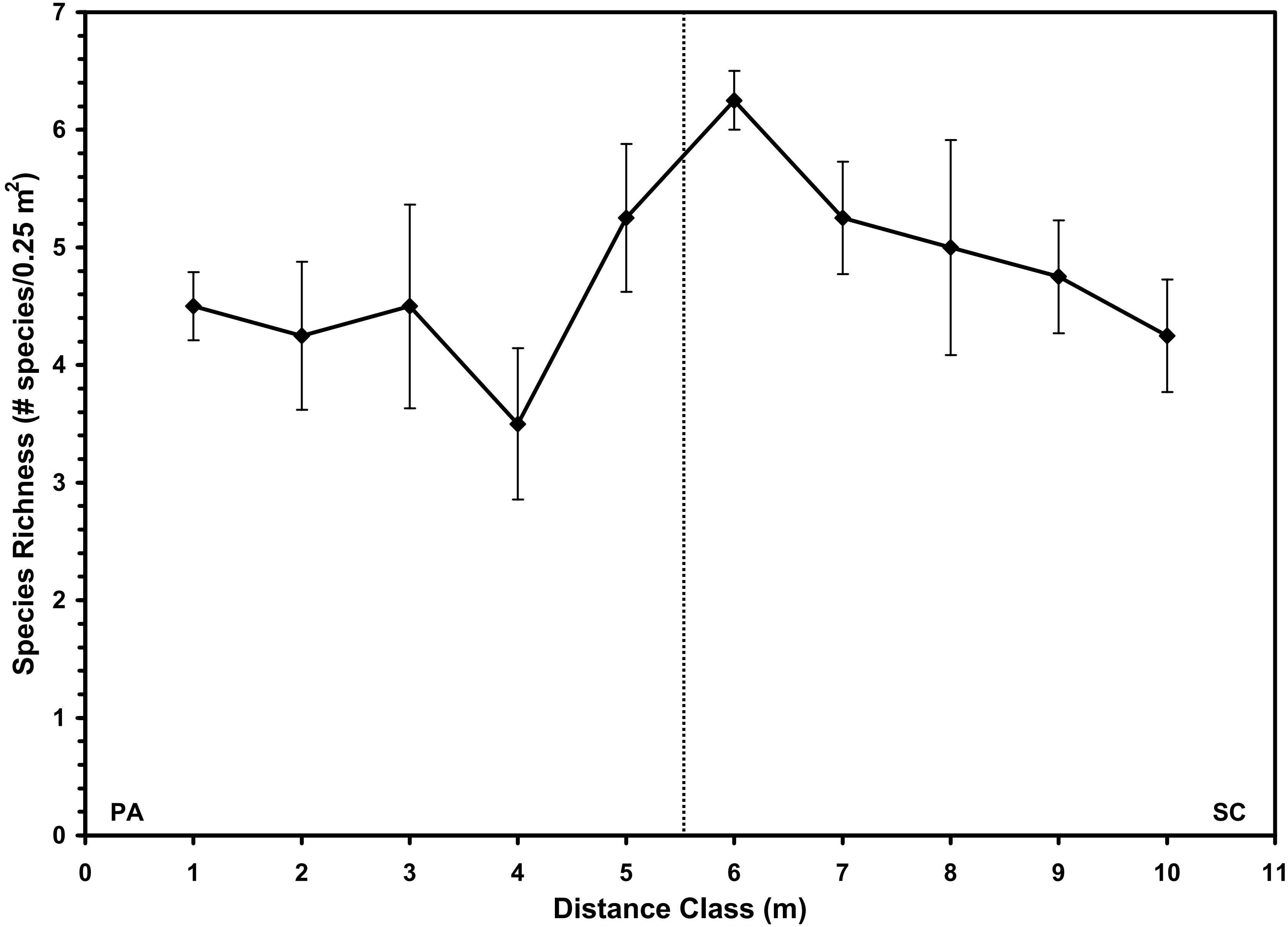
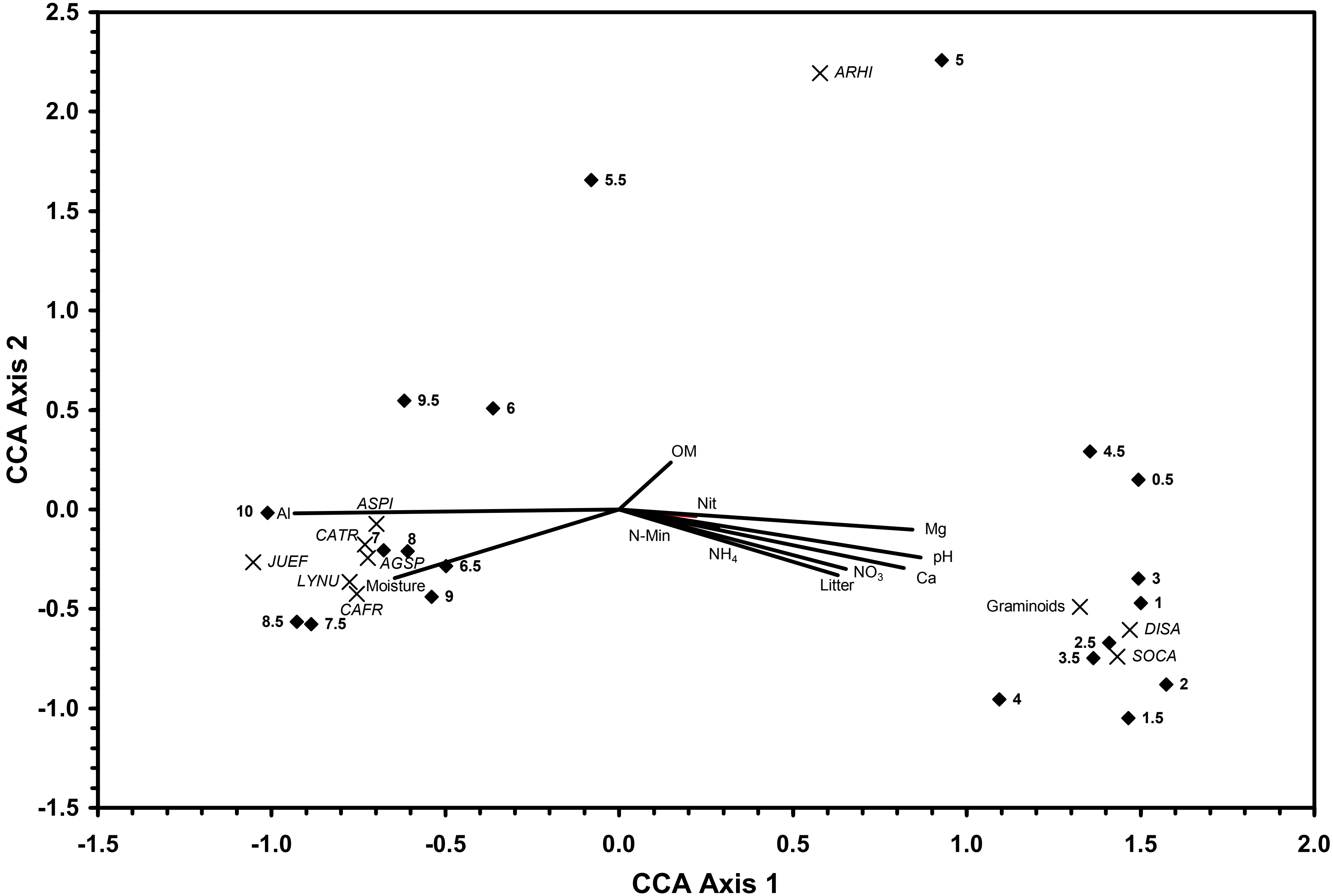

Species Richness (# species/0.25 m2)
Distance Class (m)
PA
SC
0
1
2
3
4
5
6
7
8
9
10
11

Figure 33. CCA ordination plot for transect at Mill Creek mitigation area in Wayne County, West Virginia. Lines radiating from origin represent environmental gradients. Numbers beside plot markers (diamonds) represent 0.5-m distance classes with mean data from 2 plots where 0.5-4.5 are in pasture, 5 & 5.5 are flanking boundary, and 6-10 are in wetland scar. The ten most abundant species overall were included and their positions are marked with X's. Including more than ten species made the figure too cluttered to be useful.



CCA Axis 2
CCA Axis 1
2.5
2.0
1.5
1.0
0.5
0.0
-0.5
-1.0
-1.5
-1.5
-1.0
-0.5
0.0
0.5
1.0
1.5
2.0
ARHI
5
5.5
9.5
6
OM
4.5
0.5
10
Al
ASPI
Nit
Mg
CATR
7
8
N-Min
JUEF
AGSP
6.5
NH4
pH
LYNU
Moisture
NO3
Ca
Litter
3
9
Graminoids
1
CAFR
8.5
7.5
DISA
2.5
3.5
SOCA
2
4
1.5

rare incident, but then it may also be related to sampling scale. Most studies of ecotones examine larger distances with sample points several meters to kilometers apart (e.g. Carter *et al.* 1994). This may result in missing small transitional patches within the ecotone. However, topographic gradients also play a major factor in abruptness of boundaries. For example, a long, gradual topographic gradient would show a larger ecotone than a cliff or steep embankment would. Looking at the Mill Creek site, there could be two possible scenarios. First, the pasture area could be considered upland and what is described by this transect is in fact a very abrupt ecotone. Second, the pasture is actually an ecotone between the wetland scar and old-field/forested areas, in which case this transect defines a transition from wetland to ecotone. Judging from the wetland status indicators of dominant species present in PA (Table 4), the first scenario appears to be correct.

CHAPTER V
CONCLUSIONS

Overall, three component groups, which appear to control community structure, characterized soil nutrients and processes within this floodplain. The first group consists of pH, Ca^{2+}, Al^{3+}, and organic matter with pH as a likely factor controlling Ca^{2+} and Al^{3+} solubility and decomposition rates. The second group has Mg^{2+} and moisture with moisture possibly regulating Mg^{2+} availability. This group is weakly associated with the first group and these two groups likely influence one another. Nitrogen pools and processes make up a third group, which in this system appears to have little overall relation to other factors. Again, the most striking aspect of this N data is the near 100% nitrification rates.

Several differences existed between site types within this floodplain. SC plots had the highest soil organic matter, Al^{3+}, and variability for Al^{3+}, NH_4^+, and soil organic matter along with the lowest values for pH and Ca^{2+}. PA plots had the highest moisture, NO_3^+, and variability of Ca^{2+}, Mg^{2+}, and pH along with the lowest values for net N-mineralization rate, net nitrification rate, Mg^{2+}, and species richness. OF plots had the highest pH, Ca^{2+}, Mg^{2+}, species richness and species diversity and had the lowest moisture. Variability of all OF soil properties were either low or intermediate, indicating a less heterogeneous environment compared with SC and PA. PA and OF plots had similar soil organic matter and Al^{3+} while OF and SC plots had similar NO_3^-, net N-mineralization rates, and net nitrification rates. Ammonium pools did not vary between sites.

The greatest species richness and diversity occurred at the site with the least variability, OF. Although OF was least variable with respect to most environmental variables, it was in no way homogeneous. Species richness appears to be positively related to Mg^{2+} availability and negatively related to soil moisture. This could be a result of macronutrient availability as well as inability of many species to survive in constantly wet environments.

Transect results were similar to site study results in many respects and revealed an abrupt transition from pasture to wetland soils and vegetation. This was unexpected as most ecological transitions occur gradually without hard lines. In contrast to the site study, variability along the transect was lower within the scar. This could be a result of the spatial scale at which these two studies were conducted (1-m^2 plots vs. 0.25-m^2 plots).

In conclusion, spatial variability within ecosystems is based on a complex web of interactions with no single overriding factor. To compound the issue, spatial variability is different from one scale to another (i.e. ~200, 1, and 0.5 m) and is not constant through time. Further research needs to be conducted to determine these various interactions, however to truly understand fine scale (cm) to landscape scale (km) spatial variability may require sampling schemes far too large to conduct with current technology. With future studies at this site it will be possible to determine changes in spatial variability associated with inundation as well as general comparisons of this pre (PA/OF) and post (SC) data to determine if such snapshot comparisons are valid.

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Knoepp, JD and WT Swank. 1998. Rates of nitrogen mineralization across an elevation and vegetation gradient in the southern Appalachians. Plant and Soil 204: 235-241.

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Appendix A. List of all plant species encountered at Mill Creek study site, Wayne County, West Virginia. Codes will be used to refer to species throughout thesis. Wetland indicator status for each species taken from USDA, NRCS (2002), region 1. See Appendix B for wetland indicator status definitions.

Code	**Scientific Name**	**Common Name**	**Wetland Indicator Status**
ACRH	*Acalypha rhomboidea* Raf.	Common three-seeded mercury	FACU-
AGSP	*Agrostis* sp.	–	–
AMAR	*Ambrosia artemisiifolia* L.	Common ragweed	FACU
ANVI	*Andropogon virginicus* L.	Broomsedge	FACU
ARHI	*Arthraxon hispidus* (Thunb.) Makino	Jointheaded arthraxon	NI
ASLA	*Aster lateriflorus* (L.) Britton	Calico aster	FACW-
ASPI	*Aster pilosus* Willd.	White heath aster	UPL
CAFR	*Carex frankii* Kunth	Sedge	OBL
CATR	*Carex tribuloides* Wahl.	Sedge	FACW+
CAVU	*Carex vulpinoidea* Michx.	Foxtail sedge	OBL
CIAR	*Cinna arundinacea* L.	Wood reed-grass	FACW+
CIVU	*Cirsium vulgare* (Savi) Tenore	Common thistle	FACU-
COCO	*Commelina communis* L.	Asiatic day-flower	FAC-
CYST	*Cyperus strigosus* L.	Strawcolored Flatsedge	FACW
DACA	*Daucus carota* L.	Queen Anne's lace	NI
DISA	*Digitaria sanguinalis* (L.) Scop.	Crabgrass	FACU-
DIVI	*Diodia virginiana* L.	Larger buttonweed	FACW
ECCR	*Echinochloa crusgalli* (L.) Beauv.	Barnyard grass	FACU
ELCA	*Elephantopus carolinianus* Willd.	Elephant's-foot	FACU
ERCA	*Erigeron canadensis* L.	Horseweed	NI
ERSP	*Eragrostis spectabilis* (Pursh) Steud.	Purple lovegrass	UPL
EUCO	*Eupatorium coelestinum* L.	Mistflower	FAC
EUSE	*Eupatorium serotinum* Michx.	Late-flowering thoroughwort	FAC-
FEEL	*Festuca elatior* L.	Meadow fescue	FACU-
GLHE	*Glechoma hederacea* L.	Ground-ivy	FACU
HOLA	*Holcus lanatus* L.	Velvet grass	FACU

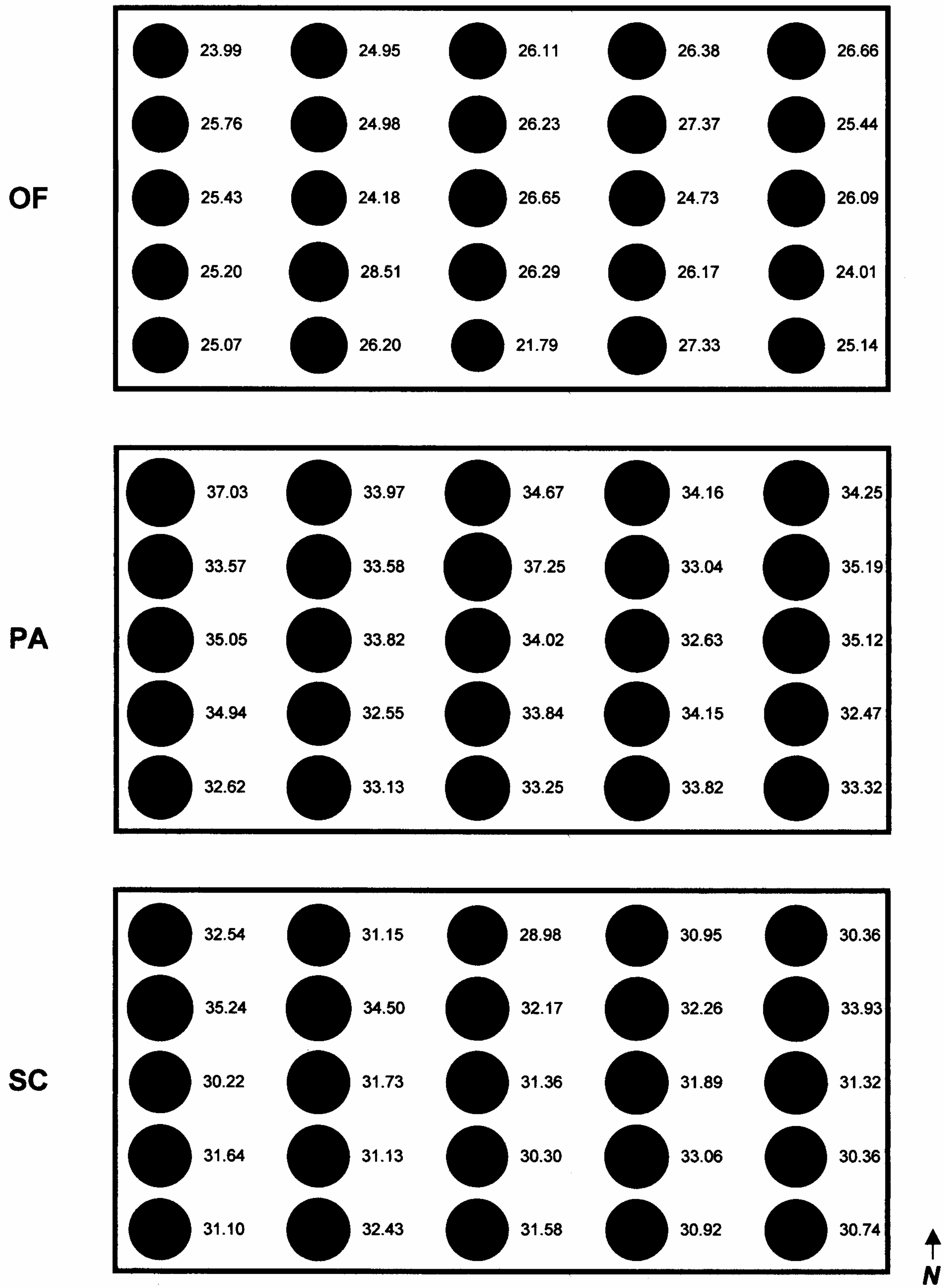
Appendix A. Continued.

Code	Scientific Name	Common Name	Wetland Indicator Status
JUEF	*Juncus effusus* L.	Common rush	FACW+
JUTE	*Juncus tenuis* Willd.	Path rush, wiregrass	FAC-
LECU	*Lespedeza cuneata* (Dumont) G. Don	Sericea	NI
LESP	*Lespedeza* sp.	–	–
LYNU	*Lysimachia nummularia* L.	Moneywort	OBL
MESP	*Medicago* sp.	–	–
MUSP	*Muhlenbergia* sp.	–	–
OXCO	*Oxalis corniculata* L.	Creeping lady's sorrel	FACU
OXST	*Oxalis stricta* L.	Upright yellow wood sorrel	UPL
PAAN	*Panicum anceps* Michx.	Flat-stemmed panic grass	FAC
PACL	*Panicum clandestinum* L.	Deertongue grass	FAC+
PALA	*Paspalum laeve* Michx.	Smooth paspalum, beadgrass	FAC+
PASP	*Panicum* sp.	–	–
PHPO	*Phaseolus polystachios* (L.) BSP.	Wild kidney bean	NI
PLSP	*Plantago* sp.	Plantain	–
POHY	*Polygonum hydropiperoides* Michx.	Mild water pepper	OBL
POPE	*Polygonum pensylvanicum* L.	Pennsylvania smartweed	FACW
POSI	*Potentilla simplex* Michx.	Common cinqufoil	FACU-
POSP	*Poa* sp.	Bluegrass	–
RUCA	*Ruellia caroliniensis* (Walt.) Steud.	Wild-petunia	NI
SEGL	*Setaria glauca* (L.) Beauv.	Yellow foxtail	FAC
SEVI	*Setaria viridis* (L.) Beauv.	Green foxtail	NI
SOCA	*Solanum carolinense* L.	Horse-nettle	UPL
TAOF	*Taraxacum officinale* Weber.	Common dandelion	FACU-
TRFL	*Triodia flava* (L.) Smyth	Purpletop	NI
TRPR	*Trifolium pratense* L.	Red clover	FACU-
VALT	*Verbesina alternifolia* (L.) Britton ex Kearney	Wing-stem	FAC
VEAL	*Vernonia altissima* Nutt.	Tall ironweed	NI
XAPE	*Xanthium pensylvanicum* Wallr.	Smooth-body cocklebur	NI

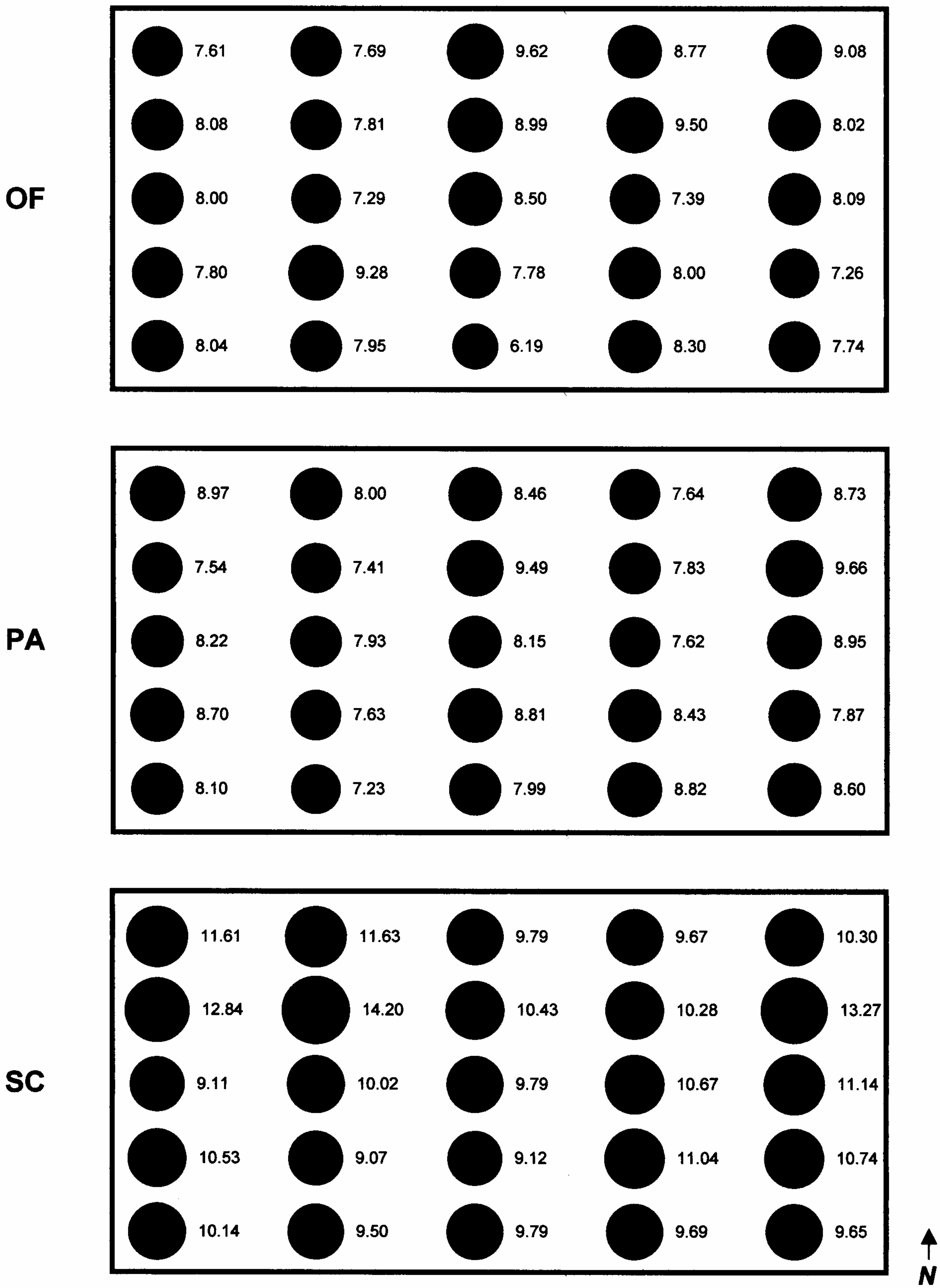
Appendix B. Definition of wetland status indicator codes used by the USDA to categorize wetland plant species. Categories abstracted by USDA from US Fish and Wildlife Service (1988).

Code	Wetland Type	Probability of Finding in Wetland
OBL	Obligate wetland	> 99%
FACW	Facultative wetland	67%-99%
FAC	Facultative	34%-66%
FACU	Facultative upland	1%-33%
UPL	Obligate upland	<1%
NI	No indicator	Insufficient information for determination
(+)	–	Frequency toward higher end of category (more likely to be found in wetlands)
(-)	–	Frequency toward lower end of category (less likely to be found in wetlands)

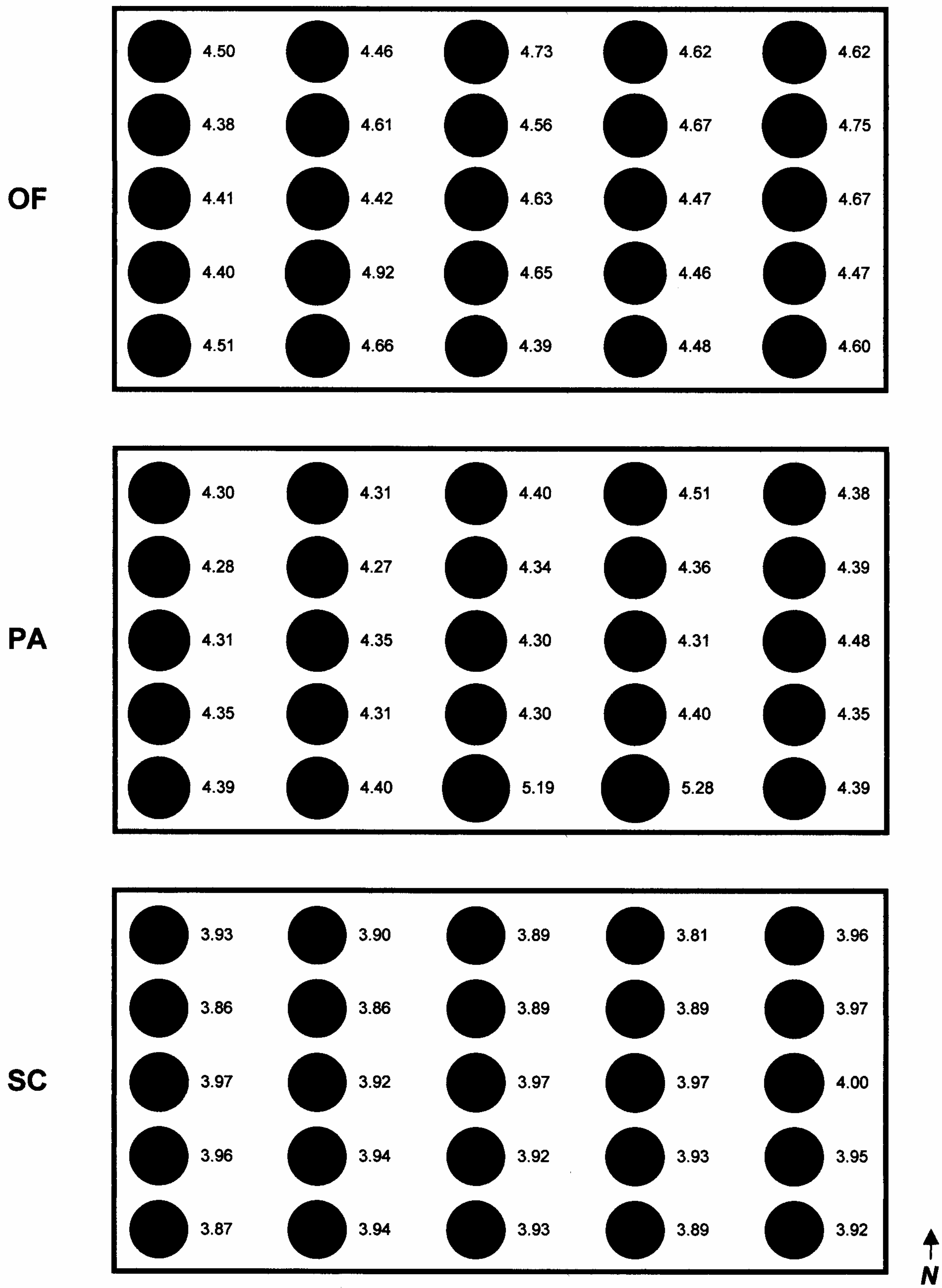
Appendix C-1. Bubble map of soil moisture (%) for individual plots of old-field (OF), pasture (PA), and wetland scar (SC) sites at Mill Creek mitigation area in Wayne County, West Virginia. Bubbles are arranged according to Figure 3. Bubble area is proportional to recorded values, which are presented next to each bubble.


OF
23.99
24.95
26.11
26.38
26.66
25.76
24.98
26.23
27.37
25.44
25.43
24.18
26.65
24.73
26.09
25.20
28.51
26.29
26.17
24.01
25.07
26.20
21.79
27.33
25.14
PA
37.03
33.97
34.67
34.16
34.25
33.57
33.58
37.25
33.04
35.19
35.05
33.82
34.02
32.63
35.12
34.94
32.55
33.84
34.15
32.47
32.62
33.13
33.25
33.82
33.32
SC
32.54
31.15
28.98
30.95
30.36
35.24
34.50
32.17
32.26
33.93
30.22
31.73
31.36
31.89
31.32
31.64
31.13
30.30
33.06
30.36
31.10
32.43
31.58
30.92
30.74
N

Appendix C-2. Bubble map of soil organic matter (%) for individual plots of old-field (OF), pasture (PA), and wetland scar (SC) sites at Mill Creek mitigation area in Wayne County, West Virginia. Bubbles are arranged according to Figure 3. Bubble area is proportional to recorded values, which are presented next to each bubble.

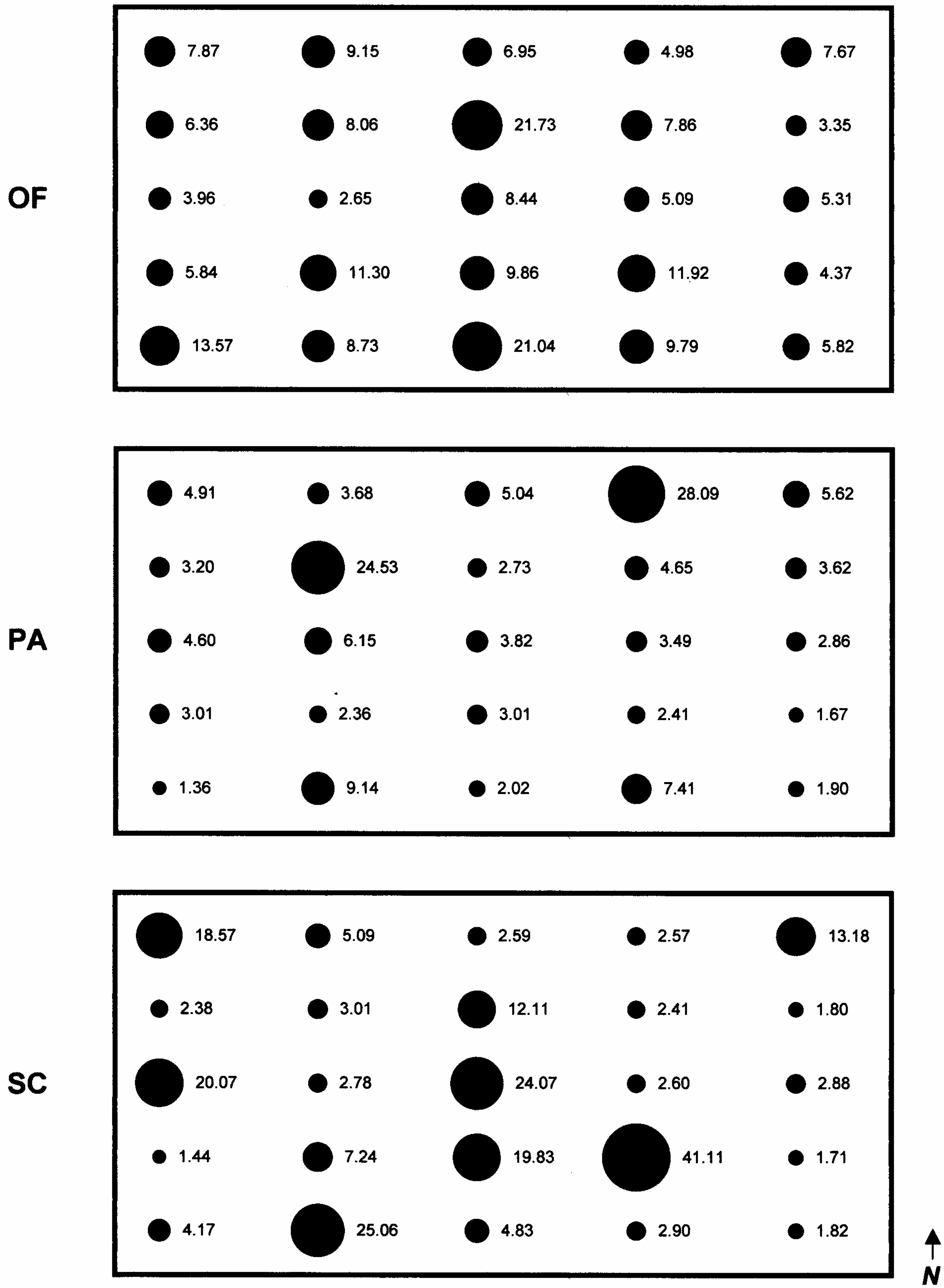

OF
7.61 7.69 9.62 8.77 9.08
8.08 7.81 8.99 9.50 8.02
8.00 7.29 8.50 7.39 8.09
7.80 9.28 7.78 8.00 7.26
8.04 7.95 6.19 8.30 7.74
PA
8.97 8.00 8.46 7.64 8.73
7.54 7.41 9.49 7.83 9.66
8.22 7.93 8.15 7.62 8.95
8.70 7.63 8.81 8.43 7.87
8.10 7.23 7.99 8.82 8.60
SC
11.61 11.63 9.79 9.67 10.30
12.84 14.20 10.43 10.28 13.27
9.11 10.02 9.79 10.67 11.14
10.53 9.07 9.12 11.04 10.74
10.14 9.50 9.79 9.69 9.65
N

Appendix C-3. Bubble map of pH for individual plots of old-field (OF), pasture (PA), and wetland scar (SC) sites at Mill Creek mitigation area in Wayne County, West Virginia. Bubbles are arranged according to Figure 3. Bubble area is proportional to recorded values, which are presented next to each bubble.

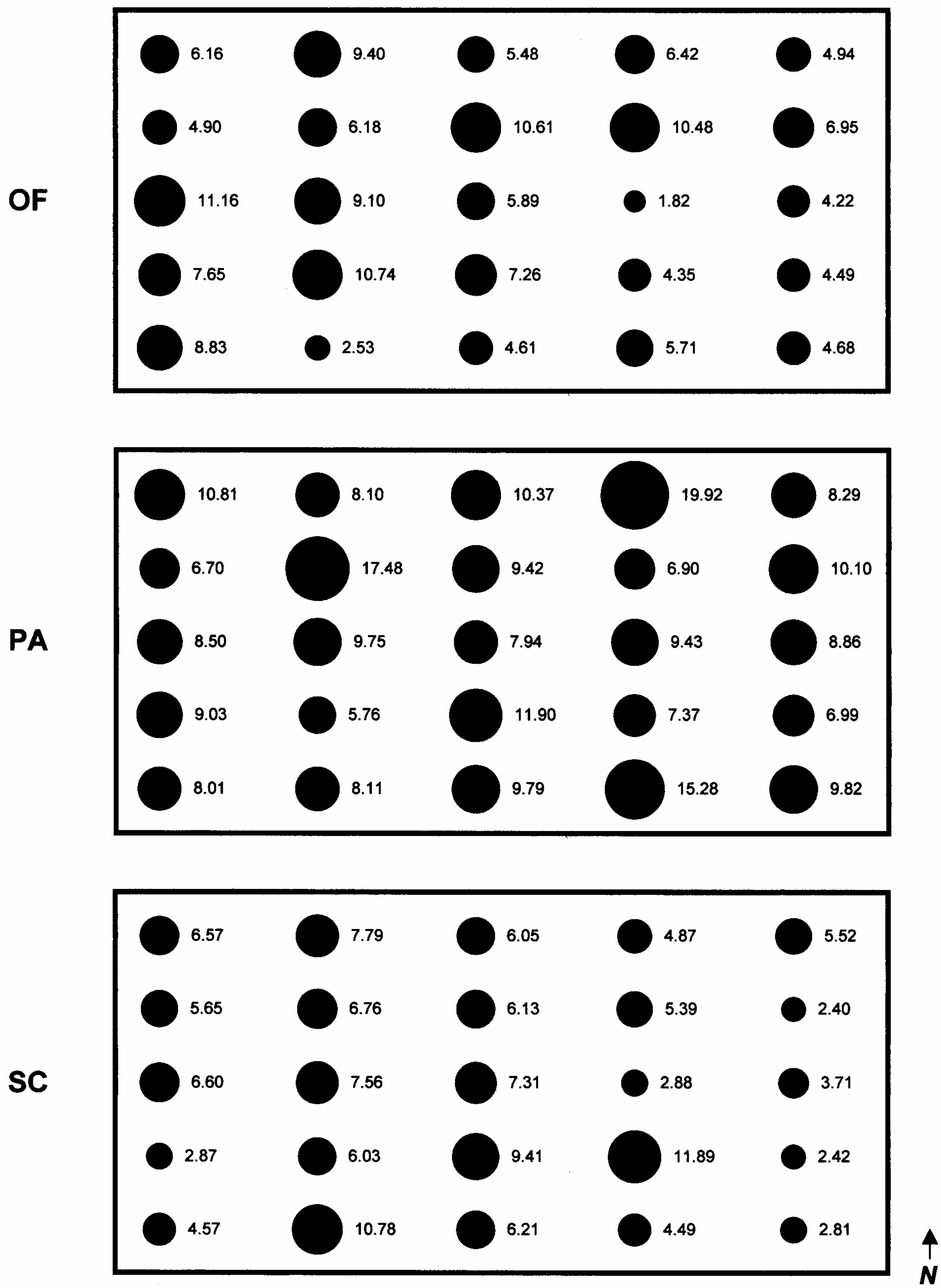


OF
4.50
4.46
4.73
4.62
4.62
4.38
4.61
4.56
4.67
4.75
4.41
4.42
4.63
4.47
4.67
4.40
4.92
4.65
4.46
4.47
4.51
4.66
4.39
4.48
4.60
PA
4.30
4.31
4.40
4.51
4.38
4.28
4.27
4.34
4.36
4.39
4.31
4.35
4.30
4.31
4.48
4.35
4.31
4.30
4.40
4.35
4.39
4.40
5.19
5.28
4.39
SC
3.93
3.90
3.89
3.81
3.96
3.86
3.86
3.89
3.89
3.97
3.97
3.92
3.97
3.97
4.00
3.96
3.94
3.92
3.93
3.95
3.87
3.94
3.93
3.89
3.92
N

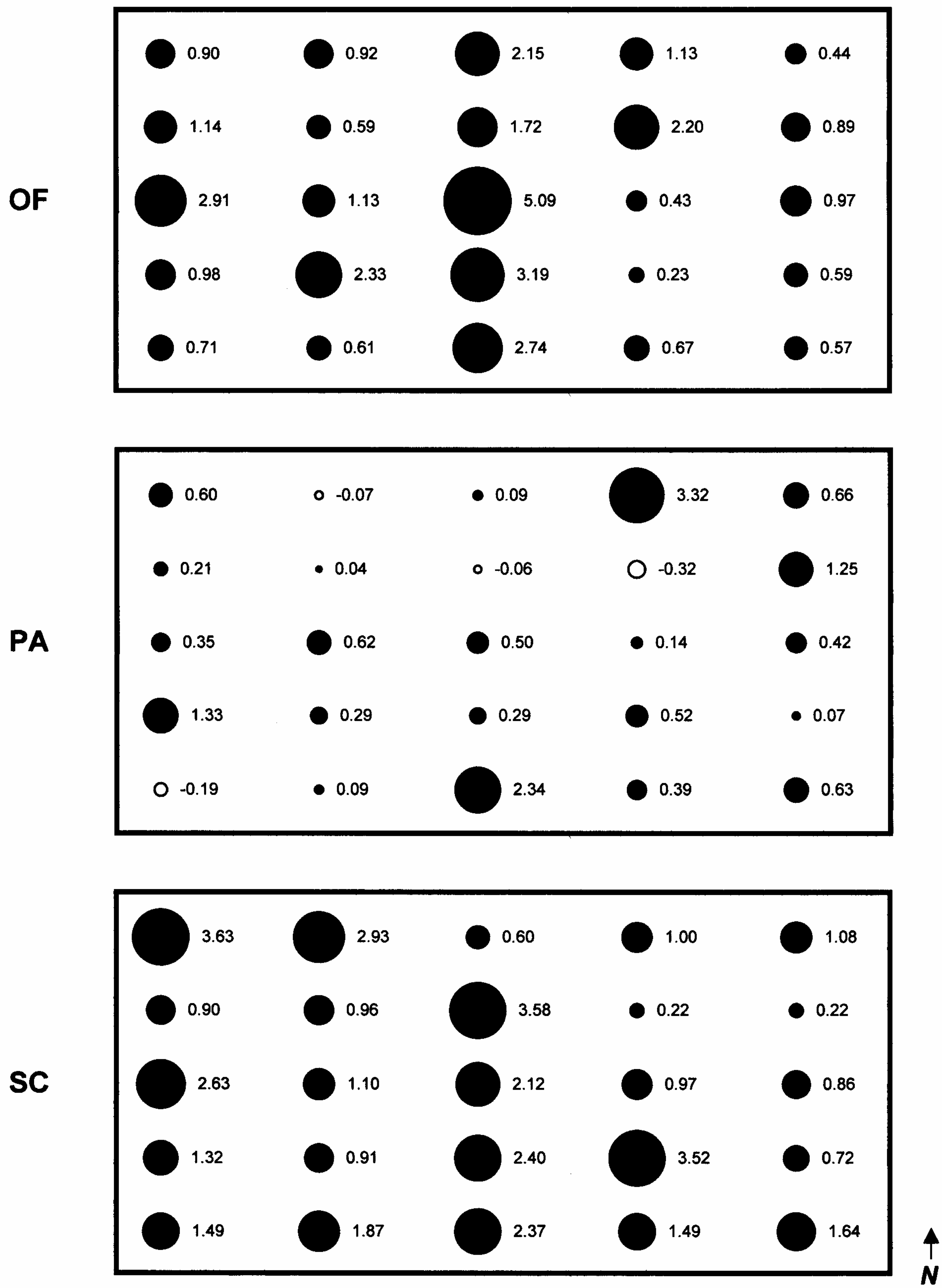
Appendix C-4. Bubble map of NH_4^+ pools (µg NH_4^+-N/g soil) for individual plots of old-field (OF), pasture (PA), and wetland scar (SC) sites at Mill Creek mitigation area in Wayne County, West Virginia. Bubbles are arranged according to Figure 3. Bubble area is proportional to recorded values, which are presented next to each bubble.


OF
7.87
9.15
6.95
4.98
7.67
6.36
8.06
21.73
7.86
3.35
3.96
2.65
8.44
5.09
5.31
5.84
11.30
9.86
11.92
4.37
13.57
8.73
21.04
9.79
5.82
PA
4.91
3.68
5.04
28.09
5.62
3.20
24.53
2.73
4.65
3.62
4.60
6.15
3.82
3.49
2.86
3.01
2.36
3.01
2.41
1.67
1.36
9.14
2.02
7.41
1.90
SC
18.57
5.09
2.59
2.57
13.18
2.38
3.01
12.11
2.41
1.80
20.07
2.78
24.07
2.60
2.88
1.44
7.24
19.83
41.11
1.71
4.17
25.06
4.83
2.90
1.82
N

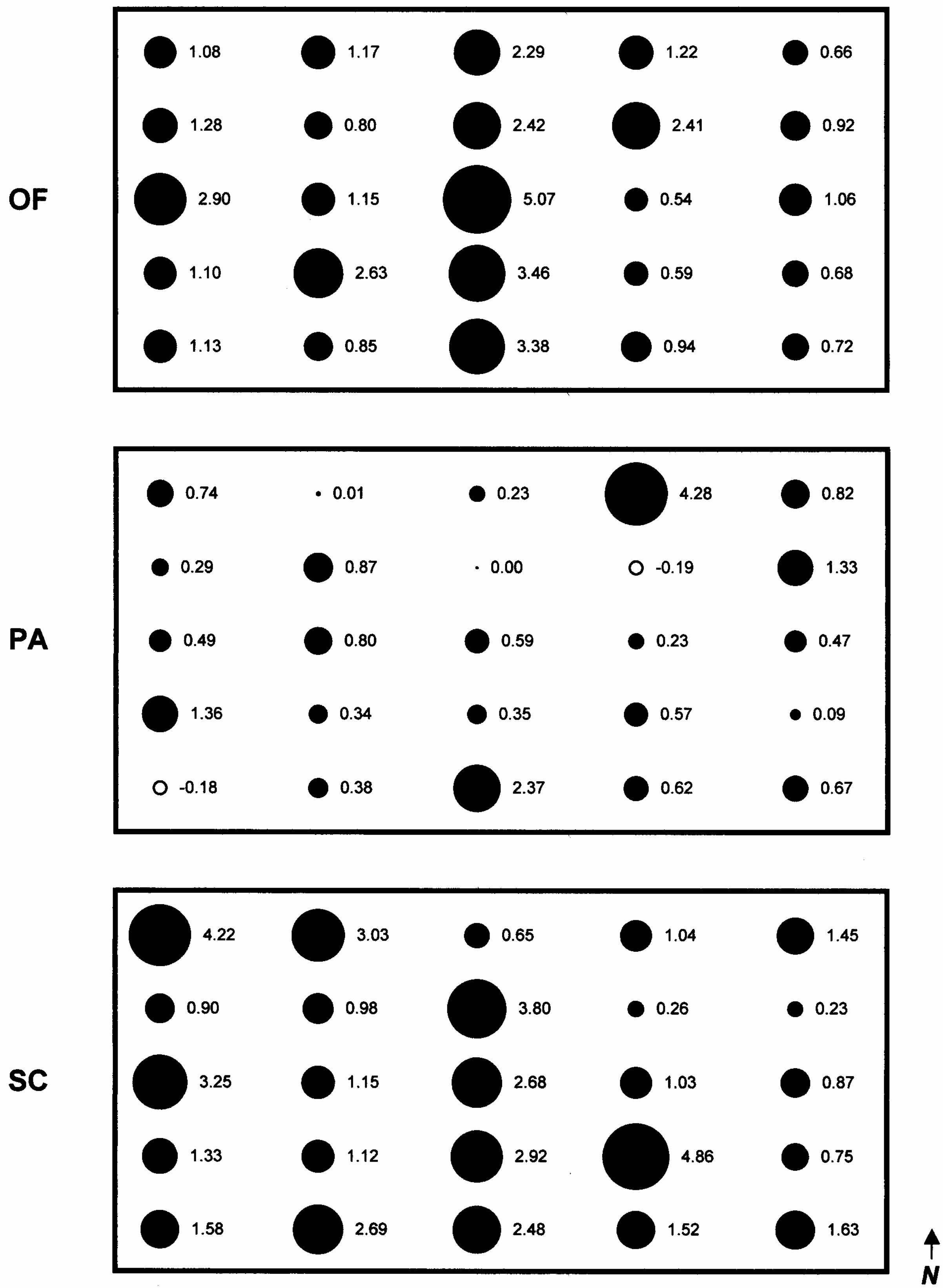
Appendix C-5. Bubble map of NO_3^- pools (µg NO_3^--N/g soil) for individual plots of old-field (OF), pasture (PA), and wetland scar (SC) sites at Mill Creek mitigation area in Wayne County, West Virginia. Bubbles are arranged according to Figure 3. Bubble area is proportional to recorded values, which are presented next to each bubble.


OF
6.16
9.40
5.48
6.42
4.94
4.90
6.18
10.61
10.48
6.95
11.16
9.10
5.89
1.82
4.22
7.65
10.74
7.26
4.35
4.49
8.83
2.53
4.61
5.71
4.68
PA
10.81
8.10
10.37
19.92
8.29
6.70
17.48
9.42
6.90
10.10
8.50
9.75
7.94
9.43
8.86
9.03
5.76
11.90
7.37
6.99
8.01
8.11
9.79
15.28
9.82
SC
6.57
7.79
6.05
4.87
5.52
5.65
6.76
6.13
5.39
2.40
6.60
7.56
7.31
2.88
3.71
2.87
6.03
9.41
11.89
2.42
4.57
10.78
6.21
4.49
2.81
N

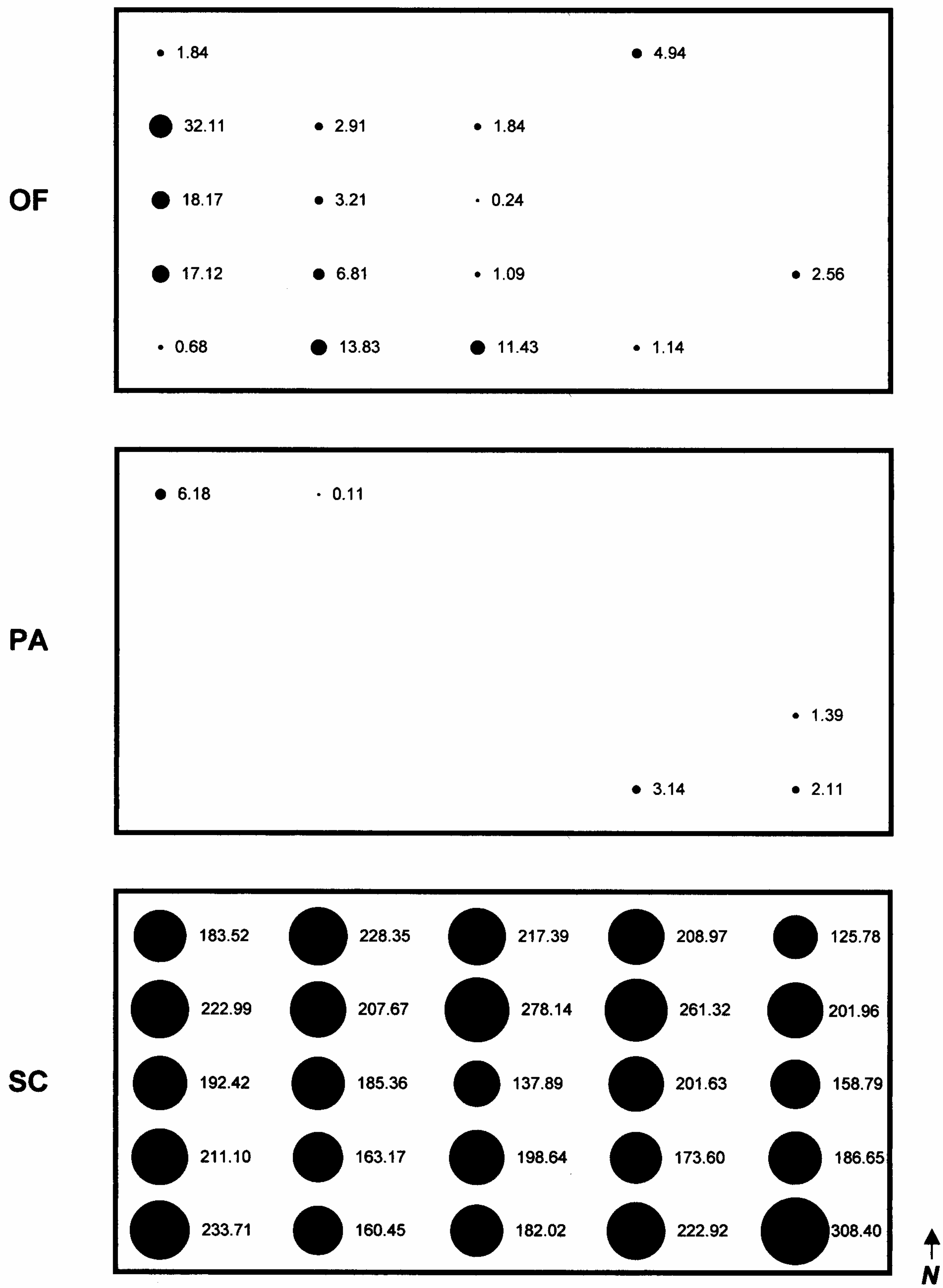
Appendix C-6. Bubble map of net N-mineralization rate (µg N/g soil/d) for individual plots of old-field (OF), pasture (PA), and wetland scar (SC) sites at Mill Creek mitigation area in Wayne County, West Virginia. Bubbles are arranged according to Figure 3. Bubble area is proportional to recorded values, which are presented next to each bubble.


OF
0.90 0.92 2.15 1.13 0.44
1.14 0.59 1.72 2.20 0.89
2.91 1.13 5.09 0.43 0.97
0.98 2.33 3.19 0.23 0.59
0.71 0.61 2.74 0.67 0.57
PA
0.60 -0.07 0.09 3.32 0.66
0.21 0.04 -0.06 -0.32 1.25
0.35 0.62 0.50 0.14 0.42
1.33 0.29 0.29 0.52 0.07
-0.19 0.09 2.34 0.39 0.63
SC
3.63 2.93 0.60 1.00 1.08
0.90 0.96 3.58 0.22 0.22
2.63 1.10 2.12 0.97 0.86
1.32 0.91 2.40 3.52 0.72
1.49 1.87 2.37 1.49 1.64
N

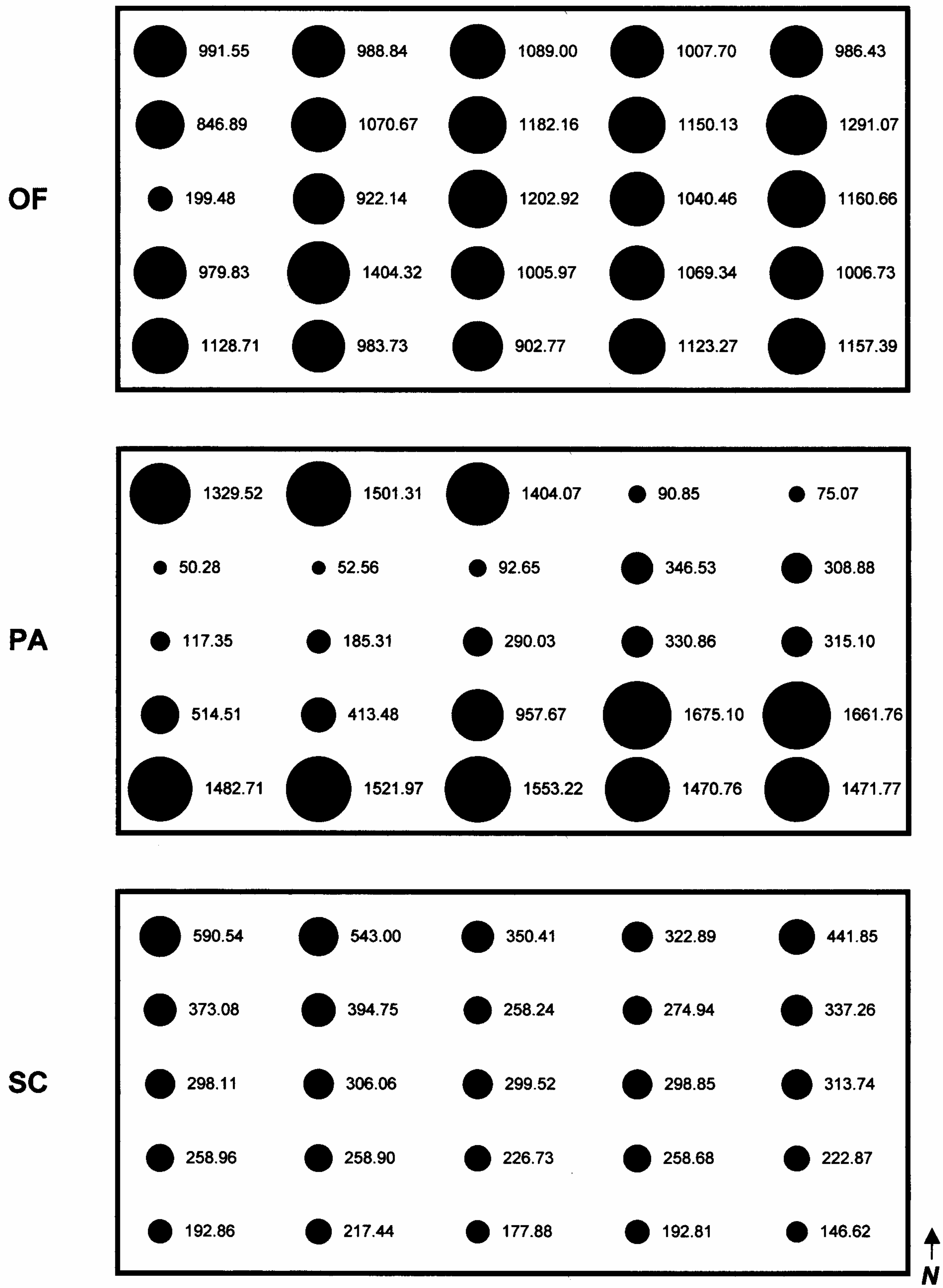
Appendix C-7. Bubble map of net nitrification rate (µg NO_3^--N/g soil/d) for individual plots of old-field (OF), pasture (PA), and wetland scar (SC) sites at Mill Creek mitigation area in Wayne County, West Virginia. Bubbles are arranged according to Figure 3. Bubble area is proportional to recorded values, which are presented next to each bubble.


OF
1.08
1.17
2.29
1.22
0.66
1.28
0.80
2.42
2.41
0.92
2.90
1.15
5.07
0.54
1.06
1.10
2.63
3.46
0.59
0.68
1.13
0.85
3.38
0.94
0.72
PA
0.74
0.01
0.23
4.28
0.82
0.29
0.87
0.00
-0.19
1.33
0.49
0.80
0.59
0.23
0.47
1.36
0.34
0.35
0.57
0.09
-0.18
0.38
2.37
0.62
0.67
SC
4.22
3.03
0.65
1.04
1.45
0.90
0.98
3.80
0.26
0.23
3.25
1.15
2.68
1.03
0.87
1.33
1.12
2.92
4.86
0.75
1.58
2.69
2.48
1.52
1.63
N

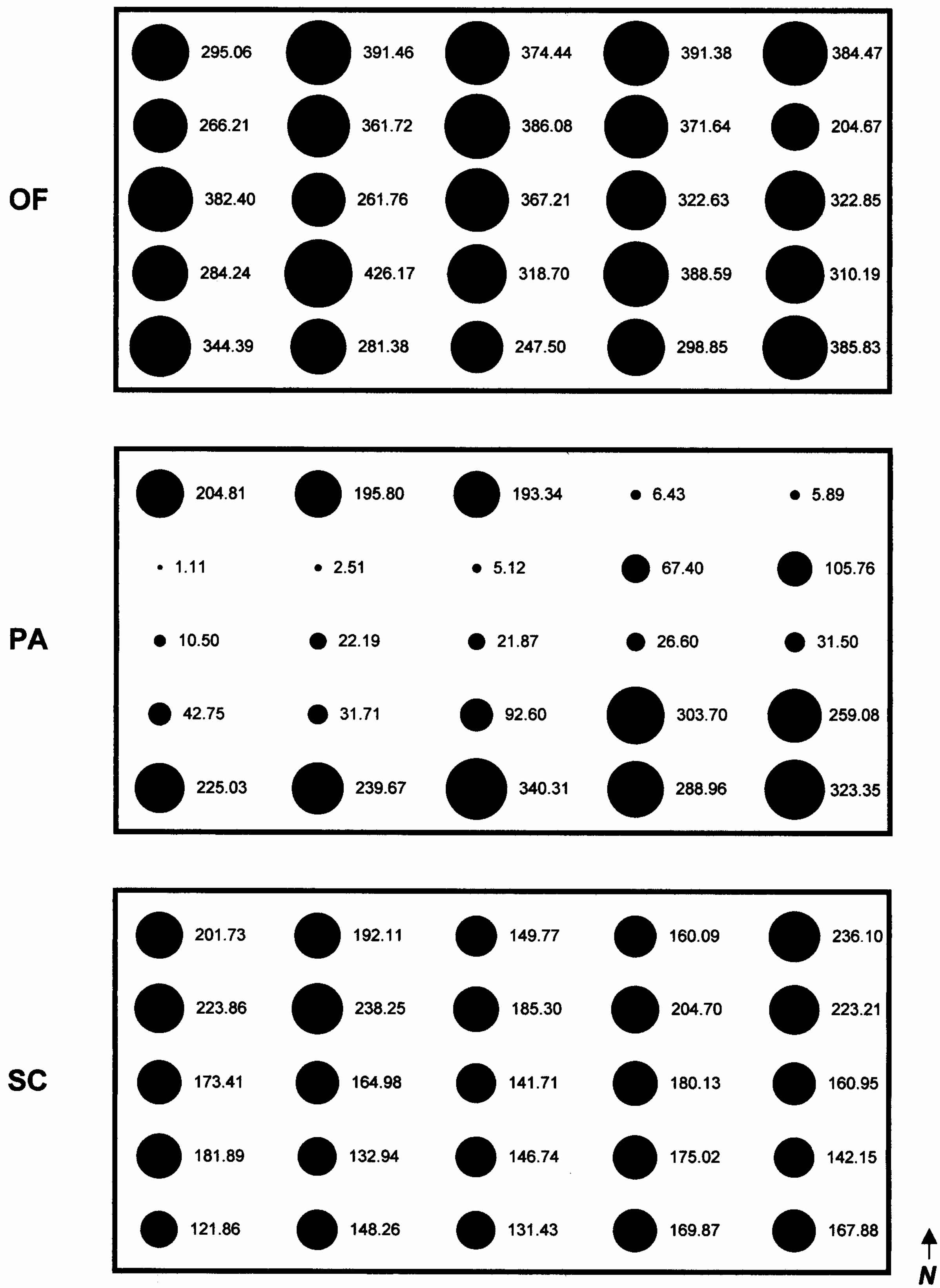
Appendix C-8. Bubble map of Al^{3+} (µg Al^{3+}/g soil) for individual plots of old-field (OF), pasture (PA), and wetland scar (SC) sites at Mill Creek mitigation area in Wayne County, West Virginia. Bubbles are arranged according to Figure 3. Bubble area is proportional to recorded values, which are presented next to each bubble.


OF
1.84
4.94
32.11
2.91
1.84
18.17
3.21
0.24
17.12
6.81
1.09
2.56
0.68
13.83
11.43
1.14
PA
6.18
0.11
1.39
3.14
2.11
SC
183.52
228.35
217.39
208.97
125.78
222.99
207.67
278.14
261.32
201.96
192.42
185.36
137.89
201.63
158.79
211.10
163.17
198.64
173.60
186.65
233.71
160.45
182.02
222.92
308.40
N

Appendix C-9. Bubble map of Ca^{2+} (μg Ca^{2+}/g soil) for individual plots of old-field (OF), pasture (PA), and wetland scar (SC) sites at Mill Creek mitigation area in Wayne County, West Virginia. Bubbles are arranged according to Figure 3. Bubble area is proportional to recorded values, which are presented next to each bubble.


OF
991.55
988.84
1089.00
1007.70
986.43
846.89
1070.67
1182.16
1150.13
1291.07
199.48
922.14
1202.92
1040.46
1160.66
979.83
1404.32
1005.97
1069.34
1006.73
1128.71
983.73
902.77
1123.27
1157.39
PA
1329.52
1501.31
1404.07
90.85
75.07
50.28
52.56
92.65
346.53
308.88
117.35
185.31
290.03
330.86
315.10
514.51
413.48
957.67
1675.10
1661.76
1482.71
1521.97
1553.22
1470.76
1471.77
SC
590.54
543.00
350.41
322.89
441.85
373.08
394.75
258.24
274.94
337.26
298.11
306.06
299.52
298.85
313.74
258.96
258.90
226.73
258.68
222.87
192.86
217.44
177.88
192.81
146.62
N

Appendix C-10. Bubble map of Mg^{2+} (µg Mg^{2+}/g soil) for individual plots of old-field (OF), pasture (PA), and wetland scar (SC) sites at Mill Creek mitigation area in Wayne County, West Virginia. Bubbles are arranged according to Figure 3. Bubble area is proportional to recorded values, which are presented next to each bubble.


OF
295.06
391.46
374.44
391.38
384.47
266.21
361.72
386.08
371.64
204.67
382.40
261.76
367.21
322.63
322.85
284.24
426.17
318.70
388.59
310.19
344.39
281.38
247.50
298.85
385.83
PA
204.81
195.80
193.34
6.43
5.89
1.11
2.51
5.12
67.40
105.76
10.50
22.19
21.87
26.60
31.50
42.75
31.71
92.60
303.70
259.08
225.03
239.67
340.31
288.96
323.35
SC
201.73
192.11
149.77
160.09
236.10
223.86
238.25
185.30
204.70
223.21
173.41
164.98
141.71
180.13
160.95
181.89
132.94
146.74
175.02
142.15
121.86
148.26
131.43
169.87
167.88
N

Appendix D-1. Picture of old-field site.

Appendix D-2. Picture of wetland scar (left) and pasture (right).

Appendix D-3. Picture of wetland site after heavy rainfall (flooded).

David Allen Dick

Education

Marshall University — *August 2003*
Huntington, WV
M.S., Biology

- Currently have 4.00 GPA

Marshall University — *Dec. 2000*
Huntington, WV
B.S., Environmental Biology

- Magna Cum Laude (3.73 GPA)
- Minors in Chemistry and Economics

Marshall University — *1998*
Huntington, WV
Summer Technology Institute

- Gained an in-depth understanding of Microsoft Office Suite
- Studied basic principles of the university's computer network

The Recording Workshop — *1995*
Chillicothe, OH
Audio Production and Studio Maintenance Programs

- Top 10% of class
- Letter of recommendation

Research

Spatial variability of soil processes in a stream floodplain of western West Virginia (in progress). Presented preliminary findings at 63rd Annual Meeting of the Association of Southeastern Biologists (ASB) and 12th Annual Sigma Xi Research Day at Marshall University. Copies of preliminary report available upon request.

Effects of temperature and salvage operations on available soil nitrogen in wind-disturbed sites in Pennsylvania (1999). Presented findings to members of the biology faculty at Marshall University. Copies available upon request.

Awards received

Marshall University Competitive Academic Scholarship during the 1999-2000 and 2000-01 academic years

West Virginia Engineering, Science, and Technology Scholarship for the 2000-01 academic year

Marshall University Dean's List 1997-2000

Work experience

West Virginia Department of Agriculture *May 2003 – Present*
Charleston, WV
Agricultural Weed Specialist

- Conduct surveys for invasive and non-native plants
- Identify pest plants submitted to the pest identification laboratory
- Train and supervise field scouts conducting weed surveys

Marshall University *Sept. 2002 – May 2003*
Huntington, WV
Graduate Teaching Assistant

- Introduced laboratory assignments, equipment, and techniques
- Maintained grading records
- Facilitated discussions

Timbral Pet Services *Jan. 2002 – Present*
Barboursville, WV
Obedience Trainer

- Teach basic through advanced combined obedience class
- Assist in examinations for conformation class

Marshall University *Sept. 2001 – May 2002*
Huntington, WV
Graduate Research Assistant (1-yr grant)

- Designed ecological study of old-field vegetation and soils
- Collected and identified/analyzed plant specimens and soil samples
- Analyzed data and prepared progress reports

SITEL Corporation *Jan. 2001 – March 2001*
Huntington, WV
Telephone Sales Representative

- Called credit card holders to inform about new products
- Verified and processed sales

NeighborCare Pharmacy *May 2000 – July 2000*
Huntington, WV
Delivery Driver

- Delivered prescriptions to long-term care facilities throughout the state
- Checked prescriptions for accuracy before delivery

Marshall University Welcome Center *May 1999 – Aug. 1999*
Huntington, WV
Tour Guide

- Guided campus tours for prospective students and their families
- Processed mail requests and internet applications

Marshall University Student Support Services *Oct. 1998 – April 1999*
Huntington, WV
Tutor

- Helped students primarily with Biology, Chemistry, and Trigonometry
- Contacted students and scheduled meeting times

TRAX DPS Recording Studio *Nov. 1997 – June 1998*
Milton, WV
Audio Engineer

- Recorded, mixed, and mastered projects for a variety of artists
- Scheduled sessions and collected payments for services
- Maintained equipment and studio organization

Kinko's Copy Center *Sept. 1995 – Dec. 1997*
Huntington, WV
Customer Service Representative

- Copied customer documents and scheduled orders
- Answered phones and assisted customers with project questions
- Designed documents using a variety of graphics and text software

Digital Recording Studio *Sept. 1996 – June 1997*
Huntington, WV
Audio Engineer

- Recorded, mixed, and mastered projects for a variety of artists
- Scheduled sessions and collected payments for services
- Installed and maintained audio equipment

Hobbies and Special Interests

Tri-State SHEd (Siberian Husky Education) Club *April 2001 – January 2003*
Huntington, WV
Treasurer

- Club founder
- Event planner

Tom Shanteau and Allegheny *April 1999 – May 2001*
Huntington, WV
Bass Player/Web Designer

- Performed at various functions including benefit shows, contests, and parties
- Designed and maintaining band web page

Shawn Christian and Headed West *March 1997 – Oct. 1998*
Huntington, WV
Bass Player

- Performed at various functions including benefit shows, contests, and parties