SOIL PROPERTIES IN NORTHERN VIRGINIA CREATED FORESTED WETLANDS

L. A. B. Giese[1] and C. T. Flannagan[2]

ABSTRACT

Created wetlands provide the opportunity to study the rate at which wetland functions develop and replace those of impacted wetlands. Quantification of soil organic matter (SOM) accumulation in Northern Virginia created wetlands is not well documented. This study quantified and compared several soil properties (organic matter, total percent C, total percent N, C:N and pH) in the topsoil of eight created forested wetlands in Northern Virginia. The state of these wetlands range from recently planted, to having gone through four growing seasons. Soil was also collected from the site of a future wetland creation site, and from an existing mature forested wetland located adjacent to one of the created wetlands. SOM content, total percent C and total percent N and pH were comparable among the created wetlands that had undergone 2-4 growing seasons, with values that were less than the natural mature forested wetland. This indicates that these soil properties take longer than four growing seasons to be on a trajectory toward a mature forested wetland. However, the C:N ratio was similar in the mature forested wetland and the created wetlands that have undergone 2-4 growing seasons suggesting that a balance has been restored.

KEYWORDS: Carbon, Created Wetlands, Nitrogen, Soil Organic Matter, Virginia

INTRODUCTION

Wetlands are recognized as providing a variety of functions and values; one of which is their integral role in nutrient cycling. However, this role may differ between natural and created wetlands implying that created wetlands do not effectively replace lost wetland function. Created wetlands provide the opportunity to study the rate at which wetland functions develop and replace those of wetlands lost to development. Monitoring soil chemical properties in created wetlands provides data that can be used to evaluate the time required for the development of these soil properties, and to determine whether these wetlands are on a trajectory toward a mature forested wetland (Ponnamperuma, 1972; Vepraskas, 1992, Windham et al., 2004).

Dahl (1990) documented a 53% decrease in wetland area within the contiguous 48 states between 1780 and 1980. In Virginia, there has been a loss of 42% of the original wetland base Dahl (1990). Residential development and associated infrastructure are the largest factors affecting the loss of wetlands in northern Virginia.

Wetlands continue to be impacted in northern Virginia and the 'no net loss' policy requires suitable mitigation for wetland impacts. Wetland creation (which is one of the options to mitigate for wetland impacts) is employed to replace those wetlands lost to development. It is believed that the constructed wetlands will possess the functions of those they are intended to replace. However, in the case of created forested wetlands, the replacement of some functions may be delayed since the constructed wetlands generally start as an earlier stage of succession.

[1] Principal environmental scientist with Wetland Studies and Solutions, Inc., 5300 Wellington Branch Road, Suite 100, Gainesville, VA 20155

[2] Soil scientist with Wetland Studies and Solutions, Inc., 5300 Wellington Branch Road, Suite 100, Gainesville, VA 20155

One function of created wetlands that is believed to differ from natural wetlands is the role of soil organic matter (SOM) and carbon cycling. Shaffer and Ernst (1999) found that SOM levels were significantly lower in created emergent and open water wetlands than in similar naturally occurring wetlands after two samplings in an eight year period in the Portland, Oregon area. Cole et al. (2001) reported similar results between created and naturally occurring wetlands in central Pennsylvania. Bishel-Machung et al. (1996) reported no correlation between time since creation and organic matter accumulation in created wetlands of Pennsylvania; however, the authors did note a correlation between organic matter content and pH level.

The purpose of this research was to record the content of SOM in created forested wetlands in varying stages of maturity to distinguish at what age the organic matter component in the soil becomes comparable to a mature, natural forested wetland. These soils were also analyzed for nitrogen and pH in order to address C:N ratio changes through time, and to examine potential correlations between SOM and pH. This paper presents the first year of data collected from a long-term experiment.

SITE DESCRIPTION

Eight created forested wetlands, collectively referred to as the Cedar Run Mitigation Bank (CRMB), were selected for this study. These wetlands are located in Prince William County, Virginia with a section in Fauquier County (Figure 1) and range in age, based on growing season, between zero (just seeded and planted with woody species referred to as no growing seasons) and four growing seasons. All of the sites used to create the wetlands were originally non-wet pasture. A wetland seed mix of approximately 26 native herbaceous species, including several woody species, was broadcast over the site. These areas were subsequently planted with a mix of native wetland shrubs and trees on 6-8 foot centers, depending on the size of the

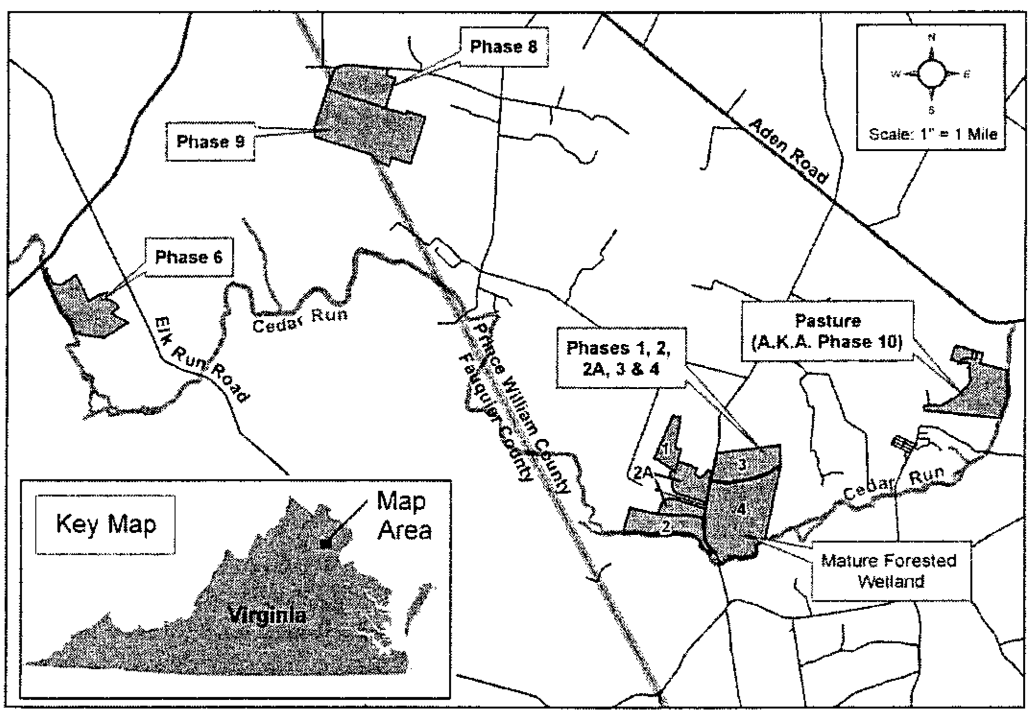

Figure 1. Map depicting the location of the created wetlands as part of the Cedar Run Mitigation Bank, non-wet pasture, and mature forested wetland in northern Virginia.

planting stock (tubelings, 1- or 3-gallon containers). Currently the plant composition within the CRMB is comprised primarily of a mix of herbaceous plants, with scattered tree and shrub seedlings and saplings. A mature forested natural wetland adjacent to one of the created wetlands and a pasture slated to become part of the CRMB were selected to serve as reference sites.

The soils within the created wetlands, natural forested wetland and the non-wet pasture are primarily alfisols with a few ultisols and inceptisols with properties ranging from poorly-drained to well-drained, and low to moderate organic matter content and fertility (Petro, 1956; Elder, 1989).

The hydrologic input to the created wetlands is primarily from precipitation, since these wetlands have a clay substrate which attenuates groundwater recharge. Occasional overbank flooding of streams associated with some of the created wetlands provides additional water input. The wetlands created in the CRMB emulate the majority of forested wetlands found in the Piedmont region of northern Virginia.

METHODS

Soil samples were randomly collected within the wetlands of the CRMB during the months of February and March 2005. Soil sample locations were similarly collected within the mature forested wetland, as well as in the pasture. Soil samples were collected to a depth of 20 cm and subsequently dried at 105°C. Dried samples were ground by hand to pass through a number 10 sieve (<2.00 mm) and submitted to the Virginia Polytechnic Institute Soil Testing Lab in Blacksburg, Virginia for analysis of soil organic matter (SOM), total percent carbon, and total percent nitrogen. SOM was measured by combustion at 950°C. Total percent carbon and nitrogen were measured on a Carlo-Erba CHN, via combustion. Soil pH was measured on a 2:1 paste using distilled water at Wetland Studies and Solutions, Inc. soil lab.

The created wetland sites, representing different stages of wetland maturity, served as treatments. Data from the SOM, and carbon and nitrogen were interpreted using analysis of variance (ANOVA) for a completely randomized design (SYSTAT, 2005). When treatment differences were detected, the Tukey multiple range test was used to test treatment mean differences. A significance level (α) of 0.05 was used for all tests.

Table 1. Means with standard deviations in parentheses for organic matter (%), total percent nitrogen, total percent carbon, the carbon to nitrogen ratio and pH in the soils of created wetlands having zero to four growing seasons, a non-wet pasture, and a mature natural forested wetland in northern Virginia. N equals the sample size. Between columns, values with similar parenthetical letters are not significantly different.

Soil Property	Pasture	Year 0	Year 2	Year 3	Year 4	Mature
	n = 27	n = 39	n = 60	n = 36	n = 30	n = 12
Organic Matter (%)	3.56 (a)	2.88 (a)	3.26 (a)	2.13 (a)	3.02 (a)	5.04 (b)
	(.99)	(0.46)	(.57)	(0.31)	(0.80)	(.35)
Total percent N (%)	0.17 (a)	0.10 (a)	0.14	0.08 (ab)	0.13 (a)	0.24 (ac)
	(0.06)	(0.04)	(ab)0.14	0.03	(0.05)	(0.08)
Total percent C (%)	1.75 (a)	1.32 (b)	1.50 (a)	0.94 (b)	1.44 (a)	2.63 (c)
	(0.60)	(0.48)	(1.0)	(0.33)	(0.48)	(0.92)
C:N	10.58 (a)	13.24 (b)	12.08 (c)	11.25 (ac)	10.94 (a)	11.03 (ac)
	(0.83)	(1.76)	(2.15)	(1.44)	(1.16)	(0.85)
pH	4.40 (a)	5.40 (b)	5.17 (b)	4.53 (a)	4.47 (a)	3.83 (c)
	(0.40)	(0.47)	(0.23)	(0.36)	(0.27)	(0.18)

RESULTS

The data from this first year of study presents several interesting findings about the soil properties of created wetlands in northern Virginia, especially when compared to the mature forested wetland (Table 1). The natural mature forested wetland is significantly different than the created wetlands in that it has a significantly higher percent SOM than the created wetlands, including the pasture (Table 1). The mature forested wetland also has significantly higher total percent nitrogen (Table 1) and total percent carbon (Table 1) than the created wetlands. However, total percent nitrogen was not significantly different between the mature forested wetland and the pasture. The pH level was significantly lower in the mature forested wetland compared to the created wetlands and the pasture (Table 1).

There were some significant differences between the age of the created wetlands and the SOM content, total percent carbon, total percent nitrogen and pH. SOM content was statistically lowest in samples from the wetlands that have undergone three growing seasons. The wetlands that experienced zero, two and four growing seasons had similar levels of SOM (Table 1). Soil total percent carbon is similar to the results for SOM, except that the wetland in its third growing season does not have significantly lower soil carbon than the wetland that is at year zero (Table 1).

In general total percent nitrogen was similar between the created wetlands and the pasture. Mean total percent nitrogen was significantly lower in the wetlands that have undergone three growing seasons compared to the pasture, and the wetland that has undergone two growing seasons (Table 1).

Mean pH results were significantly different following construction (year zero) and after two growing seasons compared to the pasture and slightly older created wetlands. The pH appears to increase from pasture to post-construction and then decreases post-construction through each growing season thereafter (Table 1). These results suggest an initial increase in soil pH followed by a decline as levels approach those of existing wetlands. There is no direct correlation between soil pH and other soil parameters measured in this study.

The C:N ratio increases from pasture to post-construction (year zero) and steadily decreases through the next four growing seasons (Table 1), with the pasture C:N ratio being significantly less than the C:N ratio at year zero and after two growing seasons. In contrast, the created wetlands that had two, three and four growing seasons were not significantly different than the mature forested wetland. The C:N ratio of wetlands with two growing seasons was significantly greater than in the wetlands with four growing seasons. The C:N ratio was not significantly different between the pasture and the natural mature forested wetland.

Discussion

The results of this study show that SOM, total percent carbon, and total percent nitrogen were significantly higher in the reference mature forested wetland than in the created wetlands within the CRMB. No significant increase was noted in the SOM content over time between the created wetlands and the pasture soils. This is similar to the study by Bishel-Machung et al. (1996) who reported no net increase in SOM accumulation with age in created wetlands.

The results showed similar SOM content for those created wetlands that had undergone two, three, and four growing seasons. However, SOM accumulation is a slow process (Paul and Clark, 1989) which may not be detected over a four year period. Windham et al. (2004) suggested that it may take 25-plus years for a restored site to reach reference conditions for SOM. The difference in plant community structure (forbs vs. trees) may affect SOM supply and associated decomposition rate (Lovett et al., 2004; Wang and McSorley, 2005). Because SOM accumulation is time-dependent, further monitoring of these wetlands is needed to determine whether time correlated trends will eventually develop.

Increased organic matter content in wetland soils, compared to more aerobic soils, is attributed to increased soil water content, which slows microbial degradation of organic matter. Furthermore, the increased organic matter content in wetland soils is indicative of anaerobic conditions since degradation of organic matter by anaerobic microbes is slower than that of aerobic microbes (Ponnamperuma, 1972). The low amount of SOM in these created wetlands, compared to the mature forested wetland, can not be attributed to lack of wetland hydrology since these mitigation sites have successfully met this success criterion (data not included).

Plant growth and subsequent annual senescence of organic matter contribute to the process of organic matter accumulation. Biological decomposition of plants is a significant source of nutrients. Tree species composition can cause different rates of litter decomposition and C and N storage in soils (Lovett et al., 2002), and vegetation cover influences both the amount and quality (C:N ratio) of SOM (Snowdon et al., 2005). Because the hydrophytic vegetation planted in the CRMB wetlands is the same for each phase, a species effect may not be a factor. Although variations in dominant species have been noted in different years (data not included), it does not appear to have a significant effect on the C:N ratio since the C:N ratio is similar to the mature forested wetland after four growing seasons.

In undisturbed ecosystems, there is a balance between the amount of carbon entering and leaving. Disturbance creates drastic changes in the soil environment causing shifts in microbial populations, which affect the nutrient cycle, and reduce SOM and nitrogen by 25 percent to 60 percent (Filimonova, 1997). A C:N ratio of 24:1 is considered an ideal balance for soils, and at higher ratios, nitrogen becomes limiting. Without adequate nitrogen, microbial organisms lack the tools necessary to break down carbon sources and the process is slowed. As decomposition of plant material proceeds after land disturbance, the C:N ratio will begin to approach that of SOM (~10 or 12: 1) (Dinnes et al., 2005). When SOM content is increasing in the soil, C increases and nitrogen is immobilized. After the SOM level comes to a new equilibrium, nitrogen processes become more balanced. The change (increase) in the C:N ratio at year zero signals a disruption in the balance and it appears to take two to three growing seasons to recover the C:N balance.

Saturated anaerobic conditions can result in very high C:N ratios, which would cause an imbalance in nutrient cycling. High C:N ratios, typical of more permanent hydrology, were not observed in the created wetlands. Hydrology in the created wetlands is generally seasonal, which replicates the hydroperiod of typical northern Virginia forested wetlands, thus we observed moderate C:N ratio levels.

The correlation between pH levels and percent organic matter within the created wetlands was not high (r^2 values were only 0.52). We did however identify a weak pattern in the data (Table 1). The mature forested wetland had both the highest mean percent organic matter and the lowest mean pH, which agrees with the data reported by Bishel- Machung et al. (1996). Although SOM degrades at a slower rate within wetlands than uplands, the significantly higher quantity of organic matter in the mature forested wetland is most likely influencing the low pH of these soils. As organic matter undergoes decomposition by detritivores, carboxyl groups associated with organic matter break down, releasing hydrogen ions into the soil which lower the pH (McBride, 1994; Sparks, 1995). Thus it stands to reason that wetland soils with higher organic matter content will have lower pH levels. However, there is no direct correlation between the results of the pH and those of the other soil parameters measured in this study, thus it is difficult to discern whether or not the pH pattern is age related.

CONCLUSIONS

Created wetlands provide the opportunity to study the rate at which wetland functions develop and replace those of disturbed wetlands. Determining whether these soil properties, and their associated wetland functions are on a trajectory toward a mature forested wetland appears to take longer than four growing seasons in a created wetland. However, the C:N balance, a critical component to nutrient cycling, appears to be restored after only three growing seasons. Future study of these created wetlands will hopefully uncover the nuances of the soil properties and develop a metric to assess whether created wetlands truly provide the functions of natural wetlands.

Acknowledgements

The authors would like to thank those people who helped with this project. Many of the staff at Wetlands Studies and Solutions played an important role in seeing this project to completion. Most notably, we would like to thank Michael Rolband for this opportunity and for funding this project. The authors gratefully acknowledge Christine Geist and Robert Wright for their assistance in the field, and Sarah Townsend for the GIS generated images.

REFERENCES

1. Bishel-Machung, L., R.P. Brooks, S.S. Yates, and K.L. Hoover. 1996. Soil properties of reference wetlands and wetland creation projects in Pennsylvania. *Wetlands* 16(4):532-541.

2. Cole, C.A., R.P. Brooks, and D.H. Wardrop. 2001. Assessing the relationship between biomass and SOM in created wetlands of central Pennsylvania, USA. *Ecological Engineering* 17:423-428.

3. Dahl, T.E. 1990. Wetlands: losses in the United States 1780's to 1980's. United States Department of the Interior, Fish and Wildlife Service. Washington, DC, USA.

4. Dinnes, D., D. Jaynes, T. Kaspar, T. Colvin, C.A. Cambardella and D. L. Karlen 10/10/2005. Plant-soil-microbe N relationships in high residue management systems. USDA-ARS National Soil Tilth Laboratory. http://www.nstl.gov/pubs/dinnes/plant_soil_microbe_N1.htm.

5. Elder,J.H. 1989. *Soil Survey of Prince William County, Virginia.* United States Department of Agriculture, Soil Conservation Service. Washington, DC.

6. Filimonova, M. 1977. Microbiological activity in native soils. Adapted from the Missouri Prairie Journal and published on the Internet by the Kerr Center for Sustainable Agriculture. Vol. 23, No. 4 http://www.pmac.net/mariaf.htm.

7. Lovett, G. M., K.C. Weathers, M.A. Arthur. 2002. Control of nitrogen loss from forested watersheds by soil carbon:nitrogen ration and tree species composition. *Ecosystems* 5: 712-718.

8. McBride, M.B. 1994. *Environmental Chemistry of Soils.* New York, NY. Oxford University Press.

9. Paul, E.A., and F.E. Clark. 1989. *Soil Microbiology and Biochemistry.* San Diego, CA, USA. Academic Press, Inc.

10. Petro, J.H. 1956. *Soil Survey of Fauquier County, Virginia.* United States Department of Agriculture, Soil Conservation Service. Washington, DC.

11. Ponnamperuma, F.N. 1972. The Chemistry of submerged soils. *Advances in Agronomy* 24:29-96.

12. Shaffer, P. W., and T.L. Ernst. 1999. Distribution of SOM in freshwater emergent/open water wetlands in the Portland, Oregon metropolitan area. *Wetlands* 19(3):505-516.

13. Snowdon, P., P. Ryan and J. Raison. 2005. Review of C:N ratios in vegetation, litter and soil under Australian native forests and plantations. National Carbon Accounting System Technical Report No.45. 60 pp.

14. *SYSTAT*. 2004. Systat 11 Data. Richmond, CA. Systat Software, Inc.

15. Sparks, D.L. 1995. *Environmental Soil Chemistry*. San Diego, CA, USA. Academic Press, Inc.

16. Vepraskas, M.J. 1992. Redoximorphic features for identifying aquic conditions. North Carolina Agricultural Research Service Technical Bulletin 301. North Carolina State University, Raleigh, NC.

17. Wang, Koon-Hui and Robert McSorley. 2005. Effects of soil ecosystem management on nematode pests, nutrient cycling, and plant health. *APSnet*. http://www.aspnet.org/online/feature/nematode.

18. Windham, L. M.S. Laska, J. Wollenberg. 2004. History, ecology, and restoration of a degraded urban wetland – evaluating urban wetland restorations: case studies for assessing connectivity and function. *Urban Habitats* Vol. 2, No. 1.