The effect of riparian buffers with controlled drainage on soil redox potential

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Abstract
Deteriorating surface water quality due, in part, to nitrogen from nonpoint sources has fueled much interest in solutions to these problems. To meet North Carolina mandates of reducing nitrogen loads in selected rivers by 30% over a five-year period, scientists proposed guidelines to meet this goal. Riparian buffers and controlled drainage are two Best Management Practices (BMPs) than have been shown to reduce the amount of nitrogen entering surface and subsurface waters as a result of denitrification, but they are not always effective or practical on all landscapes. A project to study the effect of using riparian buffers in conjunction with controlled drainage was initiated. Soil redox potential is an indicator that provides evidence as to whether or not conditions are favorable for denitrification. Four riparian buffers at widths of 7.6 or 15.2 m, with five vegetative treatments (fescue, switch grass, pine trees, field crop, and native vegetation), were established. Groundwater monitoring wells, at three depths, were installed at the edge of the ditch, the field edge, and in the field in each treatment. A water control structure was installed at the mouth of one of the ditches. A total of 176 redox electrodes were inserted to 76 cm or 152 cm at the ditch and field edges of the riparian buffers. By raising the water table with controlled drainage, conditions favoring denitrification were enhanced. Results from this one-year study show that buffers with controlled drainage at a depth of 152 cm had low redox values favorable for denitrification and subsequently lower nitrate concentrations in the groundwater as compared to areas with buffers, but no control.

Key Words
Redox, nitrate, riparian buffer, controlled drainage, water quality.

Introduction
Riparian buffers form an important transition zone between upland landscape positions and lower-lying bodies of water. This transition zone usually has soils that are somewhat poorly to very poorly drained. Riparian buffers are significant because of their recognized role in regulating the movement of pollutants, such as nitrogen, sediment, and phosphorus from upland surface and/or subsurface groundwater (Hill 1996).

Riparian Buffers
Research has consistently shown the effectiveness of riparian zones in nitrate removal. In the Middle Coastal Plain of North Carolina, Jacobs and Gilliam (1985) used chloride (Cl^-), a conservative ion, to trace the path of N leaving a cultivated field, which was located next to a riparian zone, via subsurface drainage. Chloride is not subject to gaseous losses or used in great quantities by plants. Decreases in nitrate/chloride ratios over space or time may indicate losses of nitrate possibly due to denitrification, while no change in this ratio may indicate dilution by water that contains less nitrate and chloride. This study showed decreases in nitrate/chloride ratios from the field edge and stream. The major loss of nitrate was attributed to denitrification, while a small portion of the nitrate was lost through uptake by riparian vegetation. The most important factor controlling the ability of riparian buffers to reduce nitrogen is hydrology (Gilliam *et al.* 1997). Nitrate is very mobile and is easily leached through the soil profile. Nitrate generally enters surface waters through subsurface flow. Much of the research on riparian buffers has been on similar geophysical regions in the Mid-Atlantic States and in the Southeast. Generally, soils in these areas have a restrictive layer within the profile that forces groundwater to flow laterally, rather than downward. Consequently, nitrate in groundwater enters surface water via this route. The interaction of this laterally flowing groundwater and the riparian buffer is extremely critical. Denitrifying microorganisms require an energy source, such as carbon, for this nitrogen transformation to occur. Riparian vegetation provides the denitrifying microorganisms a source of carbon, which becomes available from plant or root decomposition. Groundwater that flows too deep in the soil profile may bypass the strategic zones where riparian soils and vegetation exist, thus eliminating the possibility of the occurrence of denitrification. Researchers agree that

there is a complex interaction between hydrology, vegetation, and soil processes with regard to denitrification.

Controlled Drainage

In Eastern North Carolina, over 2,000,000 acres of cropland are grown on soils that are poorly drained (Evans *et al.* 1991). Consequently, drainage is a critical component to successful crop production in Eastern North Carolina. Much of this acreage is located near sensitive lakes, estuaries, and streams. Pollutants, such as nitrogen, phosphorus, and sediment are easily transported into these bodies of water through surface or subsurface flow. Water table management, specifically controlled drainage, has been shown to improve water quality and improve crop production (Thomas *et al.* 1992; Thompson *et al.* 1998). Controlled drainage consists of installing a structure, such as a flashboard riser, in a drainage outlet. As boards are added to the riser, the water level rises in the drainage ditch, and subsequently, in the adjacent fields. Boards can also be removed during wet periods to encourage more rapid drainage, which improves trafficability in agricultural fields. However, controlled drainage is most effective when the topography is nearly level. With regard to water quality, controlled drainage reduces the amount of N through reduced flow and higher denitrification rates due to favorable conditions provided by a higher water table. Compared to conventional drainage, controlled drainage has been shown to reduce total outflow by up to 30% during some periods, but may vary based on the amount of rainfall, soil type, drainage system, management intensity, and season (Evans *et al.* 1995).

Redox Potential

Redox potential is one of the most important electrochemical properties that distinguish a well-drained soil from soils in wetter drainage classes. A high redox potential indicates aerobic soil conditions, while a lower redox potential reflects a more reduced state. It is commonly accepted that a redox potential value of 350 mV is the critical level for denitrification. Monitoring the state of reduction of a soil provides evidence as to whether or not conditions are favorable for biological reductions, such as denitrification. Denitrification is important because it efficiently removes nitrate from a soil system. Nitrate is very mobile and easily leaches into groundwater, which can potentially lead to human health hazards and environmental problems. Measuring redox potential in situ to determine the oxidation or reduction status of the soil, is one of the parameters that researchers are using to further substantiate the conditions at which nitrate disappears. Griffith *et al.* (1997) studied the loss of nitrate from groundwater as it moved from a cultivated field through a riparian buffer. Soil redox potentials measured at a depth of 25 cm and 45 cm in the riparian buffer (soil pH ranged from 4.9 to 5.5) averaged -200 mV to –100 mV which are clearly low enough for denitrification. All sampling dates showed that nitrate concentrations were higher in the field compared to nearly undetectable levels in the riparian buffer. Their data collectively attributed to riparian processes as one of the mechanisms through which nitrate was removed. The reducing status of the soil in the riparian forest is further evidence of nitrate losses that can be attributed to denitrification. Researchers in North Carolina studying the effects of controlled drainage on nitrate losses showed that in moderately well drained soils, Eh values were well above the critical value of 325 mV for denitrification. High nitrate concentrations at this location confirmed this. While there appeared to be no differences resulting from drainage control in poorly drained soils, low nitrate concentrations associated with low Eh values below 1.0 m in the soil profile were most likely a result of denitrification (Gilliam *et al.* 1979). Similar research by Jacobs and Gilliam (1985) and Gambrell *et al.* (1975) related nitrate losses, decreases in nitrate/chloride ratios, and low Eh values to denitrification. Riparian buffers and controlled drainage are two best management practices that are effective in removing nitrates, but individually, may not be practical for all landscape positions. The purpose of this study was to determine whether or not combining these practices could create conditions favorable for denitrification. Redox potential, as related to the absence or presence of nitrate in groundwater and nitrate/chloride ratios, was the indicator of this desirable soil condition.

Methods

Study site

The study site is in the Middle Coastal Plain of North Carolina which is characterized as a moderately dissected landscape that has gentle undulating, nearly level to level sloping uplands and gentle to steep valley slopes (Daniels *et al.* 1999). Adjacent forested riparian buffers protect many of the larger streams and rivers. However, smaller drainageways, to which most agricultural subsurface waters flow, are formerly natural streams that have been channelized with their natural riparian vegetation removed. The soils at this location are terrace and flood plain soils. Because of their location next to the Neuse River, which frequently floods, the area is geologically complex. Soils series of importance in this study include Roanoke (fine, mixed, semiactive, thermic Typic Endoaquults), Tomotley (fine-loamy, mixed thermic Typic Endoaquults), Tarboro (mixed, thermic Typic Udipsamments), and Wickham (fine-loamy, thermic Typic Hapludults). The Roanoke and Tomotley soils located next to the ditches are very poorly drained and have slopes from 0 to 2 percent. The Tarboro and Wickham soils, located on slightly higher landscape positions, are somewhat excessively drained and well drained, respectively. Slopes on these soils range from 1 to 6 percent. It is important to note that all delineated soil types have inclusions. Soil investigations at this site indicate that restrictive layers are present at varying depths in the better-drained soils.

Two buffers were established along different segments of two ditches. Each buffer was divided into two widths, 7.6 m and 15.2 m. Within each buffer width are five vegetative treatments that are 25 m in length. The treatments in the buffers include fescue (commonly used for grass buffers in North Carolina), pine trees, switch grass (a deep-rooted grass), natural vegetation and the crop that is planted in the adjacent field to simulate no buffer (planting to the ditch, i.e., the control). A water control structure was installed at the mouth of the ditch. It included a flashboard riser and an adjustable V-notch weir. Well nests consisting of wells at three depths were installed in each of the treatments. Well nests were located immediately next to the ditch and at the field edge of the treatment. Also, four well nests were located outside of each buffer in the adjacent cropped field. Well depths were determined by a detailed soil investigation that ascertained the depths to restrictive layers within the profile and the expected depth to the water table. Wells were screened within the most transmissive zones, which were generally 0.6 to 1.2 m for the shallow wells, 1.8 to 2.4 m for the medium deep wells, and 3.0 to 3.7 m for the deep wells. Wells were sampled monthly, or more, during periods when leaching would possibly occur. Redox electrodes were installed at two depths, 76 cm and 152 cm, and placed in line with the adjacent well nests in vegetative treatments except switch grass. Five electrodes were placed 76 cm below the soil surface and three electrodes were placed 152 cm below the soil surface.

Results

Under normal conditions, redox potentials recorded on the buffer with no water control structure (R1) at the field edge and along the ditch were generally too high to indicate denitrification. The average Eh value for the electrodes installed to 76 cm was 667 mV. The Eh values ranged from a low of –53 mV to a high of 833 mV. Initially there was a wide range of variability at this depth that continued through late spring. However, a period of warm temperatures and little rainfall resulted in a narrower range of variability. The deep electrodes had an average Eh value of 757 mV and had a range of 429 mV to 859 mV. Low redox potentials recorded on the buffer with controlled drainage (R2N) indicated that conditions favoring denitrification existed depending on soil texture. Throughout this study, Eh values for the shallow electrodes followed a general trend of having higher values during warm and dry periods, dropping briefly following rainfall events, and rebounding shortly thereafter. Electrodes installed at 152 cm had lower redox potential values and exhibited more variability, which is consistent with the extreme variable conditions that may exist within the soil. A notable pattern difference observed at locations in the middle of the buffer may be attributed to soil texture differences observed during the soils investigation.

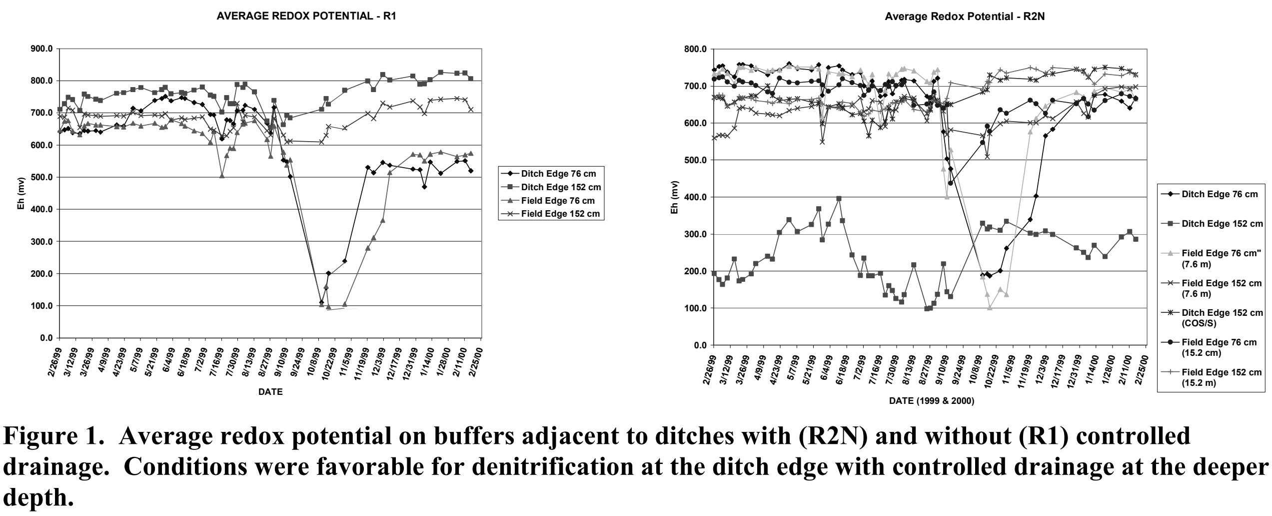

Figure 1. Average redox potential on buffers adjacent to ditches with (R2N) and without (R1) controlled drainage. Conditions were favorable for denitrification at the ditch edge with controlled drainage at the deeper depth.

Conclusion

The successful use of riparian buffers and controlled drainage is dependent on many factors, including soil type, hydrology, slope, vegetation, climate, etc. Each of these factors comes with variability. Therefore, predicting the successful use of these Best Management Practices is complicated. The 7.6-m and 15.2 m buffers with controlled drainage showed that conditions were favorable for denitrification in the vicinity of the water table or when soils restricted groundwater flow. The interaction between hydrology and the soils at this site was critical in attaining redox potential values suitable for denitrification. While there were no significant differences in nitrate concentrations with regard to buffer width, there were significant differences from the 7.6 m and 15.2 m field edges to the ditch edge. As expected, the 15.2-m buffer provided the largest decreases of 69% and 98% in nitrate concentrations from the field edge to the ditch edge in the medium and deep wells, respectively. Low soil redox potential values and decreasing nitrate/chloride ratios provide further documentation that losses were most likely attributed to denitrification. At R1 where no water control structure was present, nitrate concentration decreases in the medium wells were minimal and were significantly different than those at R2N. However, nitrate concentration losses in the deep wells on R1 were tremendous and comparable to the deep wells on R2N. This is probably a result of the presence of reducing conditions located deeper in the profile. Soil redox potential measurements at 152-cm indicated that conditions were not favourable for denitrification, which reflected the higher nitrate concentrations in the medium wells. It is clear that the interactions between soil and hydrology is critical for attaining conditions conducive to denitrification. A combination of riparian buffers with controlled drainage provided the most favorable conditions for this important nitrogen transformation at this location and understanding the relationship between the factors that influenced their effectiveness is key.

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