Nitrogen Removal as a Function of Slope, Width, and Percent Plant Cover of Riparian Buffer Zones

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Abstract Nutrient runoff from agricultural lands can be harmful to the aquatic life of nearby streams and rivers. Riparian buffer zones have been shown to be very useful in reducing this type of non-point source pollution. The effectiveness of three separate riparian buffer zones in the removal of nitrogen from surface flow was investigated based on three characteristics of the buffers: their slope, their width, and their percent plant cover. Surface water samples and physical measurements were taken nearby the Mümm winery outside of the town of Napa, CA during heavy rains between February 8, 2001 and March 4, 2001. The samples showed a decrease in nitrogen concentration from the top of the buffer zone to the edge of the nearby stream. Analysis of the data indicates a strong relationship between buffer width and nitrogen removal, while also indicating a weak qualitative relationship between the slope of the buffer and its effectiveness at nitrogen removal from surface water flow. The relationship between plant cover and nitrogen removal was statistically insignificant possibly in part to the low variability in plant cover across the buffer zones (73%-100%). The study found that riparian buffer zones of 5m or more were effective at nitrogen removal (45%) from the vineyard surface runoff.

Introduction

In recent years there has been an increase domestically in the use of commercial fertilizers (Vought et al. 1995). These fertilizers contain, as one of their key constituents, fixed nitrogen, usually found in the form of NO_2^{-2}, or NO_3^- (Ii et al. 1997). Nitrogen in its fixed forms is one of the limiting factors for plant growth and is an extremely important part of plant development. (Finzi & Canhamb, 2000) Unfortunately there are serious hazards to the environment caused by the runoff of nitrogen rich water from agricultural areas into nearby waterways. (Basnyat et al. 2000)

The leading hazard is the eutrophication of streams and rivers, a process that can lead to the death of marine fish and other species (Cirmo & McDonnell,1997). Another problem with nitrogen transport into waterways is what is commonly referred to as blue-baby syndrome, a malady by which nitrates interfere with oxygen's attachment to hemoglobin, sometimes causing death in infant mammals (Knobeloch et al. 2000).

One closely studied solution for these problems is the placement of a riparian forest buffer zone between an agricultural field and a waterway; often considered to be the best management practice for nitrogen removal (Xiang. 1995). These strips of forest or grassland have been shown to improve agricultural runoff water quality by reducing the amount of nitrogen and phosphorous that enters nearby streams and rivers (Lowrance et al. 2000).

Previous studies have focussed on ways to minimize the environmental damage caused by agricultural practices through utilization of buffer zones. One case study in particular carried out by Mander et al (1995) focused on the effectiveness of riparian buffer zones in the Porijògi river catchment. Their results showed that buffer zones, especially those composed of grey alder and/or willow bushes, were effective in reducing the concentrations of nitrogen and phosphorous in nearby waterways. The other variable that the study examined was buffer zone width. They found that the wider the riparian buffer zone is the more effective it is at removing nitrogen and phosphorous from above and below ground water sources.

A literature review conducted by Vought et al (1995) looked at the structure of buffer zones in relation to water quality in agricultural catchments. To determine the role the structure of the buffer plays in reduction of nutrients they reviewed previous studies. They concluded that vegetated buffer strips about 10 meters wide were effective at removing nitrogen from surface and subsurface flows. They also state that perennial vegetation and filtration are key to nitrogen removal in subsurface flow.

These studies indicate that the effectiveness of buffer zones is linked to physical aspects such as width, plant type, and soil type. There are no studies, however, that look at buffer zones near wineries and examine their effectiveness based on the interaction of three physical factors; namely slope, width, and percent plant cover. Since wineries do use fertilizers to grow grapes, and are prevalent in California, an excess of nitrogen in the runoff water from wineries could lead to problems with water quality. It is therefore necessary to study the buffer zones in the vicinity of these wineries to determine how the physical factors listed above effect the concentration of nitrogen in the runoff water.

Methods

All measurements and samples were taken from Mümm Vineyards in the Napa area. The study site started at 122W 27’ 34” by 38N 35’ 25” and continued to 122W 27’ 34” by 38N 32’ 35” along the winery. The region was measured out parallel to the stream and coordinates for three separate sites were chosen at random along the stream.

The width measurements were measured perpendicularly to the river at randomly selected positions. The total width ran between the edge of the river to the top of the perceivable buffer zone, which was where the native vegetation ended and the winery began. Three separate percent plant cover sample sites were randomly chosen along each width measurement, and then averaged to give the percentage plant cover (PPC) for that sample site. The slope measurement sites were randomly selected along the width measurements as well. All of the above buffer zone (ABZ) sites were located at the top of the width measurement.   The below buffer ground (BBZ) sample sites were selected by measuring up two meters from the stream edge in order to limit the amount of interference from water table flow into the stream.

Percent plant cover was determined with the aid of a 0.25m * 0.25m plastic sheet with 25 randomly selected 0.3 cm in diameter holes punched out of it. This sheet was placed on randomly selected sites and wooden sticks were pushed through the holes toward the ground. All of the plants the sticks made contact with were recorded as a hit and the number of hits divided by the number of holes times one hundred, gave the percent plant cover estimate for that sample.

The slope measurements were taken along the width measurement as well. Slope was measured by placing a 12-meter stick approximately 1 meter from the river, and another stick (1m) was placed near the top of the buffer. Atop of the 1m stick was placed a scope with a built in level (see Diagram 1). The scope was used to sight the height of the buffer, which after subtracting 1 meter became the opposite side of a right triangle (O'). The overland distance from the 1-meter stick to the 12-meter stick was the hypotenuse of this triangle (H'). The slope of the buffer was determined by calculating Tan(Sin^{-1}(O'/H')).

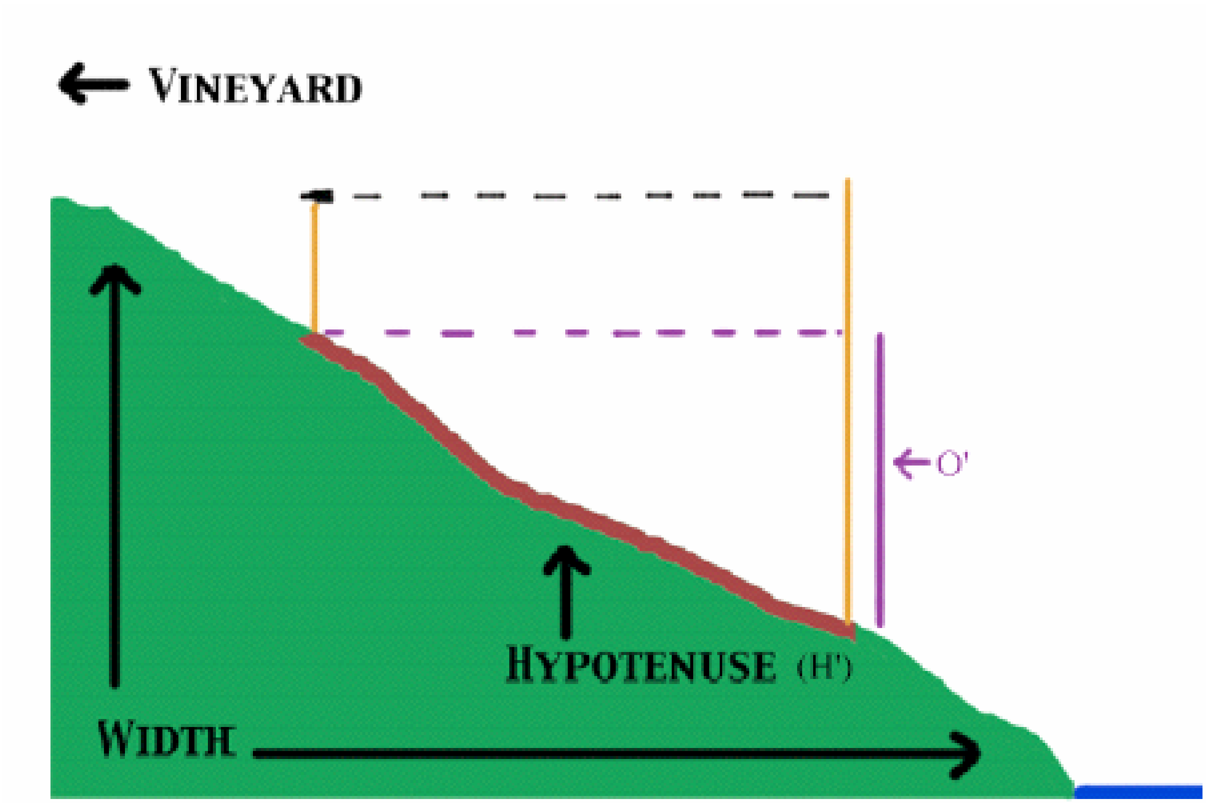

Diagram 1.

The water samples from the ABZ and BBZ sites were collected in Ziplock bags by indenting the edge of the bag into the soil and allowing runoff water to flow into the bag for three minutes. The samples were analyzed using the Accumet® Nitrate Ion Electrode method. The nitrogen concentration of the samples was determined using the Accumet® pH meter's ion electrodes. Each sample was prepared by shaking with cadmium a procedure used to convert all nitrites present into nitrate (Jones, 1984). After this, two nitrate standards were prepared whose concentration was near the expected concentration of the sample. For ABZ sites this was near 14 ppm and for BBZ sites it was near 8 ppm. Each standard and sample was then measured and the values for the concentration were taken from a calibration curve. The calibration curve was plotted using the measurements of three known standard concentrations. The calibration was checked every two hours.

Results

Regressions for width versus percent removal for the sites 1-3 showed regression line slope values that were very close to each other: 2.836, 2.747, and 2.882 (see figure 1) respectively despite significant differences in average width. For width vs. percent removal the correlation was 0.895, with a p value <0.0001 from the linear regression. Slope and percent plant cover were not correlated well with percent removal, -0.118 and 0.234 respectively with p values of 0.533 and 0.212 from their regressions (see figures 2 & 3). Residuals from the width regression plotted Vs. slope and percent cover values gave p values of 0.076 and 0.278 respectively. Mean values for all variables (separated by site) and their corresponding standard deviations are shown in the data table below. ANOVA analysis of the data shows significant differences between width measurements between the three sites (P < 0.0001), and shows that the slope and PPC measurements did not vary significantly between sites (p = 0.2061, and 0.3461 respectively).

Data Table

Site #	Width +/- SD_w	Slope +/- SD_s	PPC +/- SD_p	% Removal +/- SD_r
1	11.696 +/- 2.900	0.183 +/- 0.0603	0.85 +/- 0.0884	73.3 +/- 10.79
2	5.548 +/- 0.908	0.175 +/- 0.0631	0.82 +/- 0.0773	44.3 +/- 3.43
3	8.494 +/- 1.880	0.131 +/- 0.0800	0.87 +/- 0.0879	63.8 +/- 7.56
All sites:	8.579 +/- 3.238	0.163 +/- 0.0699	0.85 +/- 0.0850	63.5 +/- 14.44

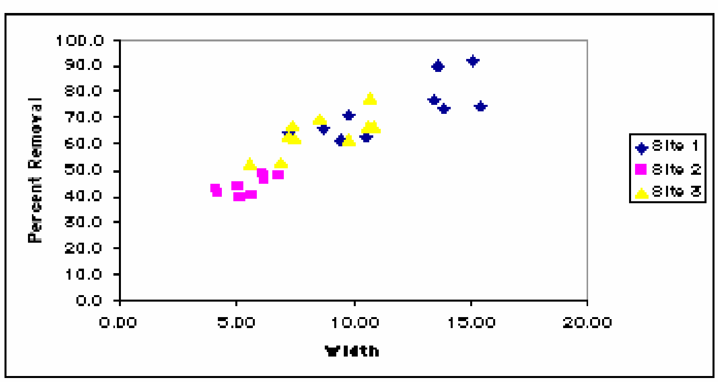

Figure 1. Regression of width Vs. percent nitrogen removal

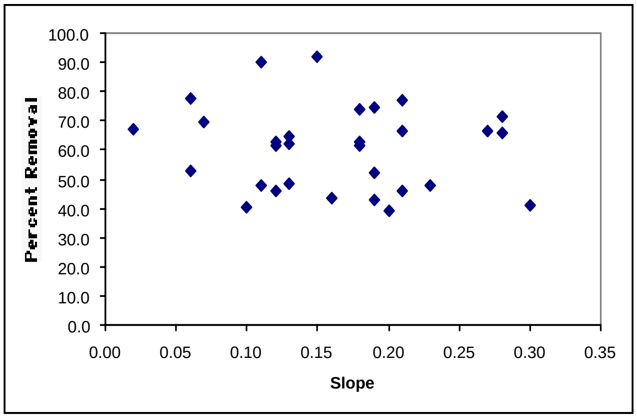

Figure 2. Regression of slope vs. percent nitrogen removal

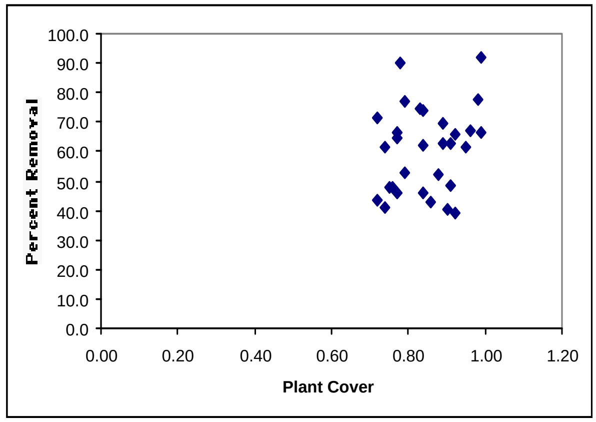

Figure 3. Regression of plant cover vs. percent nitrogen removal.

Discussion

The percent reduction in nitrogen showed significant correlation with the width of the buffer ($p<0.0001$, and correlation = 0.89). This is in line with other studies that have looked at removal of nitrogen as a function of width (Magette, 1989, Dillaha, 1989, and Vought, 1994). The other two variables do not appear to have much of an affect on the percent of nitrogen reduction as indicated by their high p values. This is the similar to the conclusions in Vought et al (1995) which state that vegetation was not a likely contributor to nitrogen reduction in surface runoff, although in this study the relationship was measured directly. In regards to slope Vought et al (1995) found little evidence of a correlation with nitrogen removal from surface runoff. The high p values of the slope and the percent plant cover allow them to be effectively ignored for the purposes of this study. This conclusion is backed up by the fact that neither of these variables relates significantly to the residuals from the regression of the width Vs. nitrogen removal meaning that they do not account for the variability in that relationship.

There is no doubt that the width is a major factor in reducing nitrogen, but the slope and percent plant cover, though they do qualitatively display the trends that were expected, do not have a statistically significant effect. The main reasons for the strong correlation between the width of the buffer and the percent removal of nitrogen lie in the two processes that are responsible for removal, plant uptake and denitrification (Wenger, 1999). Both of these processes interact with surface runoff throughout the area of the buffer, this means that the longer the buffer is the more reduction in nitrogen can be expected due to the greater surface area.

The lack of correlation between plant cover and nitrogen reduction may be due in part to the lack of variability in plant cover (ANOVA, p=.3461). This study had standard deviations for plant cover in the range of .08 to .09 (Table 1). This is very low since the mean range for percent plant cover was between .82 and .87 (Table 1). It may be that this lack of variability was the main cause for the negligible association. It is difficult to uncover a significant relationship when one of the variables is constrained, and the other is not. The lack of correlation for slope may stem from a similar constraint of variables (see Table 1 for means and standard deviations for slope). It is possible that there would be a relationship between nitrogen removal and slope or PPC if there were a greater variation in either PPC or slope between the sites.

In discussing the percent reduction of nitrogen by buffers in vineyard catchments the effectiveness of the buffer must first be addressed. Effective buffers are defined in this study as buffers that reduce the concentrations of nitrogen in runoff flows below 10ppm, which is the current EPA standard for nitrogen concentrations in surface waters (Harrison et al, 1999). For this study, the minimum effective width necessary to reduce the concentration of nitrogen to this level in surface flow is around 5m, which corresponds to about 45% removal. This varies depending on the initial concentration of nitrogen in the surface runoff. It does not take into account any other sources of nitrogen removal such as subsurface denitrification which has been shown to add a great deal to the effectiveness of the buffer zone (Wenger, 1999).

The application rates of fertilizers would also impact the effective width of the buffer, meaning that high rates of fertilization would lead to too high a concentration of nitrogen in surface runoff causing the buffer to become ineffective. This must be taken into consideration when looking at what buffer width is effective at nitrogen reduction for a particular vineyard. It should be kept in mind that the effectiveness refers to reduction to a set level (10ppm) not a percentage reduction.

In order to determine what the effective width of a buffer in a vineyard catchment should be, it is necessary to identify many factors. For example, the maximum initial concentration of nitrogen in surface runoff must be determined, which can be done by taking measurements over the course of a year. In addition it would be necessary to know what effects different soil types have on nitrogen removal (Mander et al, 1995). The effective width found in this study applies only to the specific conditions that were tested at the sites specified. Furthermore this study applies only in instances of heavy rains where there is either too much water to percolate into the ground, or the ground is too saturated to absorb anymore water.

Vegetated Buffers nearby vineyards can reduce nitrogen concentrations in surface runoff. As the width of the buffer increases, so does its nitrogen reducing capacity. Although this study found no significant relationship between nitrogen removal and slope or percent plant cover, the possibility that these two variables effect nitrogen removal cannot be ruled out. Also these two physical aspects have an effect on other important functions of buffers such as filtration of phosphorous, sediment, and as habitat for various species of insects (Vought et al, 1995). In some cases it is these other functions of the buffer that are key in maintaining water quality at acceptable levels. This is especially true in cases where nitrogen input is low while sediment or phosphorous loads are high (Vought et al, 1995).

In the case of high sediment loads buffers can effectively filter sediments from runoff water but only with enough vegetation present (Vought et al, 1995). Vegetated buffer zones also play an important role in the reduction of phosphorous in runoff water by reducing the concentrations of phosphorous by as much as 95%(Vought et al, 1995). The slope of a buffer can effect the amount of erosion that takes place on the buffer surface as well as the amount of sediment that eventually makes it into the waterway (Vought et al, 1995). A buffer zones role as habitat can bring about an increase in diversity in agricultural areas that would not exist without the presence of the buffer (Vought et al, 1995)

There is ample evidence that buffers can be extremely effective in improving water quality, not only from the standpoint of reducing nitrogen and other nutrients but also as protection from erosion and sedimentation of waterways. Future studies should focus on how all of the factors from this study as well as other factors such as soil type, carbon content of the soil, and time of year effect the ability of a buffer to improve runoff water quality. These studies should look at sites with greater variability in their physical features, and if necessary create greater variability (i.e. remove vegetation from some areas).

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