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Technical Note: Nitrogen and phosphorus in runoff from 2 montane riparian communities

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Abstract

It was hypothesized that the type and height of riparian vegetation would affect its ability to filter and retain inorganic nitrogen (nitrate-nitrogen (NO_3^--N), ammonium-nitrogen (NH_4^+-N)), and inorganic phosphorus (phosphate-phosphorus (PO_4^{-3}-P)). A rotating boom rainfall simulator was used to evaluate 2 montane riparian communities as filters for removing NO_3^--N, NH_4^+-N, and PO_4^{-3}-P nutrients from sediment laden overland flow water. One riparian community was characterized by Kentucky bluegrass (*Poa pratensis* L.) and tufted hairgrass (*Deschampsia caespitosa* (L.) Beauv.), while the second community was dominated by beaked sedge (*Carex rostrata* Stokes) and water sedge (*Carex aquatilus* Wahl.). Three vegetation height treatments were evaluated: control (natural condition), moderate treatment (clipped to 10-cm height and clipped material removed), and heavy treatment (clipped to ground level, clipped material removed, and litter vacuumed up). A 10-m wide riparian buffer zone was an efficient filter as about 84% NO_3^--N and 79% PO_4^{-3}-P was removed from the applied water and sediment. However, there were no consistent differences among specific vegetation height treatments or communities in the removal of N and P nutrients.

Key Words: Buffer strips, filtration, non-point source pollution, water quality, nutrient balance

Resumen

Se formulo la hipótesis de que el tipo y altura de la vegetación ribereña podría afectar su capacidad para filtrar y retener nitrogeno inorgánico [nitrato (NO_3^--N) y amonio (NH_4^+-N)] y fósforo inorgánico [fosfato (PO_4^{-3}-P)]. Se utilizó un simulador de lluvia rotatorio para evaluar 2 comunidades ribereñas de montaña como filtros para remover los nutrientes NO_3^--N, NH_4^+-N y PO_4^{-3}-P del sedimento contenido en el agua que fluye sobre la superficie. Una de las comunidades ribereña se caracterizó por las especies "Kentucky bluegrass" (*Poa pratensis* L.) and "Tufted hairgrass (*Deschampsia caespitosa* (l.) Beauv.), la otra comunidad estaba dominada por "Beaked sedge" (*Carex rostrata* Strokes) and "Water sedge" (*Carex aquatilus* Whal). Se evaluaron tres tratamientos de altura de la vegetación: control (condición natural), tratamiento moderado (cortado a 10 cm de altura y el material cortado se removió) y tratamiento fuerte (cortado a nivel del suelo, el material cortado y el mantillo se removieron). Una zona de amortiguamiento de vegetación ribereña de 10 m de ancho fue un filtro eficiente para remover aproximadamente el 84% del NO_3^--N y el 79% del PO_4^{-3}-P del agua aplicada y del sedimento. Sin embargo, las diferencias para remover los nutrientes N y P no fueron consistentes entre tratamientos específicos de altura de vegetación o comunidades.

Riparian areas are an important landscape component in many stream and river systems. They are the final terrestrial zone before runoff water enters a stream. They provide the last opportunity to decrease non-point source pollution delivery to streams by removing sediments and nutrients from upland areas. A key component in the effectiveness of a riparian zone for maintaining water quality is the vegetation of the area. Vegetation slows the water velocity and serves as sinks for removal of sediment and nutrients from runoff (Cooper et al. 1987, Dillaha et al. 1989, Gilliam 1994, Howard-Williams and Downes 1984, Jacobs and Gilliam 1985, Lowrance et al. 1984, McColl 1978, McNatt et al. 1980, Pearce et al. 1998b, 1998c, Sharpley 1985).

Although site specific, some studies have suggested that a minimum vegetative buffer width of 15 to 30 m is necessary to protect wetlands and streams from pollutants in overland and groundwater flows (Castelle et al. 1994, Pinay et al. 1993). Pearce et al. (1998) showed that riparian plant communities were effective in sediment filtration as long as overland flow depths were shallow. The width of the buffer zone was found to be more important than vegetation height or vegetation composition in sediment removal. Little quantitative information is available on the effectiveness of different types of riparian vegetation or vegetation heights for buffering or filtering nutrients from runoff water (Cooper et al. 1987, Jacobs and Gilliam 1985).

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A riparian zone effectiveness as a filter of non-point source pollution is related to its ability to be a source or sink for sediment and nutrients, primarily N and P. Nitrate is soluble in water and therefore moves readily with water flow (Flanagan and Foster 1989, Gambrell et al. 1975a, 1975b, Lowrance et al. 1984, Moore et al. 1979). The ammonium cation is usually associated with the cation exchange complex of soil particles and remains near the soil surface (Flanagan and Foster 1989). Microbial processes such as denitrification ($NO_3^- \rightarrow N_2$), aerobic nitrification ($NH_4^+ \rightarrow NO_3$), anaerobic dissimilatory reduction ($NO_3^- \rightarrow NH_4^+$), and N uptake by plants could all affect NO_3^- and NH_4^+ levels in runoff (Tiedje et al. 1982). Inorganic P complexes with soil and sediment particles and its release is predominantly controlled by soil surface reactions.

A rainfall simulation study was conducted to determine how species composition of riparian vegetation and height affected sediment movement (Pearce et al. 1998b), sediment deposition (Pearce et al. 1998c), and nutrients in runoff. Effects of vegetation composition and height on reducing N and P concentrations and mass totals in runoff from simulated rainfall events in 2 montane riparian communities were evaluated.

Methods and Materials

Site Location and Description

The study area was located adjacent to Sheep Creek in the Roosevelt National Forest, 80 km northwest of Fort Collins, Colo. at an approximate elevation of 2,500 m. Sheep Creek is typical of many small (4-5 m width) headwater streams in the western U.S. and is classified as a C-1 stream (Rosgen 1994). Plot slopes were gentle, ranging from 2.9 to 4.6%. The major soil series in the Sheep Creek area is Naz 70, a coarse loamy Pachic cryoboroll formed from weathered granite. Naz 70 is usually deep and well drained with an A Horizon that is a very dark, grayish brown sandy loam or clay loam ~55 cm thick (Noor 1990). Soil texture of the research area was classified as a clay loam with 38% sand, 39% silt, and 23% clay. There was a highly organic enriched O horizon sometimes exceeding 20 cm in thickness.

Vegetation Description

Vegetation of the Sheep Creek riparian zone consisted of willows (*Salix* spp.), shrubby cinquefoil (*Potentilla fruticosa* L.), several sedges (*Carex* spp.), rushes (*Juncus* spp.) Kentucky bluegrass (*Poa pratensis* L.), fowl bluegrass (*Poa palustris* L.), tufted hairgrass (*Deschampsia caespitosa* (L.) Beauv.), and other minor species (Schulz and Leininger 1990). Vegetation at one study site, referred to as the grass community, was comprised primarily of Kentucky bluegrass and tufted hairgrass. Vegetation at the other study site was dominated by beaked sedge (*Carex rostrata* Stokes) and water sedge (*Carex aquatilus* Wahl.) and is referred to as the sedge community.

Simulator Plots

Twelve rainfall simulation plots were installed in each vegetation community. Each plot, approximately 3 x 10 m, was delineated by 0.25 cm thick steel borders driven into the soil (approximately 3 cm). Water collection troughs, placed at the bottom of each plot, collected and directed the runoff water into precalibrated critical-depth, water-measuring flumes. The depth of water that flowed through the flumes was measured and recorded with bubble flow meters at 1 min intervals. Each depth measurement was converted into an equivalent runoff rate.

The rate of water applied by the rainfall simulator was measured in a 20 cm diameter recording rain gauge at 1 min intervals. The total rainfall applied and its distribution was measured by 6 small plastic volumetric rain gauges located in each plot.

Vegetation Treatment

Treatments consisted of 3 different vegetation heights: (1) natural height (representing protected areas), (2) vegetation clipped to a 10-cm stubble height (moderate clipping treatment), and (3) vegetation clipped to the soil surface (heavy clipping treatment). Vegetation on the moderate treatment plots was clipped with a lawn mower, trimmed with a weed-eater and hand clippers, and the litter raked and removed. The heavy treatment plots were clipped to the ground surface and all litter removed with a portable shop vacuum. Each clipping treatment was replicated 4 times in each vegetation community. Plots were paired by vegetation height treatment and each pair evaluated simultaneously.

Parameter Measurements

Soil samples for bulk density determinations were taken inside each plot with a small core sampler to a depth of 0 to 3 cm just prior to rainfall simulation. Following the rainfall simulations, a separate set of soil samples (0–2.5 cm) as well as standing dead and litter were taken adjacent to the plots but outside the simulator area for analyses of N and P. Vegetation height was measured at 10 random locations within each plot. Stem density and relative cover by species was measured with a 10-point frame randomly placed at 10 locations within each plot. Aboveground biomass was determined by clipping all of the vegetation in four, 0.25 m^2 quadrats, oven drying the samples, and weighing. Plot areas and slopes were obtained by surveying (Corley 1995).

Simulated Rainfall

A "Swanson-type" rotating-boom rainfall simulator was located between a pair of plots for each run (Laflen et al. 1991, Frasier et al. 1998). A gas driven centrifugal pump delivered water from Sheep Creek to the simulator through a flexible 13 cm D. hose. Each rainfall simulation run consisted of 2 rain periods (dry run and wet run) separated by a period of no rain. In the dry run, simulated rainfall was applied at an approximate rate of 60 mm $hour^{-1}$ until the runoff rate had been at equilibrium for at least 26 min on both plots or until a total run time of 60 min. Rainfall was then terminated for approximately 30 min to allow the surface soil moisture to equilibrate.

The second rainfall simulation period (wet run) consisted of simulated rain for a minimum of 45 min at the 60 mm $hour^{-1}$ rate plus additional water applied at the top of each plot (equivalent to an approximate rate of 25 mm $hour^{-1}$ over the entire plot) to simulate overland flow from upland areas. Once equilibrium runoff was reached during the wet run, sediment was added to the overland flow in 10 increments 3 min apart. This sediment was produced from a sieved (<3 mm) sandy loam soil derived from an adjacent upland site near the study area (Table 1). A total of 32 kg of added sediment was selected following pilot

Table 1. Properties of the offsite soil that was added to overland flow as sediment.

Parameter	Value
Particle size	
Sand (50-200μ)	53 %
Silt (2-50μ)	31 %
Clay (<2μ)	16 %
Nitrate (NO_3^-- N)	8.0 mg kg^{-1}
Ammonium (NH_4^+ - N)	1.1 mg kg^{-1}
Phosphate-phosphorous (PO_4^{-3} - P)	26.6 mg kg^{-1}

studies on 4 plots, 2 control and 2 heavy clipped treatment grass plots (Pearce et al. 1998c). Total periods of rainfall simulation varied among plot pairs (45 to 60 min) depending on the individual site runoff and infiltration characteristics.

Water Sample Collection

Runoff water samples were collected in 125 ml acid-washed plastic bottles at the flume outlets at periodic intervals during both the dry run and the wet run. A total of 5 samples were collected during each simulation run. The first sample was taken during the rising stage of the runoff hydrograph. Three samples were taken after equilibrium runoff had been achieved, at approximately 6 min intervals. The last sample was taken during the recession stage. The time of each collection was noted and correlated with the measured instantaneous runoff rate. All samples were cooled on ice in the field, then stored in a refrigerator at 4° C until all analyses were completed. No microbial inhibitors were added to the samples. Samples of the simulated rainfall were taken midway through each run for N and P analysis.

Chemical Analysis

Separation of runoff water from sediment or litter was performed as soon as possible after the samples were collected (within 7 days). The samples were separated by a centrifuge method (1500xg for 10 min), decanted and filtered through #40 Whatman filter paper. Standing dead and litter samples were leached for 15 min with distilled water and agitation, then filtered through #40 Whatman paper. All water samples were analyzed on an automated TRAACS 800 analyzer for inorganic N (NO_3^--N and NH_4^+-N)(Technicon July 1987, June 1987). Murphy and Riley's (1962) ascorbic acid method and a spectrometer were used for analysis of liquid phase inorganic P(PO_4^{-3}- P). The surface soil and added sediment samples were analyzed for inorganic N (1 M KCl extraction to obtain NO_3^--N and NH_4^+-N concentrations (Keeney and Nelson 1982)), and available P(PO_4^{-3}-P) ($NaHCO_3$ extraction (Olsen et al. 1954)).

Data Analysis

Differences between the dry run with antecedent soil moisture and the wet run with saturated soil and the addition of sediment laden overland flow made it necessary to analyzes the 2 runs separately. Data for each ion were analyzed as a two-way 2 x 3 factorial experiment using a repeated measures split plot analysis (SAS 1989). The analysis compared community type (2), height treatment (3), timed runoff samples (5) and the interactions. A pair of rainfall simulation plots was 1 replicated plot; whereas a separate rainfall simulation plot was referred to as a subplot. When F-values were significant ($p \leq 0.05$, unless indicated otherwise), individual means were compared using Fisher's Least Significant Difference method (Ott 1988).

Results and Discussion

The study design utilized a dry run followed by a wet run with added sediment laden overland flow. This permitted evaluation of what occurred naturally within the riparian vegetation community and the effectiveness of the riparian zone for reducing N and P pollution in sediment from upland sites. The average N and P concentrations of the input water for each set of rainfall and overland flow simulations was subtracted from the corresponding N and P concentrations in runoff samples to obtain the change in net concentration of N and P. The net N and P balance for each plot was estimated by multiplying the average concentration of the nutrients in the runoff water times the total runoff quantity, while accounting for the contribution of N and P from the creek water (simulator water) and sediment added to each plot during the wet runs. These values were converted to a total nutrient output per unit area (ha).

Nitrate

The nitrate-N concentration of the stream water used in the simulations was less than the detection limits of the TRAACS 800 analyzer (<0.05 mg liter^{-1}). To evaluate the effect of the quantity of added sediment on the nitrate-N in the collected runoff water, 4 of the grass plots were evaluated twice, once with 16 kg sediment added per plot (~0.6 kg m^{-2}) and once with 32.1 kg sediment added per plot (~1.2 kg m^{-2}) during the wet runs. Two of the plots were clipped heavily and 2 were unclipped controls. With the 16 kg per plot of added sediment, there were no measurable levels of nitrate-N detected in the runoff water samples. At the 32.1 kg per plot sediment loading rate, total measured nitrate-N in the runoff water from the wet run ranged from 3 to 8 mg plot^{-1} (concentrations of 0.06 to 0.13 mg liter^{-1}). Following this pilot study we decided to use 32.1 kg per plot as the sediment loading rate for the experiment.

During the dry run, only 2 water samples collected from all the treatments had a nitrate-N concentration above the detection limit (0.05 mg liter^{-1}). The absence of detectable nitrate-N in most of the water samples collected during the dry run precluded any statistical comparison of treatment effects.

Measurable nitrate-N was detected in about 50% of the runoff samples during the wet run when 32 kg of sediment was added in the overland flow water. Concentrations in runoff water ranged from 0.05 to 0.13 mg liter^{-1}, well below the drinking water standard of <10 mg liter^{-1} (Binkley and Brown 1993). There was no detectable nitrate-N in the runoff water from the moderate clipped treatment plots from either the grass or sedge plant communities, but there were measurable quantities of nitrate-N in water samples from both the control and heavy clipped treatment plots even though there were no significant differences among treatments. There was usually an increase of NO_3^--N concentrations in the runoff water with time during a simulated rainfall.

Table 2. Mean nitrate-N, ammonium-N and phosphate-P measured in runoff during 2 rainfall simulations from the bottom of 4 plots of each of 3 treatments in 2 riparian vegetation communites.

Nutrient	Simulator run	Grass			Sedge		
		Control	Moderate	Heavy	Control	Moderate	Heavy
		(g ha^{-1})					
Nitrate-N	Dry	0	3	0	0	0	0
	Wet[1]	22	0	30	36	0	26
Ammonium-N	Dry	8	19	6	1	1	0
	Wet[2]	25	14[4]	23	33	10[4]	31
Phosphate-P	Dry	18	16	33	1	34	13
	Wet[3]	35	72[4]	64	38	75[4]	29

Vegetation community; Clipping treatment

[1] A total of 95 g ha^{-1} of NO_3^--N was added with the sediment that was supplied as overland flow.

[2] A total of 13 g ha^{-1} of NH_4^+-N was added with the sediment that was applied as overland flow.

[3] A total of 316 g ha^{-1} of PO_4^{-3}-P was added with the sediment that was applied as overland flow.

[4] The moderate clipping treatment was significantly different from the control or heavy clipping treatment ($P \leq 0.10$).

Approximately 80% of the quantity of nitrate-N in the sediment applied during the wet run was retained on the plots, i.e. the plots were a nitrate sink (Table 2). Even though the quantity of sediment which passed through the plots was small (Pearce et al. 1998b, 1998c), it is assumed that most of the measured nitrate N in the runoff was nitrate that went into solution from the sediment applied in the overland flow water during wet runs. It is not clear why there was no nitrate-N detected in the runoff samples from the moderately clipped plots.

Ammonium

Ammonium-N was measured in the runoff water from several of the treatments during the dry runs when there was no added sediment (Table 2). Measured ammonium-N concentrations in the runoff water ranged from non-detectable to 1.24 mg liter^{-1} compared with 0.05–0.22 mg liter^{-1} in the simulator water. Although most of the samples in the dry run with detectable NH_4^+-N were from the grass community, there were no significant ($p \leq 0.10$) differences or interactions in NH_4^+-N concentrations or total output among community types, treatments, or sample times.

In the wet runs, there was a significant interaction between community and height treatment for NH_4^+-N total nutrient mass running off the plots that probably resulted from differences in runoff rates, as concentration differences were not significant. Only 1 sample with 0.06 mg liter^{-1} was above the detection limit for the moderate clipping treatment of the sedge community compared with NH_4^+-N concentrations that ranged from 0.05 to 0.14 mg liter^{-1} from the control and heavy clipping treatment. In the grass community the moderate clipping treatment had concentrations that ranged from 0.05 to 0.14 mg liter^{-1} compared with 0.06 to 0.08 mg liter^{-1} from the control and heavy clipping treatment.

While there was some measurable ammonium-N in the applied water, the differences measured in the runoff between the 2 plant communities indicated that the applied water was not the primary source of the ammonium-N. During the wet run there was approximately twice the total ammonium-N in runoff from the plots as was available in the applied sediment (Table 2). This indicated that the vegetation community or soil might be an ammonium-N source for runoff (Table 3). There was also a treatment effect, as the moderately clipped plots yielded only about half the total ammonium-N as did the heavily clipped and control plots.

Phosphate-Phosphorus

No standard for phosphate-phosphorus (PO_4^{-3}-P) concentrations in freshwater streams and lakes has been set because the risk of eutrophication is dependent on local environmental conditions. A maximum concentration of 0.5 mg liter^{-1} in streams may adequately protect lakes, however (Binkley and Brown 1993).

Table 3. Soil and vegetation characteristics of the Sheep Creek riparian site plots.

Parameter	Unit	Vegetation community Grass	Sedge
Soil			
Bulk density (0–6 cm)	(g cm^{-3})	0.69 ± 0.051	0.31 ± 0.02
Initial soil moisture	(% weight)	42 ± 4.1	84 ± 9.0
Vegetation			
Stem density	(stems m^{-2})	2280 ± 258	641 ± 26
Vegetation height			
Control	(cm)	24 ± 0.8	43 ± 1.3
Moderate clipping	(cm)	10	10
Heavy clipping	(cm)	0	0
Aboveground biomass			
Control	(g m^{-2})	263 ± 24	300 ± 12
Moderate clipping	(g m^{-2})	135 ± 12	83 ± 4
Heavy clipping	(g m^{-2})	0	0
Cover[2]			
Grass	(%)	18 ± 3	1 ± 1
Sedge	(%)	26 ± 4	83 ± 2
Litter	(%)	24 ± 4	15 ± 2
Surface	(%)	26 ± 2	14 ± 1
Canopy	(%)	76 ± 4	85 ± 2
Bare ground	(%)	<1	<1
Nitrate (NO_3^--N)			
Standing dead	(mg kg^{-1})	24.1 ± 2.9	*[3]
Soil	(mg kg^{-1})	1.0 ± 0.3	0.9 ± 0.1
Ammonium (NO_4^+-N)			
Standing dead	(mg kg^{-1})	17.1 ± 8.6	*
Soil	(mg kg^{-1})	6.8 ± 0.9	8.5 ± 1.5
Phosphate-Phosphorous (PO_4^{-3}-P)			
Standing dead	(mg kg^{-1})	62.2 ± 6.6	*
Litter	(mg kg^{-1})	31.3 ± 4.1	56.2 ± 5.8
Soil	(mg kg^{-1})	17.7 ± 3.5	36.2 ± 5.3

[1] Mean ± 1 SE

[2] Measured prior to treatment

[3] Data not collected

The mean concentration of PO_4^{-3}-P in runoff samples from the 2 riparian communities ranged from 0.05 to 1.31 mg liter^{-1}. The PO_4^{-3}-P concentrations in the simulator water were below the detection limits (0.05 mg liter^{-1}).

There were significant interactions between community and height treatments for PO_4^{-3}-P concentrations during dry runs. In the grass community there were higher PO_4^{-3}-P concentrations from the 2 clipping treatments (0.21 to 0.42 mg liter^{-1}) as compared with the control (0.09 to 0.13 mg liter^{-1}). In the sedge plant community the moderate clipping treatments had the highest PO_4^{-3}-P concentrations (0.60 to 1.31 mg liter^{-1}) with no differences between the control and the heavy clipping treatment (0.07 to 0.11 mg liter^{-1}). The treatment manipulations during plot installation may have influenced the results. The mowing, clipping and raking loosened PO_4^{-3}-P associated sediment, standing dead, and litter in the moderate treatment plots. The loosened particles may have been vacuumed from the sedge community in the heavy clipping treatment, which resulted in similar PO_4^{-3}-P concentrations for the control and heavy clipping treatments, but not the moderate clipping treatment.

In the wet runs, PO_4^{-3}-P concentrations ranged from 0.05 to 0.16 mg liter^{-1} from the control and heavy clipped treatments and 0.22 to 0.35 for the moderate clipped treatment. These were usually lower than those measured in dry runs. This implied that the PO_4^{-3}-P in the runoff water was effectively filtered as water moved across the plots.

A mass balance of PO_4^{-3}-P showed measurable amounts in runoff water during both the dry runs (34 g ha^{-1}) and wet runs (75 g ha^{-1}). A total of 316 g ha^{-1} of PO_4^{-3}-P was added to overland flow in the applied sediment. Most of this sediment was retained on the plots (Pearce et al. 1998c). There was a treatment effect, with moderately clipped plots yielding approximately twice the amount of PO_4^{-3}-P as the control and heavily clipped plots (Table 2). However, these quantities still represent a significant reduction (~80%) in PO_4^{-3}-P leaving the plots compared to the quantity added in the overland flow sediment. This indicates that the riparian community site was a very good PO_4^{-3}-P nutrient sink.

Summary and Conclusion

We hypothesized that the type and height of riparian vegetation were important factors that affected the ability of a riparian zone to act as a filter of nitrogen and phosphate-phosphorus from sediment laden overland flow. However, few differences in nutrient filtration were noted between the 2 riparian communities and 3 heights of vegetation. The riparian communities retained more nitrate-N and phosphate-P from the applied sediment than was lost in the runoff water. Whereas, there was usually more ammonium-N in the runoff water than in the applied sediment. Both nitrate and phosphate are quite reactive. Nitrate may have been taken up readily by microorgansims and vegetation as water moved across the soil surface, while phosphate attached to sediment may have deposited out of the runoff water. Ammonium ions may have been attached to fine clay particles that remained suspended and were not effectively filtered from the overland flow water. Additional ammonium may have been leached from the vegetation or plot surface. However, even when the montane riparian communities were subjected to conditions of added nutrients from sediment in overland flow water, they were an effective nutrient filter for nitrate and phosphate.

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