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Short Communication

Effects of riparian set-aside on soil characteristics in an agricultural landscape: Implications for nutrient transport and retention

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Abstract

Physical, chemical, biochemical and microbial properties of riparian soils beneath native scrub (*Leptospermum scoparium*), grazed pasture, and set-aside pasture along the edge of a third order stream near Taupo, New Zealand were compared. In the 12 years since retirement from grazing, dominant vegetation in the set-aside areas changed from pasture grasses to native tussock (*Poa cita*). Riparian set-aside soils had an extremely high hydraulic conductivity in the surface horizon (6340 mm h^{-1}) compared with that in the riparian grazed pasture (15 mm h^{-1}) indicating that surface runoff water transported into the zone would infiltrate, fill soil pores and emerge as subsurface flow at the stream edge. Phosphorus available for transport was highest in riparian set-aside soils, indicating P saturation of the zone. Nitrate pool size was strongly correlated to nitrifying potential (Spearman's $\rho = 0.897$), with both being extremely low in riparian set-aside. Microbial biomass was greater in riparian set-aside (1900 mg C g^{-1}) than riparian native (1460 mg C g^{-1}) or riparian pasture (1080 mg C g^{-1}). The results imply that riparian set-aside has led to the development of a zone likely to supply runoff to the adjacent stream that is depleted in sediment-bound nutrients and dissolved N but enriched in dissolved P.

Keywords: Riparian; Land use; Buffer strips; Microbial biomass; Nitrogen; Phosphorus

1. Introduction

Riparian zones play an important role in shaping stream ecosystems, influencing habitat complexity, biodiversity, and energy and nutrient flows (Naiman et al., 1988; Gregory et al., 1991; Sweeney, 1993). Careful management of riparian areas therefore offers a strategy for buffering streams from a variety of land use impacts while still allowing that land use to continue over the broader landscape. In New Zealand, catchment development from native forest to pastoral agriculture has usually occurred without protection of the riparian zone and, since the 1970s, stream rehabilitation efforts have focused on the setting aside of riparian areas from pastoral use. Although this riparian set-aside strategy has been usually beneficial to New Zealand's agricultural streams (Howard-Williams, 1991; Quinn et al., 1993), one key area requiring further research is the long-term sustainability of riparian buffers to act as filters of non-point source pollution.

Numerous research studies have shown buffer strips to be effective filters of sediment and nutrients from agricultural runoff (reviewed by Muscutt et al., 1993

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and Osborne and Kovacic, 1993). However, these reviews also pointed out that most studies have focused on comparing inputs with outputs and have been of short duration. Although such an approach provides answers of immediate value to resource managers, it provides little understanding of either the processes involved or the long-term sustainability of these processes. This paper describes a different approach in which we measured key soil properties within a 12 year old riparian set-aside and made comparisons with adjacent riparian lands in native scrub and grazed pasture. Our aim was to understand more about the dynamics of water and nutrients within the riparian set-aside zone from which we could make deductions about the continued ability of the zone to perform its filtering function. The soils in the study area are geologically young and respond rapidly to changes in management, making them ideal sites for detecting the influences of set-aside on soil properties.

2. Methods

2.1. Site description

The study sites were located within the Lake Taupo Catchment Control Scheme, central North Island, New Zealand. This scheme involved the setting aside of 700 km of stream edge from pastoral farming with a prime purpose being to protect the highly valued trout fishery of the lake and its tributaries from the impacts of sediment and nutrient enrichment. Studies were conducted on three adjacent riparian zones along a 750 m reach within the headwaters of the Mangakowiriwiri Stream (175°46′ E, 38°36′ S). The first area was undeveloped and its riparian zone comprised native shrubs and ferns (*Leptospermum scoparium*, *Dracophyllum subulatum*, *Blechnum penna-marina*). The second area was converted from native vegetation to grazed exotic pasture (*Lolium perenne*, N_2-fixing *Trifolium repens*, and *Agrostis tenuis*) in the early 1960s and has subsequently received annual phosphorus fertilizer applications of 60 kg P ha^{-1}. Stock (beef cattle and sheep) have unrestricted access to the stream edge. The third area was also converted to pastoral farming in the early 1960s but in 1980 a riparian zone of about 10 m either side of the stream was fenced off and stock excluded. By 1992, this set-aside area was dominated by native tussock (*Poa cita*), with some remnant pasture.

Soils of the area (Taupo sandy loam; Typic Udivitrand) have developed from recent deposits of volcanic ash and pumice, the last major eruption being 1700 years ago when Lake Taupo was formed. Under native vegetation, these soils have a partly decomposed litter layer overlying a porous, sandy loam topsoil and a pumiceous, unconsolidated gravelly sub-soil. Upon conversion to pastoral agriculture, topsoils typically become compacted, reducing their water holding capacity and increasing the propensity for surface runoff and sheet erosion.

2.2. Sampling

Soil sampling was conducted in the fall of 1992 (March). This timing was designed to detect differences in riparian zone soil properties just prior to winter when the majority of sediment and nutrient runoff occurs. For soil physical measurements, three intact cores (9.8 cm diameter and 3–6 cm long) were obtained from each of the F, A and B_w horizons for each riparian zone. For soil chemical and microbial measurements, 30 surface soil samples (0–5 cm) were taken from each of the riparian zones by sampling at approximately 15 m intervals along each side of the stream. These samples were wet sieved (<2 mm) in the field and stored at 4°C until analysis, which was completed within 5 days of collection. Sampling effort was restricted to the surface soil because we were primarily interested in the soil zone that interacted directly with surface runoff. Changes in riparian land use may be expected to have the greatest impact on surface soil properties and therefore any differences we measured are likely to be less pronounced, or non-existent, further down the soil profile.

2.3. Laboratory analyses

Soil hydraulic conductivities were measured on intact cores under saturated (ponded surface water) and unsaturated conditions (a tension of 40 mm was applied both above and below the soil core) (Cook et al., 1993). The difference between drainage rates under saturated conditions and at a tension of 40 mm provides an indication of macropore flow (diameter >0.75

Table 1
Methods used

Parameter	Method	Reference
Water soluble P	10:1 water–soil extraction	Olsen and Sommers (1982)
Labile P	0.5M $NaHCO_3$ extraction	Olsen and Sommers (1982)
Equilibrium P	Sorption isotherms	Hartikainen (1991)
Phosphatase	p-nitrophenol release from p-nitrophenol phosphate	Tabatabai (1982)
Inorganic N	KCl extraction	Keeney and Nelson (1982)
Nitrifying potential	Nitrate production in the presence of buffered ammonium	Cooper (1986)
Denitrifying activity	Anaerobic N_2O production in the presence of C_2H_2	Cooper (1990)
Microbial biomass	Chloroform fumigation, extraction and analysis of released C	Tate et al. (1988)
Microbial composition	Acridine orange fluorescence microscopy	Schmidt and Paul (1982)
Dehydrogenase	TPF release from triphenyl tetrazolium chloride	Tabatabai (1982)

mm). Bulk densities and porosities were determined using standard procedures.

Chemical and microbial methods used are presented in Table 1. Analyses were performed on all 90 samples collected, except for P sorption-desorption isotherms where equal weight sub-samples were withdrawn from each of the 30 samples gathered from a riparian zone and bulked prior to analysis. Statistical comparisons between riparian zones were made using non-parametric analysis of variance (ANOVA on ranks, Conover and Iman, 1981), as distributions were neither consistently normal nor log-normal.

3. Results

3.1. Physical properties

Surface soil differed between the three riparian zones. The native riparian soil had a moroid surface horizon (comprising twigs, leaves and roots) with a moderately developed structure whereas the grazed and set-aside soils had a structureless surface horizon dominated by a fibrous root mat. This horizon was 2–3 cm deep in the grazed soil and 9–12 cm deep in the set-aside soil. The surface soil in the set-aside was extremely porous, taking on a sponge-like appearance.

Observed differences in profile characteristics were reflected in large differences in soil physical properties (Table 2). Saturated hydraulic conductivities in the surface soil were several orders-of-magnitude higher in the native and set-aside soils than in the grazed soil. Macropore flow dominated surface drainage in the native and set-aside soils, but was of little importance in the grazed soil.

3.2. Soil P and N

Our various estimates of P readily-available for transport from the riparian zone all revealed a consistent effect of riparian land use. Water soluble P and labile P, as measured by bicarbonate extraction, were highest in the set-aside soil and lowest in the native soil (Table 3). The quantity/intensity (Q/I) plots for P show a similar effect of riparian land use (Fig. 1). These plots have similar slopes, suggesting similar P sorption mechanisms, but have different x-and y-intercepts reflecting their differing P status. Soil solution P concentrations at equilibrium (x-intercepts of Fig. 1) were higher in riparian set-aside (0.103 mg l^{-1}) than

Table 2
Physical properties of the three riparian soils

Parameter	Horizon	Riparian land use		
		Native	Grazed	Set-aside
Bulk density (g cm^{-3})	F	0.43	0.34	0.07
	A	0.48	0.47	0.38
	B_w	0.46	0.52	0.39
Porosity (%)	F	80	84	97
	A	77	78	83
	B_w	78	76	82
K_{sat} (mm h^{-1})	F	4769	15	6340
	A	411	24	88
	B_w	134	130	188
K_{-40} (mm h^{-1})	F	165	12	81
	A	74	22	34
	B_w	40	47	71

Table 3

A comparison of some N, P, and microbial properties of riparian soils in native scrub, grazed pasture, and set-aside land uses. Values shown are medians with 5%tile and 95%tiles in parentheses

Parameter	Riparian land use			Differences[a]
	Native	Grazed	Set-aside	
Water soluble P (mg kg^{-1})	0.27 (0.02–11)	1.27 (0.43–2.95)	2.09 (0.36–10.9)	R>G>N
Labile P (mg kg^{-1})	6.7 (3.5–49.2)	16.0 (9.5–29.7)	49.2 (12.8–171)	R>G>N
Phosphatase activity (mg P h^{-1} mg^{-1} biomass C)	1.8 (0.9–3.3)	2.0 (1.5–3.2)	0.89 (0.71–1.7)	N=G>R
NH_4-N (mg kg^{-1})	13.9 (3.8–197)	47.5 (4.9–209)	11.9 (1.8–78)	G>N=R
NO_3-N (mg kg^{-1})	7.8 (1.0–137)	32.5 (0.4–186)	1.1 (0.1–14.8)	G>N>R
Nitrifying potential (mg N kg^{-1} h^{-1})	0.12 (0.02–1.7)	0.29 (0.01–1.4)	0.029 (0–0.12)	N=G>R
Denitrifying potential (mg N kg^{-1} h^{-1})	0.38 (0.16–1.1)	0.58 (0.30–2.4)	0.41 (0.19–1.1)	G>N=R
Microbial biomass (mg C kg^{-1})	1460 (590–2785)	1081 (657–1828)	1900 (1068–3111)	R>N>G
Composition – % Fungi	70	35	40	
% Actinomycetes	15	10	40	
% Bacteria	15	55	20	
Dehydrogenase activity (mg TPF h^{-1} mg^{-1} biomass C)	2.7 (1.5–5.4)	7.5 (5.5–9.8)	3.8 (1.8–5.7)	G>N=R

[a] Differences between land uses were evaluated using ANOVA on ranks and Scheffe's test used to determine where differences lay ($P < 0.05$).

riparian pasture (0.064 mg l^{-1}) and riparian native (0.023 mg l^{-1}). The y-intercept of the Q/I plots can be taken as a measure of the P available for enriching runoff waters, and shows an increase in this P fraction upon development to pasture and a further increase upon set-aside. Specific phosphatase activities (phosphatase per unit microbial biomass) were lowest in the set-aside soils, reflecting the high availability of P.

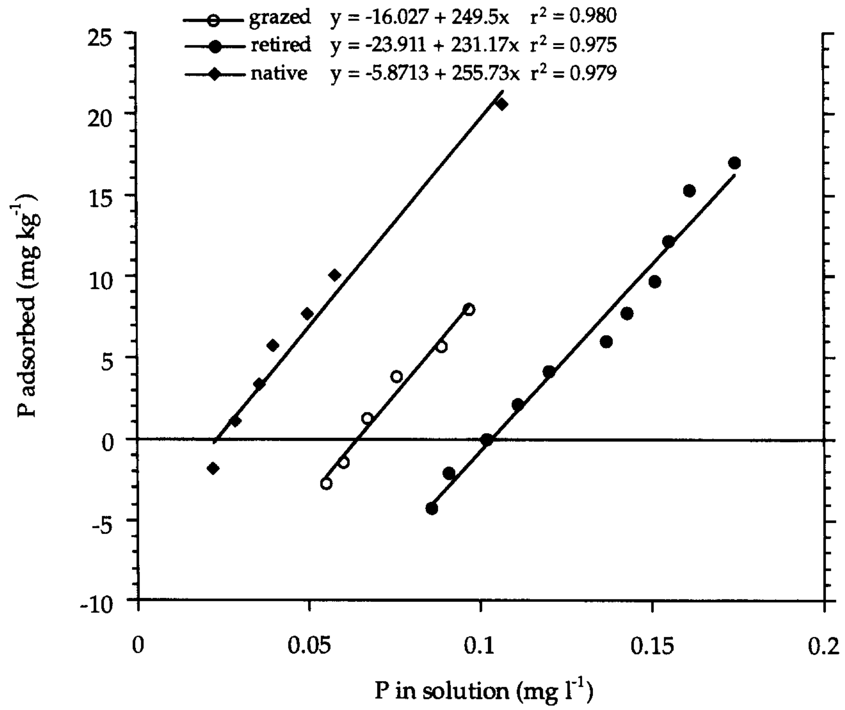

Fig. 1. Quantity/intensity plots of phosphorus sorption for riparian soils gathered from native scrub, grazed pasture, and set-aside areas.

Inorganic N concentrations (both ammonium and nitrate) were highest in the grazed soil, with nitrate concentrations being extremely low in set-aside soils (Table 3). Nitrifying potentials were an order-of-magnitude lower in set-aside soils than grazed soils, and there was a strong correlation with nitrate concentrations (Spearman's $\rho = 0.897$, $n = 90$; pooled data from the three soils). Denitrifying potential was highest in the grazed soils.

3.3. Soil microbes

Microbial biomass was highest in set-aside soils and was nearly double that in the grazed soils (Table 3). Comparison of dehydrogenase activity per unit biomass suggests that the microbes in the grazed soil were physiologically more active. Microscope estimates of biovolume showed that the microbial composition of the soils were markedly different, with a dominance by fungi in the native soil, by bacteria in the grazed soil, and a large expansion in the actinomycete population in the set-aside soil.

4. Discussion

Our comparisons of riparian soils under different land uses show large differences in several key physical, chemical, and microbial properties that have consequences for the zone's role as a buffer of material transfer across the land–water interface. After 12 years, riparian set-aside has not led to restoration of virgin conditions (nor a movement towards such conditions), but rather the development of a zone with unique vegetation and soil characteristics.

The large differences in physical characteristics between grazed and set-aside surface soils indicates that the hydrology of the riparian zone has changed markedly upon set-aside. Surface runoff generated from the compacted pasture upslope has an opportunity to infiltrate into the porous surface soil of the set-aside. During runoff events, infiltrated water will initially fill soil pores until this large storage capacity is exceeded and water then enters the stream as shallow throughflow. Using soil physics theory, Phillips (1989) derived equations showing that the relative ability of riparian buffers to retain surface runoff pollutants is a function of water storage capacity and infiltration rate. Given that these soil properties have increased by several orders-of-magnitude upon riparian set-aside, it is apparent that this zone is highly suited, from a physical standpoint, to retain pollutants derived from upslope.

Riparian set-aside soils showed a greater enrichment in readily-transportable forms of phosphorus than riparian grazed soils, despite the latter continuing to receive P fertilizer. The increase in labile forms of P is also evidenced by the decreased need of the biota to induce phosphatase production. Our data does not allow elucidation of the mechanisms responsible for these changes. The inference we draw from these findings is that while the set-aside zone may act effectively as a physical trap for incoming particulate P because of the changed physical hydrology, processes within the zone would see it act to enrich runoff waters with biologically-available soluble P. Several studies have shown buffer strips can act as a source of soluble P while still being a net sink of total P (Dillaha et al., 1989; Uusi and Ylaranta, 1992)

The effects of riparian set-aside on N within the zone are quite different from those observed for P. Inorganic N concentrations were very low in set-aside soils, being considerably lower than both grazed pasture and native soils. Nitrogen in the set-aside zone appears to be strongly held within the organic pool, and microbial release of this N to the mobile nitrate form is slow (low nitrifying potentials). We speculate that these changes in N dynamics have been caused by a change in vegetation from pasture grasses to more structurally complex tussock and the absence of N recycling via readily-mineralized urea-N in animal urine. Although our results indicate that riparian set-aside has reduced the ability of the zone itself to act as a source of N to adjacent waters, questions remain as to the long-term fate of incoming N from upslope runoff. Trapping of this N within an expanding organic pool (e.g., increased plant and microbial biomass) may describe its initial fate, but how long will net organic N accumulation continue to occur within the set-aside? In upland ecosystems, the long-term consequences of continued N enrichment are increased mineralization and nitrification, with resultant increases in nitrate loss to ground-or surface waters (Aber et al., 1989; Hill and Shackelton, 1989). For riparian zones, the long-term consequences of high N inputs are less clear, given the important role that denitrification loss can sometimes play in the N dynamics of these zones and the dependence of this loss process on carbon supply and moisture status (Groffman et al., 1992; Quinn et al., 1993).

We have shown that riparian set-aside has markedly altered the internal water and nutrient regime of riparian zones, which can be expected to have affected their role as regulators of nutrient transfer across the land–water interface. A fundamental component of nutrient dynamics in soil systems is the microbial community (Paul and Clark, 1990) and our results showed changes in microbial biomass, activity and community composition upon riparian set-aside. Biomass increased, activity per unit biomass decreased, and the community became dominated by filamentous microbes (fungi and actinomycetes). Biogeochemical research that links changes in the microbial community to changes in the nutrient dynamics of riparian zones is needed to determine the long-term sustainability of riparian set-aside as a strategy for reducing non-point source pollution.

Our study indicates that riparian set-asides should not be regarded as inexhaustible sinks for high nutrient inputs and that there is a need to match nutrient inputs to sustainable rates of nutrient removal if long-term water quality benefits are to occur. When this perspective is taken, three principles emerge for optimising the long-term value of riparian zones as nutrient filters. First, a riparian set-aside strategy needs to be accompanied by improved land use practices over the broader landscape, so that nutrient influx to the riparian zone is reduced. Second, periodic harvesting of plant material from the riparian set-aside is needed to ensure plant uptake remains a continued net nutrient removal mechanism. Third, riparian set-aside widths should be established on the basis that the sustainable net nutrient removal capacity of the zone needs to be matched to the nutrient influx from upslope. We believe that future decisions on establishing and managing riparian set-asides should use these principles as a basis, so that such areas can continue to achieve water quality goals in the long-term.

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