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Nutrient content and extractability in riparian soils supporting forests and grasslands

James A. Entry [*], William H. Emmingham

Department of Forest Science, Oregon State University, Corvallis, OR 97331, USA

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Abstract

Current agricultural practices are responsible for the deposition of large quantities of nutrients to lakes and streams. As the quantity of fertilizer applied often exceeds soil storage capacity, excess nutrients may be discharged from the surface and subsurface into lakes and streams. Riparian forests have been shown to filter some nutrients from agricultural runoff and subsurface flow. We measured nutrient stores and extractability in each season on three sites in surface organic litter and the top 10 cm of mineral soil to compare the buffering capacity of riparian soils supporting forest and grassland vegetation. In all seasons, greater total amounts of nutrients were immobilized in forest surface litter than in grassland surface litter, and greater amounts of NH_4^+, NO_3^-, P, Ca, Mg, Mn, and Fe were extracted. In the forest, more total N, P, K, Mg, and Zn were found in the surface organic litter in autumn than in other seasons; amounts in grassland did not vary with season. On like soils, the forested riparian sites had substantially greater quantities of macronutrients in the surface organic litter than did grassland sites. In the top 10 cm of mineral soil, more P, K, Ca, Mn, and Fe, but less Zn, B, and Cu, were stored in forest than in grassland ecosystems; more P, K, Ca, but less Mg, were extracted. In the top 10 cm of mineral soil, forest sites had substantially greater quantities of macronutrients but smaller quantities of micronutrients than did grassland sites.

Keywords: Riparian filter strips; Nutrient cycling; Forest soil; Pasture soil; Soil organic horizon;; Water-quality degradation

1. Introduction

Agricultural management practices contribute to the degradation of water quality through nonpoint-source input of nutrients to lakes and streams. Studies show that forest vegetation in riparian areas can filter nutrients moving through both ground and surface water. Peterjohn and Correll (1984) estimated a net removal of 45 kg nitrate ha^{-1} $year^{-1}$ from subsurface water flowing from agricultural land through 50 m of riparian forest in Maryland. Lowrance et al. (1984c) found that 68% of total N input and 30% of total P input to agricultural cropland in Georgia was retained in forest riparian soils. In a European study, forest vegetation in riparian areas retained 75% of the N and 45% of the P added to field crops (Pinay, 1986).

McNabb et al. (1986) estimated that soils in coniferous forests of the Pacific Northwest contain from 1000 to 1500 kg N ha^{-1} and from 22000 to 34000 kg C ha^{-1}. Nutrients taken up by vegetation are stored in soil organic matter, and from 25 to 30%

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[*] Corresponding author at: Department of Agronomy and Soils, 202 Funchess Hall, Auburn University, Auburn, AL 36849-5412, USA. Tel.: (205) 844-3967; fax: (205) 844-3945.

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of the C in these temperate forest ecosystems is in detrital components (Harmon et al., 1990). Organic matter can therefore be viewed as a sink in which nutrients are held until they are mineralized and thus made available for plant uptake (Qualls et al., 1991). As vegetation biomass accumulates in ecosystems, nutrients held in soil organic matter also increase (Entry and Emmingham, 1995).

This study is part of a larger study investigating the effectiveness of riparian filter belts to mitigate the input of nonpoint source pollution to lakes and streams (Entry and Emmingham, 1996; Entry et al., 1994; Entry et al., 1995; Entry et al., 1996). We hypothesized that riparian soils supporting forest ecosystems would accumulate greater amounts of vegetation and therefore more nutrients in surface organic litter than the same soils supporting grassland vegetation. The objective of this study was to compare the storage and extractability of nutrients in the surface organic litter and the top 10 cm of mineral soil of three riparian sites, each supporting pasture and forest vegetation.

2. Materials and methods

2.1. Site descriptions

Soil samples were taken in the Willamette Valley near Corvallis, Oregon from sites along Oak Creek (44°38′N, 123°15′W), Jackson Creek (44°38′N, 123°18′W), and Soap Creek (44°41′N, 123°15′W). Each of the three riparian areas selected supported both forest and grassland on one soil type. Grassland vegetation was mechanically harvested for feed; forest vegetation was not grazed.

The Oak Creek site is on a 3% slope in McDonald Forest near Oregon State University. The soil is a Fluvaquentic Haplaquoll, a fine mixed mesic in the Waldo series; pH averaged 6.3 in both forest and grassland (Knezevich, 1975). Annual precipitation is 127 cm, 2% or less occurring as snowfall. Mean annual air temperature ranges from 10 to 12°C. Overstory vegetation in the forest area is 40–60 year old *Quercus kelloggii* Newberry, understory vegetation is *Rosa woodsii* Lindl. and *Rubus parviflorus* Nutt. Grassland vegetation is *Festuca arundinacea* Schreb., *Trifolium pratense* L., and *Lolium perenne* L. Historical records describe this area as being grassland for approximately 100 years, during which it has not been fertilized or grazed (Hubbard, 1991).

The Jackson Creek site is in McDonald Forest on a 5% slope. The soil is a Vertic Haploxeroll, a fine montmorillonitic mesic in the Witham series; pH ranged from 5.9 to 6.2 in both forest and grassland (Knezevich, 1975). Annual precipitation averages from 100 to 150 cm year^{-1}. Average annual temperature is 10–12°C. Overstory vegetation in the forest zone is 30–60 year old *Pseudotsuga menziesii* (Mirb.) Franco, and 30–70 year old *Q. kelloggii*; understory vegetation is *Rosa woodsii*, *Rubus parviflorus*, and *Polystichum munitum* Roth. Grassland vegetation is *F. arundinacea*, *Trifolium subterraneum* L., *T. pratense*, and *L. perenne*. Historical records describe this area as being grassland for at least the previous 50 years, during which it has not been fertilized or grazed (Hubbard, 1991).

The Soap Creek site is on an 8% slope in Dunn Forest near Oregon State University. The soil is a Cumulic Ultic Haploxeroll, a fine silty mixed mesic in the McAlpin series (Knezevich, 1975); pH averaged 6.0 in both forest and grassland ecosystems. Annual precipitation ranges from 100 to 150 cm year^{-1}, annual temperature from 10° to 12°C. The forest overstory is 30- to 50 year old *Pseudotsuga menziesii*; understory vegetation is *Symphocarpus albus, Rubus parviflorus*, and *Polystichum munitum.* Grassland vegetation is *L. perenne, F. arundinacea, T. subterraneum*, and *Alopecurus pratensis* L. Historical records describe this area as being grassland for at least 60 years. It also has not been fertilized or grazed (Hubbard, 1991).

2.2. Experimental design

The experiment was arranged in a randomized block design (Kirk, 1982) with the three riparian sites as blocks and grassland and forest vegetation types as treatments. Sampling plots (25 cm × 25 cm) were randomly established on each site within each treatment. Total nutrient content and extractable nutrient content were analyzed separately for surface organic litter and soil cores from the top 10 cm of mineral soil taken on each sampling plot three times per season ($n = 72$: 3 sites × 2 vegetation types × 3 samples × 4 seasons). Samples were not composited.

2.3. Sampling procedures

We estimated the amount of organic matter on the soil surface of grassland and forest by weighing the litter from each plot after drying for 48 h at 80°C, then multiplying the weight by 160000. The concentration of a nutrient in the surface litter was estimated from a 10 g subsample from each plot, ground to pass a 1 mm opening. A 1 g subsample was ashed at 525 ± 2°C. The ash was then taken up in 10 ml of 6 M HCl; brought to 25 ml volume with distilled, deionized water, and analyzed for B, Ca, Cu, Fe, Mg, Mn, K, P, and Zn with an inductively coupled plasma spectrometer (Jarrol-Ash 9000, Waltham, MA). Total N was analyzed by standard microKjeldhal techniques modified for inclusion of nitrate (Bremner and Mulvaney, 1982). The amount of nutrient in a sample (N_s) was estimated by the formula: N_s = g organic matter $ha^{-1} \times$ (μg element g^{-1} organic matter).

To determine nutrient concentration in the top 10 cm of mineral soil we collected, at random, three soil cores for each site × vegetation type × season combination. Bulk density was measured with soil cores to 10 cm depth (Blake and Hartage, 1986). Each soil core was thoroughly mixed, and a 10 g subsample used for analysis for B, Ca, Cu, Fe, Mg, Mn, K, P, and Zn by digestion with hydrofluoric, sulfuric, and perchloric acids (Jackson, 1958; Lim and Jackson, 1982). A 10 g sample was ground to pass a 0.5 mm sieve, and a 5 g subsample of that material was placed in a 500 ml Erlenmeyer flask. Ten milliliters of 72% $HClO_4$ were added and swirled for 10 min, then 5 ml of 48% H_2SO_4 were added and swirled for 5 min. The sample was placed on a laboratory bench for 24 h, filtered (Whatman No. 1), and brought to 200 ml volume for the same analysis that was performed for organic matter. The amount of nutrient in a mineral soil sample was estimated by the formula: N_s = g mineral soil $ha^{-1} \times$ (g element g^{-1} mineral soil) with correction for soil bulk density. Average bulk densities for forest mineral soils were: Oak Creek 0.95, Jackson Creek 0.97, and Soap Creek 0.93. For grassland soils, average densities were: Oak Creek 1.03, Jackson Creek 1.04, and Soap Creek 1.09.

To determine the amount of extractable B, Ca, Cu, Fe, Mg, Mn, K, and Zn in organic matter and mineral soil, a 2 g subsample was extracted with four 25-ml aliquots of 0.5 M NH_4 OA_c plus 0.00025 M diethylenetriaminepentaacetic acid (DTPA), shaken for 7 min, centrifuged at 180 cycles min^{-1}, and analyzed for the elements named on an inductively coupled plasma spectrometer (Jarrol Ash 9000, Waltham, MA). Phosphorus was extracted with Bray techniques (Olsen and Sommers, 1982). N was ex-

Table 1
Seasonal total nutrient content (kg ha^{-1}) in the surface organic litter of riparian forest and grassland [a]

Measure and plot vegetation		N [b]	P	K	Ca	Mg	Mn	Fe	Cu	B	Zn
Forest	Winter	159.3B	16.8B	24.6B	282.2A	27.4B	7.7A	66.4A	1.14A	0.34A	0.38B
	Spring	175.9B	17.9B	24.1B	294.6A	26.5B	7.6A	74.3A	0.12A	0.46A	0.46B
	Summer	172.9B	16.2B	25.6B	268.5A	32.4B	7.0A	65.0A	0.15A	0.41A	0.51B
	Autumn	215.6A	20.1A	30.2A	315.8A	37.9A	8.1A	78.9A	0.18A	0.49A	0.60A
Grassland	Winter	9.2C	1.0C	1.1C	3.9B	1.1C	0.2B	0.4B	0.03B	0.02B	0.02C
	Spring	10.2C	1.5C	4.1C	8.4B	2.0C	0.1B	0.8B	0.04B	0.08B	0.01C
	Summer	16.5C	2.0C	4.6C	11.1B	2.5C	0.1B	0.7B	0.07B	0.06B	0.02C
	Autumn	12.5C	0.9C	1.4C	4.6B	1.1C	0.3B	0.5B	0.01B	0.08B	1.09C

[a] Repeated-measures analysis of variance of total nutrients stored per hectare indicated no significant differences among sites or the interactions of site × season or site × season × vegetation type; therefore, results are given only for vegetation type × season. In each block within a column, values followed by the same letter are not significantly different as determined by Fisher's protected least significant difference test ($P \leq 0.05$).

[b] Kjeldahl N.

Table 2
Total nutrient content (kg ha^{-1}) in the top 10 cm of mineral soil of riparian forest and grassland [a]

Plot vegetation	N [b]	P	K	Ca	Mg	Mn	Fe	Cu	B	Zn
Forest	2900A	770A	2400A	9800A	96A	38A	900A	1.0B	0.7A	1.0B
Grassland	2000B	620B	1600B	5300B	85A	21B	600B	1.5A	1.0B	1.5A

[a] Repeated-measures analysis of variance for total nutrient content in the top 10 cm of mineral soil indicated no significant difference among sites, seasons, or the interactions of site × season, site × vegetation type, season × vegetation type, or site × season × vegetation type; therefore, results are given only for vegetation type. In each column, values followed by the same letter are not significantly different as determined by Fisher's protected least significant difference test ($P \le 0.05$).

[b] Kjeldahl N.

tracted (as NO_3 and NH_4) by microdiffusion techniques (Keeney and Nelson, 1982) and analyzed on an Alpkem RFA 300 autoanalyzer (Alpkem, Portland, OR).

2.4. Statistical analysis

All data were subjected to repeated-measures analysis of variance for a randomized block design (Kirk, 1982). The residuals were normally distributed with constant variance. SAS programs (Statistical Analysis Systems Institute, Inc., 1982) were used for calculations. Significance was determined at $P \le 0.05$ with Fisher's protected least significant difference test.

3. Results

Where repeated-measures analysis of variance of nutrient concentrations and availability indicated no significant differences, results are not given in the tables (Kirk, 1982). In surface organic litter, concentrations of all nutrients, except N, were greater in forest than in grassland samples, but the difference expressed in micrograms per gram was significant only for Mn. In the mineral soil, concentrations of Mg, Cu, Zn, and B did not differ. Grassland contained significantly more Mn and Fe than did forest land.

In all seasons, forest samples of surface organic litter contained significantly greater amounts of all nutrients, expressed in kilograms per hectare, than did grassland samples. Significantly more N, P, K, Mg, and Zn per hectare were found in forest samples in autumn than in other seasons, but nutrients stored in the grassland organic matter did not vary with season (Table 1).

When expressed in kilograms per hectare, concentrations of N, P, K, Ca, Mn, Fe, and B in mineral soil were higher in forests than in grasslands (Table 2); only B, Zn, and Cu were greater in grasslands.

Table 3
Nutrients extracted from the surface organic litter and top 10 cm of mineral soil ($\mu g\ g^{-1}$) of riparian forests and grasslands [a]

Plot vegetation	NH_4	NO_3	P [b]	K	Ca	Mg	Mn	Fe	Cu	B	Zn
Organic matter											
Forest	8.7A	12.4A	21.7A	1130A	5693A	1255A	183A	318A	6,92A	1.8A	12.0A
Grassland	3.0B	3.0B	2.1C	1135A	3328C	233B	19A	275A	8.36A	1.7A	13.0A
Mineral soil											
Forest	86.9A	12.5A	163A	713A	5424A	23B	198A	34A	1.1A	11.6A	0.6A
Grassland	29.5B	13.0A	21B	423B	3888B	31A	183A	30A	1.2A	10.5A	0.5A

[a] Repeated-measures analysis of variance of nutrients extracted from the surface organic litter and the top 10 cm of mineral soil indicated no significant differences among sites, seasons, or the interactions of site × season, site × vegetation type, season × vegetation type, or site × season × vegetation type; therefore, results are given only for vegetation type. In each block within a column, values followed by the same letter are not significantly different as determined by Fisher's protected least significant difference test ($P \le 0.05$).

[b] Bray P.

More NH_4^+, NO_3^-, P, Ca, and Mg were extractable from forest organic matter than from grassland organic matter (Table 3). More NH_4^+, P, K, and Ca were extractable from mineral soil in forests than in grasslands, but more Mg was extractable from grassland. The amount of NO_3^-, Mn, Fe, Cu, B, and Zn extracted did not differ between vegetation types.

4. Discussion

Our data indicate that forest riparian sites contain more nutrients in both the surface organic litter and top 10 cm of mineral soil than do riparian grasslands, and that they contain more extractable nutrients. Most of the largest difference between the amount of nutrients can be attributed to forest woody debris that decomposes slowly to create an appreciable litter layer. The results, based on forest and pasture vegetation growing on identical soils on each site, should be free of differences due to varying soil types among treatments.

Previous case studies have demonstrated that forest ecosystems can act as filterstrips to reduce large quantities of nutrients from agricultural fertilizers moving in both surface and subsurface flows (Schlosser and Karr, 1981; Omernik et al., 1981; Peterjohn and Correll, 1984; Lowrance et al., 1984a), preventing sediment deposits into streams (Lowrance et al., 1984b; Cooper et al., 1987) and increasing denitrification rates, thereby removing N from soil water (Ambus and Lowrance, 1991; Lowrance, 1992). Our analysis shows that a substantial amount of nutrients are held in the soil organic horizon. However, Smith (1992) found that close planting of coniferous trees in riparian areas increased sediment and N and P additions to stream water. Once the conifer canopy matured, light to the forest floor, and thus to ground cover, was reduced. Establishing forests in grassland riparian areas may therefore initially increase rather than decrease nutrient deposition in lakes and streams until the forests are mature and have accumulated an appreciable understory and organic horizon.

As riparian forests increase in biomass, more nutrients will be held in vegetation and organic matter, although the amount of macronutrients stored in the organic layer of the forest floor can be expected to fluctuate with leaf fall in deciduous forests. If forests reach a point at which organic-matter input from litter fall equals organic-matter degradation, the accumulation of organic matter on the forest floor will no longer increase. At that point, nutrient storage capacity in the vegetation and forest floor will also no longer increase, but selective whole-tree harvesting of trees should remove sufficient quantities (Boyle et al., 1973; Kimmins, 1977) to promote continued biomass accumulation and continued nutrient removal from surface and subsurface water. The design of riparian filterstrips to mitigate nutrient input from agricultural lands, and thus to improve water quality, will require more thorough understanding of nutrient storage by forest and grassland ecosystems.

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