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Total phosphorus concentrations and compaction in riparian areas under different riparian land-uses of Iowa

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ABSTRACT

Reducing non-point source phosphorus (P) pollution is often necessary to improve water quality in agricultural streams. Soil total P (TP) concentrations and compaction are soil characteristics that can influence P losses to streams. The objective of this study was to compare these two soil characteristics among riparian forest buffers, grass filters, pastures with cattle fenced out of the stream, intensive rotational, rotational and continuously grazed pastures and row-cropped fields in three physiographic regions of Iowa. Soil TP and compaction for the seven riparian land-uses were determined in stream bank and surface riparian soils. Total P concentrations in stream bed material along the seven riparian land-uses were also measured. Total P concentrations in riparian stream bank soils among land-uses ranged from 303 to 398 mg kg^{-1} in the central region, to 432–518 mg kg^{-1} in the northeast, to 360–555 mg kg^{-1} in the southeast. In the surface riparian soils TP among land-uses ranged from 434 to 649 mg kg^{-1} in the central region, to 493–764 mg kg^{-1} in the northeast region, to 428–716 mg kg^{-1} in the southeast region. Finally, the TP concentrations in the stream bed sediments among land-uses ranged 194–307 mg kg^{-1} in the central region, to 169–461 mg kg^{-1} in the northeast, to 389–964 mg kg^{-1} in the southeast. Few soil TP significant differences among riparian land-uses within regions were found. Soil compaction under some of the grazing practices was significantly higher than under the conservation practices. Limited differences in soil TP concentrations and compaction were partially due to the young age of the conservation practices and the rotational and intensive rotational pastures. Past land-use on these sites had been either continuous grazing or row-cropping and those uses were still influencing these soil parameters. Within riparian land-uses, surface riparian soils generally had higher TP than the stream bank riparian soils. Stream bed samples had lower TP concentrations than the riparian soils in the northeast and central regions but were higher than the riparian soils in some of the land-uses in the southeast region. Overall TP concentrations in the stream bank, surface riparian soils and stream bed material were high indicating that these areas can potentially be important source areas of P and the focus should be on reducing the transport of P.

1. Introduction

The United States Environmental Protection Agency (1996) has recognized eutrophication as the main cause of impaired waters. In most cases, the accelerated input of phosphorus (P) is the main reason for eutrophication in fresh water systems (Sharpley et al., 1994). To efficiently reduce P inputs to streams, management plans should focus on areas that are both high P sources and have high potential for transport (Sharpley et al., 2003). These areas are called "critical source areas."

Stream banks and surface riparian soils with high levels of P and short transport paths can be critical sources of P. Many indicate that agricultural erosion and runoff from soils with high P concentrations are the major contributing factors to the eutrophication of surface waters (Sharpley et al., 2003). Another source of P can be stream bed material that can become part of the P load in the stream water through re-suspension. Overland flow (Daniel et al., 1994), stream bank erosion (Kronvang et al., 2002) and stream bed re-suspension (Evans et al., 1997; Owens and Walling, 2002) are the major transport paths of P for many streams. The accumulation of P in agricultural riparian soils or bed material means a larger pool of P that can be transported (Pote et al., 1996). Fixen and Roberts (2002) reported that 61% of the soil samples

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analyzed by the State of Iowa had P concentrations in the high or above category, meaning these soils required little or no P fertilization. In general, P losses in overland flow are linked to surface soil P concentrations although other soil characteristics and land management can influence this relationship (Sharpley et al., 2003).

One of the important soil characteristics that can influence this relationship is soil compaction. Generally, an increase in soil compaction leads to more erosion and overland flow (Thurow et al., 1988) that can lead to an increase in P inputs to streams. Riparian areas are sensitive to compaction because they tend to be wet for long periods (Warren et al., 1986).

Soil and stream bed P concentrations and soil compaction are influenced by land-use practices (Gburek et al., 2000; Mapfumo et al., 1999; Wohl and Carline, 1996). van der Perk et al. (2007) found that soil total P (TP) was dependent on land cover although parent material was the major controlling factor.

This study compared soil and sediment TP concentrations and soil compaction among different riparian land-uses in three physiographic regions of Iowa. Specifically, rotational and intensive rotational grazing and pastures with cattle fenced out of the stream were compared to the traditional Iowa agricultural practices, annual row-cropping and continuous grazing as well as to the conservation practices, riparian forest buffers and grass filters. The goal of the study was to develop an overall picture of variability of soil TP and compaction across the state to identify sensitive areas that need further study. Only TP was analyzed because of limited time and resources and because all forms of P have the long-term potential of being a source. The objectives of the study were to compare: (1) TP concentrations in stream bank and surface riparian soils and stream bed material among and within seven riparian land-use practices in three physiographic regions of Iowa, and (2) compaction of riparian soils among seven riparian land-use practices in three physiographic regions of Iowa.

Riparian soil TP concentrations were hypothesized to increase in the following order: riparian forest buffers (RF), grass filters (GF), pastures with cattle fenced out of the stream (PF), intensive rotational pastures (IP), rotational pastures (RP), continuous pastures (CP) and annual row-cropped fields (RC). Soil compaction was hypothesized to increase in the same order with the difference that CP would have higher compaction than RC. Finally, surface riparian soils were expected to have higher soil TP concentrations than stream banks soils and stream bed material.

In the past, most Iowa riparian areas were managed as RC or CP. Today many riparian areas are being placed in conservation practices like RF and GF through the Conservation Reserve Program (CRP). In addition, the Natural Resource Conservation Service (NRCS) is recommending RP and IP to replace CP (USDA-NRCS, 1997a). Farmers are slowly adopting RP and IP in Iowa because these practices better utilize pasture forages, increasing profitability (USDA-NRCS, 1997a). These land-use changes in Iowa make it important to investigate if the establishment of these new riparian land-uses will have an impact on soil characteristics such as soil TP and compaction.

2. Methods and materials

2.1. Study area

The research was conducted in central, northeast and southeast Iowa. Northeast and southeast Iowa were selected because they are major livestock grazing regions and the central Iowa region was selected because sites in the *Bear Creek National Restoration Demonstration Watershed* could be used and data compared to many other studies conducted by our research group. The Iowan Surface and the Paleozoic Plateau are the major landforms in the northeast region (Prior, 1991). The Iowan Surface has gently rolling terrain created by material moved by strong weathering events under permafrost conditions during Iowa's last glaciation. The Paleozoic Plateau is the oldest landscape in Iowa with deeply incised narrow valleys and almost no glacial deposits. The Des Moines Lobe landform, in the central region, has poorly developed natural drainage, flat terrain, with some broad ridges, and small hills and prairie wetlands because it is the most recently glaciated landscape of Iowa (Prior, 1991). The Southern Iowa Drift Plain in southeast Iowa, has a highly developed drainage network with steeply rolling hills and valleys developed from incision through a loess cap into glacial material deposited 500,000 years ago (Prior, 1991).

2.2. Riparian land-uses

The RF and GF are conservation practices that are widely used in the Midwest to protect surface waters from non-point source pollution. The RF in this study consisted of tree, shrub and warm season grass zones (USDA-NRCS, 1997b). The GF consisted of cool-season grasses and forbs (USDA-NRCS, 1997c). Many potential RF and GF sites were relatively young when this project started because these two practices became available for cost-share with the CRP, part of the 1996 Farm Bill. Only those sites that had been established for at least 5 years at the beginning of the study were selected for this study. Most of these were on land that had previously been managed as RC or CP. Studies have shown that re-established RF on previously cropped sites can significantly change certain soil characteristics after only 3–5 years (Schultz et al., 2000).

The RC and CP are traditional Iowa farming practices. Annual row-crops of corn (*Zea mays* L.) and soybean (*Glycine max* (L.) Merr.) were grown in alternating years on RC selected for this study. While some stream banks had narrow strips (<4 m) of grasses and/or annual weeds along them, many others were cropped up to the edge of the stream bank. In CP, cattle had full access to the stream and the entire pasture throughout the grazing period. In the CP of northeast and central Iowa, grazing started approximately in early May and ended approximately in early November. In the southeastern region, one of the CP followed similar dates, while in the other two CP, the cattle grazed year around with supplemental feed provided during the winter.

The IP and RP were grazed from approximately early May to early November in all regions. Most of these pasture sites had been previously managed as CP, but were only selected if they had been established as IP and RP for at least 3 years. Older sites were difficult to find when this project started because the NRCS in Iowa had only recently started recommending the practice for managing grazed beef cattle. The typical RP were divided into 2–3 paddocks, with each paddock grazed 15–30 days and rested for 30 days. The IP were divided into 6 or more paddocks, with each paddock grazed 1–7 days and rested for 30–45 days.

We must note that grazing started and ended on different dates for every pasture site used in the study leading to different numbers of grazing days per year. All pasture systems were grazed by beef cattle and consisted primarily of cool season grasses and forbs.

The last riparian land-use was PF with the fence on both sides of the stream. Pastures selected for this study had to have the stream fenced for at least 3 years. Previously on these PF sites, livestock had complete access to the stream channel. This is a practice that farmers in Iowa are often not willing to adopt because the stream is the main water source for cattle and the high cost of maintaining fences.

Table 1
General characteristics of the riparian land-uses across three physiographic regions of Iowa

Riparian land-use	Sites (#)	Soil series[a]	Soil texture[a]	Stocking rate (cow-calf ha^{-1})	P application
Central					
Row-cropped fields	2	Spillville[b]–Coland[b] complex	Clay loam, Loam	N/A[c]	No
Continuous pastures	2	Coland, Colo[b], Spillville–Coland complex	Silt loam, Clay loam, Loam	1.5–2.0	No
Rotational pastures	2	Coland, Coland-Terrill[b] complex	Clay loam	1.0–2.5	No
Grass filters	2	Spillville[b], Spillville–Coland complex	Clay loam, Loam	N/A[c]	No
Riparian forest buffers	2[d]	Coland, Hanlon[b]-Spillville and Spillville–Coland complexes	Clay loam, Loam	N/A[c]	No
Northeast					
Continuous pastures	3	Dorchester[e], Radford[b], Otter[b]–Ossian[b] complex	Silt loam	1.2–2.0	No
Intensive rot. Pastures	3	Dorchester, Dorchester–Cheseburg[e]–Vinje[b] and Dorchester–Cheseburg complexes	Silt loam	1.0–1.7	No
Streams fenced	2	Radford, Spillville	Silt loam	N/A[e]	No
Riparian forest buffers	2	Colo–Otter–Ossian complex, Spillville	Silt loam, Loam	N/A[e]	No
Southeast					
Continuous pastures	3	Nodaway[e], Nodaway–Cantril[f] complex	Silt loam, Loam	1.2–2.2	Fertilizer (2 sites) No (1 site)
Rotational pastures	2	Nodaway	Silt loam	0.7–2.4	Manure (1 site) No (1 site)
Intensive rot. Pastures	2	Nodaway, Nodaway–Cantril complex	Silt loam, Loam	0.7–1.2	Fertilizer (1 site) No (1 site)
Stream fenced	1	Nodaway	Silt loam	N/A[e]	No
Grass filters	2	Amana[c], Nodaway	Silt loam	N/A[e]	No

[a] Soil Survey Geographic (SSURGO), 2004.
[b] Mollisol soil order.
[c] N/A = not applicable.
[d] In this region a natural forest along the stream was used as a riparian forest buffer site.
[e] Entisol soil order.
[f] Alfisol soil order.

2.3. Selection of riparian land-use sites

In addition to land use, the main criteria for selecting sites were: (i) similar soil mapping units and (ii) stream order (Strahler, 1957). We used SSURGO (2004) data and selected sites that had similar soil textures within each region (Table 1). All soils had an alluvial origin. To minimize the impact of fluvial geomorphic processes all selected riparian land-use sites where located along 1–3rd order (low order) streams. Fluvial geomorphic processes (erosion and deposition) can heavily influence the nature of riparian soils. As the order of the stream changes these processes change and influence the riparian soils.

The sites were located on private farms to evaluate actual farmer management practices and because it would be easier to convince farmers to change their management practices by demonstrating results from practices on their neighbor's farm. After meeting with more than 70 landowners and visiting more than 120 sites over a 6-month period, 30 sites were selected. Suitable sites of all riparian land-uses could not be found in every region. The riparian land-uses found in each region can be seen in Table 1.

2.4. Measurements

Soil samples for TP concentration and bulk density analysis were collected from the stream bank (Fig. 1a) and surface (Fig. 1b) riparian areas. In the surface riparian soils penetrometer resistance was also measured. The soil penetrometer had a cone diameter of 1.3 cm (Bush, Mark 1 Model 1979, Findlay, Irvine Ltd., Penicuik, Scotland). Samples for TP concentration analysis were collected from the stream bed (Fig. 1c). The samples from the stream bed included both the bed material (the underlying original material) and the sediments deposited on the stream bed, part of the bed load.

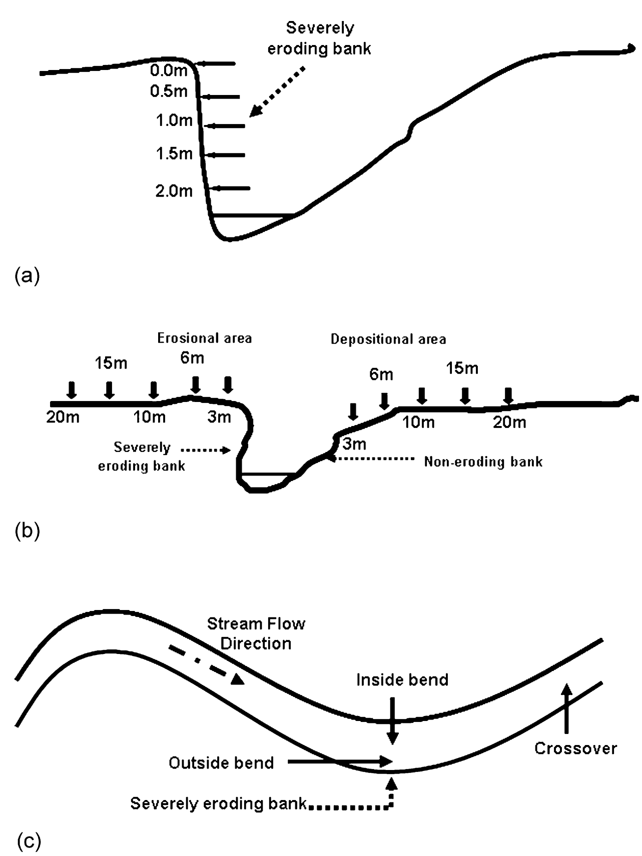

Fig. 1. Sampling design for: (a) stream bank riparian soils; (b) surface riparian soils, and (c) stream bed material. The severely eroding bank is the same for all three sampling designs.

2.5. Sampling design for riparian soils

Riparian areas are disturbance driven and have highly variable soils resulting from numerous varying depositional events. The dynamics of the disturbance tends to be similar along similar order streams in a given physiographic region. Since we were also interested in stream banks as a critical source area for TP all of the surface sampling sites were located perpendicular to severely eroding stream banks. Severely eroding banks are bare with slumps, vegetative overhang and/or exposed tree roots (USDA-NRCS, 1998). The first step of the sampling design was to randomly select three severely eroding banks within each riparian land-use site after all its severely eroding stream banks were identified.

2.5.1. Stream bank riparian soils

Only the severely eroding banks were sampled because of their greater potential as a critical source area for eroded sediment (Beeson and Doyle, 1995) and TP. At each eroding bank, two 5 cm × 3 cm (depth × circular diameter) soil cores for TP analysis and two 7.5 cm × 3 cm (depth × circular diameter) cores for bulk density analysis (Naeth et al., 1990) were collected every 0.5 m from the top (0.0 m) to the bottom of the bank (Fig. 1a). The two soil cores collected at each depth were consolidated into one sample. The total number of soil samples for each bank varied depending on its depth. Typically, 15 (ranging from 12 to 16) consolidated samples each, for TP and bulk density, were collected and analyzed for each site.

2.5.2. Surface riparian soils

Riparian soil samples for TP and bulk density were collected at sampling distances of 3, 6, 10, 15 and 20 m perpendicular to each of the randomly selected severely eroding stream banks on both sides of the channel (Fig. 1b). This way, both erosional and depositional surface riparian soils were sampled, since both have the potential of overland flow. At each sampling distance, three 15 cm × 3 cm (depth × circular diameter) soil cores were collected for TP analysis and divided into 0–5 and 6–15 cm depths. At each depth the three cores were consolidated into one composite sample. Fifteen centimetres is the typical sampling depth for agronomic P tests while the 0–5 cm depth is typically the maximum depth of interaction between overland flow and the soil (Sharpley et al., 1994). Thus, typically 30 consolidated soil samples for each depth were collected and analyzed for TP at each site, in most cases. The number of consolidated samples at some sites was as low as 20 because some riparian land-uses did not extend 20 m from the stream bank edge. Three additional soil cores 7.5 cm × 3 cm (depth × circular diameter) (Naeth et al., 1990) were collected at the same sampling distances and combined into one composite sample for bulk density analysis. Studies have shown that cattle trampling increases compaction down to depths of 7–10.5 cm (Mulholland and Fullen, 1991). At the same sampling distances three penetrometer resistance measurements were taken at depths of 3.5, 7.0 and 10.5 cm. Typically, 90 penetration measurements were taken for each depth at each site. The number of measurements in some sites was as low as 60.

Soil samples and penetration measurements were only collected out to 20 m since many of the pastures had sections that were not much wider or even less than that. It has also been noted in the literature that in many riparian landscapes most of the P contributions to streams come from narrow bands along the stream (Johnes and Heathwaite, 1997; Gburek et al., 2000).

2.6. Sampling design for stream bed material

Stream bed samples were collected in the spring, summer and fall of 2002, to measure TP concentration. Different seasonal flow regimes can influence deposition, uptake and adsorption of P by bed materials changing stream bed TP concentrations (Dorioz et al., 1998). Samples of 5 cm × 5 cm (depth × circular diameter) were collected adjacent to the randomly selected severely eroding stream banks (Fig. 1c). Specifically one sample was collected on the inside bend (adjacent to the non-eroding bank), one on the outside bend (adjacent to the eroding banks) and one at the first downstream thalweg crossover point. These locations were selected to better capture the variation in stream bed material across the channel. Inside bends experience primarily deposition while outside bends experience scouring and crossover points tend to have coarser material because stream velocity is faster than in the other two locations. A total of nine samples were collected and analyzed for each site, every sampling season.

2.7. Laboratory analysis

The TP soil samples were air dried for 48 h and then sieved through a 2 mm screen. Samples were then digested with a sodium hypobromide solution and the extracted P was identified colorimetrically by a modified molybdenum blue reaction (Dick and Tabatabai, 1977). The bulk density soil samples were weighed after being dried for 1 d at 105 °C (Blake and Hartge, 1986).

2.8. Data analysis

The *mixed* SAS procedure was used to conduct the analysis of variance because the datasets were unbalanced (SAS, 1996). The model used for TP (dependent variable) in the stream bank riparian soils included the independent variables regions, riparian land-uses, and depth. Depth in this model referred to as top (0.0 m), middle (0.5, 1.0 m) and bottom (1.5, 2.0, 2.5 m) of the stream bank (Fig. 1a). The same model was used with bulk density as the dependent variable. In the surface riparian soils the model used for TP (dependent variable) included the independent variables regions, riparian land-uses and locations. Locations referred to whether the soil samples were collected on the erosional or depositional side of the channel (Fig. 1b). The same model was used with bulk density and penetrometer resistance as the dependent variables. For the stream bed, the TP concentration (dependent variable) model included the independent variables regions, riparian land-uses, seasons and locations. Seasons included spring, summer and fall while locations included the crossover point, inside bend and outside bend (Fig. 1c). For all the above models specific mean comparisons among riparian land-uses, stream bank and surface riparian soils and stream bed samples, locations and seasons were also conducted using the *lsmeans pdiff* command in SAS (SAS, 1996). Differences were considered statistically significant at the 10% level (when $p < 0.100$) because this was an observational study and riparian soils are highly variable.

3. Results and discussion

3.1. Total phosphorus concentration differences among riparian land-uses

Total P concentrations among riparian land-uses within a region showed few significant differences (Table 2). The range of TP concentrations for stream bank soils among riparian land-uses were from 303 to 398 mg kg^{-1} in the central region, 432–518 mg kg^{-1} in the northeast and 360–555 mg kg^{-1} in the southeast (Table 2). Stream bank riparian soil TP concentrations in the northeast and southeast regions were generally similar to those found in stream banks of a Minnesota agricultural watershed (441 mg kg^{-1}) (Sekely et al., 2002), while those in the central

Table 2
Total P concentrations for stream bank riparian soils, surface riparian soils at depths of 0–5 and 6–15 cm, and stream bed material for different riparian land-uses in three Iowa physiographic regions

Total P concentrations ($mg\ kg^{-1}$)								
	Stream bank[a]	Sig. diff. land-uses[b]	Surface 0–5 cm[a]	Sig. diff. land-uses[b]	Surface 6–15 cm[a]	Sig. diff. land-uses[b]	Stream bed[a]	Sig. diff. land-uses[b]
Central								
Row-cropped fields	354 (68)	A	640 (64)	A	528 (64)	A	228 (65)	A
Sig. diff.[c]	*b*		*a*		*a*		*c*	
Continuous pastures	349 (68)	A	552 (65)	A	472 (65)	A	194 (65)	A
Sig. diff.[c]	*b*		*a*		*ab*		*c*	
Rotational pastures	398 (68)	A	649 (64)	A	524 (64)	A	209 (65)	A
Sig. diff.[c]	*b*		*a*		*ab*		*c*	
Grass Filters	303 (68)	A	567 (64)	A	434 (64)	A	307 (65)	A
Sig. diff.[c]	*b*		*a*		*ab*		*b*	
Riparian forest buffers	350 (68)	A	589 (65)	A	495 (64)	A	237 (65)	A
Sig. diff.[c]	*b*		*a*		*ab*		*c*	
Northeast								
Continuous pastures	518 (56)	A	764 (53)	A	584 (53)	A	461 (56)	A
Sig. diff.[c]	*b*		*a*		*b*		*b*	
Intensive rot. Pastures	432 (58)	A	615 (53)	B	493 (53)	A	335 (53)	B
Sig. diff.[c]	*b*		*a*		*ab*		*c*	
Pastures streams fenced	464 (71)	A	601 (65)	B	544 (65)	A	169 (65)	C
Sig. diff.[c]	*b*		*a*		*ab*		*c*	
Riparian forest buffers	479 (70)	A	552 (65)	B	526 (65)	A	220 (72)	BC
Sig. diff.[c]	*b*		*a*		*ab*		*c*	
Southeast								
Continuous pastures	360 (56)	B	557 (53)	B	454 (53)	A	441 (53)	B
Sig. diff.[c]	*c*		*a*		*ab*		*b*	
Rotational pastures	459 (70)	AB	528 (64)	B	428 (64)	A	389 (65)	B
Sig. diff.[c]	*ab*		*a*		*ab*		*b*	
Intensive rot. Pastures	531 (70)	A	716 (64)	A	574 (65)	A	801 (65)	A
Sig. diff.[c]	*c*		*b*		*bc*		*a*	
Pasture stream fenced	555 (98)	A	660 (94)	AB	591 (95)	A	964 (91)	A
Sig. diff.[c]	*b*		*b*		*b*		*a*	
Grass filters	406 (70)	AB	506 (64)	B	536 (65)	A	434 (65)	B
Sig. diff.[c]	*b*		*ab*		*a*		*b*	

[a] The values in parenthesis are the standard error.
[b] Different letters (upper case) indicate significant differences ($p < 0.100$) among riparian land-uses.
[c] Different letters (lower case italics) indicate significant differences ($p < 0.100$) among stream bank riparian soils, surface riparian soils at depth 0–5 cm and 6–15 cm and stream bed sediments within a specific riparian land-use.

region were lower. Despite the wide range of TP concentrations among some of the riparian land-uses, significant differences were only found in the southeast region. In this region, the CP had significantly lower TP concentrations than the PF ($p = 0.084$) and the IP ($p = 0.056$), something opposite to what we expected. Incorporating sampling depths in the statistical models of the stream bank riparian soils did provide some more statistical differences but no real trends.

Total P concentrations of riparian soils at 0–5 and 6–15 cm across all three regions were within the range of naturally occurring TP of 300–1200 $mg\ kg^{-1}$ (Daniel et al., 1994) (Table 2). In the northeast region TP concentrations at 0–5 cm depth ranged from 552 to 764 $mg\ kg^{-1}$. The TP concentrations of the CP surface riparian soils at the 0–5 cm depth were significantly higher than those of the PF ($p = 0.057$), IP ($p = 0.046$) and RF ($p = 0.011$). Total P concentrations in the southeast region were similar to those in the northeast ranging from 506 to 716 $mg\ kg^{-1}$ among the different riparian land-uses. Total P concentrations were significantly higher in the 0–5 cm depth of the IP surface riparian soils than in the CP ($p = 0.058$), RP ($p = 0.040$) and GF ($p = 0.021$). Some of these differences were not expected. Total P concentrations at the 0–5 cm depth in the central region had the smallest range (552–649 $mg\ kg^{-1}$) of all regions with no significant differences among land uses.

Total P concentrations at the 6–15 cm depth for surface riparian soils ranged from 434 to 524 $mg\ kg^{-1}$ in the central region, 493–584 $mg\ kg^{-1}$ in the northeast region and 428–591 $mg\ kg^{-1}$ in the southeast region (Table 2). There were no significant differences in TP concentrations at this depth among riparian land-uses. Incorporating locations into the statistical model of the surface riparian soils (both 0–5 and 6–15 cm depth) did provide some more statistical differences but no real trends.

Land-use practices can have a major impact on TP concentrations in soils. Intensive row-crop agriculture can produce a surplus of P from fertilizer and animal waste inputs, while in pastures soil P can increase because of animal fecal deposition (Haygarth and Jarvis, 1999; Capece et al., 2007). In this study the hypothesized TP concentrations differences among the riparian land-uses were not consistently found. This is probably related to the fact that most sites other than the RC or CP had been in their present land-use for only 5 or more years (for RF and GF) or 3 or more years (for RP, IP and PF). The past land-use practices for these sites were RC or CP for decades (Burkhart et al., 1994) and they are still influencing the soil's TP concentrations. Although changing RC to RF have shown significant difference in other soil characteristics (Schultz et al., 2000) this was not true for soil TP. Soil TP takes considerable time to be depleted by leaching or plant uptake (Sharpley et al., 1994). In addition, there are no biogeochemical transformations that reduce P, in contrast to nitrogen, and this can lead to the accumulation of P in GF and RF in their role as buffers (Dorioz et al., 2006).

In the central region, the stream bed TP concentrations among riparian land-uses ranged from 194 to 307 mg kg^{-1} and were generally lower than concentrations in the stream bank or surface riparian soils (Table 2). The range of TP concentrations among riparian land-uses was wider for the stream bed samples in both the northeast (169–461 mg kg^{-1}) and the southeast (389–964 mg kg^{-1}) regions compared to their riparian soil counterparts. Interestingly, the highest concentration of the range in the central region was lower than the lowest concentration in the southeast region. These differences are attributed to the different landforms of each region. The southeast region had a higher percentage of fine substrates in the stream channel (Zaimes, 2004) compared to the other regions, probably the result of the loess originated material. Higher percentages of finer substrates in the stream bed samples can increase the TP concentrations. In comparison the glacial till derived samples in the central regions had comparatively much lower percentages of fine substrates (Zaimes, 2004).

The small range of TP concentrations in the stream bed samples among riparian land-uses in the central region led to no significant differences. In the northeast region, the CP bed samples had significantly higher TP concentrations than the IP ($p = 0.098$), RF ($p = 0.008$) and PF ($p = 0.001$). In this region the bed samples of the IP also had higher TP concentrations than the PF ($p = 0.046$). In the southeast region, the bed samples of the PF and IP had significantly higher TP concentrations than the bed samples of the CP, RP and GF (all $p < 0.001$). The high TP concentrations in the bed material of the IP and PF, while not the relationship that was hypothesized, correlates to the results found in both the 0–5 cm depth of the surface soils and the stream bank soils (Table 2) suggesting that differences are probably more tied to stratigraphy than land use. Incorporating locations into the statistical model of the stream bed samples provided some more statistical differences but no real trends.

As with the soil TP concentrations, stream bed TP concentrations did not show all the differences we had hypothesized. Since part of the stream bed material originates from the adjacent stream banks and surface riparian soils you might expect some correlations, however, because of the constant movement of suspended and bedload these sediments are almost constantly in flux. It is also possible that upstream land-uses in this highly disturbed landscape have contributed high TP sediments that have moved and accumulated downstream (Lyons et al., 2000). Finally, all stream beds in this study are embedded with finer material because their watersheds are heavily disturbed because of the agricultural activities of the last 50–100 years.

We also did not find any significant seasonal differences among stream bed TP concentrations within riparian land-uses (Fig. 2). The lack of seasonal differences may be because sediments in the stream bed of low order streams have greater sensitivity to smaller precipitation events that tend to occur frequently throughout the year. Small precipitation events, like 5 cm d^{-1} in the spring, when there is little vegetation cover in the uplands of the Iowa landscape, can cause discharges that can move substantial amounts of sediment in low order streams. In contrast, Dorioz et al. (1998) found seasonal differences in bed P concentrations in large rivers

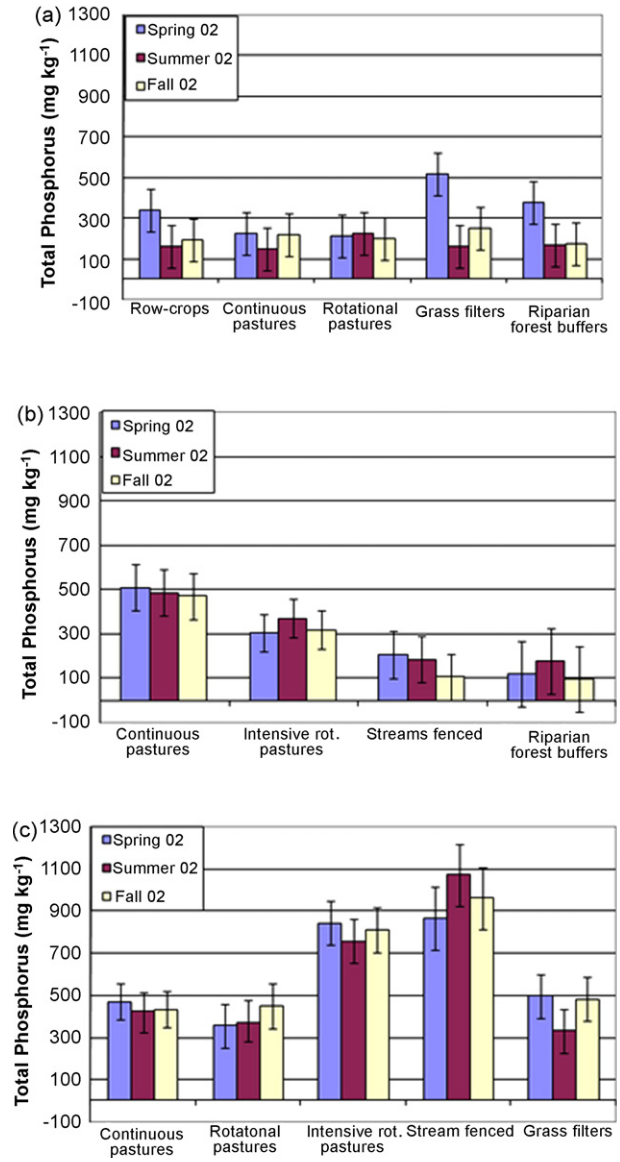

Fig. 2. Total P concentrations for stream bed material for spring, summer and fall of 2002, along different riparian land-uses in three Iowa physiographic regions: (a) central, (b) northeast, and (c) southeast.

that are influenced by larger precipitation and discharge events that are more season specific.

3.2. Total phosphorus concentration differences among stream bank and surface riparian soils and stream bed material within a riparian land-use

Total P concentration comparisons among stream bank riparian soils, surface riparian soils at depths of 0–5 and 6–15 cm and stream bed material within a riparian land-use had many significant differences (Table 2). In the central and northeast regions surface riparian soil TP concentrations at the 0–5 cm depth for all riparian land-uses were significantly higher than those in stream bank soils (all $p < 0.010$) and bed material (all $p < 0.001$). Comparing between the two surface riparian soil depths in these two regions, only in the CP in northeast Iowa did the 0–5 cm depth have significantly higher TP concentrations than the 6–15 cm depth ($p = 0.016$). The TP concentrations of riparian soils at the 6–15 cm depth (all $p < 0.034$) and stream bank soils (all $p < 0.009$) in these two regions were significantly higher than those in the bed material in all riparian land-uses except in the GF in the central region and the CP in the northeast region. Finally, the riparian soils at the 6–15 cm depth had only significantly higher TP concentrations than those in stream bank soils in the RC in the central region ($p = 0.064$).

In the southeast region, surface riparian soil TP concentrations at 0–5 cm depth were also significantly higher than concentrations in stream bank soils (all $p < 0.020$) and stream bed material (all $p < 0.031$) in the GF, CP and RP (Table 2). In the other two land-uses, IP and FP, we found some unexpected results. Specifically, the bed material in the IP ($p = 0.012$) and FP ($p < 0.001$), had significantly higher TP concentrations than those in the surface riparian soils at 0–5 cm depth. The TP concentrations in bed material of IP and FP were also significantly higher than those in the surface riparian soils at the 6–15 cm depth (both $p < 0.013$) and stream bank soils (both $p < 0.001$). Finally, the TP concentrations in bed material in the CP were significantly higher than those in the stream bank soils ($p = 0.017$).

In most soils, surface horizons have greater P concentrations than the lower horizons because of sorption of the added P from fertilizers, manure or livestock feces, greater biological activity, cycling of P from roots to aboveground plant biomass, and more organic material in the surface horizons (Sharpley et al., 2003). So TP concentrations of the surface riparian soils at the 0–5 depth and even at 6–15 cm depth were expected to be higher than those of stream banks. Stream bed material concentrations were also expected to be lower than the surface riparian soils because the deposited sediment originates from both the stream bank and surface riparian soils. In the central and northeast regions we did see many significant differences among the riparian surface soils (particularly the 0–5 cm depth) and the stream bank soils and stream bed material. In the southeast this was the case only in some of the land-uses. Although the soil TP concentrations at the 0–5 cm depth were expected to be higher than the 6–15 cm (Haygarth and Jarvis, 1999; Cooper and Gilliam, 1987) this difference was only significant in the CP in northeast region. The lack of significant differences between the two sampling depths of the surface riparian soils in the other land-uses, was probably due to the continuous agriculture activities (either RC or CP) on these sites over the last 50–100 years, that led to high accumulations of TP even in deeper depths. Overall, soil P can increase rapidly by fertilizer and manure applications and feces deposition but will take a significant time to decrease even if all P additions are stopped (Sharpley et al., 2003).

In the southeast TP concentrations in the stream bed material were higher compared to the other two regions. Phosphorus concentrations are impacted by management practices but also heavily depend on parent material (Daniel et al., 1994; van der Perk et al., 2007). The material at all sampling sites were alluvium, but differed because the alluvium originated in different landforms. In the northeast region the major parent material was limestone, in the central region glacial till and in the southeast it was loess. High percentages of P are correlated with high percentages of fine stream bed substrate, especially silt and clay. The stream bed material of the riparian land-uses with high TP concentrations had high percentages of silt and clay (southeast region) (Zaimes, 2004). The high percentages of these substrates found in the beds of some south-eastern streams are primarily related to the loess parent material.

3.3. Soil compaction differences among riparian land-uses

Bulk densities in the stream bank soils of the CP were significantly higher than those of the GF ($p = 0.069$) in the central region and the RF ($p = 0.081$) in northeast region (Fig. 3a and b). In the surface riparian soils, bulk densities in CP were significantly higher than those of the GF ($p = 0.072$) and RF ($p = 0.084$) in the central region (Fig. 3a). In the southeast region the bulk densities of the surface riparian soils in the RP were significantly higher than the GF ($p = 0.066$) (Fig. 3c).

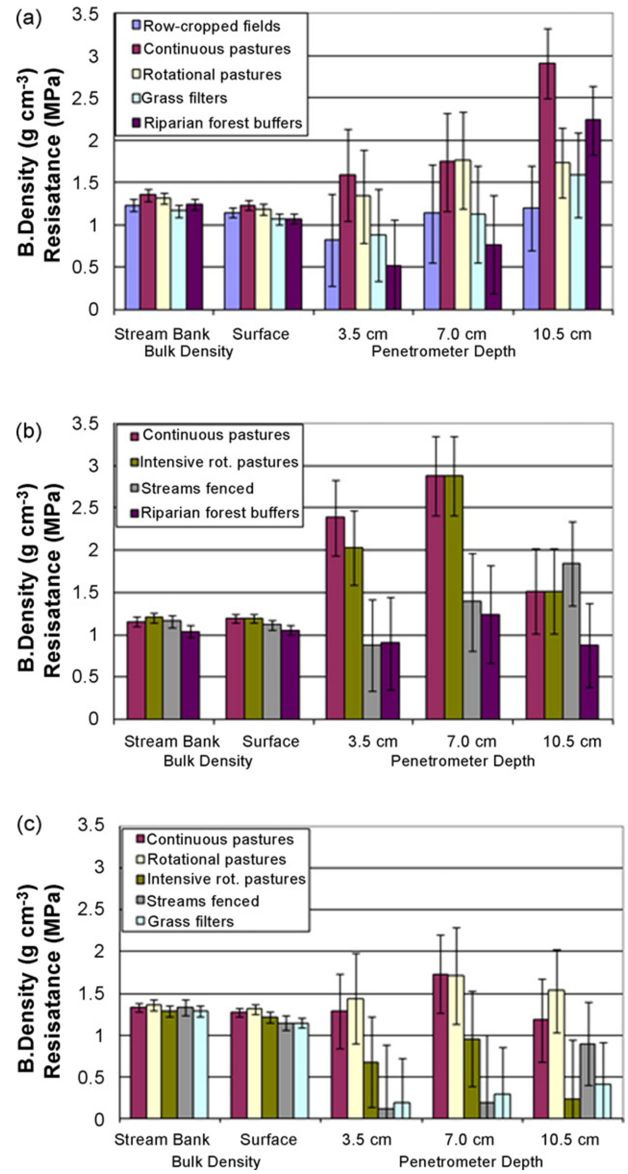

Fig. 3. Bulk density and penetrometer resistance under different riparian land-uses in three physiographic Iowa regions: (a) central, (b) northeast, and (c) southeast. Bulk density samples were collected from stream bank and surface riparian soils. Penetrometer resistance was only measured in the surface riparian soils at depths of 3.5, 7.0, and 10.5 cm.

Penetrometer resistance measurements were taken only in the surface riparian soils. In the northeast region, penetrometer resistance was significantly higher at the 3.5 cm depth in CP than in the FP ($p = 0.048$) and RF ($p = 0.050$) (Fig. 3b). Similarly, at the 7 cm depth, CP had higher resistance than the FP ($p = 0.064$) and RF ($p = 0.043$). Even at the 10.5 cm depth, the CP in the northeast region had higher penetrometer resistance than the RF ($p = 0.049$). In the southeast region, RP had higher penetrometer resistance than the GF at the 3.5 cm ($p = 0.096$) and 7 cm ($p = 0.057$) depths. Similarly, RP had higher resistance than the FP but only at 3.5 cm depth ($p = 0.084$). There were no significant differences among riparian land-uses in the central region.

Penetration points in livestock loafing areas and paths had the highest resistance readings. In most of these cases, penetrometer insertion would stop at the 0–3.5 cm depth, because resistance exceeded the instrument's maximum resistance of 3.1 MPa. Typically, livestock loafing areas and paths occupy a small percentage of the pasture but their locations near the stream provide direct routes for overland flow to reach the stream channel.

Penetrometer resistance and bulk density primarily, identified significantly higher values under grazing practices than the conservation riparian land-uses in the surface riparian soils although the two methods did not identify the same differences. Bharati et al. (2002) also found significantly lower bulk densities and higher infiltration rates in 5 year old riparian buffers compared to continuously grazed riparian pastures or row cropped fields in the central Iowa region. Other scientists have found significant differences in compaction among grazing practices using either soil bulk density or penetrometer resistance (Chanasyk and Naeth, 1995; Mapfumo et al., 1999) while others have not (Abdel-Magid et al., 1987). The lack of differences in this study may be because RP and IP had been established only in the last 3 or more years on previously CP. In general the past land-use practices (CP and RC) probably still have lingering effects on the current land-use practices.

3.4. Surface riparian soil TP concentrations and compaction

Combining the results of both soil TP concentrations and compaction of the surface riparian soils indicate that CP and RP would be more important potential sources of TP than the conservation practices. Although there were minimal to no significant difference in TP concentrations among riparian land-uses, the compaction in CP and RP soils based on both bulk density and penetrometer resistance, were significantly higher than those of the conservation practices. Soil characteristics such as compaction can heavily influence P losses by overland flow (Sharpley et al., 2003). Considering that RF and GF can also significantly reduce overland flow (Dillaha et al., 1989; Lee et al., 1999, 2000) indicates that these practices can significantly contribute to the reduction of P inputs to the stream.

4. Conclusions

Differences in TP concentrations among riparian land-uses in the stream bank and surface riparian soils were in most cases not significant. The historical riparian land-uses for all sites including those converted to conservation practices or rotational grazing practices were CP or RC. These historical land-use practices have led to high riparian soil TP concentrations that are difficult to decrease once elevated. Significant differences in stream bed TP concentrations were also limited and in some cases the opposite of what was expected. This is probably related to higher natural stream velocities, because of higher channel slopes that result in more significant upstream contributions, or because the stream reaches have been embedded by past land-use practices such as CP and RC.

Within a given land-use in the central and northeast region, riparian surface soils had the highest TP concentrations followed by the stream bank soils and then stream bed material. In the southeast region, stream bed TP concentrations were higher than in the other two regions indicating regional differences in TP concentrations that could be attributed to differences in parent materials among the regions. The stream bed TP concentrations in some sites in the southeast were even significantly higher than the surface riparian soils. The high TP concentrations in stream bank soils and bed material (especially in the southeast region), indicate that these areas have the potential of being critical source areas for P transported by stream bank erosion and stream bed re-suspension.

Soils in CP and RP in some regions had higher bulk densities and penetrometer resistances than the GF, RF and PF. These differences suggest that CP and RP would have lower infiltration rates and higher overland flow and P losses, compared to the conservation practices. Comparing the three grazing practices there were no significant differences, probably attributed to the lingering effects of past land-uses.

Overall the high total TP concentration in all riparian land-uses indicate that the key to reducing non-point source P from reaching the streams is by reducing it is transport paths, especially overland flow and stream bank erosion. Other studies have shown that RF and GF can effectively reduce sediments and TP from overland flow (Dillaha et al., 1989; Lee et al., 1999, 2000; Dorioz et al., 2006) although they are more effective in removing the coarser material (sand and silt), that have lower P concentration, than the clays and more effective in removing particulate P than dissolved P. In addition, other studies have shown reduction of stream bank erosion under RF and GF (Lyons et al., 2000; Zaimes et al., 2004, 2006, in press) and indications that PF can also be effective (Zaimes et al., in press). Based on the studies just mentioned and the results of this study, setting aside or planting GF or RF along critical areas adjacent to streams is probably the most effective way to reduce non-point source P from reaching them.

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