



Phosphorus Equilibrium Characteristics for Soils in the Upper Eau Galle River Watershed, Wisconsin

by *William F. James*

PURPOSE: The purpose of this demonstration was to examine phosphorus adsorption-desorption and equilibrium characteristics for soils collected from different land use practices in the Upper Eau Galle River watershed (Wisconsin). Land use practices included grazed pasture, row and perennial crop production, conservation reserve program or fallow land, and woodlots. This information will be important for watershed model algorithm improvements and applications that require categorization of soils as a function of phosphorus (P) concentration and equilibrium characteristics.

BACKGROUND: Runoff of soluble P is related to land use and soil management practices that influence the P content of the source soils in hydrologically sensitive areas of watersheds (Sharpley et al. 1994; Gburek and Sharpley 1998; Walter et al. 2000, 2001). Soil fertilization and manure application in excess of crop P requirements can lead to the buildup of high soil P levels over time that can become desorbed during rainfall and contribute to soluble P concentrations in the runoff (Sharpley et al. 1994). Research has found general linear relationships between soil extractable P and soluble P in the runoff (Pote et al. 1996, 1999; Fang et al. 2002). However, factors such as water infiltration and runoff volume can be affected by soil preparation practice (i.e., till versus no-till) and crop coverage, leading to variability in overall soluble P runoff mass for different land use practices (Sharpley 2003). If equilibrium reactions between soils and aqueous phases are playing an important role in regulating soluble P concentrations in the runoff (Sharpley et al. 1981), then linear relationships should also exist between soil extractable P and the equilibrium phosphate concentration and this pattern should be affected by land use practices that result in the buildup of soil P. The objectives of this demonstration were to examine relationships among soil extractable P forms, the degree of soil P saturation, and equilibrium P concentrations for soils collected from different land use practices in a Wisconsin watershed that drains into a eutrophic Corps of Engineers impoundment.

METHODS: The Upper Eau Galle River watershed drains a 123.3-km² area above the Eau Galle Reservoir, a Corps of Engineers impoundment (USACE District, St. Paul) located in west-central Wisconsin that provides flood protection and recreation (see James et al. (2004a)). Agricultural practices account for greater than 80 percent of the land usage in the watershed; these include annual and perennial crop production (i.e., corn, oats, alfalfa, grass hay, soybeans), pasture, and livestock dairy production. Other land uses include Conservation Reserve Program (CRP), fallow lands, and wooded areas. The watershed is located within the glaciated region of Wisconsin and the dominant soil associations are the Vlasaty-Skyberg, located in the eastern portion of the watershed, and Saltre-Pillot Antigo, located in the western portions (Ashby 1985).

Soils used for P adsorption-desorption analysis were collected as part of another study (see James et al. (2004b)). Land use practices sampled for this study were dairy livestock grazed pasture fields (n=4), row crop corn production (n=9), perennial crop alfalfa production (n=9), CRP or fallow land (n=10), and woodlot areas (n=8). At each site, three replicate samples of the upper 5 cm of soil were collected using a 5-cm-diam tube corer and composited into one sample. In the laboratory, soil

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samples were sieved through a 2-mm mesh screen, air-dried, and stored in a desiccator until analysis.

P adsorption-desorption assays were conducted by modifying standard methods described in Nair et al. (1984). Homogenized soil samples (0.5 to 1.0 g) were subjected to initial concentrations of 0, 0.125, 0.250, 0.500, and 1.000 mg P L⁻¹ as potassium phosphate using a soil:solution ratio of 1:25. P solutions were prepared using phosphate-free tap water (conductivity = 422 µS; Ca = 57 mg L⁻¹; Mg = 28 mg L⁻¹; K = 0.83 mg L⁻¹; pH = 7.8) to simulate the ionic strength and pH of surface water located in the watershed. Chloroform (0.1 percent) was added to the P solutions to inhibit microbial activity during the assay procedure. Soil solution tubes were shaken in a darkened incubator at 20 °C for 24 hr. The equilibrated samples were centrifuged at 500 g for 20 min and the supernate was filtered through a 0.45-µ filter before determining soluble reactive phosphorus (SRP; American Public Health Association (APHA) 1998).

The change in SRP mass (i.e., initial SRP - final SRP; milligrams) over the 24-hr period was divided by soil dry mass to determine the quantity of P desorbed or adsorbed (mg P kg⁻¹ soil). These data were plotted as a function of the equilibrium SRP concentration after 24 hr of incubation to determine the linear adsorption coefficient (*k*; L kg⁻¹), the native adsorbed P (*S*₀; mg P kg⁻¹ sediment; initial P adsorbed to the sediment), and the equilibrium P concentration (EPC; mg P L⁻¹; the point where net sorption is zero). The *k* and *S*₀ were calculated via regression analysis as the slope and the y-intercept, respectively, from linear relationships between equilibrium SRP concentrations and the quantity of P sorbed at low equilibrium concentrations (Southern Extension/Research Activity – Information Exchange Group (SERA-IEG) 2000). The EPC was calculated as *S*₀ divided by *k*.

Extractable soil P fractions were determined using a sequential extraction with 1 M ammonium chloride followed by 0.11 M sodium bicarbonate-dithionate (i.e., loosely bound and iron-bound P; Hieltjes and Lijklema (1980); Psenner and Puckso (1988)). Other P fractions determined for soil characterization included Mehlich-3 crop-available P (Mehlich 1984) and water-extractable P (SERA-IEG 2000). Methods are described in James et al. (2004b). The degree of soil phosphorus saturation (DPS; Sharpley (1995)) was calculated as:

$$DSP (\%) = \text{extractable soil P} / (\text{phosphorus sorption maximum} + \text{extractable soil P}) * 100$$

The extractable soil P was estimated as the sum of the loosely bound and iron-bound P fraction. The phosphorus sorption capacity (PSC) of soils was measured using the single-point isotherm method described in Nair et al. (1998; also see James and Barko (2005)).

RESULTS AND DISCUSSION: For all soils examined, the EPC ranged between 0.02 and 1.22 mg L⁻¹. It varied as a positive linear function of various extractable soil P content measures and the degree of soil P saturation (Figure 1). Variation in the mean EPC was high within land use practices (Figure 2); however, there was a general trend of greater mean EPC and mean extractable soil P content for agriculturally managed land use practices versus unmanaged land uses (Figure 3). Soils collected from grazed pastures exhibited the greatest mean EPC, corn and alfalfa production soils had intermediate means, and woodlot and CRP soil exhibited the lowest mean EPC.

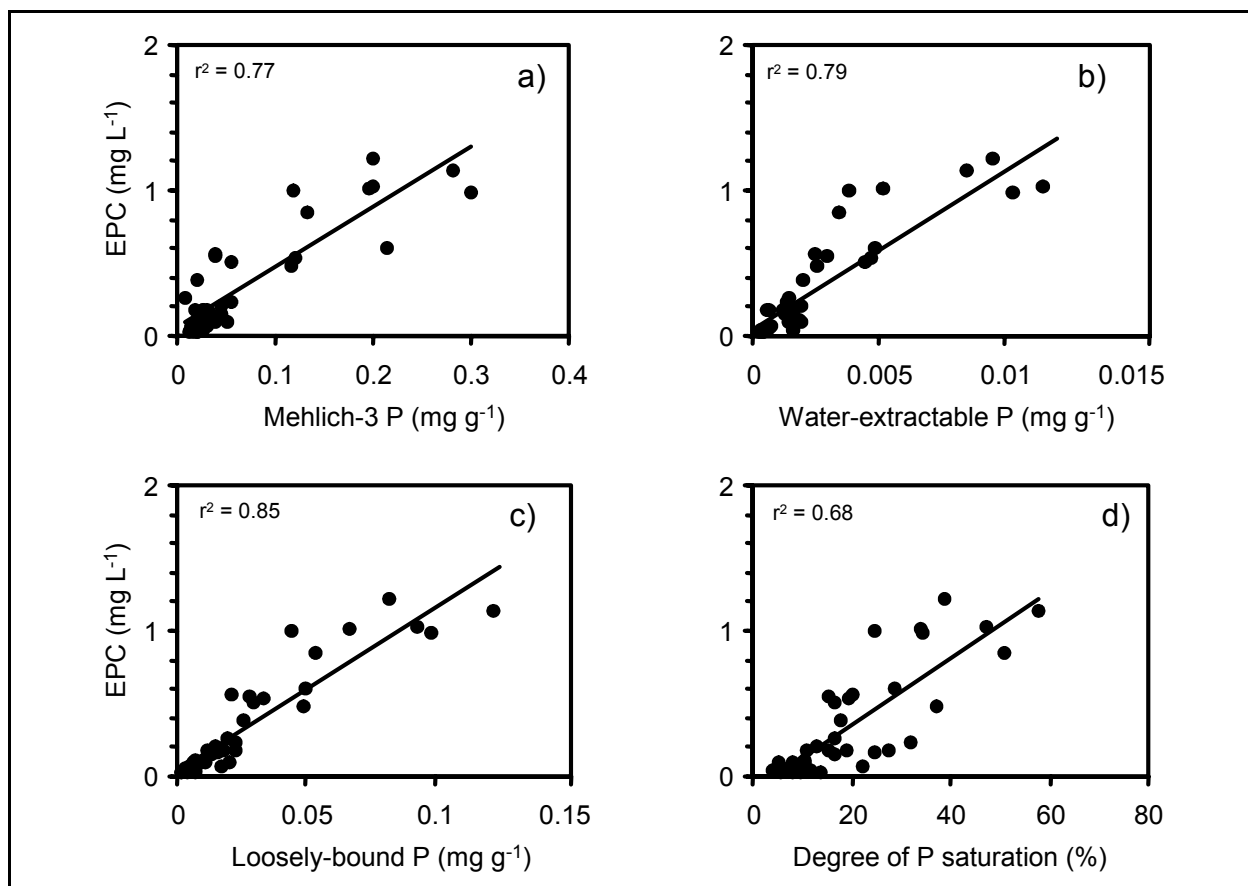


Figure 1. Linear regression relationships between the soil equilibrium phosphate concentration (EPC) and (a) Mehlich-3 P, (b) water-extractable P, (c) loosely bound P, and (d) the degree of soil phosphorus saturation

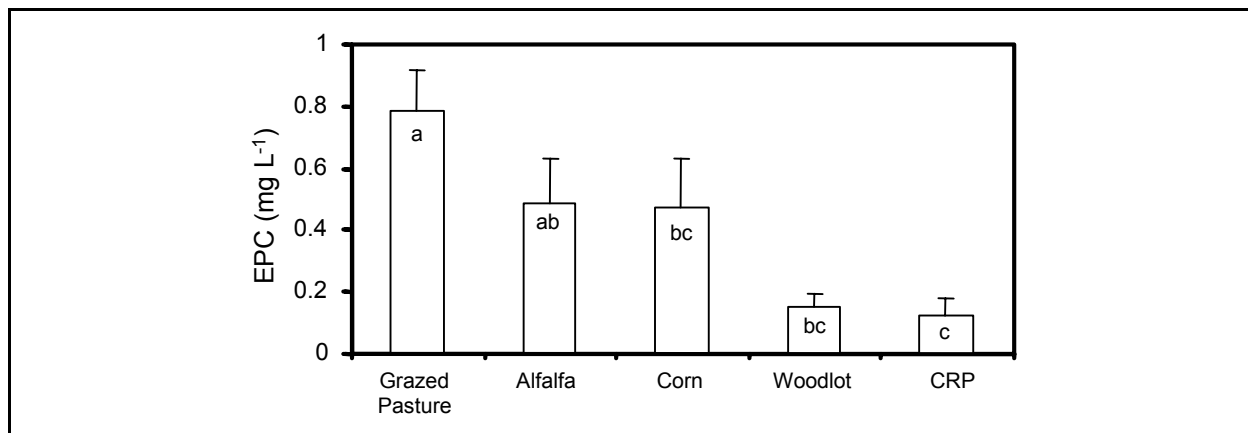


Figure 2. Variations in the mean soil equilibrium phosphate concentration (EPC) for different land uses in the Upper Eau Galle River watershed. Vertical lines denote 1 standard error. Letters indicate significant differences at the 5-percent level or less based on an analysis of variance (Duncan-Waller ANOVA; Statistical Analysis System (SAS) 1994)

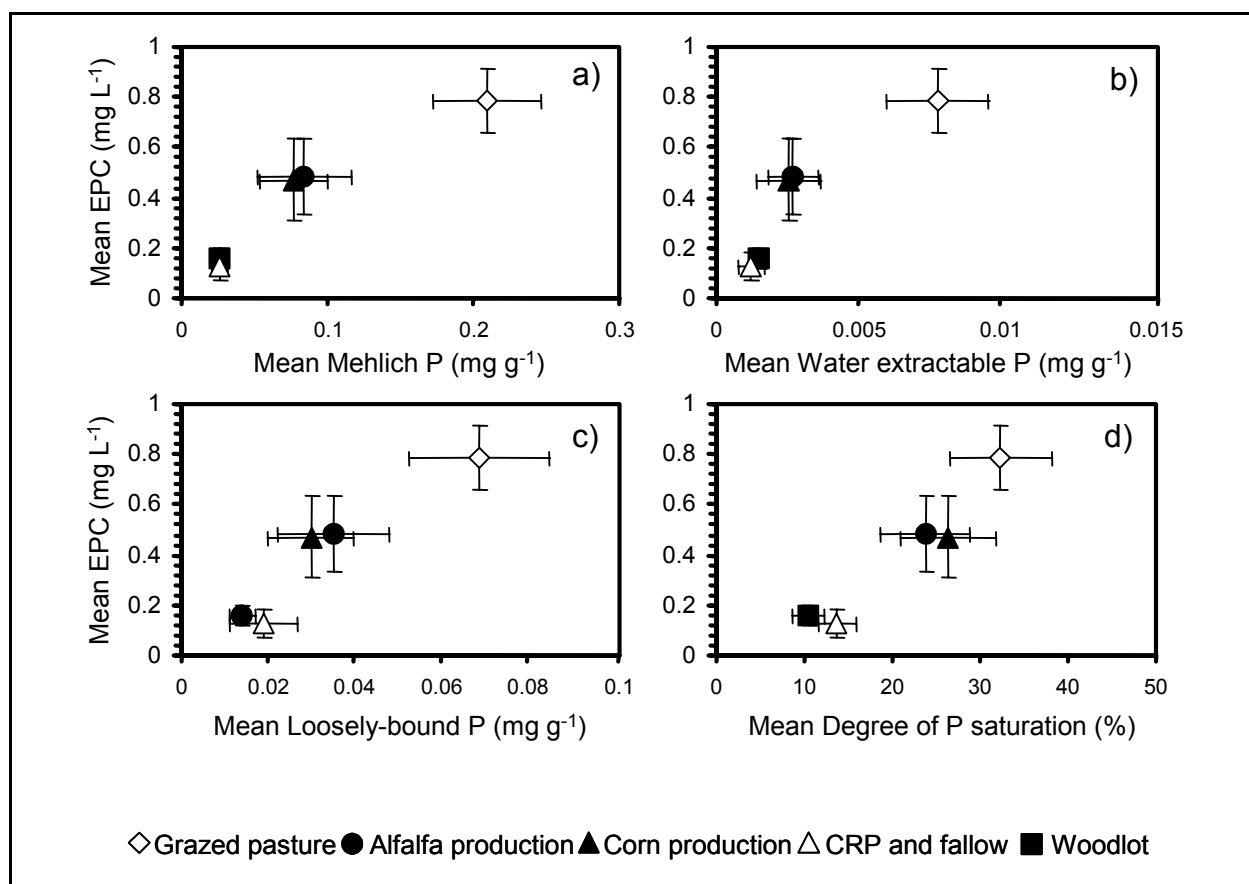


Figure 3. Relationships among the mean soil equilibrium phosphate concentration (EPC) and (a) mean Mehlich-3 P, (b) mean water-extractable P, (c) mean loosely bound P, and (d) the mean degree of soil phosphorus saturation for different land use practices. Vertical and horizontal lines represent 1 standard error

These trends indicated that extractable soil P content and the degree of soil P saturation can influence P equilibrium conditions and, therefore, the potential for runoff of soluble P to receiving waters. In this study, greater extractable soil P contents translated into greater EPC. Although variation was high, land use practices associated with soil management (fertilization, crop and livestock production) appeared to be coupled with greater mean extractable soil P contents and a greater mean EPC. The opposite pattern occurred for unmanaged soils. Soil management practices that amend soils with fertilizers and manure based on crop nitrogen requirements only (versus both N and P requirements) in order to obtain optimal yield can result in the buildup of excessive soil P levels over time, which can become desorbed during runoff (Sharpley et al. 1994, Sharpley 1995, Nair et al. 1998, Nair and Graetz 2002, Fang et al. 2002).

The strong relationship between the EPC and various extractable soil P contents implies that transport control strategies (i.e., BMP's that target erosion of particles from fields and transport to receiving streams) may not be sufficient to reduce P runoff to levels required to slow eutrophication. If soil P contents are high, watershed rehabilitation may have to also target source control (i.e., reduction of P in soils) coupled with hydrologic detention to reduce soluble P delivery to receiving

streams. Thus, BMP's such as abating soil P amendments and allowing crop uptake to deplete concentrations over a period of years in hydrologically sensitive areas would be needed in order to effect a change in the EPC between particulate and aqueous phases and reduce soluble P runoff.

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