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Surface applied water treatment residuals affect bioavailable phosphorus losses in Florida sands

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Abstract

Water treatment residuals (WTR) can reduce runoff P loss and surface co-application of P-sources and WTR is a practical way of land applying the residuals. In a rainfall simulation study, we evaluated the effects of surface co-applied P-sources and an Al-WTR on runoff and leacheate bioavailable P (BAP) losses from a Florida sand. Four P-sources, namely poultry manure, Boca Raton biosolids (high water-soluble P), Pompano biosolids (moderate water-soluble P), and triple super phosphate (TSP) were surface applied at 56 and 224 kg P ha^{-1} (by weight) to represent low and high soil P loads typical of P- and N-based amendments rates. The treatments further received surface applied WTR at 0 or 10 g WTR kg^{-1} soil. BAP loss masses were greater in leachate (16.4–536 mg) than in runoff (0.91–46 mg), but were reduced in runoff and leachate by surface applied WTR. Masses of total BAP lost in the presence of surface applied WTR were less than ~75% of BAP losses in the absence of WTR. Total BAP losses from each of the organic sources applied at N-based rates were not greater than P loss from TSP applied at a P-based rate. The BAP loss at the N-based rate of moderate water-soluble P-source (Pompano biosolids) was not greater than BAP losses at the P-based rates of other organic sources tested. The hazards of excess P from applying organic P-sources at N-based rates are not greater than observed at P-based rates of mineral fertilizer. Results suggest that management of the environmental P hazards associated with N-based rates of organic materials in Florida sands is possible by either applying P-sources with WTR or using a moderate water-soluble P-source.

Keywords: Bioavailable; Leachate; Runoff; Residuals; Biosolids; Manure; Phosphorus; Aluminum; Amendments

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1. Introduction

A major issue confronting agriculture in most US states is the environmental challenge of land-applied phosphorus (P) and the subsequent potential for off-site movement and environmental contamination. The issue is particularly important in Florida, where approximately 3.4 million hectares have been mapped as Spodosols with sandy texture and poor P sorption capacities in surface horizons (Collins, 2003). Applied P often impacts surrounding sensitive waters, and careful P management is an important goal (Harris et al., 1996). Numerous studies have been conducted in Florida utilizing a wide variety of amendments, amendment rates, soils, P-sources, and P loss mechanisms to identify best managements practices to reduce negative environment P impacts on aquatic systems (e.g., Allen, 1988; Anderson et al., 1995; Alcordo et al., 2001; Matichenkov et al., 2001). There is an increasing interest in using soil amendments to sorb excess soil P, to reduce dissolved P in runoff and leachate from manure- and biosolids-amended soils. Surface application of WTR has been shown to reduce runoff P (Peters and Basta, 1996; Basta and Storm, 1997; Dayton et al., 2003). Also, leachate P can be reduced when WTR is incorporated into the soil (Elliott et al., 2002b; O'Connor et al., 2002; Novak and Watts, 2004; Dayton and Basta, 2005). O'Connor and Elliott (2001) co-applied Al-water treatment residuals (Al-WTR) with several biosolids, fertilizer, and two manures to a Florida sand initially low in P. They demonstrated dramatic reduction in P leaching from the soil columns regardless of P-source.

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The forms of P that promote organism growth, referred to as bioavailable P (BAP), include dissolved P and bioavailable particulate P (Sharpley, 1993a, b; Myers and Pierzynski, 2000). Dissolved reactive P results from desorption, dissolution, and extraction of P from soil amendments including biosolids, manure, or recently applied P fertilizer (Daniel et al., 1998; Sauer et al., 1999; Sharpley et al., 1999). Bioavailable particulate P includes a portion of P bound to soil particles or to organic matter that enters surface water bodies and subsequently is made available for aquatic organisms. Desorption of particulate P can be an important reaction that increases the P pool utilized by primary producers such as algae. Thus, dissolved reactive P alone is not the best criterion for use in eutrophication control measures.

Standard methods to measure BAP to algae in waters and agricultural runoff involve lengthy algal assays and culturing *Selenastrum capricornutum* with sediment samples. Hence, chemical extractions that sum soluble and desorbable particulate P have been suggested as alternatives to costly biotests for assessing P bioavailability in water environments (Dorich et al., 1985; Hanna, 1989; Sharpley, 1993b). Extraction of P with Fe-impregnated filter paper (i.e., iron strip P (ISP)), correlates well with P uptake in algal assays (Hanna, 1989; Uusitalo and Ekholm, 2003), and is a good measure of BAP (Sharpley, 1993a, b; Myers and Pierzynski, 2000). In an incubation study with runoff as the sole source of P, the growth of P-starved *S. capricornutum* was strongly related ($r^2 = 0.96$) to runoff ISP (Sharpley, 1993a). The ISP method is a fast and easy method to estimate P that may be potentially available for algae uptake. Theoretically, P sinks such as ISP imitate the depletion of surface-adsorbed P which takes place in fresh waters with low P concentrations.

Surface co-application of P-sources and WTR could be a practical way of applying these residuals to reduce P hazards in the environment. However, studies on the impact of WTR on soluble P that do not account for bioavailable particulate P may be inadequate, as both dissolved forms and portions of particulate P could promote eutrophication. Our objective was to determine the effects of surface applied P-sources and an Al-WTR on runoff and leaching BAP losses in Florida sand using indoor rainfall simulation techniques.

2. Materials and methods

The top soil (0–15 cm) of the Immokalee fine sand series (sandy, siliceous, hyperthermic Arenic Alaquods) used for the rainfall simulation experiments was collected from the Southwest Florida Research and Education Center (SWFREC), 3 km north of Immokalee, FL. The site from where the soil was taken was fallow land and had had no P input for >10 years. The four P-sources used included both organic and inorganic sources of P (biosolids, poultry manure, and triple super phosphate (TSP)). Two biosolids were used, Boca Raton biosolids containing high water-soluble P ($\mathrm{WEP} = 5.52\,\mathrm{g\,kg^{-1}}$) and Pompano biosolids containing moderate water-soluble P ($\mathrm{WEP} = 1.16\,\mathrm{g\,kg^{-1}}$). Poultry manure was obtained from Tampa Farms in Indiantown, FL, a large egg-laying poultry operation that land applies poultry manure. The fertilizer (TSP) is a typical mineral P-source applied to Florida crops. The Al-WTR was obtained from a domestic water treatment plant in Bradenton, FL.

Samples of the soil used were air-dried, thoroughly mixed, and sieved (<2 mm) before analysis. Both the soil and the amendments (P-sources and WTR) were analyzed for total P, Fe, Al, Ca, Mg by inductively coupled argon plasma (ICAP) spectrometry, following digestion according to EPA Method 3050A (USEPA, 1986). Oxalate extractable P, Fe, and Al were determined by ICAP after extraction with solutions of 0.1 M oxalic acid plus 0.175 M ammonium oxalate (pH = 3.0) at a 1:60 solid:solution ratio, following the procedures of Schoumans (2000). The suspensions were equilibrated for 4 h in the dark with continuous shaking, centrifuged, filtered through a 0.45-μm filter, and analyzed for P, Fe, Al, Ca, and Mg by ICAP within 24 h after extraction. Total C and N of the amendments were determined by combustion at 1010 °C using a Carlo Erba NA-1500 CNS analyzer. Total C was determined on representative soil samples. Soil reaction (pH) was determined on fresh materials at 1:2 solid or soil:solution ratio.

The soil was also analyzed for varying measures of P including Mehlich-1 P, Water extractable P (WEP) and ISP. WEP was determined by extracting soil sample with water at a 1:10 soil to water ratio for 1 h, and determining P on the filtrate collected after passing through a 0.45-μm filter (Self-Davis et al., 2000). The amendments (P-sources and WTR) were also analyzed for WEP as in soil but the extraction was at 1:200 amendment:water ratio. ISP determination involved extracting soil in a centrifuge tube containing a strip of filter paper coated with Fe-oxide (a strong adsorbent for P) in 0.01 M $\mathrm{CaCl_2}$ (Chardon et al., 1996). The suspension was shaken with the Fe-strip paper for 16 h, and the P sorbed by the Fe-oxide on the filter paper was extracted by 0.1 M $\mathrm{H_2SO_4}$. Mehlich-1 P was determined by shaking the sample with 0.0125 M $\mathrm{H_2SO_4}$ in 0.05 M HCl solution at a ratio of 1:4 soil:solution ratio for 5 min (Hanlon et al., 1997). Extracts were immediately filtered through Whatman No. 42 filter paper and analyzed colorimetrically by the Murphy and Riley method (1962). Water-soluble-P and ISP concentrations were determined colorimetrically in each of the extracts with the Murphy and Riley (1962) procedure.

2.1. Rainfall simulation experiment

The rainfall simulation was carried out as prescribed in the National Phosphorus Research Project indoor runoff box protocol (National Phosphorus Research Project, 2001). However, the box design was modified to quantify P leached in addition to runoff P by adding a second,