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Surface runoff phosphorus (P) loss in relation to phosphatase activity and soil P fractions in Florida sandy soils under citrus production

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Abstract

Phosphorus losses by surface runoff from agricultural lands have been of public concern due to increasing P contamination to surface waters. Five representative commercial citrus groves (C1–C5) located in South Florida were studied to evaluate the relationships between P fractions in soils, surface runoff P, and soil phosphatase activity. A modified Hedley P sequential fractionation procedure was employed to fractionate soil P. Soil P consisted of mainly organically- and Ca/Mg-bound P fractions. The organically-bound P (biological P, sum of organic P in the water, $NaHCO_3$ and NaOH extracts) was dominant in the acidic sandy soils from the C2 and C3 sites (18% and 24% of total soil P), whereas the Ca/Mg-bound P (HCl-extractable P) accounted for 45–60% of soil total P in the neutral and alkaline soils (C1, C4 and C5 soils). Plant-available P (sum of water and $NaHCO_3$ extractable P fractions) ranged from 27 to 61 mg P kg^{-1} and decreased in the order of C3 > C4 > C1 > C2 > C5. The mean total *P* concentrations (TP) in surface runoff water samples ranged from 0.51 to 2.64 mg L^{-1}. Total P, total dissolved P (TDP), and PO_4^{3-}-P in surface runoff were significantly correlated with soil biological P and plant-available P forms ($p <$ 0.01), suggesting that surface runoff P was directly derived from soil available P pools, including H_2O– and $NaHCO_3$– extractable inorganic P, water-soluble organic P, and $NaHCO_3$- and NaOH-extractable organic P fractions, which are readily mineralized by soil microorganisms and/or enzyme mediated processes. Soil neutral (55–190 mg phenol kg^{-1} 3 h^{-1}) and natural (measured at soil pH) phosphatase activities (77–295 mg phenol kg^{-1} 3 h^{-1}) were related to TP, TDP, and PO_4^{3-}-P in surface runoff, and plant-available P and biological P forms in soils. These results indicate that there is a potential relationship between soil P availability and phosphatase activities, relating to P loss by surface runoff. Therefore, the neutral and natural phosphatase activities, especially the natural phosphatase activity, may serve as an index of surface runoff P loss potential and soil P availability.

Keywords: Phosphatase activity; Phosphorus fractionation; Phosphorus loss; Surface runoff; Sandy soils

1. Introduction

Bioavailable P, including dissolved- and particulate- P in surface runoff from agricultural lands accelerates surface water eutrophication (Sharpley et al., 1995). In the USA, P has been the major nutrient affecting fresh water quality (US Environmental Protection Agency, 1996a). It was estimated that over 70% of total P discharging into rivers originated from agricultural land (Lowrance, 1991). Therefore, best management practices (BMPs) are required to optimize P fertilization to meet the demands of crop production with minimal environmental impacts. According to the Everglades Forever Act in Florida (EFAF, 1994), concentrations of total P in surface runoff that discharges into the Everglades are mandated to be reduced to a threshold level of 0.05 mg P L^{-1}. Sharpley et al. (1996) reported that runoff water is considered as degraded if total P exceeds a guideline concentration of 0.10 mg P L^{-1}. Mean concentrations of total P in surface runoff from the five commercial citrus groves we monitored in the last three years were 9.6–34.5 times greater than the EFAF threshold and, hence, 4.8–17.3 times greater than the Sharpley's guideline level (unpublished data). Results from Koch (1991) and Newman

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and Pietro (2001) from the Stormwater Treatment Areas, part of the Everglades restoration program, have arrived at similar conclusions.

The P load in surface runoff is mainly derived from desorption in surface soils and suspended solids or sediment (Douglas et al., 1998; Hooda et al., 2000; Ng Kee Kwong et al., 2002). Phosphorus concentration in surface runoff is often observed to relate to fertilization rate, to P cycling in the plant-soil system, and to the amount of labile P in soils. However, P loadings in surface runoff are also influenced by topography, precipitation (intensity and duration), temperature, land use, and other field management practices.

Phosphorus cycling in soils and P bioavailability are regulated by biological (short term) and geochemical (long term) processes (Cross and Schlesinger, 1995). The Hedley P sequential extraction procedure that has been broadly applied in soil P studies provides an operational and chemical fractionation of soil P (Hedley et al., 1982). The P fractions are categorized as plant-available P and refractory P forms, or biological P (all the extractable organic fractions) and geochemical P forms (the remaining fractions) based on P availability (Cross and Schlesinger, 1995). Using the Hedley P fractionation procedure in three southern alpine Spodosols, Beck and Elsenbeer (1999) found that 65% of total P in topsoil (0–30 cm) was in organic forms, and that bicarbonate extractable organic P reached a maximum of 80% of the total available soil P. Graetz and Nair (1995) estimated that nearly 80% of total soil P in the A horizon of Florida Spodosols was leachable.

Phosphatases play a key role in soil P cycling by catalyzing mineralization of organic P and potentially relate to soil P bioavailability. Acid and alkaline phosphatases (orthophosphoric monoester phosphohydrolase), so classified because they show optimal activities in acid and alkaline ranges (Tabatabai, 1994), have been extensively studied. In addition, PO_4^{3-} is a competitive inhibitor of acid and alkaline phosphatases in soils (Juma and Tabatabai, 1978). No information, however, is available regarding the relationships between phosphatase activity and soil labile P fractions, that are readily lost by surface runoff.

Citrus is an important Florida agricultural crop with a 200-year planting history. Florida has the largest citrus production area (about 294,455 ha) in the USA, and produced about 15 million tons of fruit in the 2001–02 season, representing 78% of the total USA citrus production (Florida Agricultural Statistics Service, 2003). Phosphorus in surface runoff from citrus groves is suspected to contribute to the eutrophication of surface water bodies, such as the Indian River Lagoon and Lake Okeechobee in South Florida. Data from five citrus groves in South Florida monitored in 2002, indicated that, an average about 0.5–2.1 kg P ha^{-1} was transported by surface runoff into ditches at concentrations ranged from 0.6–2.0 mg P L^{-1} (unpublished data). Most soils in Florida are sandy and have low P-retention capacity in their upper horizon (Graetz and Nair, 1995; He et al., 1999). Therefore, the potential of P loss by surface runoff from sandy soils under citrus production is considerable.

The objectives of this study were to evaluate the relationships among P loadings in surface runoff, soil P fractions, and soil phosphatase activities, and to understand the linkage of P losses by surface runoff with soil phosphatase activity. Findings from this study are expected to finetune BMPs, by incorporating phosphatase activity as an indicator of soil P availability, with an adequate balance of agro-economical and environmental concerns.

2. Material and methods

Topsoil samples (0–15 cm) were collected in February, 2003 from five commercial citrus groves (named C1, C2, C3, C4, and C5) in St Lucie and Martin counties, Florida, USA. Three field replicates were taken from each site and each sample was a composite of 10 cores. Taxonomically, the soils of C1, C2 and C3 were Riviera sand (loamy, siliceous, hyperthermic Arenic Glossaqualfs), Nettles sand (sandy, siliceous, hyperthermic, ortstein Alfic Arenic Alaquods), and Wabasso sand (sandy, siliceous, hyperthermic Alfic Alaquods), respectively, and C4 and C5 were Pineda sand (loamy, siliceous, hyperthermic Arenic Glossaqualfs) (US Department of Agriculture, 1980, 1981). Visible plant materials were removed from soil samples and samples were air-dried and ground to pass through a 2-mm sieve in preparation for measuring pH, electrical conductivity (EC). Soil phosphatase activities were measured in the air-dried soils because the field moisture of these sandy topsoils (0–15 cm) was very low (less than 3% of oven-dried weight) except on rainy days. It has been reported that by using air-dried soils, enzyme assays can effectively discriminate between different field management practices even though activities were reduced by drying (Babdick and Dick, 1999). In this study, air-dried soils was used to provides a common basis for comparing soil phosphatase activity among different sandy soils and with phosphorus fractions. Subsamples were ground to pass through a 0.25-mm sieve for further chemical analyses and phosphorus fractionation. Some basic physicochemical properties of the soils are shown in Table 1.

Soil pH was measured in a 1:1 soil-deionized water mixture using a pH/ion/conductivity meter (Fisher Scientific, Accumet model 50, Pittsburgh, PA, USA) after 30 min shaking. Electrical conductivity (EC) was measured in a 1:2 soil-deionized water mixture after 30 min shaking, using the pH/ion/conductivity meter. Soil particle distribution was determined by a micro-pipette method (Miller and Miller, 1987). Soil total organic carbon and nitrogen were determined using a CN-analyzer (Vario Max CN, Macro Elemental Analyzer System GmbH, Hanau, Germany). Total P, Ca, Mg, Al, and Fe were determined by digesting the soil samples following the procedure of EPA method 3050B (US Environmental Protection Agency, 1996b)