Agriculture, Ecosystems and Environment 162 (2012) 15–23

Contents lists available at SciVerse ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Phosphorus saturation of a tropical soil and related P leaching caused by poultry litter addition

Dalton Belchior Abdala[a], Amlan Kumar Ghosh[a,b,*], Ivo Ribeiro da Silva[a], Roberto Ferreira de Novais[a], Victor Hugo Alvarez Venegas[a]

[a] Department of Soils, Federal University of Vicosa, MG, Brazil
[b] Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, India

ARTICLE INFO

Article history:
Received 28 February 2012
Received in revised form 8 August 2012
Accepted 10 August 2012
Available online 18 September 2012

Keywords:
Adsorption
Desorption
Phosphorus sorption saturation
P leaching
Oxisol

ABSTRACT

Phosphorus deficiency is well known as a major agronomic constraint in the highly weathered Oxisols of Brazil and reasonable economic returns are not possible without application of high rates of phosphorus. Poultry litter, which is enriched in P, is increasingly being used in organic management of cultivated lands. Due to the great P fixing capacity of these soils, any limit to the soil sink of P is not recognized. The study was undertaken to evaluate the risk of P loss due to increase in phosphorus sorption saturation (PSS) from land application of poultry litter and to establish a relationship between PSS and water soluble phosphorus. No till corn-fallow rotation was followed for three years with annual application of 0, 5, 10, 25, 50 and 100 Mg ha^{-1} of poultry litter in a highly weathered clayey dystrophic red-yellow Argisol of Brazil. The effect of poultry litter application on soil was evaluated and Mehlich-3 P (P_{M-3}) concentrations increased 3–134 times over control after three years of poultry litter application. Poultry litter application increased pH and decreased the concentration of exchangeable Al; whereas concentrations of K^+, Na^+, Zn^{2+}, Mg^{2+} and Ca^{2+} increased substantially over control. Increase in soil pH and total organic carbon due to poultry litter application reduced the P sorption capacity of soils and P sorption. The PSS increased considerably at higher rates of poultry litter application (>10 Mg ha^{-1}) and strongly increased the amount of desorbable P. Total water extractable P was mostly accounted for by reactive P forms and increased with poultry litter rates. In a plot of dissolved reactive P (DRP) against PSS, a change point was observed at 22.7% PSS corresponding to a dissolved reactive P (DRP) concentration of 0.92 mg kg^{-1} soil after which a sharp increase in DRP was observed. P concentration >0.1 mg L^{-1} was observed in soil solution at 60 cm soil depth with increasing rates of poultry litter application, thus providing evidence of P leaching. In the absence of an environmental soil test criteria for P, the break point PSS of 22.7% could be used to practically monitor whether soils have reached a level of P loading that constitutes an environmental risk of P losses from soil to surface and ground waters.

1. Introduction

Management of the organic matter content of cultivated lands has increased substantially in Brazil (Xavier et al., 2009) and organic fertilizers have become a vital source for supplying plant nutrients. This has been facilitated by the great increase in animal manure production in recent years. The poultry industry in Brazil is now the third largest in the world (ABEF, 2008) producing a massive amount of waste products. In the past, poultry litters were allowed to be used as feed for ruminants, but since the prohibition of their use as animal feed supplement, the main concern confronting the poultry industry in Brazil today is the economically sound and environmentally safe disposal of its waste products. Soil application of poultry wastes will most likely continue to be the most practical and economic disposal method. However, the risk of applying poultry litter to soil based on N agronomic rates is that N and P are not present in the same proportion in poultry litter as needed by crops (Sharpley et al., 2007) resulting in over-application of P exceeding plant requirements. This leads to a buildup of soil P, saturation of P sorption sites and greater potential for P desorption into soil solution and loss by transport mechanisms such as overland flow and leaching (Ulén et al., 1998; McDowell et al., 2001).

* Corresponding author at: Department of Soil Science and Agricultural Chemistry, Institute of Agricultural Sciences, Banaras Hindu University, Varanasi, India. Tel.: +91 9451363054; fax: +91 542 2368465.
E-mail address: amlankumar@yahoo.com (A.K. Ghosh).

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http://dx.doi.org/10.1016/j.agee.2012.08.004

The solubility of P in soil is controlled by the chemistry of liquid and solid phases of the manure matrix and the surface chemistry of inorganic and organic particulates in that environment (Lindsay, 1979). Soils have a finite capacity to sorb P depending on the type and amount of adsorbing surfaces. Application of manures rich in P can result in saturation of P sorption sites, decreasing P sorption capacity of many soils, which consequently increases the rate of P release or desorption (Labosky and Lamb, 2004). Most of the attention of P loss to the environment has otherwise been focused on the sandy soil regions of the world which have less adsorption surfaces that get saturated more easily with respect to P and thus pose a great risk of P loss to the environment (Siemens et al., 2004). P movement in non-sandy soils has been reported to be low (Hubbard et al., 1989), and surface runoff is considered to be the main P transport pathway due to limited mobility of P in soils resulting from high P-adsorption capacity of clay soils. However, Djodjic et al. (2000) reported considerable amounts of P loss by leaching in a structured clay soil. The potential of soils for P release, the capacity of the subsoil to adsorb the released P and the water transport mechanism in the soils were found to be the most important factors influencing P leaching (Djodjic et al., 2004). There is, however, little information on the P loss potential of soils having high adsorbing capacity, such as Oxisols of Brazil.

Oxisols cover around 46% of the tropics, and in Latin America, most of these soils are found in the Brazilian savannas (Neufeldt, 1999), which cover >60% of the country by area, and occur in association with other soils. These highly weathered soils occupy the major areas developed for agricultural use in Brazil. Similar soils and climate exit in Colombia, Venezuela, Bolivia and Miombo woodlands of Africa, which cover about 100 million hectares in Angola, Zaire, Zambia, Malawi, Mozambique and Tanzania (Neufeldt et al., 1999). These soils are low in pH and cation exchange capacity but rich in Al and Fe oxide complexes that tightly sorb large amounts of P (Fontes and Weed, 1991; Novais and Smith, 1999). It is thus generally believed that there is little possibility of P loss to the environment from such soils. However, repeated or heavy application of P rich sources, like poultry litter, to the soil can lead to accumulations of N and P resulting in elevated levels of one or both of these nutrients in surface runoff and subsurface water (Kingery et al., 1994). Further, increase in pH can lower the adsorption capacity of phosphate by oxides in soil (Strauss et al., 1997) and presence of organic matter can further modify the P sorption characteristics that influence the movement of P to greater soil depths. Sharpley (1996) found that application of animal manure can significantly decrease the P sorption capacity of soils that increase the risk of P losses. Increased availability of P following additions of organic manures has been attributed to the production of organic acids during the decomposition of the manure that can form stable complexes with Fe and Al and consequently block available P retention sites (Siddique and Robinson, 2003) favoring downward movement of P in soil. Moreover, the amount of P loss necessary to cause water quality problems usually is very small, and water bodies fall under the eutrophic category if the $P–PO_4$ is >0.34 mg L^{-1} (Ignatiades et al., 1992), emphasizing the vulnerability to eutrophication of fresh waters.

From an environmental point of view, concerns related to water quality and excess P inputs to highly weathered soils of the tropics through poultry litter warrant increased understanding (Ghosh et al., 2011). Relationship between soil test P and soil P saturation are of interest because they can be used to classify agricultural lands for risk of P loss to water resources. Therefore, the objective of this research was to study the relationship between P loading rates, soil test P and their relationship to the degree of P saturation to provide evidence of the possibility of P loss from highly weathered soils of Brazil receiving poultry litter.

2. Materials and methods

2.1. Site characteristics and experimentation

The experiment was carried out at the Experimental Farm of the Federal University of Viçosa, located in Coimbra County, MG, situated 20°45′ S and 45°51′ W, at an altitude of 650 m above the mean sea level. The climate is classified as Cwa (warm and humid summers with a mild and dry winter season) according to Köppen's Climate Classification with the mean annual rainfall and relative humidity being 1350 mm and 85% respectively. The soil is a clayey dystrophic Red-Yellow Argisol (Ultisol) with less than 1% slope and had been cultivated over thirty years with annual crops such as corn (*Zea mays* L.), common bean (*Phaseolus vulgaris* L.), soybean (*Glycine max* (L.) Merrill) and wheat (*Triticum aestivum*) and received regular chemical fertilization and liming over the cultivation period prior to setting up of the current experiment. The soil characteristics are presented in Table 1.

The experiment consisted of increasing rates of poultry litter (0, 5, 10, 25, 50 and 100 Mg ha^{-1} on a dry weight basis) applied each year to the same plots, over three cropping years (2004, 2005 and 2006) in a completely randomized block design with four replicates. Corn was planted each year under no till in plots (4.0 m × 5.4 m) in the beginning of October, in rows 0.9 m apart and 7 plants m^{-1} to yield a stand of about 70,000 plants ha^{-1}. Each year, the poultry litter was broadcast on the soil surface 20 days prior to planting of no till corn. Weeds were controlled with pre- and post-emergence herbicides as needed. A corn fallow rotation was followed and corn was harvested at maturity on similar dates and the plots remained fallow during winter. However only the effect of poultry litter application on soil was evaluated in the present study.

2.2. General characterization of soil and poultry litter

Five cores per plot were obtained from 0 to 10, 10 to 20 and 20 to 40 cm soil depth in the beginning of the experiment and after corn harvest in 2006, air dried and 2 mm sieved prior to analysis. Particle size distribution was determined by a modification of the pipette method (Ruiz, 2005) and pH measured in $CaCl_2$ (1:2.5 soil:solution ratio). P, Fe, Al and Zn were extracted with Mehlich-3 (P_{M-3}) extractant (Mehlich, 1984) and measured by ICP-OES. K in the Mehlich-3 extract was measured by a flame photometer. Exchangeable Ca^{2+}, Mg^{2+}, Na^{+} and Al^{3+} were extracted by 1 mol L^{-1} KCl and analyzed

Table 1
Initial soil characteristics of the experimental field.

Soil layer (cm)	Soil texture			pH $CaCl_2$	TOC* (g kg^{-1})	Ca (Cmol (+) kg^{-1})	Mg (mg kg^{-1})	M_3P	K
	Sand	Silt (%)	Clay						
0–10	18	17	65	4.2	21.27	1.84	0.71	4.9	142.2
10–20	18	17	65	4.1	19.35	1.61	0.47	10.1	70.7
20–40	12	17	71	4.4	–	1.69	0.55	0.7	41.9

* TOC: total organic carbon; M_3P: P extracted by Mehlich 3.