Science of the Total Environment 490 (2014) 397–404

Contents lists available at ScienceDirect

Science of the Total Environment

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

Soil microbial properties after long-term swine slurry application to conventional and no-tillage systems in Brazil

Elcio L. Balota [a,*], Oswaldo Machineski [a], Karima I.A. Hamid [a], Ines F.U. Yada [a], Graziela M.C. Barbosa [a], Andre S. Nakatani [b], Mark S. Coyne [c]

[a] IAPAR — Agronomic Institute of Paraná State, 86001-970 Londrina, Paraná, Brazil
[b] EMBRAPA Soja, Caixa Postal 231, CEP 86001-970 Londrina, Paraná, Brazil
[c] Department of Plant and Soil Sciences, University of Kentucky, Lexington KY 40546, USA

HIGHLIGHTS

- Microbial properties were evaluated after 15 years of swine slurry application.
- Swine slurry addition and no-tillage increased soil microbial quality indicators.
- Tillage degraded while no-tillage increased soil quality with time.
- Short-term effects of swine slurry on microbial indicators reflected long-term trends.
- The soil microbial indicators were good indicators of soil quality change.

ARTICLE INFO

Article history:
Received 23 January 2014
Received in revised form 25 April 2014
Accepted 5 May 2014
Available online xxxx

Editor: Simon Pollard

Keywords:
Swine manure
Soil management
Microbial biomass
Soil enzymes
Polysaccharide
No-tillage

ABSTRACT

Swine waste can be used as an agricultural fertilizer, but large amounts may accumulate excess nutrients in soil or contaminate the surrounding environment. This study evaluated long-term soil amendment (15 years) with different levels of swine slurry to conventional (plow) tillage (CT) and no tillage (NT) soils. Long-term swine slurry application did not affect soil organic carbon. Some chemical properties, such as calcium, base saturation, and aluminum saturation were significantly different within and between tillages for various application rates. Available P and microbial parameters were significantly affected by slurry addition. Depending on tillage, soil microbial biomass and enzyme activity increased up to 120 m^3 ha^{-1} $year^{-1}$ in all application rates. The NT system had higher microbial biomass and activity than CT at all application levels. There was an inverse relationship between the metabolic quotient (qCO_2) and MBC, and the qCO_2 was 53% lower in NT than CT. Swine slurry increased overall acid phosphatase activity, but the phosphatase produced per unit of microbial biomass decreased. A comparison of data obtained in the 3rd and 15th years of swine slurry application indicated that despite slurry application the CT system degraded with time while the NT system had improved values of soil quality indicators. For these Brazilian oxisols, swine slurry amendment was insufficient to maintain soil quality parameters in annual crop production without additional changes in tillage management.

1. Introduction

Brazil produces more than 38 million swine annually, the fourth largest producer worldwide, and about 300 million liters of liquid swine waste each day. This represents a production of more than 100 million cubic meters of liquid waste annually. The waste is a mixture of urine, feces, ration remains, excess drinking water, and water used to clean facilities. After cleaning the facilities, the swine wastes are typically stored in tanks for at least 120 days to reduce environmental risk prior to soil application as biofertilizer (Seganfredo, 2007).

The use of waste slurry as an agricultural fertilizer is a simple and inexpensive solution to dispose and recycle swine residue on agricultural property. Although swine waste can enhance plant growth and reduce mineral fertilizer application, it can be an environmentally risky activity (Seganfredo, 2007). Almost 50% of Brazil's swine production occurs in just three southern states (Paraná, Santa Catarina, and Rio Grande do Sul), which are characterized by a high density of swine on mostly small farms. In many regions, the swine slurry produced exceeds the quantity that can be safely accommodated by the available agricultural land, and repeated annual applications of large amounts of swine slurry may lead to excessive nutrient accumulation and environmental damage by leaching nutrients into the surrounding environment (Hernández et al., 2013).

* Corresponding author.
E-mail address: balota@iapar.br (E.L. Balota).

http://dx.doi.org/10.1016/j.scitotenv.2014.05.019
0048-9697/

Positive and negative effects to physical and chemical soil properties, and improved plant growth due to swine manure addition have been reported for Brazilian soils (e.g. Guardini et al., 2012; Lourenzi et al., 2013). There are a few studies that have similarly examined soil microbial parameters after swine manure application for long periods in temperate climates (Lalande et al., 2000; Rochette et al., 2000; Plaza et al., 2004), but no such studies have focused on long-term application in the tropical conditions of Brazil. The consequences of swine slurry application at high levels in different soil tillage systems for long periods are of interest because 50% of the land devoted to grain production in Brazil (25.5 M ha) is in no-tillage management.

Microbial indicators of soil quality can reflect soil alteration before physical or chemical parameters change (Dick, 1997; He et al., 2003; Bastida et al., 2007; Kaschuk et al., 2010). Therefore, microbial parameters may be used as sensitive indicators of soil quality change due to soil management, manure addition, or soil pollution (He et al., 2003; Mandal et al., 2007; Balota and Auler, 2011; Nakatani et al., 2012; Stefanowicz et al., 2012; Asensio et al., 2013). For example, microbial biomass typically accounts for <5% of total organic carbon, but represents an important reservoir of nutrients because these nutrients are released from microbial cells many times faster than from the decomposition of plant residue. Polysaccharides produced by soil microorganisms can represent about 25% of the soil organic matter and have high correlation with soil aggregate stability (Spaccini et al., 2004; Liu et al., 2005). Soil nutrient release is mediated by microorganisms, which produce enzymes catalyzing innumerable reactions necessary for metabolism. Extracellular enzymes can accumulate in soil with considerable impact on nutrient recycling, and also allow soil enzyme activity to be used to indicate the intensity of biochemical processes (Tabatabai, 1994; Dick, 1997).

The use of swine slurry in agriculture has become a common practice for its disposal and use to replace mineral fertilizers disregarding its effect on soil microbial properties. The objective of this study, therefore, was to characterize changes in microbial soil quality indicators due to the long-term application (15 years) of swine slurry in different soil tillage systems. A specific question was whether swine slurry application alone was sufficient to maintain soil microbial parameters with time. The observed changes will provide greater knowledge of the environmental impact and potential benefits caused by long-term swine slurry application in tropical environments.

2. Material and methods

2.1. Experiment design and soil description

The study had been in place for 15 years (since 1996) at the IAPAR Experimental Station in Palotina, west of Paraná State (24° 17′ S, 53° 50′ W), Brazil. The soil is a clayey oxisol that is classified as a typical Eutroferric Red Latosol according to the Brazilian Soil Classification system (rhodic Eutrudox, by Soil Taxonomy) with a composition of 60% clay, 16% silt, and 24% sand. At the beginning of the study the soil had a pH of 5.2 ($CaCl_2$), 14.8 mg kg^{-1} extractable P (Mehlich) and 20.0 g kg^{-1} organic carbon (Walkley and Black) in the surface layer (0–20 cm).

The study was conducted using a split plot design with tillage as the main plot (100 × 5 m) and the addition of swine slurry as the subplot (20 × 5 m). Each plot was separated by a 2.0 m buffer. The experiment design consisted of blocks with four replicates. Soil tillage treatments used no tillage (NT), which entailed planting into undisturbed soil by opening a narrow trench, or conventional tillage (CT) in which one disk plowed at a depth of 20 cm and the field was lightly harrowed twice for seedbed preparation. Swine slurry was applied prior to soil preparation at five levels (0, 30, 60, 90 and 120 m^3 ha^{-1} $year^{-1}$). Half of the dose was applied before the summer crop (November) and the other half before the winter crop (June). The swine slurry was collected every year from the same swine farm, which employed a consistent production system, to avoid great variation in slurry composition. On average, the swine slurry had the following composition on a dry mass basis: dry matter, 2.0%; pH, 7.0; organic C, 1%; total N, 3.0%; total P, 2.7%. The swine slurry was the only nutrient source applied to crops and was applied by surface spreading, after which the soil was immediately prepared for sowing of the crop.

The area was cultivated with soybean (*Glycine max* L.) and maize (*Zea mays* L.) in summer and wheat (*Triticum aestivum* L.) or oat (*Avena sativa* L.) in winter. Each year, crop residue was either retained on the surface in the NT system or conventionally tilled (plowed to 20 cm depth) following harvest in both the fall and spring operations. Pre- and post-emergence herbicide (glyphosate and/or atrazine and tembotrione) and seed fungicide treatment were used for soybean and maize. Insecticide was used when necessary.

Ten sub-samples of soil were randomly collected within each replicate at 0–10 cm depth in February 2011 (at the end of the maize summer crop) and composited. Large plant material was removed from each sample and the soil was sieved through a 4 mm screen. The samples were stored at 4 °C until analysis. The laboratory analyses were conducted in triplicate and expressed on a dry mass basis. Chemical analyses were performed as described for routine analyses adapted for IAPAR by Pavan et al. (1992). Organic C (C_{org}) concentration was measured by the Walkley–Black potassium dichromate sulfuric acid oxidation procedure. Available P, Ca, and Mg were determined by Mehlich 1 extraction and analysis by ICP.

2.2. Microbial biomass (MBC and MBN)

The microbial biomass C (MBC) was determined by the fumigation–extraction method according to Vance et al. (1987) with a correction factor (k_c) of 0.33. The microbial biomass N (MBN) was determined by the method of Brookes et al. (1985) with a correction factor of 0.54. Basal respiration was obtained from the measurement of CO_2 released from the non-fumigated control. Metabolic quotient (qCO_2) was obtained by dividing the basal respiration by the microbial biomass C.

2.3. Soil enzymes

Arylsulfatase activity (arylsulfate sulfohydrolase, EC 3.1.6.1) and acid phosphatase activity (EC 3.1.3) were determined by colorimetric determination of *p*-nitrophenol released when soil samples were incubated 1 h with *p*-nitrophenyl sulfate and *p*-nitrophenyl phosphate, respectively (Tabatabai, 1994). Activities of arylsulfatase and phosphatase are expressed as μg *p*-nitrophenol (PNP) g^{-1} h^{-1}.

2.4. Polysaccharides

The labile polysaccharides (LPS) and total polysaccharides (TPS) were measured by a method proposed by Lowe (1993). The TPS in soil was determined by pre-treating the samples with 12 M H_2SO_4, autoclaving 1 h, filtering, and adding phenol followed by concentrated H_2SO_4. The absorbance of the solutions was measured in a spectrophotometer at 490 nm. The conversion of the absorbance to polysaccharide concentration was performed using a standard curve constructed with absorbance values of known glucose concentrations. The LPS content (polysaccharides except cellulose) was determined following the same procedures utilized to determine TPS, except that samples were pretreated with 0.5 M H_2SO_4 rather than 12 M H_2SO_4.

2.5. Statistical analyses

All data were submitted to the tests of normality of the variables and the homogeneity of variances according to Bartlett's test. After all assumptions required for the analysis of variance (ANOVA) were verified, an ANOVA was conducted to evaluate the effect of soil tillage, rate of swine slurry, and interaction of the two factors by F-test ($p < 0.05$).