Available online at www.sciencedirect.com
ScienceDirect
Geoderma 139 (2007) 388–396
GEODERMA
www.elsevier.com/locate/geoderma

Phosphorus bioavailability affected by tillage and crop rotation on a Chilean volcanic derived Ultisol

Yonathan D. Redel, Rosa Rubio, Juan L. Rouanet, Fernando Borie *

Universidad de La Frontera, Casilla 54-D, Temuco, Chile

Received 27 February 2006; received in revised form 28 December 2006; accepted 15 February 2007

Abstract

The effect of management systems and crop rotation on soil phosphorus (P) fractions and selected soil properties were studied from 2002 to 2005 on an experiment established in 2001 in a volcanic derived Ultisol from southern Chile. Two tillage systems, no tillage (NT) and conventional tillage (CT), and two crop rotations, oat–wheat and white lupine–wheat were evaluated in order to determine the effects of such management in the lability of P in this soil. Seasonal additions of phosphate fertilizer at a rate of 80 kg P ha^{-1}, to oat and lupine, and 200 kg P ha^{-1} to wheat were applied to the high P fixing soil used. Soil analyses were performed each year after growing season. Total P increased from 1643 to 2053 mg kg^{-1} after 4 years of cultivation but most of this added P (72%) became unavailable. The application of the Hedley P fractionation procedure indicated that P was mainly distributed as relatively labile P, extractable with NaOH (43.5% of the total P), and that only 9.6% was labile P, extractable with resin and $NaHCO_3$. In NT soils the largest soil surface P accumulation was produced, mainly as inorganic P. In the oat–wheat rotation, the largest accumulation of moderate labile organic P was observed, preventing it from becoming unavailable; the lupine–wheat rotation left the greatest phosphatase activity in soil (738 µg PNFF g^{-1}). Tillage and crop rotation exerted the same level of effects on labile + relatively labile P fractions (*F*-probabilities of 0.045 and 0.040, respectively), but cropping systems affected the soil properties much more. Over fertilization caused high levels of soluble P (66 mg kg^{-1} of resin extractable P in the last year), but also promoted the P accumulation under unavailable fractions, especially in CT systems. Wheat cropping resulted in a greater accumulation of soil total P and no labile P; whereas oat and particularly lupine cropping showed a reduction of no labile P and an increase of relatively labile P.

Keywords: Phosphorus fractionation; Tillage; Crop rotation; Total P; Acid phosphatase

1. Introduction

Phosphorus (P) is commonly a limiting nutrient for plant growth in many soils around the world, and Chilean soils are no exception. Volcanic ash derived soils, mainly Andisols and Ultisols, are very common and abundant in the south of the country, where they cover more than 5×10^4 km^2 with cereals as the main crop. Since these soils have high P adsorption capacity, they need to be fertilized yearly with moderate to high amounts of phosphate fertilizers, which eventually accumulate in the soil as unavailable P forms (Borie and Zunino, 1983). Furthermore, these soils have a high content of total P (P_T); organic P (P_o) may represent more than 50% of the P_T, mainly present as inositol penta- and hexaphosphates (Borie et al., 1989; Borie and Rubio, 2003). The bulk of the P accumulates as macromolecular-P complexes closely associated with organic matter, possibly through Al and Fe bridges (Borie and Zunino, 1983). Thus, organic carbon (C_o) levels are controlled through aluminum stabilization in the soils (Matus et al., 2005), and physical protection of soil aggregates (Huygens et al., 2005). As inorganic P (P_i) as hydrogen phosphate ion is largely the preferred source for plant uptake, knowledge of the different fractions present within soils is fundamental to understanding bioavailability of P and the sustainability of agricultural practices (McDowell and Stewart, 2006).

Since these soils are at risk of erosion, local farmers have begun to shift from plowing systems to reduced tillage. Some benefits of long term no tillage (NT) over conventional tillage (CT) include reduced soil erosion, higher infiltration rate, higher soil biological activity and reduced evaporation (Duiker and Beegle, 2006). The levels of organic matter, microbial activity and nutrients like P are, in general, higher in the surface layers of NT soils compared with CT soils (Rheinheimer and Anghinoni, 2003). In addition, soil disturbance during tillage

* Corresponding author. Tel.: +56 45 325430; fax: +56 45 325440.
E-mail address: fborie@ufro.cl (F. Borie).

0016-7061/$ - see front matter © 2007 Elsevier B.V. All rights reserved.
doi:10.1016/j.geoderma.2007.02.018

operations may increase the degree of contact between fertilizer-derived P and soil particles, thereby promoting the formation of stable insoluble P compounds (Phiri et al., 2001). The influences of cropping practices on soil P distribution in pools of differing bioavailability is of increased interest due to the importance of P forms in relation to environmental, agronomic and economic concerns.

Different crops have a diverse productive potential and absorption of P from the soil, due to the differences in the strategies developed by their roots for enhancing nutrient acquisition. In crop rotations, the introduction of plants like lupine can enhance P availability, through the secretion of chelating acids by proteoid roots and phosphatase production when they grow in a soil with P deficiency (Neumann and Römheld, 1999). Such mechanism is inhibited by high levels of available P (Rubio et al., 2002). Therefore, mycorrhizable crops like wheat and oat can enhance the potential of inoculation of mycorrhizal fungi and phosphatase activity of their roots, thus promoting the organic P hydrolysis (Borie et al., 2002).

Chemical sequential extraction procedures have been and are still widely used to split extractable soil P into P_i and P_o (Chang and Jackson, 1957; Hedley et al., 1982; Cross and Schlesinger, 1995). The underlying assumption in these approaches is that readily available P or fractions with higher lability are removed first with mild extractants; while less available and/or unavailable P only are extracted with stronger acids or alkali (Cross and Schlesinger, 1995).

There are few antecedents of systematic study of sequentially extractable P fractions in acid volcanic ash derived soils of southern Chile. Although there are many studies about the effects of cropping systems in P fractions in the literature, studies about P fractionation in Ultisols of volcanic origin are lacking, with the exception of the soils used by Linquist et al. (1997), Guo et al. (2000) and Van der Eijk et al. (2006) in Hawaiian and Kenyan soils. Knowledge of P behavior is thus important to evaluate the possible effects of crop management on P bioavailability. Therefore, the objective of this study was to assess the impacts of tillage systems and crop rotation sequence on the lability of P fractions and vertical distribution of a cultivated Ultisol in southern Chile.

2. Materials and methods

2.1. Site description study

The site used for the assay established in 2001 is located at Pumalal, near Temuco. in the south of Chile (38° 40′ 23″ S; 72° 30′ 59″W, 185 m altitude; mean annual precipitation 1200 mm, mean temperature: 14.6 °C). The assay, which was conducted on a slightly acid (pH 5.7) fine and mesic Metrenco soil (Typic Palehumult), consists of a lupine (*Lupinus albus* L. c.v. Rumbo)–wheat (*Triticum aestivum* L. c.v. Kumpa-INIA) and oat (*Avena sativa* L. c.v. Nehuen-INIA)–wheat rotation under two conventional (CT) and no-tillage (NT) cropping systems. The plots, 20 m long and 7 m wide, were prepared as follows: a) CT with disk tillage and residue burning and b) NT, in which crops were directly drilled in the previous year stubble. Fertilization was performed at a rate of 150–200–80 kg N–P–K ha^{-1} for wheat, 150–80–80 kg N–P–K ha^{-1} for oat, and 20–80–80 kg N–P–K ha^{-1} for lupine. The plots managed with NT were weed controlled with glyphosate. The crops were established in May–June (autumn) of each year and were harvested on February (summer) of the following year (2002–2005).

Soils samples used for this study were taken in April (autumn) prior to the establishment of the crop, during the years 2002–2005. Each treatment had 8 plots randomly distributed from which four were selected. Twenty cores were collected and bulked to give a composite sample representing the plot. Samples were collected 0–10 cm deep in the years 2002 and 2003, and 0–5, 0–10 and 10–20 cm in the years 2004 and 2005. Selected soil properties at the beginning of the experiment are indicated in Table 1.

2.2. Analysis of soils

The soils were sieved (<2 mm) and kept field moist and stored at 4 °C in plastic containers until analysis. Soil pH was determined in a 1:2.5 soil/water (w/v) suspension using a glass electrode. Acid phosphatase (P-ase) in the rhizosphere soil was determined as Rubio et al. (1989) described for volcanic soils with high organic matter, using ρ-nitrophenyl-phosphate as substrate and 0.1 M Tris, pH 5.5 as buffer. Organic carbon (C_o) and total N (N_T) were determined by dry combustion. Olsen-P was measured by extracting with 0.5 M $NaHCO_3$ adjusted to pH 8.5, according to the Olsen and Sommers (1982) method. Total P (P_T) was determined by the alkaline oxidation method of Dick and Tabatabai (1977) and organic P (P_o) was measured as described by Borie and Zunino (1983). Exchangeable cations and Al were extracted with 1 M CH_3COONH_4 pH 7 and determined in an EAA Unicam 969 Spectrophotometer.

2.3. P fractionation

Phosphorus was fractionated according to a modified Hedley fractionation methodology (Hedley et al., 1982; Tiessen and

Table 1
Characteristics of the Ultisol used at the beginning of the experiment (in 2001)

Depth	pH	C_o	N	C/N	Olsen-P	S	Ca	Mg	K	Na	CEC[a]	Al sat[b]
		(%)	(%)		(mg kg^{-1})		(cmol$_c$ (+) kg^{-1})					(%)
0–10 cm	5.6	5.1	0.36	14	20.0	9.14	6.86	1.64	0.97	0.09	9.93	1.50
10–20 cm	5.3	3.9	0.19	20	8.2	5.83	4.32	0.94	0.42	0.09	6.39	9.55

[a] Cationic exchange capacity.
[b] Al saturation.