Soil & Tillage Research 175 (2018) 276–280

Contents lists available at ScienceDirect

Soil & Tillage Research

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

Short communication

Assessing linkage between soil phosphorus forms in contrasting tillage systems by path analysis

Tales Tiecher[a,b,*], Murilo Veloso Gomes[b], Vítor Gabriel Ambrosini[b], Magno Batista Amorim[b,c], Cimélio Bayer[a,b]

[a] Departament of Soil Science, Federal University of Rio Grande do Sul, Bento Gonçalves Ave. 7712, 91540-000, Porto Alegre, RS, Brazil
[b] Graduate Program in Soil Science, Federal University of Rio Grande do Sul, Bento Gonçalves Ave. 7712, 91540-000, Porto Alegre, RS, Brazil
[c] Federal Institute of Rondonia, Department of Agronomy, BR435 km 63, CEP 76993-000, Colorado do Oeste, RO, Brazil

ARTICLE INFO

Keywords:
Soil phosphorus fractionation
Conventional tillage
No tillage
Hypothetical models

ABSTRACT

Path analysis applied to sequential chemical fractionation of Hedley may improve our understanding on the linkage between P forms and its availability in soils. In this work, we assessed the role of Hedley-P fractions in buffering Resin-P (a plant-available soil P index) in a very clayey Oxisol (720 g kg^{-1} clay) and the validity of the postulated causal models for two long-term (23-yr) tillage systems (conventional-CT and no-till-NT) by path analysis. The model that accounted for the path from the less labile organic and inorganic P fractions to more labile ones, and from these fractions to the Resin-P showed the highest p value in NT (p = 0.36) and CT (p = 0.05), showing that the proposed models are a plausible representation of the tested causal relationships. These models explained 75 and 93% of Resin-P (U = 0.25 and 0.07) in CT and NT systems, respectively. The buffering flux of organic fractions was more pronounced in NT. However, the organic P pool has a higher direct contribution to buffer Resin-P in CT (94%) than in NT (35%), due to higher mineralization of organic P forms with moderate lability caused by soil disturbance. On the other hand, in the long-term NT, moderate inorganic P showed a high contribution to directly buffer Resin-P (40%). Although inorganic P associated with Ca is a very small fraction of P in strongly weathered soils, the path analysis showed that this fraction was a direct source of P in both soil tillage systems, but it was more important source to buffer Resin-P in NT (16.7%) than in CT (1.9%) due to the higher P content and path coefficient of this fraction in NT. Residual organic and inorganic P fraction were not related to any fraction of P, indicating that these fractions were neither a sink nor a source of P in both tillage systems, or that they become a temporary source and sink at the same time in the long-term experiment. The path analysis showed to be an important tool to interpret the results obtained in sequential chemical fractionation of P, improving our understanding of the soil P dynamics in contrasting tillage systems.

1. Introduction

Phosphorus (P) is considered one of the nutrients that most limits crop yields in tropical and subtropical environments, where large amounts of phosphate fertilizers are annually applied to crop fields to overcome this problem. However, sources of phosphate fertilizers are limited and the maximum exploitation capacity of P reserves is expected for the next decades (Cordell et al., 2009). Moreover, high P input levels in agriculture triggers environmental problems (Zafar et al., 2016). Therefore, the knowledge of soil P dynamics is essential to develop good practices to ensure the maximum fertilizer efficiency.

One of the most widespread techniques to evaluate soil P dynamics is the sequential chemical fractionation proposed by Hedley et al. (1982), which provides information on both the lability and the nature of soil P. P fractionation methodology may be adapted to the most diverse laboratory conditions, has low cost, requires a small amount of samples and may be performed with a relatively large set of samples and/or repeats (do Nascimento et al., 2015).

Hedley fractionation has provided great advances in the understanding of the soil P dynamics, but its interpretation has often been limited to individual comparisons of each form of P between treatments, depths, sampling periods, or comparisons by exploratory multivariate analyzes, such as principal component analysis (Gatiboni et al., 2007; Guardini et al., 2012; Schmitt et al., 2013; Teles et al., 2017; Yang and Post, 2011). On the other hand, some studies have shown the potential of path analysis to provided a better understanding of interactions between Hedley P fractions in soils of differing pedogenesis in United States of America (Tiessen et al., 1984), in

* Corresponding author at: Departament of Soil Science, Federal University of Rio Grande do Sul, Bento Gonçalves Ave. 7712, 91540-000, Porto Alegre, RS, Brazil.
E-mail addresses: tales.tiecher@gmail.com, tales.tiecher@ufrgs.br (T. Tiecher).

http://dx.doi.org/10.1016/j.still.2017.09.015
Received 15 March 2017; Received in revised form 7 September 2017; Accepted 29 September 2017
Available online 09 October 2017
0167-1987/

nonfertilized and fertilized system in Peru (Beck and Sanchez, 1994), in different crop rotation systems and nutrient sources (mineral fertilizer and liquid dairy manure) in Canada (Zheng et al., 2004, 2002), in a wide range of unfertilized soil types under different land use systems in tropical regions (Gama-Rodrigues et al., 2014; Sales et al., 2015), in Eucalyptus plantation (Costa et al., 2016) and in cacao agroforests (Aleixo et al., 2016) in Brazil. Accordingly, path analysis allows to distinguish functional pools and identify processes of P transformation in the soil between pools based on a source-sink relationship. However, so far, path analysis has not been used to evaluate these relationships in contrasting soil tillage systems.

Therefore, we used data from previous studies that limited their discussion to individual comparisons of each soil P form between tillage systems (no tillage − NT, and conventional tillage − CT) (Tiecher et al., 2012a, 2012b). This study aimed to evaluate the links between the Resin-P (a plant-available soil P index) and the other Hedley-P fractions and to use the postulated causal models obtained by path analysis for a better understanding of soil P dynamics in a very clayey Oxisol from Southern Brazil managed for 23-yrs in NT and CT.

2. Material and methods

2.1. Data source

This study was based on a dataset of organic and inorganic soil P forms published by Tiecher et al. (2012a,b), which are presented in Table 1. The P forms were obtained from the sequential chemical fractionation of Hedley et al. (1982): inorganic labile P extracted by anion exchange resin (Resin-P); labile organic (Po_{BIC}) and inorganic (Pi_{BIC}) P extracted by $NaHCO_3$ 0.5 mol L^{-1} at pH 8.5; moderately labile organic ($Po_{HID\text{-}0.1}$) and inorganic ($Pi_{HID\text{-}0.1}$) P extracted by NaOH 0.1 mol L^{-1}; moderately labile inorganic (Pi_{HCl}) P extracted by HCl 1.0 mol L^{-1}; poorly labile organic ($Po_{HID\text{-}0.5}$) and inorganic ($Pi_{HID\text{-}0.5}$) P extracted by NaOH 0.5 mol L^{-1}; and non-labile residual organic ($Po_{RESIDUAL}$) inorganic ($Pi_{RESIDUAL}$) P. Data of P fractions comprised three soil layers (0–5, 5–10, and 10–20 cm) from conventional (CT) and no-tillage (NT) systems, totaling 18 samples per soil layer and per soil tillage system (total *n* per system = 54). Summer crops received fertilizer every year and the total amount of P applied during 23 years was 659 kg P ha^{-1} in the form of inorganic soluble phosphate. Moreover, during this period, lime was applied six times for a total of 11.5 Mg ha^{-1} (1.0, 2.0, 3.0, 1.5, 2.0 and 2.0 Mg ha^{-1} of lime (dolomite) in all plots, in 1989, 1992, 1995,1999, 2001 and 2006, respectively). A more detailed description about the study site and the history of experimental area can be obtained in Tiecher et al. (2012a).

2.2. Building path analysis models

Path analysis was used in causal test models to explain the contribution of Hedley P fractions to buffer the Resin-P, which is a soil index that estimates the plant-available P. Despite to be only an index, the Resin-P has a strong relationship with P availability to the crops, and it is taking into account in the fertilization programs of the most regions of Brazil (CQFS-RS/SC, 2016). In the analysis, we used the *d*-separation approach, in which a set of independent relations among the variables included in the model were defined for each proposed causal model by linking P fractions to the Resin-P and their combinations with each other. Each of these independent relationships involved correlations and partial correlations that were tested by permutation (Manly, 2007).

Each causal model generated a value of probability for a composite statistic (C of Fisher's statistic; Shipley 2000), which was tested using the χ^2 probability distribution. A valid causal model must have *p*-value greater than an acceptable probability threshold ($p > 0.05$). For a valid model, regression models were used to determine the path coefficients and corresponding probabilities, found by permutation (Manly, 2007), in addition to a non-determination coefficient. The variables (responses and factors) were centralized and standardized for the unit of variance and, therefore, the path coefficients (β) were compared between the models.

Table 1
Direct potential contribution of soil P forms to buffer Resin-P after 23-yrs of no-till and conventional tillage systems in a very clayey Oxisol from Southern Brazil.

Soil P form	Lability	No-tillage system					Conventional tillage system				
		P content (mg kg^{-1})	Path-analysis		Resin-P buffer		P content (mg kg^{-1})	Path-analysis		Resin-P buffer	
			β	*p*-value	Potential contribution (mg kg^{-1})[3]	Relative contribution (%)		β	*p*-value	Potential contribution (mg kg^{-1})	Relative contribution (%)
Inorganic											
Pi_{BIC}[a]	Labile	7.0	0.56	0.0040	3.9	8.3	5.2	0.60	**0.0030**	3.1	4.1
$Pi_{HID-0.1}$[a]	Moderately labile	42.6	0.44	**0.0300**	18.8	39.8	35.0	0.18	0.6800	–	–
Pi_{HCl}[a]	Moderately labile	8.4	0.93	**0.0001**	7.9	16.7	4.2	0.35	**0.0100**	1.5	1.9
$Pi_{HID-0.5}$[a]	Poorly labile	94.4	0.02	0.9100	–	–	87.5	0.06	0.2700	–	–
Sum		152.4	–	–	30.6	64.8	131.9	–	–	4.6	6.0
Organic											
Po_{BIC}[b]	Labile	23.7	0.70	**0.0100**	16.6	35.2	23.9	0.32	**0.0300**	7.6	9.9
$Po_{HID-0.1}$[b]	Moderately labile	273.2	0.26	0.3000	–	–	209.8	0.31	**0.0500**	65.0	84.2
$Po_{HID-0.5}$[b]	Poorly labile	193.4	0.01	0.9700	–	–	144.5	0.16	0.2600	–	–
Sum		490.3	–	–	16.6	35.2	378.2	–	–	72.6	94.1
Total		642.7			47.1	100.0	510.0			77.3	100.0
P_{AER}[a]	Plant-available	19.9					8.8				

Bolt values indicate significant β-coefficient at $p < 0.1$.
[c] Potential contribution = P content × β-coefficient, for $p < 0.1$.
[a] Tiecher et al. (2012b).
[b] Tiecher et al. (2012a).