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Prediction of P concentrations in soil leachates: Results from 6 long term field trials on soils with a high P load

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ABSTRACT

We tested if a single soil P capacity test allows for a reliable forecast of P leaching from agricultural soils with a high P load. In regions with intensively managed arable soils, the soil P content has been dramatically increased by overfertilization with significant P leaching losses as a result. As a consequence, in order to control the P losses, P fertilization has been legally restricted. In several EU28 countries, the ammonium lactate extraction method (P-AL) is used as a soil test for P fertilizer advice, but sometimes also to determine the allowed P fertilizer dose to reduce leaching losses. We hypothesize that P-AL as an estimator of soil P capacity should be combined with 0.01 *M* $CaCl_2$ extractable P (P-$CaCl_2$) and/or hot water extractable P (HWP), both estimators of the soil P intensity, to predict P leaching losses in soils with a high P load.

Six long term field trials with a high P load (P-AL: 123 to 375 mg P kg^{-1}) on silt loam soils with a specific history of organic and inorganic fertilizer application were sampled for soil analysis and to conduct leaching experiments in the laboratory. P concentrations in the leachates served as a proxy for P leaching. Five field trials were used for model calibration and a sixth one for model validation. Two models, either with P-$CaCl_2$ or with HWP as independent variables, have proven to be suited to distinguish soils with low and high risk for P leaching. In the range of P-AL in this study, P-AL proved to be a non-significant factor and was therefore not retained in either of the models. We conclude that for soils with large soil P stocks (high P-AL concentrations), both P-$CaCl_2$ and HWP are suitable to detect the ones with a higher risk of P leaching losses. We suggest a threshold value for P-$CaCl_2$ and HWP to be used in combination with P-AL, to select those soils where further P fertilization restrictions or other measures to reduce P leaching losses are needed most urgently. This threshold value however depends on what is considered as an acceptable P concentration in the leaching water of the tillage layer.

1. Introduction

Decennia of imbalance between P fertilization and P uptake by crops in regions with intensive agriculture in Europa and North America have resulted in an increase in soil P content above those required for optimum plant growth (McDowell and Sharpley, 2002; Chardon and Schoumans, 2007; Jordan-Meille et al., 2012). Risk of non-point P losses from flat areas, i.e. P leaching losses increase with increasing soil P content (Haygarth et al., 1998; Maguire and Sims, 2002; Jordan-Meille et al., 2012; De Bolle et al., 2013; Svanbäck et al., 2013). Soils have a finite capacity to retain P, and the environmental limit of safe P storage can ultimately be reached at continued large fertilizer application rates (Nair, 2014). Since the 1990s, the European nitrates (91/676/EEC, 2016) and water framework (2000/60/EC, 2016) directives, urged several member states and/or regions of the European Union, including Flanders (northern Belgium) and the Netherlands, to decrease P leaching losses to the environment by restriction of the total P fertilization of agricultural soils (De Clercq et al., 2001; Amery and Schoumans, 2014). Therefore the P fertilization legislation of both Flanders and the Netherlands was recently adapted to include the soil P content (Rijksdienst voor ondernemend Nederland, 2015; VLM, 2015), as measured with ammonium lactate extract (P-AL)

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(Egnér et al., 1960). Many different soil P tests are used among the EU member states (Jordan-Meille et al., 2012), which makes it hard to compare data of different countries. P-AL was chosen in both Flanders and The Netherlands as it is widely used as a soil test to estimate the available or desorbable P. The lactate extract contains acid leading to dissolution of Al and Fe from their oxides followed by P release. In addition, the acid inhibit any secondary resorption of P in the extracts (Eriksson et al., 2013). P-AL is therefore an estimator of the so called soil P capacity. In Flanders a P-AL concentration above 180 mg P kg^{-1} is considered as excessive (Jordan-Meille et al., 2012). The larger the P-AL content of the soil, the smaller the maximum allowed total P fertilization dose (VLM, 2015), based on the hypothesis that a larger P-AL in the soil results in a larger risk for P leaching.

Previous studies to develop or to test an indicator for the risk of P leaching can be roughly divided in two groups: (i) studies that focus on soil parameters that indicate the immediate P availability or P intensity and that are based on 'mild' extractions with demineralized water or 0.01 M $CaCl_2$, and (ii) studies that focus on 'available' soil P stocks or P capacity measurements and are based on chemical extractions such as degree of P saturation (oxalate extraction), P-AL, Olsen-P and Mehlich-3. Mehlich-3 is well suited for both acidic and basic soils and the acidic extraction solution contains both ammonium fluoride and acetic acid. Olsen-P is more suited for calcareous soils and the extraction solution consists of $NaHCO_3$ (pH 8.5) (Pierzynski, 2000).

Svanbäck et al. (2013) reported a good relationship between the P-AL and the P concentrations of the leachates in a soil column experiment in Sweden in soils of both light and heavy texture and with a large range of P-AL levels (15–236 mg P kg^{-1}). Also Liu et al. (2012) observed increasing P leaching losses with increasing P-AL levels (140–280 mg P kg^{-1}). Maguire and Sims (2002) stated that a tipping point could be defined in the relationship between Mehlich-3 extracted P and the P concentrations in the leachates. Below this point there is hardly any P leaching loss, whereas above it the P concentration in the leachate increases very rapidly with increasing Mehlich-3 extracted P. Based on these studies, it seems that the P concentrations of the leachates are mainly determined by the P stocks as quantified in a 'capacity' measurement. However, we have to acknowledge that the data in the study of Svanbäck et al. (2013) and Maguire and Sims (2002) are less representative for soils with an excessively high P content (P-AL > 180 mg P kg^{-1})

Table 1
Start and sampling years, location, replicates per treatment, crop rotation and number of treatments per fertilizer category of the 6 long term.

Field experiment	Start year	Sampling year	Site	Soil type[a]	Graphical coordinates	Replicates per treatment	Crop rotation	Number of treatments per fertilizer category				
								Zero P fertilization	Mineral P fertilizer	Cattle slurry	Farmyard manure	Compost
M97.01	1997	2010	Ghent University Melle, Belgium	Eutric Endogleyic Retisol (Loamic)	50° 59′ 06“N 03° 48′ 34“E	3	Forage maize	–	1	1	–	2
Qualiagro	1998	2013	INRA Feucherolles, France	Glossic Luvisol	48° 53′ 48′′N 01° 58′ 24′′E	4	Corn maize Winter wheat	1	–	–	1	2
ORG G9/ G10	2005	2010	ILVO Melle, Belgium	Haplic Luvisol (Colluvic, Loamic)	50° 59′ 11“N 03° 47′ 09“E	4	Forage maize Potato Spring barley Red clover	–	–	2	–	2
M05.01	2005	2011	Ghent University Melle, Belgium	Eutric Endogleyic Retisol (Loamic)	50° 58′ 50“N 03° 48′ 59“E	4	Fodder beet Winter wheat Red cabbage Perennial ryegrass Forage maize Fodder beet Red cabbage	2	1	1	1	3
M10.01	2010	2013	Ghent University Melle, Belgium	Eutric Endogleyic Retisol (Loamic)	50° 58′ 47“N 03° 48′ 55“E	3	Forage maize Potato Fodder beet Oat	1	1	1	1	1
BOPACT	2010	2014	ILVO Melle, Belgium	Bathygleyic Cambisol	50° 59′ 06“N 03° 46′ 24“E	4	Forage maize Potato Spring barley Leek Forage maize	Treatments: cattle slurry, cattle slurry + compost, pig slurry, pig slurry + compost				

[a] WRB classification, based on Chalhoub et al. (2013) for the Qualiagro field trial and based on Dondeyne et al. (2014) for all other field trials.