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Phosphorus saturation and mobilization in two typical Chinese greenhouse vegetable soils

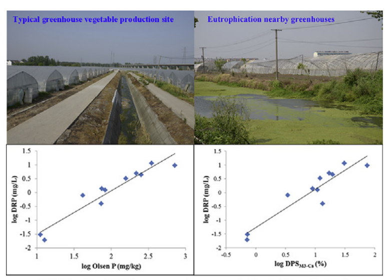
Yusef Kianpoor Kalkhajeh [a, b, c], Biao Huang [b, c, *], Wenyou Hu [c], Peter E. Holm [a, b], Hans Christian Bruun Hansen [a, b]

[a] Department of Plant and Environmental Sciences, University of Copenhagen, Thorvaldsensvej 40, DK-1871, Frederiksberg C, Denmark
[b] Sino-Danish Center for Education and Research (SDC), China
[c] Key Laboratory of Soil Environment and Pollution Remediation, Institute of Soil Science, Chinese Academy of Sciences, Nanjing, 210008, China

HIGHLIGHTS

- Longer history of greenhouse vegetable production caused excessive P accumulation.
- Exponential P losses occurred with increasing soil labile P in coarse-textured soils.
- Higher levels of Particulate P were found in soil column leachates of smaller labile P.
- Soil Olsen P test was found superior to assess the potential risk of P losses.

GRAPHICAL ABSTRACT



Soil Olsen P and DPS$_{M3-Ca}$ are good measures for leachability of P (DRP)

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ABSTRACT

Chinese greenhouse vegetable production can cause eutrophication of fresh waters due to heavy use of fertilizers. To address this, phosphorus (P) leaching was compared between two major greenhouse vegetable soils from Jiangsu Province, Southeast China: clayey and acid-neutral Guli Orthic Anthrosols and sandy and alkaline Tongshan Ustic Cambosols. A total of 20 intact soil columns were collected based on differences in total P content varying between 1360 and 11,220 mg kg^{-1}. Overall, six leaching experiments were carried out with collection of leachates over 24 h. Very high P concentrations, with a mean of 3.43 mg L^{-1}, were found in the leachates from P rich Tongshan soils. In contrast, P leaching from fine-textured but less P rich Guli soils rarely exceeded the suggested environmental P threshold of 0.1 mg L^{-1}. Strong linear correlations were found between different soil test P measures (STPs) or degree of P saturations (DPSs) and dissolved reactive P (DRP) for Tongshan soil columns. The correlations with Olsen P ($r^2 = 0.91$) and DPS based on MehlichIII extractable calcium (DPS$_{M3-Ca}$) ($r^2 = 0.87$) were the most promising. An Olsen P value above 41 mg kg^{-1} or a DPS$_{M3-Ca}$ above 3.44% led to DRP leaching exceeding 0.1 mg L^{-1}. Accordingly, more than 80% of Tongshan soils resulted in DRP leaching exceeding the environmental P threshold. In conclusion P rich alkaline sandy soils used for greenhouse vegetable production are at high risk of P mobilization across China.

* Corresponding author. Key Laboratory of Soil Environment and Pollution Remediation, Institute of Soil Science, Chinese Academy of Sciences, Nanjing, 210008, China
E-mail addresses: ykk@plen.ku.dk (Y.K. Kalkhajeh), bhuang@issas.ac.cn (B. Huang), wyhu@issas.ac.cn (W. Hu), peho@plen.ku.dk (P.E. Holm), haha@plen.ku.dk (H.C. Bruun Hansen).

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Abbreviations

Al	Aluminum
Al_{Ox}	Oxalate extractable Al
Ca	Calcium
DPS	Degree of P saturation
DPS_{Ox}	Degree of P saturation based on oxlate extraction
$DPS_{M3\text{-}Ca}$	Degree of P saturation based on MehlichIII extractable Ca
$DPS_{Ox\text{-}Al}$	Degree of P saturation based on oxlate extractable Al
$DPS_{Ox\text{-}(Al+Fe)}$	Degree of P saturation based on oxlate extractable Al and Fe
DRP	Dissolved reactive P
Fe	Iron
Fe_{Ox}	Oxalate extractable Fe
STP	Soil test for P
P	Phosphorus
PP	Particulate P
OM	Organic matter
Mg	Magnesium
Mn	Manganese
N	Nitrogen
LOD	Limit of detection
PFPs	Preferential flow pathways
WEP	Water extractable P
TP	Total P
TN	Total N

1. Introduction

Phosphorus (P) is one of the main elements for biota productivity which on excessive input may cause freshwater eutrophication (Carpenter et al., 1998). Although, surface runoff/erosion is a main pathway of P emission from agricultural soils to water bodies (Sharpley et al., 1993), subsurface P leaching is also an important pathway (Kronvang et al., 2005). Worldwide, intensive agriculture is estimated to be the main nonpoint source of P losses to surface waters (Kronvang et al., 2005; Reckhow et al., 2011). Continuous fertilization exceeding crop requirement results in residual P accumulation in soil which, in turn, leads to eutrophication of surface waters (Sharpley, 2000) through export of excessive P from agricultural lands to water bodies. Greenhouse vegetable cultivation in China has increased considerably, more than 300 fold, from 1980 to 2010 (Chen et al., 2013), accounting for over half of total vegetable production in the world (FAO, 2012). Compared to cereal crops, vegetables have different nutrient requirements with a higher P uptake (Yan et al., 2014), encouraging Chinese vegetable producers to apply substantial amounts of manure and fertilizers to increase productivity (Yu et al., 2010). Furthermore, manure is being applied heavily based on the N requirement of vegetables leading to excessive P input and accumulation. This excessive P input has caused the majority of Chinese vegetable soils to have high contents of Olsen P exceeding critical levels for optimum vegetable production, viz. 58 and 46 mg per kg soil for fruity and leafy vegetables, respectively (Yan et al., 2014). In addition, there is a growing concern over the mobilization of accumulated P which eventually leads to eutrophication of surface waters.

In southeast China with relatively high precipitation (>1000 mm per year), accumulated soil P can transport to surface waters by erosion (Bai et al., 2013), while P leaching to downstream waters also take place via subsurface leaching (Shi et al., 2009). For greenhouse soils in Jiangsu Province, Southeast China, with N application rates up to 1100 kg ha^{-1} y^{-1}, Min et al. (2012) observed the highest N losses in the range 181–276 kg ha^{-1} y^{-1}, during the period greenhouse fields were uncovered with polyethylene film. In another study, excessive N and P fertilization to greenhouse plots was identified as a possible source for contamination of water bodies in urban areas of Nanjing City, China (Chen et al., 2013).

Previous studies have verified that various soil tests for P (STP) developed for agronomic and environmental purposes along with the degree of P saturation (DPS) can be successfully combined with the information of P transport pathways as a useful tool to assess the potential risk of P losses from soils to the aqueous environment (e.g. Hesketh and Brookes, 2000; Wang et al., 2012). Hesketh and Brookes (2000) reported a change-point value in terms of Olsen P above which the soluble P increased dramatically. The degree of P saturation based on MehlichIII extractable Al has been suggested as the best index for dissolved reactive P (DRP) losses via leaching from Ontario soils with pH differing from acid to neutral (Wang et al., 2012). In an early work, Heckrath et al. (1995) found a change-point value of 60 mg kg^{-1} for Olsen P above which DRP concentration in tile drains increased markedly from heavy soils. Although, various STPs and DPSs are widely accepted as good indicators of leachate DRP concentration, Djodjic et al. (2004) found no correlation between topsoil Olsen P, varying from 3.3 to 90.2 mg kg^{-1}, and leaching DRP concentrations for Swedish soils ranging from clay to sandy loam. On the contrary, they identified preferential flow pathways (PFPs) to be more important for P losses with particulate P as the main P fraction in the soil effluents.

In spite of the large-scale greenhouse vegetable production that takes place in China, there is no detailed study demonstrating the risk of subsurface P mobilization from greenhouse soils. It is important to quantify the effects of topsoil properties on soil available P and on subsurface P leaching to establish the critical labile P values over which P losses will markedly increase. Jiangsu Province, located along the coast of the Yellow Sea, which is one of the main areas of greenhouse vegetable production in China, was selected for the current study. The greenhouse vegetable cultivation in this region is accompanied with intensive agricultural inputs including synthetic and organic P fertilizers particularly chicken manure. Overall, this study aimed to (1) Identify the effect of physical and chemical properties of topsoil on P losses, (2) Test the use of both soil agronomic and environmental STPs as well as different DPSs as indicators to assess the risk of P losses, and (3) Estimate threshold values of STP/DPS as indicators for risk of subsurface P losses from the cultivation layer of greenhouse vegetable soils.

2. Materials and methods

2.1. Site description

Two contrasting greenhouse vegetable soils representing two major soil types used for greenhouse vegetable production in Southeastern China were selected in Jiangsu Province, along the coast of the Yellow Sea (Fig. 1). The first site, Tongshan County, located in Northwest of Jiangsu Province (Fig. 1a), has an annual mean temperature and precipitation of 14.5 °C and 832 mm, respectively (Yang et al., 2014). The greenhouses in this region are placed on Ustic Cambosols (Entisols) (CRGCST, 2001). The second