Journal of Integrative Agriculture 2016, 15(1): 200–208

Available online at www.sciencedirect.com

ScienceDirect

ELSEVIER

RESEARCH ARTICLE

Long-term phosphorus accumulation and agronomic and environmtal critical phosphorus levels in Haplic Luvisol soil, northern China

XI Bin[1], ZHAI Li-mei[1], LIU Jian[1, 2], LIU Shen[1], WANG Hong-yuan[1], LUO Chun-yan[1], REN Tian-zhi[3], LIU Hong-bin[1]

[1] *Key Laboratory of Nonpoint Source Pollution Control, Ministry of Agriculture/Institute of Agricultural Resources and Regional Planning, Chinese Academy of Agricultural Sciences, Beijing 100081, P.R.China*
[2] *USDA-Agricultural Research Service, Pasture Systems and Watershed Management Research Unit, PA 16802, USA*
[3] *Institute of Agro-Environmental Protection, Ministry of Agriculture, Tianjin 300191, P.R.China*

Abstract

Sufficient soil phosphorus (P) content is essential for achieving optimal crop yields, but accumulation of P in the soil due to excessive P applications can cause a risk of P loss and contribute to eutrophication of surface waters. Determination of a critical soil P value is fundamental for making appropriate P fertilization recommendations to ensure safety of both environment and crop production. In this study, agronomic and environmental critical P levels were determined by using linear-linear and linear-plateau models, and two segment linear model, for a maize (*Zea mays* L.)-winter wheat (*Triticum aestivum* L.) rotation system based on a 22-yr field experiment on a Haplic Luvisol soil in northern China. This study included six treatments: control (unfertilized), no P (NoP), application of mineral P fertilizer (MinP), MinP plus return of maize straw (MinP+StrP), MinP plus low rate of farmyard swine manure (MinP+L.Man) and MinP plus high rate of manure (MinP+H.Man). Based on the two models, the mean agronomic critical levels of soil Olsen-P for optimal maize and wheat yields were 12.3 and 12.8 mg kg^{-1}, respectively. The environmental critical P value as an indicator for P leaching was 30.6 mg Olsen-P kg^{-1}, which was 2.4 times higher than the agronomic critical P value (on average 12.5 mg P kg^{-1}). It was calculated that soil Olsen-P content would reach the environmental critical P value in 41 years in the MinP treatment, but in only 5–6 years in the two manure treatments. Application of manure could significantly raise soil Olsen-P content and cause an obvious risk of P leaching. In conclusion, the threshold range of soil Olsen-P is from 12.5 to 30.6 mg P kg^{-1} to optimize crop yields and meanwhile maintain relatively low risk of P leaching in Haplic Luvisol soil, northern China.

Keywords: critical phosphorus value, crop yield, Olsen P, phosphorus leaching, soil phosphorus test, water quality

1. Introduction

Soils should contain a certain amount of plant-available phosphorus (P), together with other nutrients, to ensure optimum crop yields (Poulton *et al.* 2013). However, excessive P applications have caused low P use efficiency, large amounts of P accumulation in the soil, and thus resulted in an increasing environmental risk in many Chi-

Received 23 October, 2014 Accepted 30 December, 2014
Correspondence LIU Hong-bin, Tel: +86-10-82108763, Fax: +86-10-82106225, E-mail: liuhongbin@caas.cn

doi: 10.1016/S2095-3119(14)60947-3

nese agricultural fields (Li *et al.* 2011). In order to maintain optimum crop yields but also to reduce the risk of P loss, it is essential to determine critical P levels that can be used in fertilization recommendations to farmers. Such values can be determined by testing of soil P contents (McDowell 2012; Bai *et al.* 2013). There are two aspects of the critical soil P levels: (i) an agronomic critical P level, which corresponds to an optimum crop yield; and (ii) an environmental critical P level, corresponding to a change point of the risk of P loss, above which level the risk of P loss dramatically increases (Sibbesen and Sharpley 1998). Several studies, mainly based on long-term experiments with different fertilization treatments, have determined either agronomic or environmental critical P level (Colomb *et al.* 2007; Tang *et al.* 2009; Bai *et al.* 2013; Poulton *et al.* 2013), but few considered both critical values in the same study. In principle, the upper limit of P in the soil should be set by considering both critical values, to maximize crop production and minimize environmental risk of P loss.

Transport of the P accumulated in the agricultural fields can be a major contributor to eutrophication of aquatic systems (Chakraborty *et al.* 2012; Zhang F *et al.* 2013). Dissolved reactive P (DRP) in drainage from high-P soils has been frequently observed above the P concentrations associated with eutrophication (Rory and Thomas 2002). Several studies have identified a significant relationship between P loss in tile drainage and soil test P (STP) content (i.e., agronomic P tests such as Bray, Mehlich, or Olsen) (Brookes 2000; Hesketh and Brookes 2000; Wang *et al.* 2008; Djodjic and Mattsson 2013; Qiu *et al*. 2013). This relationship between P loss and STP can be split into two straight lines by a change point, which is determined as an environmental critical P value (Hesketh and Brookes 2000). Below the critical P value, the leachate DRP concentrations increase slowly with per unit increase in STP; while above the critical value, DRP concentrations increase dramatically (Rory and Thomas 2002). For example, the long-term Broadbalk experiment showed low total-P concentration (<0.15 mg P L^{-1}) in the drainage water from the corresponding soils with Olsen-P content below 60 mg kg^{-1}, but a linearly rapid increase in total-P concentrations while soil Olsen-P was above 60 mg kg^{-1} (Brookes *et al.* 1998). When making a risk assessment, potential DRP losses *via* surface runoff or subsurface flow can be estimated by the soil P concentrations tested after extraction with water or 0.01 mol L^{-1} $CaCl_2$ solution (McDowell and Sharpley 2001). Based on this, some USA states have established environmental critical P values according to different STP, and such values have been used in P management recommendations, with the aim to protect water quality (Sibbesen and Sharpley 1998; Weld *et al.* 2001; Van Bochove *et al.* 2012; Mardamootoo *et al.* 2013).

In China, Li and Jin (2011) estimated national farmland P balance and reported that China had a surplus of about 1 030 t P in the soil, which is about 50% of the total annual input of P in mineral fertilizers and farmyard manures. From 1980 to 2007, an average of 240 kg P ha^{-1} accumulated in the soil, resulting in an increase of soil Olsen-P from 7.4 to 24.7 mg kg^{-1} (Li *et al.* 2011). Phosphorous from agricultural land has become the dominant factor controlling freshwater quality in many Chinese catchments (Zhang F *et al.* 2013). Driven by an urgent need to both produce more food and lessen the environmental stress of agriculture, the Chinese scientists are making many efforts to seek critical P levels that can be used to ensure both crop yields and environmental quality (Zhang F *et al.* 2013). It is desirable that such critical P values are both agronomically and environmentally sound and from a practical point of view they should be based on the same STP method that can be routinely used in P recommendations (Moody 2011; Mardamootoo *et al.* 2013).

The objective of this study was to suggest agronomic and environmental critical soil P values that can be used to ensure both crop yields and water quality. This study was based on a long-term maize (*Zea mays* L.) and wheat (*Triticum aestivum* L.) rotation cropping system on a Haplic Luvisol soil in northern China. We used three steps to determine the critical P values. Firstly, we used two different models to determine the agronomic critical values of soil Olsen-P corresponding to optimum maize and wheat yields. Secondly, we determined the environmental critical value of Olsen-P above which $CaCl_2$-P would dramatically increase. Finally, we suggested a P threshold range that can be used in P fertilization recommendations on this type of soil.

2. Results

2.1. Crop yields and soil P balance

Mean annual grain yields and straw biomass of wheat and maize during the 22 experimental years are presented in Table 1. Grain yields ranged from 0.48 t ha^{-1} yr^{-1} in wheat and 1.71 t ha^{-1} yr^{-1} in maize in the control treatment which did not receive any fertilizer, to 3.58 t ha^{-1} yr^{-1} in wheat and 5.87 t ha^{-1} yr^{-1} in maize in the treatment with mineral P fertilizer in combination with low rate of manure (MinP+L.Man). The yields in the mineral fertilizer but no P treatment (NoP) were significantly lower than the yields in all the treatments with P applications. Application of manure in addition to mineral P fertilizer significantly (P<0.05) increased crop yields compared with the treatment with only mineral P fertilizer. This suggests that application of mineral P fertilizer in combination with manure is important to maximize crop yields over long term. However, the yields did not increase