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Effects of 29-year long-term fertilizer management on soil phosphorus in double-crop rice system

Zhenzhen LV, Xiumei LIU, Hongqian HOU, Yiren LIU*, Jianhua JI,
Xianjin LAN, Zhaobin FENG

Institute of Soil Fertilizer and Resource Environment, Jiangxi Academy of Agricultural Sciences, Nanchang, P.R. China

**Corresponding author: jxnclyr@163.com*

ABSTRACT

Lv Z.Z., Liu X.M., Hou H.Q., Liu Y.R., Ji J.H., Lan X.J., Feng Z.B. (2018): Effects of 29-year long-term fertilizer management on soil phosphorus in double-crop rice system. Plant Soil Environ., 64: 221–226.

Rational soil phosphorus (P) management is significant to crop production and environment protection. Little information is available on soil Olsen-P balance and critical values in double-crop rice in China. The main aim of the study was to relate soil Olsen-P to apparent P balance and to determine Olsen-P critical value for early and late rice using data from a 29-year study (1984~2012) at the Jiangxi province. The results showed that Olsen-P decreased by 0.12~0.26 mg/kg/year without P addition and increased by 0.56~2.52 mg/kg/year with P fertilization. Olsen-P decreased by 0.30 mg/kg for CK and NK under an average deficit of 100 kg P/ha, and increased by an average of 9.10 mg/kg in treatments with organic manures and were 4.55 times higher than chemical fertilizers with 100 kg/ha of P surplus. The critical values for early and late rice were 22.70 and 22.67 mg/kg, respectively. The average Olsen-P content is 90.89 mg/kg after 29-year application of chemical fertilizer and manures. Therefore, decreasing the amount of total P input and increasing the compost portion should be recommended to improve food production and protect environment in red paddy soils in south China.

Keywords: organic-inorganic fertilizers; agronomic thresholds; evolution; Chinese milk vetch; pig manure

Rice is one of the most important food crops worldwide. China has been the world's largest rice producer and consumer (Peng et al. 2009). The paddy field in Red Soil Region of south China is one of the major rice producing areas. Since the 1960's, as people recognized the importance of phosphorus (P) for plant growth and grain yields, it has drawn more and more attention. Especially since the 1980's, with the creation of high concentration compound fertilizers, P has been applied intensively in farmland. Continuous and intensive application of P causes P accumulation in the plough layer (Nagumo et al. 2013, Ma et al. 2014). Accumulated P in surface soils could be leached with the runoff in the farmyard and soil erosion to water, which causes the eutrophication of water bodies (Lv et al. 2015). The soil Olsen-P content is an important index to evaluate the supply capacity of soil P and environmental risks in paddy soils. Thus, it is necessary to understand the dynamics, balance of soil Olsen-P after P supplied in an agro ecosystem and to determine its critical values for both maximizing the agronomic returns of P fertilization while minimizing the risks of P environmental pollution.

With the constantly emerging negative effects of chemical fertilizers application on soil health and

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environment, organic fertilizers (e.g., manure and crop straw return) as a source of nutrients applied in soil have drawn more attention. Organic fertilizers have different N:P ratios, such as crop straws are higher than manure (Hua et al. 2016). Manure has low N:P ratios and the application rates are normally based on the nitrogen (N) requirements of the crop, which leads to the over-application of P (Pizzeghello et al. 2011). Numerous studies reported that long-term excessive application of farmyard manure can cause P accumulation and high soil P mobility, which aggravate the risk of P environmental pollution (Yan et al. 2013, Pizzeghello et al. 2014). In contrast, crop straws or compost with proper N:P ratios based on plant material are considered an effective means to increase crop yields and P cycling efficiency (Zhu et al. 2010, Nest et al. 2014). It is interesting and important to understand the effects of different organic manures above in common use on soil P characteristics.

The objectives of the present study were: (1) to investigate the temporal changes in Olsen-P concentration under long-term application of mineral fertilizer and manures in double cropping rice system in red paddy field; (2) to explore the depletion or residual effect of soil P and relationship with soil Olsen-P; (3) using three different models to determine the critical values of soil Olsen-P for early rice and late rice yield.

MATERIAL AND METHODS

Site descriptions. The experiment was conducted in the experimental farm of the Jiangxi Academy of Agricultural Sciences, located in the Nanchang County, Jiangxi province, China (28°57'N, 115°94'E). The paddy soil of this station is yellow clayey soil that developed form soil parent material for the quaternary red clay. The initial topsoil (0–20 cm) characteristics were as follows: soil organic carbon (SOC) 25.6 g/kg, total N (TN) 1.36 g/kg, total P (TP) 0.49 g/kg, alkali solution (AN) 81.6 mg/kg, available P (AP) 20.8 mg/kg, available K (AK) 30.5 mg/kg, cation exchange capacity (CEC) 7.54 $cmol_+$/kg, pH 6.50, and the bulk density 1.25 g/cm^3.

Experimental design. The experiment consisted of eight treatments including: CK; fertilized with mineral P and K (PK); mineral N and P (NP); mineral N and K (NK); balanced fertilization with mineral N, P and K (NPK), integrated with mineral and organic N, with a ratio of 7:3 (70F + 30M), 5:5 (50F + 50M), 3:7 (30F + 70M). Every treatment was fertilized in the equal nitrogen level. N application was 150 and 180 kg/ha/year for early and late rice, respectively. P and K were 275 and 362 kg/ha/year for early and late rice. Chinese milk vetch was used as organic amendment for early rice, and fermented pig manure for late rice. The content of N, P and K in the Chinese milk vetch was 0.30, 0.37 and 0.55%, respectively, and 0.45, 0.87 and 1.45% in fermented pig manure.

Soil and plant sampling and analysis. Straw and grain yield were measured each year (1984~2012). The samples were air-dried and put through a 2 mm sieve, for soil Olsen-P determination. Soil Olsen-P was measured in the $NaHCO_3$ extraction solution (0.5 mol/L, pH 8.5) using a molybdenum-antimony colorimetric method. Plant total P was determined by the molybdenum-antimony colorimetric method after extraction with concentrated H_2SO_4-$HClO_4$ (Lu 1999).

Data processing and calculation. The change in soil Olsen P (Δ Olsen P, mg/kg) was calculated by Eq. (1):

$$\text{Olsen-P} = P_i - P_0 \tag{1}$$

Where: P_i – soil Olsen-P concentration (mg/kg) at year i; P_0 – initial concentration of soil Olsen-P (mg/kg).

The crop P uptake (PC, kg/ha/year) was calculated by Eq. (2):

$$P_C = Y_G \times C_G + Y_S \times C_S \tag{2}$$

Where: Y_G – grain yield (kg/ha); C_G – grain P concentration (%); Y_S – straw yield removed (kg/ha); C_S – straw P concentration (%).

The P balance (kg/ha) was calculated by Eq. (3):

$$\text{P balance} = \Sigma\,(P_F - P_C) \tag{3}$$

Where: P_F – P application (kg/ha/year).

Three models (linear-linear (LL), linear-plateau (LP) and Mitscherlich (Exp)) were used to calculate the critical values of soil Olsen-P. Three models were performed in the Sigmaplot 12.0 (Las Vegas, USA).

RESULTS AND DISCUSSION

Soil Olsen-P changes in the conditions of long-term fixed fertilization. Compared to 1983, after 29-year continuous cropping, soil Olsen-P content

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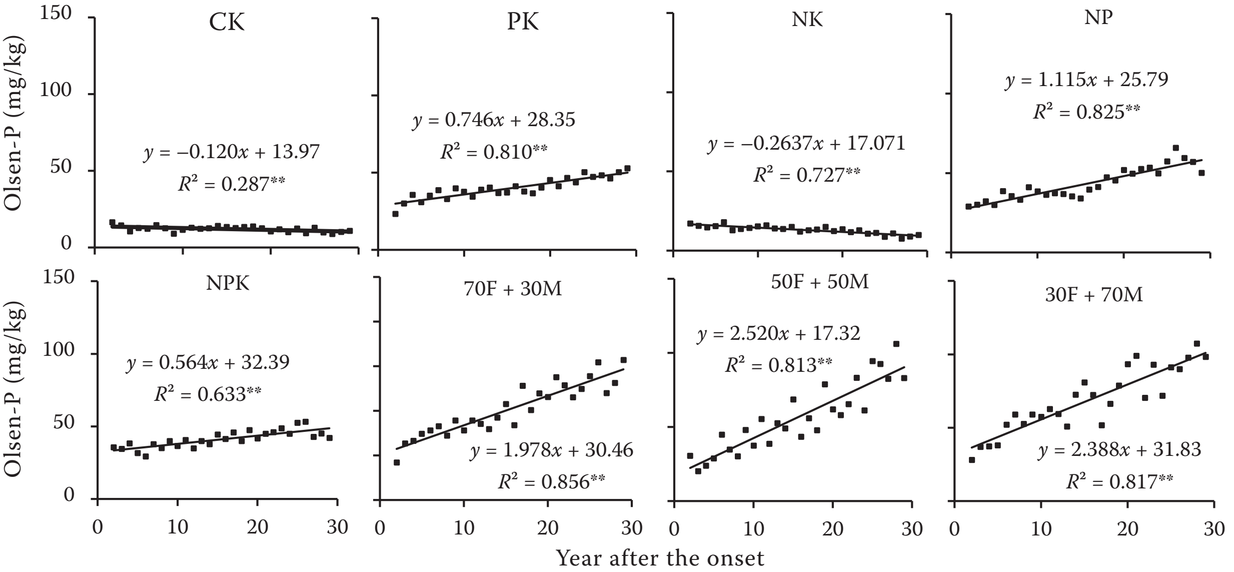

Figure 1. Change of Olsen-P in the long-term fertilized paddy soils (1984~2012)

(average 2010~2012) in CK and NK were reduced by 52.21% and 58.46%, respectively (Figure 1). The descending rates were 0.12 and 0.26 mg/kg/year. Similar to our observation, other researchers found soil Olsen-P decreased under long-term phosphorus free supply in the process of planting (Cao et al. 2012, Shen et al. 2014). A decrease threshold value is about 3~5 mg/kg, it was related to soil types and cropping systems (Ma et al. 2009, Shi et al. 2015). In this study, soil Olsen-P concentration has not reached the threshold range and it may continue to decline.

In PK, NP and NPK, Olsen-P increased 1.39, 1.66 and 1.08 times, respectively, after 29 years of continuous application of inorganic phosphorus and the increase rates were 0.75, 1.12 and 0.56 mg/kg/year. The Olsen-P of 70F + 30M, 50F + 50M and 30F + 70M were found significantly raised over time and increased to 90.60, 101.15 and 81.52 mg/kg after 29 years. The increase rates of organic-inorganic fertilizer treatments were 3.54~4.50 times of NPK, and 50F + 50M was the highest among the three organic-inorganic fertilizer treatments.

Balance of phosphorus and its relation with Olsen-P. For CK and NK, P had been deficient in 29 consecutive years without applying P, with a mean of 46.27 and 76.91 kg/ha, respectively (Figure 2). Soil P of treatments with P fertilizers were found surplus each year. There were significant differences in P surplus between different P application treatments, in which the highest average surplus was that of PK (60.22 kg/ha), followed with NP (49.03 kg/ha), and 30F + 70M being the lowest (21.75 kg/ha). The results showed that chemical fertilizers combina-

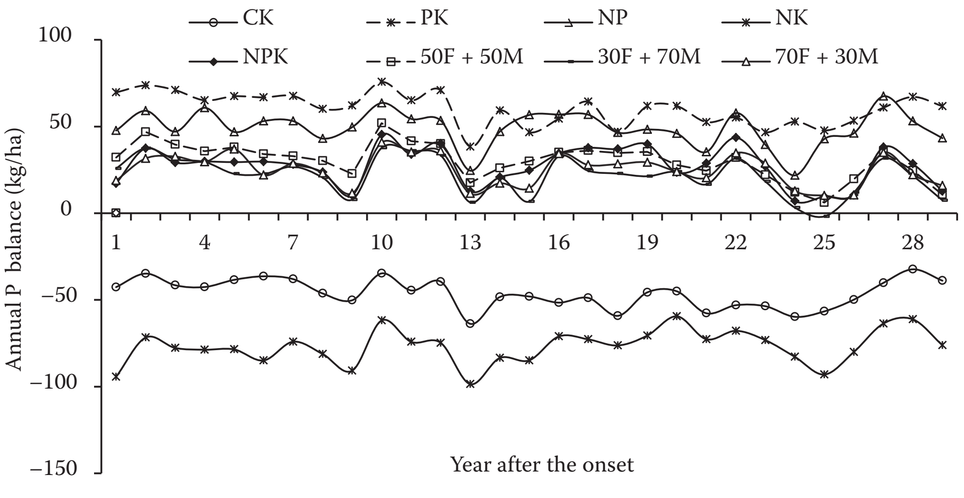

Figure 2. Evolution of phosphorus (P) balances over years (1984~2012) of eight different long-term fertilizer treatments

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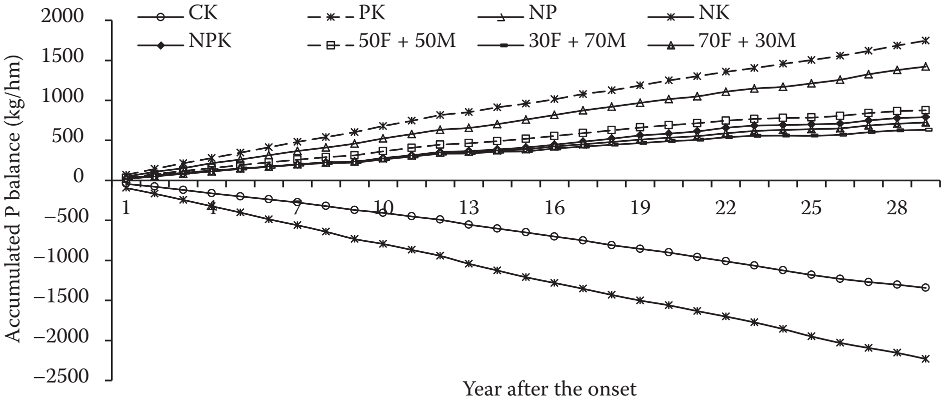

Figure 3. Evolution of cumulative phosphorus (P) balances over years (1984~2012) of eight different long-term fertilizer treatments

tion with organic materials could increase Olsen-P content much more than chemical fertilizers under the same amount of P application level. This has also been shown by other researches (Shen et al. 2014). Olsen-P content is directly related to soil organic matter level. Some materials, such as organic and humic acid produced in the process of decomposition, can decrease P fixation in soil and enhance the utilization efficiency of P fertilizer (Johnston et al. 2013). In our previous work, it was revealed that chemical fertilizers combination with organic materials increased the content of organic matters by 22.5~41.8% than chemical fertilizers (Lv et al. 2017). However, an Olsen-P value of 40 mg/kg has been considered a critical level for having a risk of P leaching loss (Zhong et al. 2004). In this research, Olsen P content reached the critical level after an average 15-year application of chemical P fertilizer, while it was 5 years for organic-inorganic P fertilizer.

The cumulative P balance over time showed two evolution directions, which were the ‘accumulating’ and ‘exhausting’ (Figure 3). For CK and NK, the cumulative P balance decreased by the rate of 48.13 and 76.18 kg/ha/year from 1984 to 2012, respectively. For PK, NP, NPK, 70F + 30M, 50F + 50M and 30F + 70M, the cumulative P balance increased continuously with a slope of 58.47, 48.56, 28.31, 25.19, 30.50 and 21.47 kg/ha/year.

Cumulative P balance relationship with soil Olsen-P. The relationships of soil Olsen-P over accumulated P balance of all the treatments were a straight line, with the correlation coefficient among 0.289~0.848 (Figure 4). This agrees with the results of long-term fertilization experiment studies (Messiga et al. 2010, Cao et al. 2012). For CK and NK, Olsen-P content both decreased 0.30 mg/kg, with soil P deficit 100 kg/ha. The soil Olsen-P content increased by 1.3, 2.3 and 2.0 mg/kg while soil P surplus by 100 kg/ha for

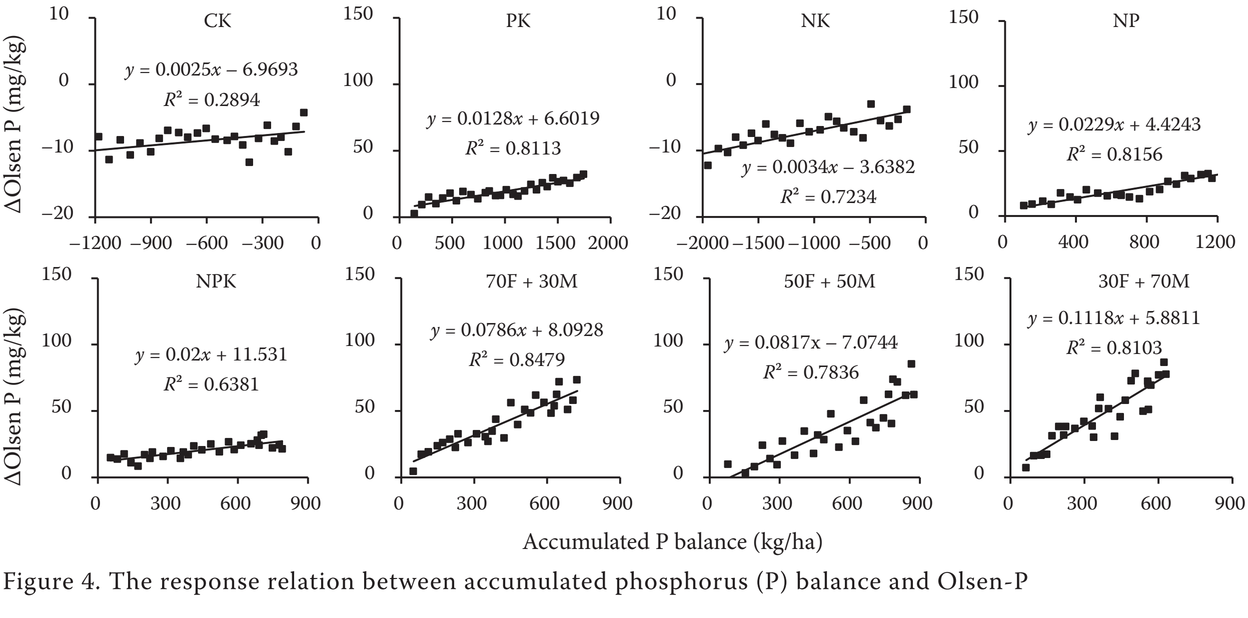

Figure 4. The response relation between accumulated phosphorus (P) balance and Olsen-P

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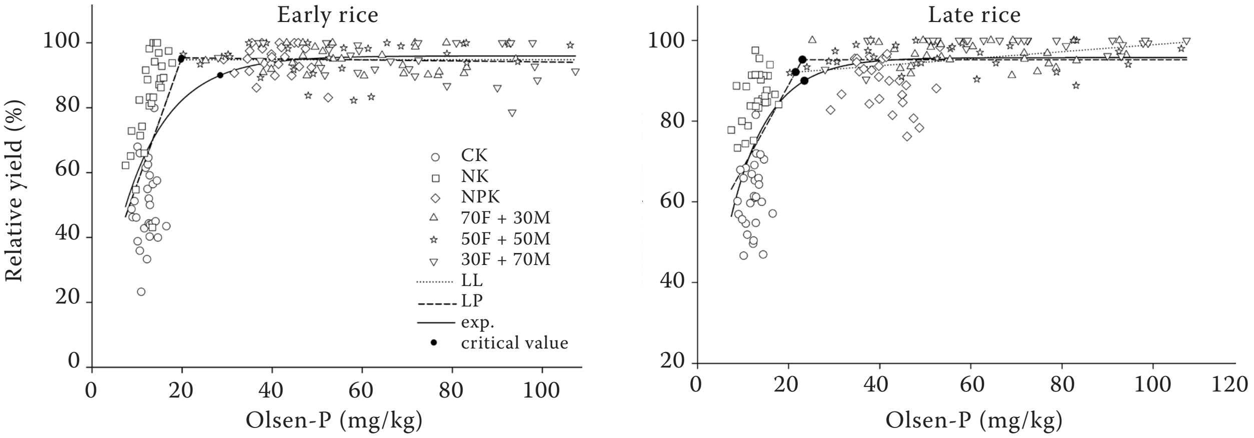

Figure 5. Early and late rice relative increased yield response on soil Olsen-P fitted by three models. The solid points (critical values of soil Olsen-P) were drawn from the parameters listed in Table 1. LL – linear-linear; LP – linear-plateau; Exp – Mitscherlich

PK, NP, and NPK treatments, respectively. For organic-inorganic fertilizer treatments, with soil P surplus of 100 kg/ha, Olsen-P increased by 7.9, 8.2 and 11.2, respectively, with a mean of 9.1 mg/kg. The application of organic fertilizer combined with chemical fertilizer can increase Olsen-P more than single chemical phosphorus fertilizer, which was widely reported in other studies (Shen et al. 2014, Zhan et al. 2015). However, there were some contradictory results (Zhan et al. 2015, Huang et al. 2016). It can be concluded that whether or not chemical fertilizers combined with manure enhance the changes in the soil Olsen-P by each 100 kg P/ha surplus compared with NPK, they are relative to P availability, species of manure, soil types and cropping system, etc.

Agronomic thresholds for soil Olsen-P. The relationship between yields and Olsen-P were fitted by linear-linear, linear-plateau and Mitscherlich model (Figure 5). Early and late rice yield responses to Olsen-P were well simulated by all three models, but the correlation coefficients and critical values of Olsen-P showed a difference in the three models (Table 1).

For early rice, a critical value by the Mitscherlich model was 1.43 and 1.44 times those values by LL and LP, respectively, but there was no significant difference between LL and LP model. For late rice, the critical values identified by LL, LP and Mitscherlich model were 21.52, 23.03 and 23.46 mg/kg. Critical values of late rice were similar by LP and the Mitscherlich model, and higher than the values in the LL approach. The mean critical values of the three models for early and late rice were 22.70 and 22.67 mg/kg, respectively. Semoka and Mnguu (2015) reported a similar critical Olsen-P for rice as 20 mg/kg in Tanzania. However, lower critical Olsen-P values were reported by other authors. A critical Olsen-P value of 10.9 mg/kg for rice was found in Chongqing (Bai et al. 2013). 9.0 mg/kg for direct seeded rice (Rathore et al. 2017) and 8.0 mg/kg in the Kilombero Valley (Kalala et al. 2016). A relatively high critical Olsen-P value in this study might be due to a higher initial phosphorus concentration (20.8 mg/kg) and also due to low soil pH (5.8) and relatively high soil organic matter content (21~36 g/kg). Soil P availability is relatively low in acid soils because

Table 1. Models used to determine the agronomic thresholds of soil Olsen-P for early and late rice

Crop	Model	Equation	R^2	Critical value	N
Early rice	LL	$Y = 17.23 + 3.93X$; $Y = 95.69 - 0.0156X$	0.60**	19.89	168
	LP	$Y = 17.22 + 3.93X$; $Y = 94.80$	0.60**	19.74	168
	Exp	$Y = 95.97(1 - e^{-0.098X})$	0.57**	28.46	168
Late rice	LL	$Y = 47.90 + 2.06X$; $Y = 90.28 - 0.0866X$	0.59**	21.52	168
	LP	$Y = 47.90 + 2.06X$; $Y = 95.23$	0.58**	23.03	168
	Exp	$Y = 95.74(1 - e^{-0.12X})$	0.57**	23.46	168

LL – linear-linear; LP – linear-plateau; Exp – Mitscherlich

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P becomes tightly bound with aluminum and iron oxides (Hinsinger 2001) and the Olsen-P method may have overestimated bioavailable P in acidic soil (Bai et al. 2013). The movability of inorganic phosphorous may be enhanced due to higher soil organic matter content (Weng et al. 2006).

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