Effects of P application method on P utilization in an upland soil: 12-year field micro-plot trials

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Abstract
Data from 12-year field micro-plot trials were analysed to investigate the efficacy of four different phosphorus (P) application methods in a soil-corn system. P was applied annually or once every six years at rates equivalent to 25 or 75 kg P/ha/yr. Grain and stalk yields were little affected by P applications, presumably due to the non limitation of P in the test soil. Nevertheless, P application increased P uptake by plant and Olsen-P in soil. When P was applied less frequently, P uptake and Olsen-P were higher in the first several years but gradually reversed over time. Overall, the 12-year averages in P uptake and Olsen-P were not significantly affected by P application frequency at either P application rate, suggesting that P may be applied at suitable rates once for multiple years in upland soils to lower labor input, although the risk of P loss needs to be carefully considered under field conditions, especially in the first several years.

Key Words
P application rate, P application frequency, P uptake, Olsen-P.

Introduction
P is one of most important nutrient elements limiting agricultural production in most regions of the world. It has a high affinity to soil and, therefore, generally less likely to be lost unless the soil itself erodes away (Eghball *et al.* 1990; Sims *et al.* 1998). Meanwhile P is a vital nonrenewable natural resource. The imbalance in the demand and production of P fertilizer frequently causes its fluctuating prices. To reserve P and save labor input, we carried out a long-term study to the efficacy of various P application methods on P utilization in agroecosystems. Here, we report our results from 12-year field micro-plot trials on P utilization in a soil-corn system treated with fertilizer P at different frequencies and rates.

Methods
Study Site and Experiment Management

A 12-year field experiment was conducted at the Shenyang Experimental Station of Ecology (41°31′N，123°22′E), Chinese Academy of Sciences, a CERN site in the lower reaches of the Liaohe River Plain in Northeast China from 1997 to 2008. The Station is located in the continental temperate monsoon zone, with dry-cold winter and warm-wet summer. The annual mean temperature is 7.0-8.0°C with a cumulative temperature of 3100~3400°C (not less than 10°C), annual precipitation 650 to 700 mm, and annual non-frost period 147 to 164 days. The soil is an aquic brown soil (silty loam Hapli-Udic Cambisols in Chinese soil taxonomy). The main soil physical and chemical characters are shown in Table 1.

Table 1. Physical and chemical characters of soil.

	Total N g/kg	Total P g/kg	Organic C g/kg	Olsen-P mg/kg	Available K mg/kg	pH
0-20cm	1.01	0.41	10.65	6.99	103.53	7.02
20-40cm	0.83	0.39	7.98	4.76	97.38	7.06

The experiment was installed with six fertilization treatments as follows: T1 (non-fertilization control), T2 (none P application), T3 (annual P application at 25 kg/ha), T4 (once every six years P application at 150 kg/ha, equivalent 25 kg/ha/yr), T5 (annual P application at 75 kg/ha) and T6 (once every six years P application at 450 kg/ha, equivalent 75 kg/ha/yr). Based on the P treatment, the experiment was conducted in two six-year periods (1997-2002 and 2003-2008). Each treatment had triplicates with a completely randomized block design. Each plot (1m×1m) was bordered with concrete walls (depth 1 m) to prevent lateral flow of water and nutrients. The single cropping system was adopted in the study. Four corn seeds (variety Fuyou 1) were planted in each plot in May every year. Triple superphosphate (P content 20%) was broadcasted before soil harrowing. Nitrogen fertilizer as urea was applied annually as top dressing at 150 kg N/ha in all treatments Except T1 at the elongating stage.

1 – 6 August 2010, Brisbane, Australia. Published on DVD.

Samples Collection and Analysis

Plants were harvested annually in late September and separated into stalk and grain. The samples were dried at 105°C for >72 h and weighted. The samples for P analysis were ground to pass a 1-mm screen. Total P (TP) in plant samples were determined by the molybdenum-ascorbic acid method (Murphy and Riley 1962) after digestion with H_2SO_4 and H_2O_2. Soil samples from 0-20 cm layer were collected annually after harvest using a 3 cm diameter soil auger. All the samples were air-dried and ground to <2 mm prior to P analysis. Olsen-P was determined using the method of Olsen (1954) and the extract P was analyzed colorimetrically using the method of Murphy and Riley (1962). P uptake and Olsen-P from each treatment were normalized against to the no P application treatment (T2) in a specific year for student t test on the 12-year averages in P uptake and Olsen-P among treatments. All other data were subjected to statistical analysis of variance (ANOVA) in the SPSS 13.0 statistical package.

Results

Corn yield

Large annual variations in corn grain and stalk yields were found in each treatment, primarily due to annual climate variations over the twelve years of study (data not shown). N application was found to have a significant effect on the average yields of corn grain and stalk from 1997 to 2008. With N fertilization, the yields were averagely increased by 36% for grain and 22% for stalk (Table 2). Nevertheless, the grain and stalk yields were neither significantly affected by P fertilization rate and frequency among all N fertilization treatments throughout the 12-year experiment (Table 2). This implies that the soil used in this study was limited by N but not likely by P, resulting in little effects of P fertilization on corn grain and stalk yields.

Table 2. Effects of N and P applications on corn grain and stalk yields from 1997 to 2008.

Treatments	N(kg/ha)	P application	Grain (kg/ha)	/T1(%)	Stalk (kg/ha)	/T1(%)
T1	0	0	88833b	100	89867b	100
T2	150	0	121000a	136	110319a	123
T3	150	25 kg/ha per year	120072a	135	110035a	122
T4	150	150 kg/ha per 6 years	120533a	136	108306a	121
T5	150	75 kg/ha per year	122378a	138	109980a	122
T6	150	450 kg/ha/ per 6years	120900a	136	110856a	123

Different letters following the numbers in a column represent a significant difference at $P< 0.05$.

P uptake

The amount of P uptake was increased with the increase of the P application rate during the 12-year experiment (Table 3). The amount of P uptake from the two no P application treatments (T1, T2) were significantly lower than those P fertilization treatments, as reported by Ferguson (2005). The two high P application treatments (T5, T6) had greater amounts of P uptake by grain and stalk than the two low P application treatments (T3, T4). Moreover, the frequency of P application was also found to affect the temporal pattern of P uptake. The once per six years P application treatments (T4, T6) had greater P uptake by grain and stalk than their corresponding annual P application treatments (T3, T5) in the first several years of each period (Figures 1, 2), and gradually reversed thereafter. The t test showed that the 12-year averages of P uptake by grain and stalk were not significantly affected by application frequency at either of the two P application rates. Due to the insignificant differences in yields between P application treatments in all years (Table 2), such difference in temporal pattern of P uptake between P treatments was ascribed to the luxury uptake of P.

Table 3. Effects of N and P applications on P uptake from 1997 to 2008.

Treatments	P uptake (kg/ha)		
	Grain	Stalk	Sum
T1	275.35e	110.02c	385.37c
T2	344.97d	130.31bc	475.28b
T3	373.38cd	145.68ab	519.06b
T4	380.68bc	134.84abc	523.10b
T5	419.49a	158.54ab	586.53a
T6	411.54ab	170.80a	582.33a

Different letters following the numbers in a column represent a significant difference at $P< 0.05$.

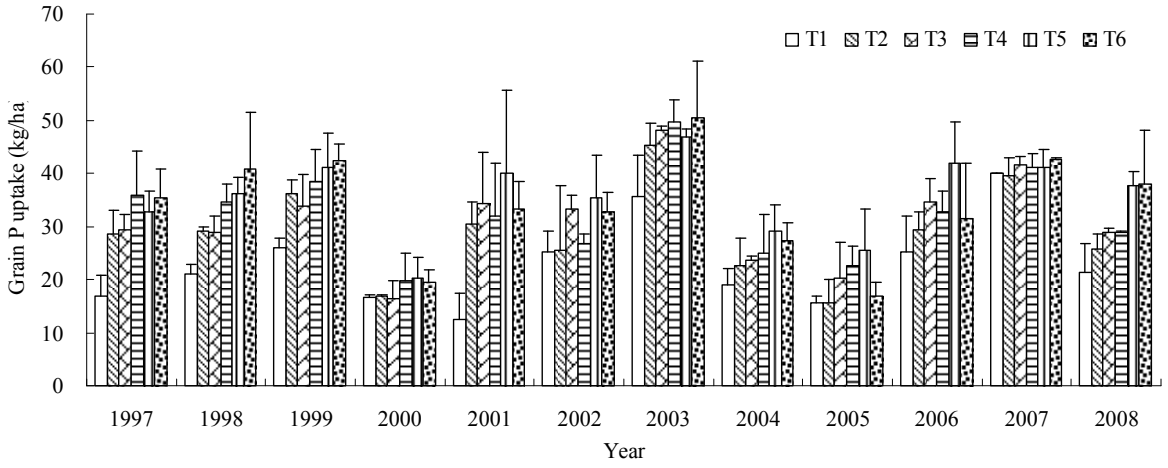

Figure 1. Grain P uptake as influenced by P and N treatments.

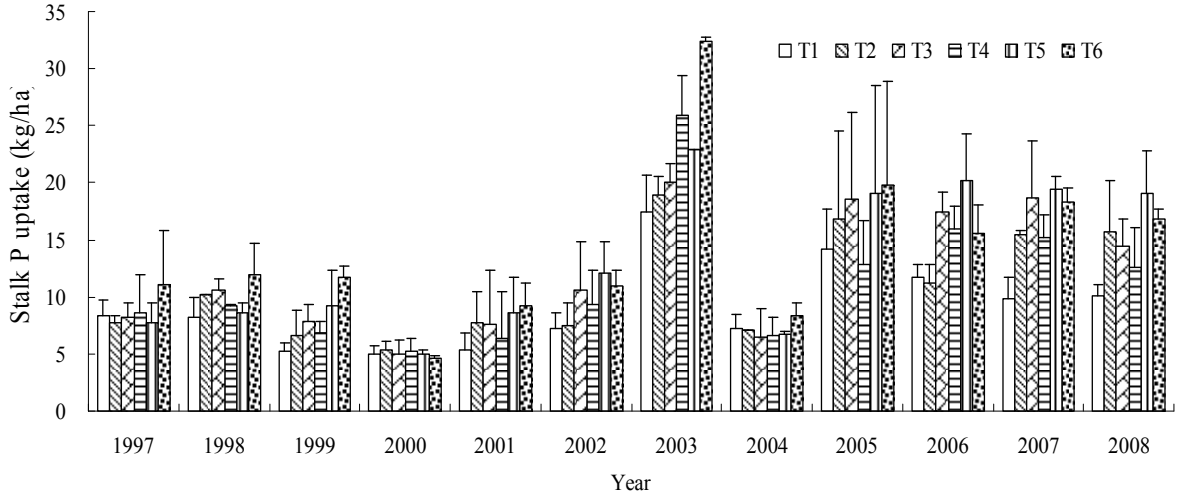

Figure 2. Stalk P uptake as influenced by N and P treatments.

Soil test P (Olsen-P)

Variations in soil Olsen-P from these treatments followed a similar pattern in the two periods (1997-2002, 2003-2008) (Figure 3). Here, we mainly focused our discussion on the first period (1997 to 2002). Olsen-P in surface soil was not much changed in the no P fertilization treatments (T1 and T2) over the first 6-yr period even P being respectively removed at 385.37 and 475.28 kg P/ha with corn. Similar results have been reported by Rehm (1984) and Zhang (2004). Olsen-P was maintained through mineralization of soil organic P, desorption and dissolution of native soil inorganic P. So, it was closely related to soil type and the initial soil P status, which is affected by the previous fertilization and cropping history (Dodd *et al.* 2005). As such, no P fertilization for long years may cause a decrease in Olsen-P in some soils (Webb *et al.* 1992; Randall *et al.* 1997), but may not in some other soils as mentioned above.

Both the rate and frequency of P application affected the residual effect of fertilizer P. Soil Olsen-P tended to gradually increase over time in the annual application treatments (T3 and T5), and increased with the increase of P application rate. For example, Soil Olsen-P from treatments T3 and T5 were increased at 2.22 mg/kg/yr and 4.90 mg/kg/yr, respectively. The annual P application treatments (T3, T5) had less Olsen-P than the once every six years P application treatments (T4, T6) in the first several years, but gradually reversed over time. However, the 12-year average of Olsen-P was not significantly affected by application frequency ($p=0.28$ at the low P application rate, $p=0.09$ at the high rate). The turning time was delayed with increased P application, occurring at the 5th year for the high P application treatments (T5, T6) while at the 4th year for the low P application treatments (T3, T4).

In contrast, the Olsen-P contents in the once per six-year P application treatments (T4 and T6) increased to their maximums in the 1st year after P application but decreased after the 2nd year. The decrease rate of Olsen-P in treatment T4 was small (5.84 mg/kg/yr) at the beginning and stably maintained at 12 mg/kg after 2000. Olsen-P content in treatment T6 decreased at 10.76 mg/kg/yr after the first year.

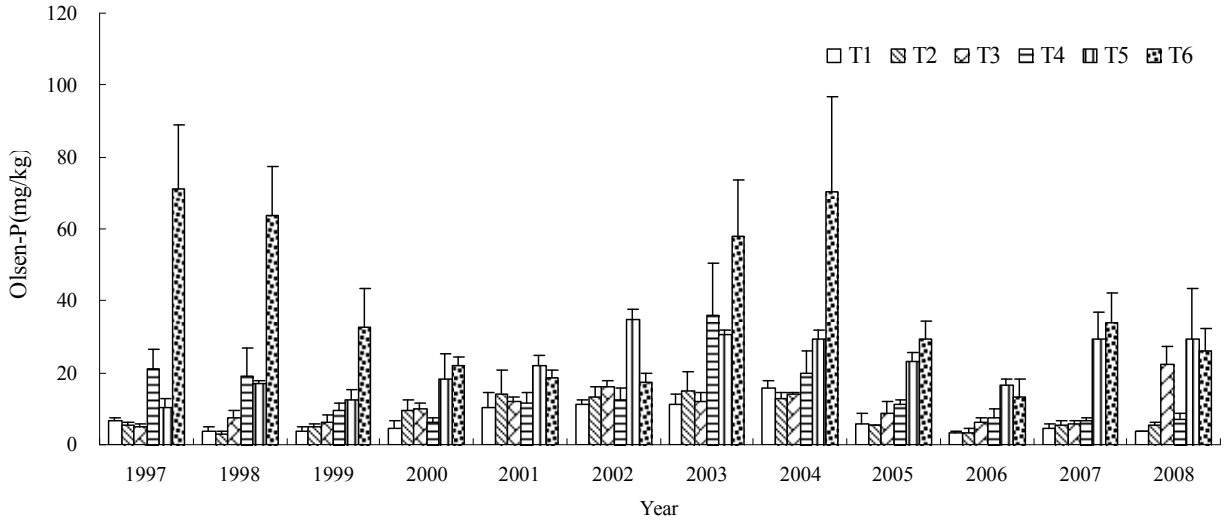

Figure 3. Olsen-P in the topsoil (0-20cm) as affected by N and P treatments.

Conclusion

Although P fertilization had little effect on corn grain and stalk yields in the 12-year experiment, P uptake and Olsen-P were increased with an increase in P application. When P was applied once every six years instead of annually, P uptake and Olsen-P were higher in the first years of each 6-year period but gradually reversed over time. Olsen-P tended to gradually increase over time when P was applied annually but reached a maximum at the 1st year and decreased after the 2nd year when applied once every six years. The average amounts of Olsen-P and P uptake from the low P application treatments in the 12-year experiment was not significantly affected by P application frequency, suggesting that P may be applied once at suitable rates for multiple years in upland soils to lower labor input, although the risk of P loss from P application needs to be carefully considered under field conditions, especially in the first several years.

Acknowledgements

This research was financially supported by National Key Technology R&D Program of China (No.2008BADA7B08) and the National Natural Science Foundation of China (No. 30670378 and 309780479).

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