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Phosphorus Vertical Migration in Aquic Brown Soil and Light Chernozem Under Different Phosphorous Application Rate: A Soil Column Leaching Experiment

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Abstract A soil column leaching experiment was conducted to study the vertical migration of phosphorus in aquic brown soil and light chernozem under different phosphorus fertilization rates. The results showed that total dissolved phosphorus concentration in the leachates from the two soils was nearly the same, but dissolved inorganic phosphorus concentration was obviously different. In all fertilization treatments, aquic brown soil had a higher content of phosphorus in calcium chloride extracts compared with light chernozem. But Olsen phosphorus content was higher at the soil depth beneath 0–20 cm, and increased with increasing phosphorus application rate.

Keywords Phosphorus vertical migration · Phosphorous application rate

Phosphorus (P) is an essential element for plant growth. In recent years, chemical P fertilization in China has been increasing, bringing about a potential risk of P losses from cultivated soils. Although surface runoff is considered to be the main pathway of P losses, leaching has also attracted increasing attention (Sharpley et al. 2007; Yang et al. 2007; Brock et al. 2007). A 71 times higher P leaching loss was observed from structured clay column than from sand column after chemical P fertilization (Djodic et al. 1999), but the P leaching loss from some soils was rather low in spite of high P application rate, due to the high P sorption capacity of their subsoil (Djodjic et al. 2004). Manure application resulted in a significant increase of leachate P concentration (Kleinman et al. 2005), e.g., 0.45–0.79 mg P L^{-1} was measured in the drainage water from manured fields (Hooda et al. 1999).

Many studies were made on the influence of manure application on soil P leaching (Chrysostome et al. 2007; Brock et al. 2007; Chardon et al. 2007), but Chinese farmers are more used to apply chemical fertilizers. Therefore, to study the vertical migration of P in our cultivated soils under chemical P fertilization is of significance in approaching the potential risk of soil P losses. In this paper, aquic brown soil and light chernozem, the main agricultural soils in north and northeast China, were chosen as test soils, and a soil column leaching experiment under different chemical P fertilization rate was conducted to monitor the contents and dynamics of different P forms in leachate, examine the downward movement of soil P, and compare the P leaching characteristics of test soils.

Materials and Methods

Surface soil (0–20 cm) and subsurface soil (20–60 cm) samples were collected from the aquic brown soil at Luancheng Agro-Ecological Experimental Station (37°53′ N, 114°40′ E, elevation 50 m) of Chinese Academy of Sciences in Hebei Province, and from the light chernozem in Baicheng County (45°51′ N, 123°11′ E, elevation 134 m) of Jilin Province, with their basic physical and chemical

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characters listed in Table 1. The samples were air-dried and 2 mm- sieved.

A set of thick-walled plexiglass columns (70 mm in inner diameter and 700 mm in length) was mounted vertically on a metal frame (Fig. 1). A hole was drilled into each column's end-cap for leachate collection, and other six holes were equidistantly set on the side-wall of each column for soil digging. A piece of nylon filter screen was set at the bottom of each column, and then, 150 g acid-washed sand was slowly packed into the column. Another piece of nylon filter screen was set above the sand, and 2 kg air-dried subsurface soil was slowly packed into and slightly pressed until its bulk density reached about 1.3 g cm^{-3}. After then, 1 kg surface soil applied with tri-superphosphate (TSP) at the rates of 0, 100, 200, 400, 800, and 1,600 kg P hm^{-2} (designated as treatments P0, P100, P200, P400, P800, and P1600, respectively) was packed into, and also, slightly pressed until its bulk density reached about 1.3 g cm^{-3}. Each treatment was triplicated. The soil packed in column was wetted with distilled water by slow converse flow until completely water-saturated. Each day, 400 mL (10.4 cm in depth) distilled water was added to each soil column from the top, and each column was required to stop leaching by clipping the tube when there was a 5 cm water layer on the top of the column. The leaching experiment lasted for 31 days, and soil samples were dug from the holes on the side-wall at the depths of 0, 10, 20, 30, 40, 50, and 60 cm, respectively, when the leaching experiment was completed.

The leachate from light chernozem was collected every other day, and that from aquic brown soil was collected at day 1, 2, 3, 4, 8, 10, 18, and 31. After collection, the leachate was filtered with a 0.45-µm millipore membrane, and then stored at 4°C in dark for further analysis. Its total dissolved P (TDP) concentration was determined colorimetrically according to the method of Murphy and Riley (1962) after a Kjeldahl digestion (Taylor 2000), dissolved inorganic P (DIP) concentration was determined colorimetrically according to the method of isobutanol-molybdenum blue (Lu 2000), and dissolved organic P (DOP) was calculated from the difference between TDP and DIP. Soil samples dug from the columns were air-dried, ground to <2 mm, and analyzed for 0.01 M $CaCl_2$-extractable P ($CaCl_2$-P) (McDowell and Sharpley 2004) and 0.5 M $NaHCO_3$-extractable P (Olsen-P) (Olsen et al. 1954). All data were subjected to statistical analysis of variance (ANOVA) in the SPSS 13.0 statistical package.

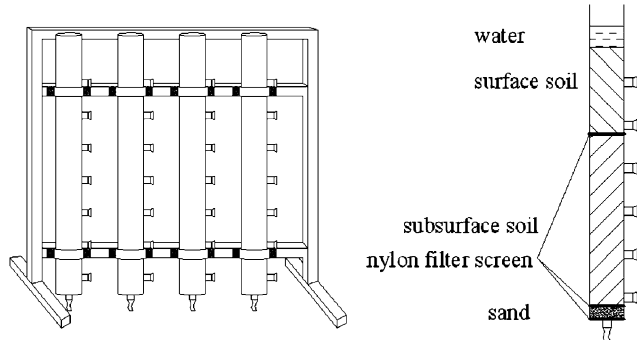

Fig. 1 Schematics of soil columns used for leaching experiment

Results and Discussion

Figure 2 showed that in all treatments, the TDP and DIP in the leachate from light chernozem had the same variation trend, i.e., decreased with time. The TDP and DIP were the maximum on day 1, with an average of 0.43 mg L^{-1} and 0.20 mg L^{-1}, and decreased sharply from day 1 to day 19 and from day 1 to day 15, respectively, with an average decreasing rate being 0.014 mg L^{-1} day^{-1} for TDP and 0.006 mg L^{-1} day^{-1} for DIP. Thereafter, the TDP and DIP decreased slowly over time, with the same decreasing rate of about 0.001 mg L^{-1} day^{-1}, and finally reached to about 0.13 mg L^{-1} and 0.05 mg L^{-1}, respectively. No significant difference was observed among the treatments, suggesting that chemical P fertilization rate had lesser effects on the concentrations of TDP and DIP in the leachate from light chernozem.

Table 1 Physical and chemical characters of test soils

	Aquic brown soil		Light chernozem	
	Surface soil	Subsurface soil	Surface soil	Subsurface soil
Bulk density (g cm^{-3})	1.39	1.43	1.42	1.49
Organic C (g kg^{-1})	5.36	5.43	26.39	13.14
Total N (g kg^{-1})	0.98	0.45	1.84	0.73
Total P (g kg^{-1})	0.57	n.d.	0.58	n.d.
Clay content (%)	18.8	12.3	25.1	29.0
pH	8.4	8.6	8.2	8.1

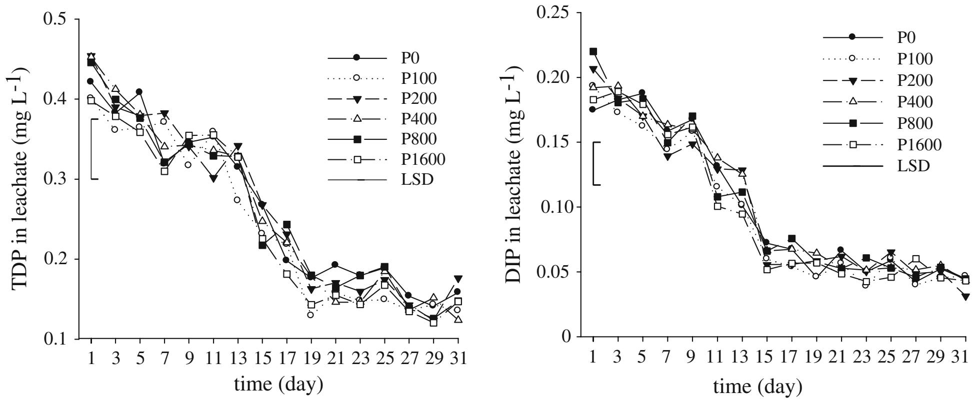

Fig. 2 Dynamics of TDP and DIP in the leachate from light chernozem

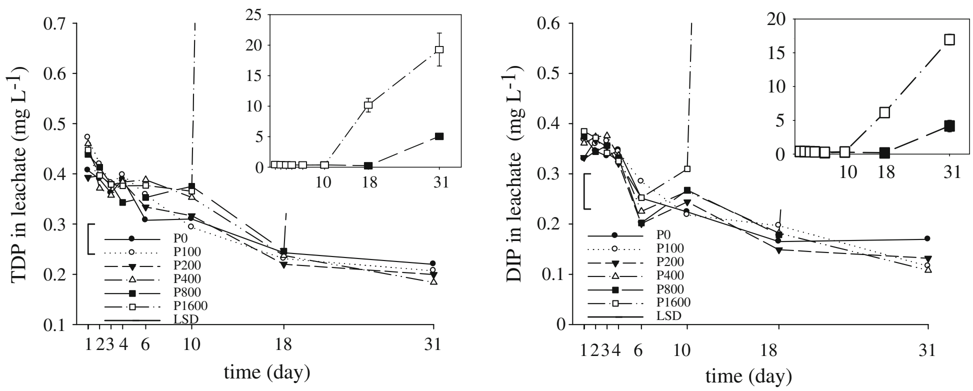

Fig. 3 Dynamics of TDP and DIP in the leachate from aquic brown soil

Somewhat different scenes were observed about the variation trend of TDP and DIP in the leachate from aquic brown soil (Fig. 3). When the P application rate was less than 400 kg hm^{-2}, the TDP and DIP decreased slowly with time. From the beginning to the end of the experiment, the TDP decreased from 0.43 mg L^{-1} to 0.20 mg L^{-1}, and the DIP decreased from 0.35 mg L^{-1} to 0.13 mg L^{-1}. In treatments P800 and P1600, an obvious increase of TDP and DIP was observed on day 31 and day 18, respectively. The concentrations of TDP and DIP in treatment P800 were 5.05 mg L^{-1} and 4.15 mg L^{-1} on day 31, respectively, being about 10 times of the concentrations when the experiment started, and those in treatment P1600 reached to 20 mg L^{-1} and 17 mg L^{-1}, respectively, being about 4 times in treatment P800.

It was found that the TDP concentration in the leachates from the two soils was nearly the same, but the DIP concentration was obviously different, being higher from aquic brown soil than from light chernozem, probably duo to the higher clay content in light chernozem. Similar result was obtained by Djodjic et al. (2004).

A comparison of Olsen-P and $CaCl_2$-P contents at the same depths of the two soils under different P application rate (Tables 2 and 3) showed that in light chernozem, Olsen-P content was significantly higher in upper soil layers when the P application rate was high, but had less

Table 2 Comparison of Olsen-P and $CaCl_2$-P contents (mg kg^{-1}) at the same depths in light chernozem under different P application rate

	0 cm		10 cm		20 cm		30 cm		40 cm		50 cm		60 cm	
	Olsen-P	$CaCl_2$-P	Olsen-P	$CaCl_2$-P	Olsen-P	$CaCl_2$-P	Olsen-P	$CaCl_2$-P	Olsen-P	$CaCl_2$-P	Olsen-P	$CaCl_2$-P	Olsen-P	$CaCl_2$-P
P0	21.1a	0.07a	19.8a	0.06a	13.7a	0.04a	5.9a	0.04a	4.3a	0.05a	5.0a	0.03a	4.3a	0.04ab
P100	29.2a	0.04a	30.4ab	0.05a	28.0a	0.04a	5.0a	0.03a	5.7a	0.04a	4.6a	0.05ab	5.4a	0.03b
P200	34.8ab	0.06a	47.3b	0.07a	46.1ab	0.06a	6.1a	0.05a	5.3a	0.05a	5.6a	0.04a	5.1a	0.05abc
P400	65.2bc	0.15ab	118.6c	0.25ab	91.5c	0.21b	5.9a	0.10a	4.9a	0.05a	6.2a	0.09b	5.4a	0.07bc
P800	73.2c	0.14ab	177.7d	0.36b	193.7d	0.33b	25.5a	0.20b	5.8a	0.09ab	5.2a	0.09b	6.0a	0.07abc
P1600	128.1d	0.35b	243.3e	0.65c	292.3e	0.89c	155.7b	0.87c	16.9b	0.11b	5.4a	0.09b	5.5a	0.08c

Different lowercase in a column represents significant difference at $p < 0.05$

Table 3 Comparison of Olsen-P and $CaCl_2$-P contents (mg kg^{-1}) at the same depths in aquic brown soil under different P application rate

	0 cm		10 cm		20 cm		30 cm		40 cm		50 cm		60 cm	
	Olsen-P	$CaCl_2$-P	Olsen-P	$CaCl_2$-P	Olsen-P	$CaCl_2$-P	Olsen-P	$CaCl_2$-P	Olsen-P	$CaCl_2$-P	Olsen-P	$CaCl_2$-P	Olsen-P	$CaCl_2$-P
P0	1.7a	0.06a	2.5a	0.08a	3.1a	0.25a	2.9a	0.24a	1.8a	0.18a	0.6a	0.16a	0.5a	0.14a
P100	2.8a	0.11a	7.7a	0.36a	21.2ab	0.46a	14.4ab	0.44a	2.7a	0.19a	0.9a	0.16a	0.4a	0.15a
P200	3.7a	0.19a	13.2a	0.56a	29.7b	0.93a	29.1bc	0.77a	10.9a	0.62ab	1.1a	0.25a	0.4a	0.15a
P400	8.3b	0.20a	24.6b	0.93a	50.4c	1.90a	41.8c	1.79a	26.1b	1.64b	11.7b	0.67a	4.6b	0.53a
P800	18.8c	0.34a	39.0c	1.06a	84.6d	6.34b	65.0d	4.90b	34.8b	4.74c	36.7c	3.89b	25.1c	2.70b
P1600	20.4c	0.75b	67.5c	2.83b	256.2e	17.69c	94.1e	10.90c	77.2c	10.42d	70.8d	9.56c	50.2d	6.65c

Different lowercase in a column represents significant difference at $p < 0.05$

difference in deeper layers among all treatments. No significant difference was observed for $CaCl_2$-P content among the treatments except P800 and P1600 that always contained more $CaCl_2$-P. In aquic brown soil, the contents of Olsen-P and $CaCl_2$-P were higher in treatments P800 and P1600, but no significant differences were observed in other treatments.

Figure 4 showed that Olsen-P content was higher in light chernozem than in aquic brown soil at the depth of 0–20 cm, but mostly in adverse beneath this depth and increased with increasing P application rate. $CaCl_2$-P content was higher in aquic brown soil than in light chernozem in the profile in all treatments. All of these suggested that aquic brown soil had a greater potential of P

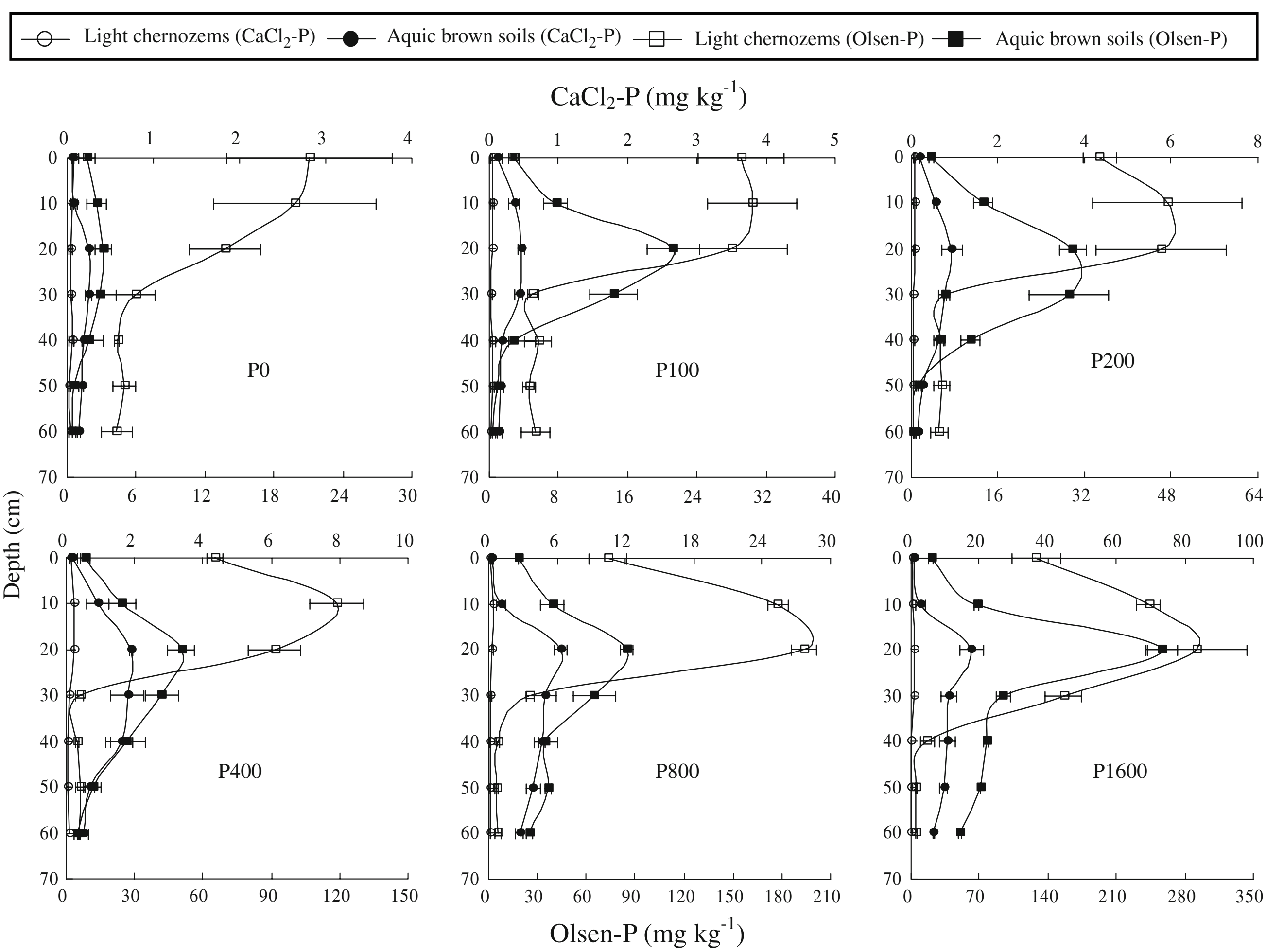

Fig. 4 Vertical distribution of Olsen-P and $CaCl_2$-P contents in aquic brown soil and light chernozem columns under different treatments

leaching loss under chemical P fertilization, compared with light chernozem.

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