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Evaluation of fertigation technique for phosphorus application of maize in the semi-arid region of Northeast China

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Abstract: To determine the best phosphorus (P) fertilizer management strategy in chernozem soil in the semi-arid region of Northeast China, a field experiment under film mulched drip irrigation was conducted for two consecutive years. Five P application methods were tested, including no P fertilizer applied (P0); P fertilizer one-time basal application (P1); one fertigation one time (P2); fertigation twice (P3) and fertigation four times (P4). The shoot dry matter weight, phosphorus accumulation, yield and P_{Olsen} in soil were measured regularly during the maize growing season. The results demonstrated that P fertilizer application methods imposed significant effects on dry shoot matter, the apparent P loss, P fertilizer use efficiency and yield of maize ($P < 0.05$). The yield, P agrinomic efficiency and P recovery efficiency of P4 treatment were significantly higher than P1 treatment by 4.2, 39.7, and 66.4% across two year. In addition, P4 treatment significantly enhanced the shoot dry matter weight after V12 stage, post-silking P uptake and reduced the apparent P loss. In conclusion, P fertigation and a rational frequency (e.g., fertigation four times) enable to keep the maximum grain yield, the shoot dry matter, and recovery efficiency of P fertilizer (66.4%) though changing agronomic methods for efficient acquisition of P toward a sustainable and productive agricultural fertigation system.

Keywords: phosphorus management; fertigation frequency; maize production; soil P balance; irrigated agriculture

Phosphorus (P) is one of the most important nutrients for crop production. And a major constituent of the fertilizers required to sustain high-yield agriculture (Vance et al. 2003). In maize production of China, only 15–20% of the P applied which was taken up by plants in the growing season (Zhang et al. 2008) and the rest accumulated in the soil P pools, it becomes immobile and unavailable to plants due to adsorption, precipitation, or conversion to organic forms (López-Bucio et al. 2000). Existing rock phosphate reserves could be exhausted in the next 50–100 years though P is mostly obtained from mined rock phosphate (Cordell et al. 2009). Therefore, it is important to apply phosphate fertilizer in scientific approaches to improve maintaining the growth of maize and the sustainable development of agriculture in China. Situated in the semi-arid region of Northeast China, Jilin province is one of the most important grain production regions of China. The annual maize production directly affects the food security and crop trades of China (Xiong et al. 2007). Drought, infertile soil, and extensive management are the main limiting factors in this area of maize production. In the semi-arid area of Jilin province, the main soil type is light chernozem, which is too sandy and has little clay content.

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As a consequence, phosphorus in this type of soil is easy to fix. Individual farmers in this area have been used to regard phosphorus fertilizer as the basal fertilizer and flood irrigation once or twice in the growth season. Some large farms or cooperatives adopt drip irrigation to supplement water and fertilizer. Generally, nitrogen (N) fertigation has been practiced by large farms for many years. However, phosphate fertilizers are considered unsuitable for fertigation. Soluble P fertilizers are mostly used in drip irrigation system (Munir et al. 2004). Phosphorus fertigation is an effective means of controlling the time and rate of fertilizers and improving fertilizer use efficiency by reducing nutrient losses from leaching, and fixation in the soil to less available forms (Zafar et al. 2013). Achieving high maize yields requires adequate soil P concentration in the root zone (Bai et al. 2013), matching P supply with P uptake requirements of maize grain yield without excess or deficiency is important for crop yield and mitigation of environment risks (Li et al. 2011).

The study of P fertigation is mostly concentrated in P fertilizer rate or compared to traditional P fertilizer application methods (Latif et al. 1997, Muhmood 2014), however, little research has been done on P fertigation frequency, which was about economic crops, such as eggplant, tomato, bell pepper and so on (Silber et al. 2005, Zhang et al. 2010, Feleafel and Mirdad 2013). And the P fertigation frequency was very high, which was several times a week or even a day. Such high P frequency is not practical for field crops, and approaches should be employed to simplify the production process and to reduce the labor costs.

In the present study, we conducted a 2-year field experiment to investigate the effects of phosphorus fertigation P fertilizer efficiency and yield of maize. Our study aims were as follows: (i) to assess the responses of maize yield, growth and phosphorus utilization efficiency to P fertigation; (ii) to explore the impact of P fertigation frequency on P uptake, remobilization, and apparent P loss; (iii) to determine the optimum frequency of fertilizer P for maize in the semi-arid region of Northeast China.

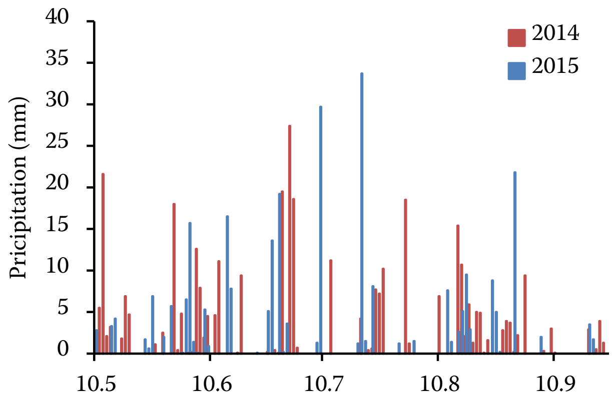

Figure 1. The precipitation in 2014 and 2015

MATERIAL AND METHODS

Site description. The two-year field experiments were both conducted in Qian'an Experimental Station (41°52'N, 124°04'E), located at 15 km north of Songyuan City, Jilin province in 2014–2015. Long-term mean temperatures in this area were 16.2–20.9°C. The total rainfall was 341.2 mm and 273.6 mm in 2014 and 2015, respectively (Figures 1 and 2). The soil type at the study site is Chernozem sandy loam. In before sowing. The chemical properties of the 0–30 cm soil layers were analyzed as follows: pH 7.9, 10.45 g/kg organic carbon, 1.32 g/kg total nitrogen, 13.2 mg P_{Olsen}/kg, and 104 mg K/kg.

Experimental design. Experiments were conducted in 2014 and 2015 at identical sites. Five treatments were set out: P0 – no P fertilizer applied; P1 – one-

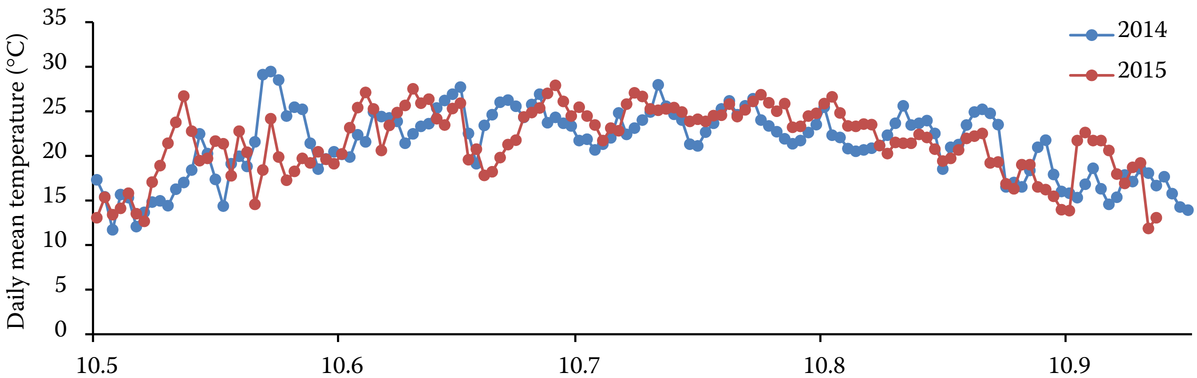

Figure 2. The daily mean temperature in 2014 and 2015

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time basal application; P2 – fertigation one-time; P3 – fertigations twice and P4 – fertigation four times. Nitrogen fertilizer, phosphorus fertilizer, and potash fertilizer were applied in the forms of urea, water-soluble monoammonium phosphate and water-soluble potassium sulfate. The specific applications of fertilizer in each treatment are summarized in Table 1.

A randomized complete block design using three replications for each treatment was employed with a plot area of 40 m^2. The maize cultivar was Limin 33, and which sown on 10^{th} May in 2014 and 13^{th} May in 2015 in the identical density of 75 000 plants/ha. Weed growth on the plots was controlled with pre-emergence herbicides and cultivation.

Plants were seeded in broad-narrow ridges pattern, with broad and narrow rows' spaces of 80 cm and 40 cm, respectively. The ridges were covered with the plastic film. Each plot was supplied with an independent unit of the gravity drip irrigation system, which was a drip line placed in the middle of each narrow row, and the emitter space was 30 cm. The total volume of water was supplied with drip irrigation. 20 mm irrigation water was applied before sowing, and at growth stage R1 and R3, while 30 mm irrigation water was applied at growth stage V8 and V12.

Sampling and measurements

Yield, dry matter, and soil P_{Olsen} measurements. Plants were harvested at 138 days after sowing (DAS) in 2014, and at 134 DAS in 2015. Grain yield was measured from the center two rows in each plot according to the 15.5% water content. Harvest ear density was calculated from the ears. Grain number per ear and 100-grain weight were calculated from 10 randomly selected ears. At the V6, V8, V12, R1, R3 and R6 stages, two neighboring plants were taken for plant sample analysis. Plants at the R1 and R6 stages were separated into leaves, stalks, and grains. All samples were dried at 105°C for 1 h and then at 75°C for 72 h, prior to weighed the dry weight (DW). Plant total P content was also analyzed by ammonium molybdate vanadate method. Soil P_{Olsen} was analyzed in top soil (0–40 cm) for each plot at sowing and final harvest stage (Bao 2000).

Table 1. Schedule of fertigation

Treatment		Total amount (kg/ha)	Growth stages of application (kg/ha)				
			sowing	V8	V12	R1	R3
N		220	66	66	44	22	22
K		75	37.5	15	11.3	7.5	3.7
	P0	0	0	0	0	0	0
	P1	44	44	0	0	0	0
P	P2	44	22	22	0	0	0
	P3	44	22	15	0	7	0
	P4	44	22	8.8	6.6	4.4	2.2

Data analysis. Based on the measured shoot dry weight and nutrient content, the following parameters were calculated (Chen et al. 2016):

Harvest index (HI, %) = grain DW at maturity/total DW at maturity × 100 (1)

Phosphorus fertilizer recovery efficiency (PRE, %) = [(UP – U0)/FP] × 100 (2)

Phosphorus agricultural efficiency (PAE, kg/kg) = (YP – Y0)/FP (3)

Partial fertilizer productivity of phosphorus (PFPP, kg/kg) = Y/FP (4)

P remobilization amount (kg/ha) = = vegetative P content at silking – – vegetative P content at maturity (5)

Contribution to grain P content by P remobilization (%) = (vegetative P content at silking – vegetative P content at maturity)/ grain P content at maturity (6)

Post-silking P uptake (kg/ha) = total P uptake at maturity – total P uptake at silking (7)

Contribution to grain by post-silking P uptake amount (%) = (total P uptake at maturity – total P uptake at silking)/grain P content at maturity (8)

Apparent P loss (kg/ha) = soil P_{Olsen} (start) + + P fertilizer – soil P_{Olsen} (end) – plant P take (9)

Where: UP – maize phosphorus uptake in the P application treatments; U0 – no P treatment; YP – grain yield in the P application treatments; Y0 – no P application treatment; FP – P fertilizer application rate; DW – dry weight.

Treatment effects were evaluated by two-way analysis of variance using the Statistical Analysis System, with year as the main plot and phosphorus fertilization methods as subplot (SAS Institute 1998). The means were compared using Fisher's protected least significant difference (*LSD*) at a probability level of 0.05.

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Table 2. Maize yield, its component and harvest index

Treatment	Yield (kg/ha)	Grain number (No./ear)	100 grain weight (g)	Harvest index (%)
Phosphorus				
P0	10 822^{d}	505^{c}	25.5^{c}	56.5^{a}
P1	12 082^{c}	528^{b}	26.7^{b}	56.5^{a}
P2	12 225^{bc}	540^{b}	27.3^{ab}	57.0^{a}
P3	12 401^{ab}	572^{a}	27.9^{ab}	57.0^{a}
P4	12 583^{a}	592^{a}	28.1^{a}	57.5^{a}
Year				
2014	12 356^{a}	570^{a}	27.9^{a}	57.7^{a}
2015	11 688^{b}	525^{b}	26.5^{b}	56.0^{b}
Source of variation				
Year (Y)	**	**	**	*
P application methods (P)	**	**	**	ns
Y × P	ns	ns	ns	ns

Within different phosphorus (P) treatments, numbers followed by different letters indicate significant differences ($P < 0.05$). ns – not significant; *$P < 0.05$; **$P < 0.01$. P0 – no P fertilizer applied; P1 – one-time basal application; P2 – fertigation one-time; P3 – fertigations twice; P4 – fertigation four times

RESULTS AND DISCUSSION

Maize yield and yield components. It was observed that phosphorus application methods had significantly impact on maize yield, 100-grain weight and grain number, which were greater in 2014 than in 2015 (Table 2), possibly because of the much higher accumulated temperature (Figure 1). With the increase of P fertigation frequency, the yield, 100-grain weight, and grain number of maize showed an increasing tendency. P4 treatment was significantly higher than P1 treatment by 4.2, 12.1, and 5.2%, respectively. No difference in harvest index was found among these P treatments. The P application

Table 3. Shoot dry matter accumulation (kg/ha)

Treatment	Growing stage					
	V6	V8	V12	R1	R3	R6
Phosphorus						
P0	69.4^{b}	1577.4^{b}	4194.6^{b}	8225.5^{d}	12 761.2^{b}	19 764.0^{c}
P1	71.7^{ab}	2007.5^{a}	4604.4^{ab}	8650.0^{cd}	13 234.5^{b}	20 493.8^{c}
P2	70.9^{b}	1928.9^{a}	4718.8^{a}	8955.1^{bc}	14 252.5^{a}	21 560.8^{b}
P3	73.5^{ab}	2072.5^{a}	4721.9^{a}	9362.5^{ab}	14 470.2^{a}	22 234.2^{ab}
P4	76.3^{a}	2014.1^{a}	4920.4^{a}	9671.3^{a}	14 677.5^{a}	22 763.7^{a}
Year						
2014	75.1^{a}	2084.7^{a}	5222.3^{a}	9493.8^{a}	15 889.1^{a}	23 692.4^{a}
2015	69.7^{b}	1755.6^{b}	4041.8^{b}	8451.9^{b}	11 869.3^{b}	19 034.2^{b}
Source of variation						
Year (Y)	**	**	**	**	**	**
P application methods (P)	ns	ns	*	**	**	**
Y × P	ns	ns	ns	ns	ns	ns

Within different phosphorus treatments, numbers followed by different letters indicate significant differences ($P < 0.05$). ns – not significant; *$P < 0.05$; **$P < 0.01$. P0 – no P fertilizer applied; P1 – one-time basal application; P2 – fertigation one-time; P3 – fertigations twice; P4 – fertigation four times

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Table 4. Pre- and post-silking phosphorus (P) uptake, P remobilization and P remobilization efficiency of maize grown in 2 years

Treatment	P content at silking (g/plant)	P content at maturity (g/plant)			Post-silking P uptake		P Remobilization	
		grain	straw	total	amount (g/plant)	contribution to grain (%)	amount (g/plant)	contribution to grain (%)
Phosphorus								
P0	0.37^{c}	0.66^{c}	0.11^{d}	0.77^{c}	0.40^{c}	58.0^{d}	0.26^{c}	39.8^{a}
P1	0.44^{b}	0.83^{b}	0.13^{c}	0.97^{b}	0.53^{b}	61.5^{bc}	0.31^{b}	38.5^{a}
P2	0.47^{b}	0.86^{b}	0.15^{b}	1.00^{b}	0.54^{b}	61.0^{c}	0.32^{ab}	37.8^{a}
P3	0.49^{a}	0.93^{a}	0.15^{a}	1.09^{a}	0.59^{a}	63.3^{ab}	0.34^{a}	36.8^{a}
P4	0.50^{a}	0.95^{a}	0.16^{a}	1.11^{a}	0.61^{a}	64.6^{a}	0.34^{a}	36.7^{a}
Year								
2014	0.48^{a}	0.98^{a}	0.15^{a}	1.13^{a}	0.65^{a}	66.9^{a}	0.32^{a}	32.7^{b}
2015	0.43^{b}	0.77^{b}	0.13^{b}	0.84^{b}	0.41^{b}	56.5^{b}	0.31^{b}	43.2^{a}
Source of variation								
Year (Y)	**	**	**	**	**	**	*	**
P application methods (P)	**	**	**	**	**	**	**	ns
Y × P	ns	ns	**	ns	ns	ns	ns	ns

Within different P treatments, numbers followed by different letters indicate significant differences ($P < 0.05$). ns – not significant; *$P < 0.05$; **$P < 0.01$. P0 – no P fertilizer applied; P1 – one-time basal application; P2 – fertigation one-time; P3 – fertigations twice; P4 – fertigation four times

methods × year interaction was not significant for all these parameters.

P fertigation improved the growth and yield of maize. Similar results were reported by Wang et al. (2017) and Zafar et al. (2013) that maize and wheat yield of phosphorus fertigation treatment in more than one split gave a higher yield than that obtained from a single application. It was because of that P fertigation allows placement and amount of P fertilizer directly into the plant root zone during critical times of nutrient demand (Earl and Jury 1977), this directed application of P can result in more efficient plant use of the fertilizer than when P is band-applied (Mikkelsen 1989).

Maize shoot dry matter weight. The ANOVA results indicated that the P fertigation imposed a significant effect on shoot dry matter weight (DW) after V12 stage (Table 3), which was similar to the previous results (Muhmood 2014). DM of P4 treatment at R1, R3, and R6 stages increased by 11.8, 10.9, and 11.1%. There was no significant difference between P3 and P4 treatments. The performance of maize shoot dry matter weight was consistent with the yield.

Table 5. Soil phosphorus (P) residue, total P input in two years and apparent P loss (kg/ha)

Treatment	P_{Olsen} content in 0–40 cm soil		Total P input	Total P uptake	Apparent P loss
	before sowing of 2014	at harvest of 2015			
P0	55.8	15.7^{c}	0	115.9^{c}	–75.8^{e}
P1	55.8	18.7^{c}	200	144.9^{b}	92.2^{a}
P2	55.8	22.7^{b}	200	150.4^{b}	82.7^{b}
P3	55.8	19.3^{bc}	200	163.0^{a}	73.5^{c}
P4	55.8	36.4^{a}	200	166.7^{a}	52.8^{d}

Within different P treatments, numbers followed by different letters indicate significant differences ($P < 0.05$). P0 – no P fertilizer applied; P1 – one-time basal application; P2 – fertigation one-time; P3 – fertigations twice; P4 – fertigation four times

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Pre- and post-silking P uptake, P remobilization, and its contribution to the grain. Phosphorus application methods significantly affected post-silking P uptake amount, P remobilization amount, and contribution to grain by post-silking P uptake (Table 4). Increasing fertigation frequency could increase the P accumulation after silking and P remobilization. The 57–66.8% of phosphorus in grain came from post-silking P uptake across the two years. This result was line with the previous findings of Bender et al. (2013) that optimal maize production is dependent on the season-long supply of P, and the majority of total uptake occurred post-silking by 56%. Therefore, the improved plant P accumulation was mainly because of the increased post-silking P uptake, which was a consequence of high fertigation frequency and delayed P fertilizer application.

Apparent P loss. Phosphorus application methods affected apparent P loss and P_{Olsen} content at harvest 0–40 cm soil profile (Table 5). In detail, the apparent P loss of P4 treatment was significantly lower than the others. However, the P_{Olsen} content was dramatically increased. P4 treatment could reduce apparent P loss remarkably, while its P_{Olsen} content at harvest maintained at an appropriate level to balance soil fertility. The repeated application of mineral P fertilizer increases the soil available P concentration (Ziadi et al. 2013). All these processes led to fixation the delayed fixation when the fertilizer was applied through fertigation as plant absorbed this nutrient quickly and directly from the soil solution.

Table 6. Partial fertilizer productivity of phosphorus (PFPP), phosphorus agricultural efficiency (PAE) and phosphorus fertilizer recovery efficiency (PRE)

Treatment	PFPP (kg/kg)	PAE (kg/kg)	PRE (%)
Phosphorus			
P0	108.2[d]		
P1	120.8[c]	12.6[c]	15.2[b]
P2	122.3[bc]	14.1[bc]	17.2[b]
P3	124.0[ab]	15.8[ab]	23.5[a]
P4	125.8[a]	17.6[a]	25.3[a]
Year			
2014	123.6[a]	10.4[b]	21.5[a]
2015	116.9[b]	19.6[a]	19.0[a]
Source of variation			
Year (Y)	**	**	ns
P application methods (P)	**	**	**
Y × P	ns	ns	ns

Within different P treatments, numbers followed by different letters indicate significant differences ($P < 0.05$). ns – not significant; *$P < 0.05$; **$P < 0.01$. P0 – no P fertilizer applied; P1 – one-time basal application; P2 – fertigation one-time; P3 – fertigations twice; P4 – fertigation four times

Phosphorus fertilizer recovery efficiency, phosphorus agricultural efficiency, and phosphorus particle fertilizer productivity. The data present in Table 6 indicated that P application methods significantly affect the PFPP, PAE, and PRE. P2 to P4 fertigation treatments increased by 1.2–4.1, 18.9–39.7 and 13.2–66.4%, respectively, compared with P1 treatment. The PRE of P3 and P4 were 23.6% and 25.4% across two years, which were significantly higher than P1 treatment. The P application methods × year interaction was not significant for PFPP, PAE, and PRE.

Several studies have shown that P fertigation was particularly effective in increasing the efficiency of P fertilizer (Bar-Yosef et al. 1989, Ben-Gal and Dudley 2003, Wang et al. 2017). Yue et al. (2013) considered the P use efficiency of the one-time basal application was lower than fertigation treatments, which may be the direct cause of low utilization of fertilizer due to the unsynchronized of water and fertilizer. More frequent fertigation increases labile P, enhance P diffusion across the sectional area for diffusion increases, and tortuosity of the path is decreased.

In this study, compared with the farmer practice management – single basal application (P1), the yield of P fertigation four times (P4) increased by 4.12% and the PRE increased by 66.7% on average two years. On the other hand, P4 treatment also increased the shoot dry matter after V12 stage, P accumulation at mature and post-silking P uptake, reduced apparent P loss significantly. In conclusion, the P fertigation four times (elongation, bell, silking and milking stage) could be a useful, economical and environment-friendly technique to increase maize yield and P use efficiency in the field crop.

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