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PHOSPHORUS ABSORPTION AND UTILIZATION OF RAPESEED (*BRASSICA NAPUS* L.) CULTIVARS WITH DIFFERENT YIELDS

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Abstract

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By using rapeseed (*Brassia napus* L.) cultivars with different seed yields, we measured the organ dry weight and phosphorus content, and then used cluster analysis (average linkage method) to classify different cultivars' yields, and further investigated different cultivars' phosphorus accumulation and allocation. Our study showed that, different cultivars' yields have distinct change and can be divided into six types according to clustering dendrogram. Different cultivars' yields are significantly different. Both phosphorus absorption total volume and phosphorus utilization efficiency for grain production (PUEg) for different types are significantly different. When yield increases, different types' phosphorus absorption total volume and PUEg values are increased significantly. The accumulation and allocation ratio of phosphorus in seeds from High-yield cultivars are significantly higher than those from low-yield cultivars. The implication is, if we'd like to increase rapeseed's PUEg, the priority method is to select high PUEg cultivars, and the second choice is to employ appropriate planting strategies so that more phosphorus can be transported to seeds from stems and leafs.

Key words: rapeseed (*Brassica napus* L.), phosphorus utilization efficiency for grain production, phosphorus accumulation, phosphorus distribution

Introduction

Rapeseed is one of the most important oil-bearing crops, the planting area and total product can occupy around 30% of the world (Wang, 2007). Along with the improvement of people's living quality, the intaking amount of plant oil per person is gradually increasing (Shen and Zhang, 2005). In the production of rapeseed, the yield volume is the most essential factor should be considered. Phosphorus is one of the key nutrient elements for plant growth and development. Therefore, phosphorus is very vital to increase yield volume of rapeseed.

There are a number of works on the phosphorous absorption effectiveness, for example, a previous research (Shen et al., 2006) showed that treating phosphorous-poor soils with phosphorous fertilizer can remarkably increase the seedling dry weight, mature

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seed yield and the accumulation of different nutrients.

In previous works, most used the dry biomass and seed yield to compare the effectiveness of phosphorous utilization in the absence and presence of phosphorous (Duan et al., 2001; Li et al., 2001; Yan et al., 2002). In our study, we based on the research experiences and methods on the effectiveness of nitrogen utilization (Dong et al., 2006; Lu et al., 2006; Dong et al., 2008; Zlatko and Zdenko, 2006), we employed the phosphorus utilization efficiency for grain production (PUEg) to reflect the phosphorous usage effectiveness. High-yield cultivars are those which can yield high volume of seed by absorbing phosphorous per unit, vice versa.

In this study, we used some of the common rapeseed cultivars to reveal the phosphorous absorption and utilization characteristics of rapeseed, with the purpose to better screen high-yield and high-efficiency cultivars and provide references on sustainable cultivation strategies.

Materials and Methods

Testing cultivars

73 cultivars were tested during 2006 and 2007, 25 ones were added in the year period 2007-2008. In total, 98 were tested (Table 1).

Soil fertilizing and field design

During 2006 and 2007, the experimental fields have the following chemical properties: 17.7 g/kg soil organic matter, 64.8 mg/kg alkali-hydrolyzable nitrogen, 13.4 mg/kg rapidly available phosphorous, and 37.6 mg/kg rapidly available potassium. The nitrogen fertilizer volume used is 150 kg/ hm^2, consisting of 90 kg/hm^2 basic fertilizer, P_2O_5 150 kg/hm^2, K_2O 150 kg/hm^2.

By using direct seeding technique at Nov 28th, 2006, we planted all the cultivars with row spacing 40.0cm, inter plant spacing 16.8 cm, the estimated density is 148810 plants per hm^2.

During 2007 and 2008, the experimental fields have the following chemical properties: 24.5 g/kg soil organic matter, 126.3 mg/kg alkali-hydrolyzable nitrogen, 38.6 mg/kg rapidly available phosphorous, and 98.8 mg/kg rapidly available potassium. No fertilizers were added in the fields. By using seedling transplanting technique, we seed all the cultivars at 22nd Sep, 2007 and transplanted them at 24th Oct. The row spacing is 45.0 cm, inter plant spacing 21.2 m, and the estimated density 104822 plants per hm^2.

All the cultivars are randomly planted and two replicates are set.

Measurement methods

Five rapeseed samples in maturation period were randomly selected at each plot, and their roots were cut off from the cotyledon node. All the samples were dry out in 80^{0}C, and the dry weights for stem, shell and grain are measured. The phosphorous content for each organ is measured by the Soda-melting phosphorus vanadium molybdenum yellow method (citation here).

Statistical analysis

Grain yields for all the tested cultivars were analyzed using UPGMA clustering method (average linkage method). The cluster analysis was performed in the software SPSS 11.0 (SPSS Company, 2005). The groups were decided based on the clustering dendrogram.

Results and Discussion

Clustering based on cultivars' yields and biomass comparison

The results showed that, different cultivars have a high discrepancy on yields. The range of variation for 2007 and 2008 years were 13.77-21.90 g/plant and 21.99-34.66 g/plant respectively, with the average of 18.91 g/plant and 29.34 g/plant. From the clustering analysis, all the cultivars used for the study can be classified into A, B, C, D, E, F groups according to their productivity (Table 2). In the two years, all cultivars' variation can reach the significant level. For the highest yield cluster group F, the average for 2007 and 2008 were 44.30% and 46.89% respectively. Cultivars from different clustering groups increase their

Table 1
Cultivars used in this study for different planting years

Experiment year	Cultivars
2006-2007 2007-2008	Dongyou-1, Hongyou-3, Ningyou-12, Ningyou-14, Ningyou-16, Ningyou-18, Luyou-16, Luyou-17, Shilijia, Suyou-1, Yangyou-4, Yangyou-6?, Yangyou-7?, Zheping-1, Zheshuang-3, Zheyou-18, Nannong-1, Yang-0401, Yang-0660, Yang-5005, Yangxuan-215, Xiang-05472, Xiang-05483, Xiang-05484, Xiang-05487, Xiang-05499, Xiang-05507, Xiang-05509, 1087, 96-8, 98-8, B01, G01, G02, G03, G04, G05, G06, HY01, HY02, HY03, HY04, SY01, SY02, SY03, SY04, SY05, SY06, SY07, SY08, SY2001, TK-1, Y0301, Y88, YC1, YC2, YC3, YC6055, YN01, YN02, YN03, YN04, YN05, YN06, YN07, YN08, YN09, YN10, YN11, YN12, YN13, ZJ1, ZJ2
2007-2008	Luyou-15, Ningyou-7, Ningyou-10, Suyou-211, Suyou-4, Nannong-2, Nannong-3, Xiang-05470, Hua-2008, 4029, G07, G08, G09, N05-3, N06-5, N24-1, N24-2, S10, SY2002, TK-2, YC4, YC5, YC6, YC7, YN14

Table 2
Six groups of cultivars' yields based on cluster analysis and difference of biomass. Values within a column followed by a different letter are significantly different at the 0. 05 probability level, ** and * denote significant difference at the 0. 01 and 0.05 probability ;evels, respectively

Type	Number of cultivars		Yield, g/plant		Biomass, g/plant		Representative cultivars
	2007	2008	2007	2008	2007	2008	
A	3	3	14.93±1.02f	22.78±0.78f	55.68±7.46c	91.82±2.62d	YN13, Y88
B	12	11	16.82±0.36e	25.28±0.50e	60.54±3.46c	99.08±6.69c	Dongyou-1, Suyou-1
C	18	22	17.99±0.29d	27.26±0.46d	62.41±3.62c	103.17±7.95c	Luyou-16, Zheyou-18
D	14	24	19.26±0.30c	29.08±0.43c	69.50±5.40b	109.99±6.91b	Yangyou-4, Ningyou-16
E	17	19	20.37±0.30b	31.32±0.60b	69.23±5.33b	113.56±7.05b	Xiang-05487, Zheping-1
F	9	19	21.54±0.23a	33.47±0.67a	73.83±4.47a	121.19±5.73a	Hongyou-3, Yangyou-7
F value			360.91**	543.92**	16.60**	24.94**	

yields along with the increase of their total biomasses. The biomasses among different yield clustering groups have significant difference.

Phosphorus absorption and PUEg differences in the cultivars of different yields

PUEg is an important indicator to reflect the absorption efficiency of phosphorus absorption, which can be calculated as the absorbed phosphorus at the mature period divided by the seed yield. Table 3 showed that, the PUEg and phosphorus absorption are both significantly different among the cultivars with different yields. For 2007 and 2008, the phosphorus absorption amount ranges 150.30-234.36 mg/plant and 309.49-466.92 mg/plant, with the average 189.09 mg/plant and 380.31 mg/plant respectively. For 2007 and 2008, the PUEg ranges 88.42-111.77 $g.g^{-1}$ and 67.16-92.07 $g.g^{-1}$, with the average 100.10

$g.g^{-1}$ and 77.23 $g.g^{-1}$, respectively.

Along with the increase of yield, the total phosphorus absorption amount and PUEg are increased gradually (Table 3). Correlation analysis showed that, either for 2007 or 2008, the phosphorus absorption amount and PUEg can showed linear positive correlations with yields (Figure 1). For the two years, the F type and A type, the highest and lowest phosphorous absorption groups respectively, can increase 25.86% and 28.05%. Analogously, they can increase 14.89% and 15.29% respectively at the aspect of PUEg.

Phosphorus content, accumulation and allocation differences among the organs of cultivars with different yields

The phosphorus contents for different organs and the whole plant are shown in Table 4, phosphorus contents in the stem and shell are significantly different, and other organs do not appear significant differences on phosphorus content. More interesting, lower-yield cultivars have higher content of phosphorus. In summary, phosphorus content in the seeds is remarkably higher than those in stem and shell. The averages in seeds for 2007 and 2008 are 7.21 mg/g and 8.63 mg/g respectively.

Table 5 showed that, the phosphorus accumulation amounts in different clustering groups of cultivars are not significantly different in the organs of stem and shell, however, the difference becomes significant in the organ of seed. The significance can be found in both 2007 and 2008 year. The ranges of phosphorus accumulation amounts in different cultivars were 102.91-169.91 mg/plant and 196.11-300.13 mg/plant respectively, with the individual averages of 136.20 mg/plant and 252.86 mg/plant. In general, along with the increase of yield, the accumulation of phosphorus in the seeds is gradually increased. For the two years, the F type and A type, the highest and lowest phosphorus accumulation groups respectively, can increase with extents of 40.37% and 40.01%.

The ratios of accumulated phosphorus in the stem, shell and seed compared to the amount of total plant are showed in Table 6. Results suggest that, phosphorus is mainly concentrated in the seeds when

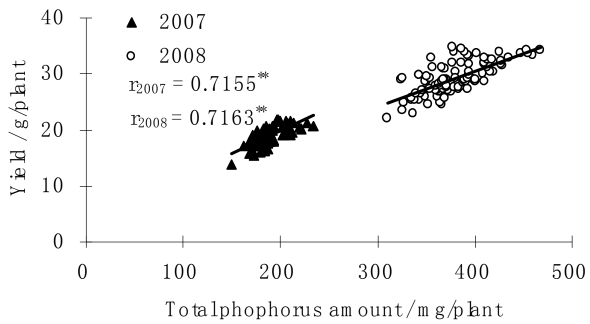

Fig. 1. Relationships between the total phosphorus amounts, PUEg and yield, g/plant

Table 3

Difference of the total phosphorus accumulation and phosphorus use efficiency (PUEg). Values within a column followed by a different letter are significantly different at the 0. 05 probability level, ** and * denote significant difference at the 0. 01 and

Type	Total phosphorus amount, mg/plant		PUEg, $g.g^{-1}$	
	2007	2008	2007	2008
A	163.71± 11.78d	323.62± 13.30d	91.21± 2.10c	70.44± 2.26c
B	177.86± 7.53cd	348.89± 14.86c	94.73± 5.06c	72.57± 3.37bc
C	180.86± 8.42c	366.10± 14.04b	99.62± 4.32b	74.54± 2.57b
D	190.85± 13.30b	373.72± 26.23b	101.39± 7.12ab	78.21± 5.98a
E	199.79± 14.98ab	398.15± 23.02a	102.42± 6.94a	78.91± 4.47a
F	206.04± 10.14a	414.40± 31.96a	104.79± 5.92a	81.21± 6.44a
F value	14.04**	19.74**	5.20**	7.67**

the plant is in the mature period; the averages for 2007 and 2008 of the phosphorus ratio in the seed were 71.99% and 66.50% respectively. The phosphorus ratio in the shell does not show significant differences among the cultivars from different yield groups. When the yield increases, the phosphorus ratio in the stem is significantly decreased, while the ratio in the seed is significantly increased. In general, along with the yield increases, the ratios of phosphorus in the seed from different yield types are increased gradually.

Further implications

Our study showed that, there is a slight difference of phosphorus content in different clustering types. However, because of apparent difference in the biomass, the phosphorus accumulation amount in difference yield types becomes remarkably different. Different types can increase their phosphorus absorption amount and PUEg when their yields increase. The phosphorus accumulation amounts in the stem and shell for different yield types have a small difference, the ratio of accumulated phosphorus in the stem compared to total plant showed a decreasing trend when the yield increases. Along with yield increases, the phosphorus accumulation amount in the seed for different yield types are gradually increasing. Correla-

Table 4

Difference of phosphorus content of different organs (mg.g^{-1}). Values within a column followed by a different letter are significantly different at the 0. 05 probability level, ** and * denote significant difference at the 0. 01 and 0. 05 probability leve

Type	Stem		Shell		Seed		Total plant	
	2007	2008	2007	2008	2007	2008	2007	2008
A	1.50±0.09a	1.70±0.24	1.13±0.19ab	1.81±0.27	7.31±0.17	8.97±0.18	2.96±0.24	3.53±0.24
B	1.30±0.18b	1.77±0.22	1.11±0.21a	1.73±0.31	7.42±0.29	8.69±0.37	2.95±0.19	3.53±0.25
C	1.30±0.12b	1.76±0.17	1.00±0.21abc	1.64±0.28	7.19±0.43	8.68±0.32	2.90±0.17	3.56±0.25
D	1.21±0.24bc	1.55±0.41	0.87±0.18c	1.55±0.32	7.15±0.55	8.55±0.54	2.75±0.20	3.41±0.27
E	1.27±0.18b	1.64±0.40	0.90±0.21bc	1.45±0.25	7.18±0.52	8.64±0.49	2.90±0.27	3.52±0.27
F	1.10±0.14c	1.45±0.43	0.93±0.17bc	1.49±0.40	7.11±0.42	8.54±0.38	2.80±0.17	3.42±0.26
F value	3.25*	2.26	2.73*	1.99	0.69	0.77	1.65	1.22

Table 5

Difference of phosphorus accumulation of different organs (mg/plant). Values within a column followed by a different letter are significantly different at the 0. 05 probability level, ** and * denote significant difference at the 0. 01 and 0. 05 probability levels, respectively

Type	Stem		Shell		Seed	
	2007	2008	2007	2008	2007	2008
A	36.55±5.31	68.01±4.56	18.18±2.37	51.32±3.14	108.98±5.26e	204.29±7.14f
B	31.53±5.22	74.38±10.20	21.65±4.72	54.78±10.58	124.68±4.71d	219.73±9.25e
C	31.51±3.17	76.48±9.95	19.94±3.88	52.98±8.67	129.41±8.12c	236.63±9.97d
D	33.38±7.84	71.40±18.14	19.74±4.61	53.65±12.69	137.73±10.91b	248.67±13.97c
E	33.56±5.92	74.23±17.49	20.06±5.33	53.29±11.04	146.17±10.95a	270.63±15.78b
F	30.26±5.33	68.21±20.47	22.81±3.09	60.17±16.35	152.98±7.86a	286.02±14.95a
F value	0.97	0.68	0.99	1	22.16**	59.94**

Table 6

Difference of ratio of phosphorus accumulation amount of different organs to total phosphorus amount (%).Values within a column followed by a different letter are significantly different at the 0.05 probability level, ** and * denote significant difference at the 0.01 and 0.05 probability levels, respectively

Type	Stem		Shell		Seed	
	2007	2008	2007	2008	2007	2008
A	22.25±1.80a	21.01±0.93a	11.10±1.13	15.85±0.41	66.65±1.70d	63.14±0.77c
B	17.70±2.58b	21.31±2.71a	12.12±2.30	15.64±2.55	70.18±3.19c	63.05±3.05cd
C	17.42±1.54b	20.86±2.37a	11.04±2.13	14.46±2.25	71.54±2.66bc	64.67±2.43bd
D	17.41±3.39b	18.95±4.01b	10.33±2.20	14.35±3.27	72.26±4.86abc	66.70±3.74a
E	16.77±2.42b	18.52±3.78bc	9.99±2.25	13.38±2.68	73.24±3.49ab	68.10±4.25a
F	14.67±2.34c	16.27±3.89c	11.07±1.40	14.43±3.53	74.26±2.17a	69.30±5.03a
F value	4.67**	4.93**	1.67	1.03	3.49**	6.08**

tion analysis indicated that there is significantly positive correlation between yield and phosphorus absorption total amount (r_{2007}=0.7155, $p<0.05$ and r_{2008}=0.7163, $p<0.05$), which indicated that increasing phosphorus absorption can increases the yield level of rapeseed. Therefore, in agricultural practice, for the purpose of guaranteeing high productivity, we should select those cultivars with strong capability of phosphorus absorption, at the meanwhile, appropriate planting strategies are required so as to increase PUEg, and in turn, increase the accumulation ratio of seed phosphorus.

Our experiment design crossed two years, involving a lot of experimental factors, for example, planting ways, density, and soil fertility. In 2008, the experimental rapeseed is planted in a lower density and higher fertility. In this manner, the total amount of phosphorus accumulation per plant and for each organ is remarkably increased. From the view of a whole population, the averaging yields for 2007 and 2008 were 2813.35 kg/hm^2 and 3075.25 kg/hm^2, while the total amount of phosphorus accumulation were 28.14 kg/hm^2 and 39.86 kg/hm^2 respectively. The yield amount only increases 9.31% when comparing the two years, but the phosphorus accumulation amount can increases 41.67%. Previous studies showed that (Wang et al., 1997; Yan and Liu, 2003), when the soil fertility increases, the yield amount and nutrient accumulation amount can increase, while the return rate of fertilizer decreases. From the change of PUEg, in 2008 the PUEg is 77.23 g.g^{-1} in average, remarkably smaller than 100.10 g.g^{-1} in 2007. PUEg is affected by the soil fertility, so it becomes a contradiction needing further reconciliation between the high productivity and high efficiency (PUEg).

Conclusion

Phosphorus is essential for rapeseed production in agricultural practices. By using ninety-eight typical rapeseed cultivars, our work indicated that the best way to increase phosphorus absorption effectiveness for rapeseed farming is to select high PUEg cultivars, and the second choice is to employ appropriate planting strategies so that more phosphorus can be transported more effectively.

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