# Critical phosphorus concentrations in winter wheat genotypes with various phosphorus efficiencies*

Wang Qing-ren, Li Ji-yun

Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China

Li Zhen-sheng

Research Institute of Genetics, Chinese Academy of Sciences, Beijing 100101, China

**Abstract** Under greenhouse conditions, a pot experiment was conducted to seek critical phosphorus concentrations of wheat genotypes with high and low phosphorus use efficiency. Results indicated that low efficient genotype was much more sensitive to phosphorus deficiency, with low or without phosphorus application, seed yield and dry matter of biomass were much lower. The yield of all the genotypes gradually got higher as application rate increased, but high efficient genotype——Lofflin produced relatively higher yields of seeds and biomass with low or without phosphorus input. Highly tolerate to low availability of soil phosphorus and efficient activation and absorption for soil unavailable phosphorus had been displayed. As application rates increased, yields of both genotypes were increased but high efficient genotype maintained stable while low efficient one showed continuously increase with remuneration decrease progressively.

Critical phosphorus concentrations in high efficient genotypes of winter wheat were lower than that in low efficient ones and changed with various development stages, for example, at seedling state, the concentrations of high efficient genotype were 4.50—4.60 g/kg while low efficient one was 5.0 g/kg. They were 2.25—2.30 g/kg and 2.52 g/kg at flower stage, 1.96—2.05 g/kg and 2.15 g/kg at maturity respectively. But the values in seeds were reversal, higher in high efficient genotype(4.05—4.10 g/kg) than that in low efficient(3.90 g/kg). Therefore, phosphorus high efficient genotypes belong to the phosphorus resource saving type.

**Keywords**: critical phosphorus concentration, wheat genotypes, phosphorus efficiency.

## 1 Introduction

As an unrenewable mineral resource, phosphorus is one of the important essential elements for living beings. Phosphorus has made a great contribution in agricultural production since its necessity for plants was found in the 17th century. In recent decades however, as the population increase dramatically but usable phosphorus resource for human being decrease, many scientists and politicians over the world have paid their attention to the resource crisis, especially in some developing countries like China (Li, 1986). Therefore, relying to develop plant genetically potential, saving and effectively use natural resource, maintaining ecological balance, protecting environment from pollution in order to set up a sustainable developing agricultural ecosystem have become an important task for mankind, so that studies on crop screening, physiological characteristics of high efficient genotypes to reactivate, uptake and transport, and utilize soil phosphorus effectively have been focused on world widely (Marshner, 1995; Wang, 1998).

Many experiments have been proven that, species or genotypes with high phosphorus use efficiency usually can mobilize and uptake the less available phosphorus in calcareous soil through changing their morphological, physiological and biochemical characteristics induced by phosphorus deficiency. But research on the requirement and critical phosphorus concentrations by plants so far

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seems not enough. Furthermore, critical value of a plant for an element is an important indicator for nutrient requirement (Pinkerton, 1991), therefore, pot experiments under greenhouse condition for some typical genotypes of wheat with high and low phosphorus efficiency use based on the primary screening for phosphorus efficiency(Li, 1995) were carried out in order to determine the critical values for phosphorus, characterize their phosphorus requirements and discuss the principle of phosphorus fertilizer supply for various genotypes of wheat.

## 2 Materials and methods

### 2.1 Soil characteristics for the experiment

Soil for the experiment was taken from Experiment Site Biological Breeding Techniques, Research Inst. of Genetics, Chinese Academy of Sciences, Pingxifu Town, Changping County, Beijing suburb area, China. The soil texture is clay loam with pH 7.8, consists of 8.6 g/kg of soil organic matter, 0.56 g/kg of total nitrogen, 0.24 g/kg of total phosphorus, 45.2 mg/kg of alkali nitrogen, 6.5 mg/kg of Olsen-P, 78.2 mg/kg of exchangeable K, 12.6 cmol/kg of CEC and 52 g/kg of $CaCO_3$.

### 2.2 Design and treatment of experiment

Based on the previous abundantly screening and selections of wheat genotypes for phosphorus high efficiency, three genotypes of winter wheat: Lofflin, Ji87-4617(high P-efficient) and 80—55 (low P-efficient) were used in the experiment. Eight levels of phosphorus rates, 0, 0.25, 5, 10, 20, 40, 80 and 160 mg/kg soil (that is $P_0$, $P_{2.5}$, $P_5$, $P_{10}$, $P_{20}$, $P_{40}$, $P_{80}$ and $P_{160}$) were designed. Phosphorus fertilizer $NH_4H_2PO_4$(AR) was used with N 12.2%, P 26.92% and $CO(NH_2)$ was used to balance to N 120mg/kg soil (of which 1/3 was used as top dressing), K 40 mg/kg (KCl, K 43.2%). Eight kg/pot of soil with 3 replicates in the experiment was carried out. Twenty seeds in each pot were sown on 20 Oct. 1996. Seedlings were thinned to 15 per pot at 3-leaf stage. Sampling times were at tillering, stem elongation and flower stages respectively. Seven plants per pot were kept to maturity for final harvest. Temperatures were maintained between 12—30℃ at various growth stages according to the crop development. Equal amount of water was put into each pot regularly and some actions were taken to prevent pests and diseases.

### 2.3 Sampling and analysis

Plant samples were taken to laboratory to invest the number of tillers, seedling height, dry matter of biomass, ears per plant. Seed number per ear were counted after maturity. Dry weight of seeds, biomass and 1000-seed weight were measured. Finally, samples were ground in various parts for total phosphorus analysis(wet digestion, colorimetric method).

## 3 Results and discussion

### 3.1 Effect of phosphorus rates on crop development

Crop growth and development did not appear much difference among the treatments before tillering. But plants without phosphorus supplied(CK) grew slowly with thin and weak stems, dark colour leaf, reduced plant height and tiller numbers, thinner and longer roots, and the number of roots and root weight were lower than normal during tillering to stem elongation stages. The observations for crop development indicated that enough phosphorus supply could improve the plant development, shorten growth periods. No much difference were found among the genotypes.

Seedling development in various treatments and genotypes is shown in Table 1, which indicated that tillers per plant and plant height with the same genotypes but different treatments were quite different, increasing with increase of phosphorus rates for all three genotypes.

**Table 1 Effect of phosphorus supply on growth and development of wheat genotypes**

| Genotypes | $P_0$ | $P_{2.5}$ | $P_5$ | $P_{10}$ | $P_{20}$ | $P_{40}$ | $P_{80}$ | $P_{160}$ |
|---|---|---|---|---|---|---|---|---|
| | | | | Tillers per plant | | | | |
| 80-55 | 0 | 0.8 | 1.3 | 1.3 | 1.5 | 1.6 | 2.0 | 2.3 |
| Ji 87-4617 | 0.4 | 2.2 | 2.3 | 2.3 | 2.5 | 2.7 | 2.8 | 3.3 |
| Lofflin | 1.2 | 1.6 | 2.6 | 2.8 | 3.3 | 3.7 | 4.7 | 4.8 |
| l.s.d, $p<0.05$ | 0.42 | 0.58 | 0.61 | 0.64 | 0.71 | 0.78 | 0.86 | 1.25 |
| | | | | Plant height, cm | | | | |
| 80-55* | 18.6 | 23.0 | 23.3 | 24.7 | 27.0 | 34.8 | 39.5 | 40.6 |
| Ji87-4617 | 16.5 | 21.0 | 21.3 | 22.8 | 23.2 | 23.3 | 23.3 | 24.0 |
| Lofflin | 11.6 | 19.8 | 20.8 | 21.5 | 23.0 | 23.1 | 23.3 | 24.3 |
| l. s. d, $p<0.05$ | 5.62 | 4.21 | 1.83 | 2.83 | 3.56 | 8.51 | 12.32 | 15.35 |

* With its vernal trait 80-55 had been in stem elongation stage while sampled

### 3.2 Effect of phosphorus on shoot and seed weight

Changing of dry matter with increase in P rates for three genotypes is shown in Fig. 1, indicating that dry matter of high P efficient genotype increased sharply with increase of P in low P rate range, reached a stable level quickly, while for low P efficient genotype, the dry matter increased slowly throughout the whole range of P supply.

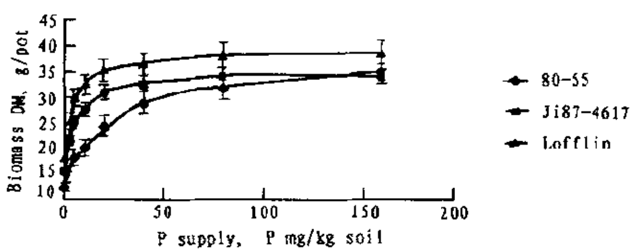


Fig. 1 Effect of P supply on biomass of wheat genotypes with various P efficiency

### 3.3 Uptake and utilization rates of phosphorus

There was a positive correlation between shoot phosphorus concentration and phosphorus fertilizer supply, especially during early stage. Shoot phosphorus concentration was increased as the fertilizer phosphorus increase in all of the three genotypes($r=0.78$—$0.89$). At lower phosphorus rates(e.g. 20 mg/kg), shoot phosphorus concentration in genotype Ji87-4617 was the highest, and that in genotype 80-55 was the lowest and Lofflin was in the middle. At the highest phosphorus rate( 160 mg/kg), shoot phosphorus concentration in Lofflin was the highest, 80-55 was still the lowest while Ji87-4617 was in the middle (Fig. 2a).

Phosphorus concentrations at flowering stage were different from that at seedling stage. High efficient genotype-Lofflin showed the highest phosphorus concentration but phosphorus concentration in genotype 80-55 was higher than that in Ji87-4617 although all of them showed a same pattern(Fig. 2b).

On the contrary after the maturity, phosphorus concentration in the straw of low efficient

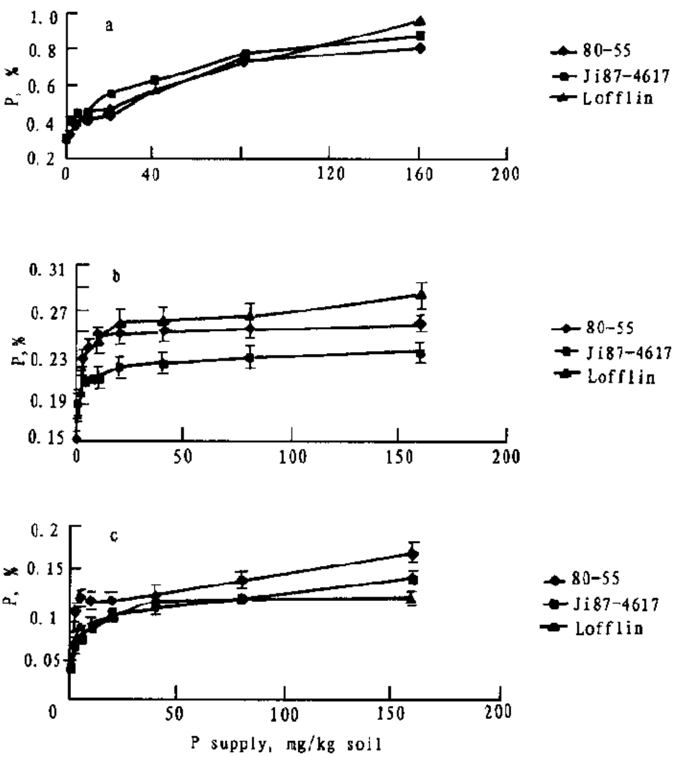


Fig. 2 Effect of P supply on tissue P concentration of wheat genotypes with various P efficiency

genotypes were significantly higher than that of high efficient(Fig. 2c). This is possibly related to phosphorus transportation and metabolism in plant of various genotypes because phosphorus concentration in seeds of high efficient genotypes were higher than that in low efficient ones (Fig. 3), most of phosphorus taken up was transported to seeds for economical yield production so that phosphorus left in the straw must be lower.

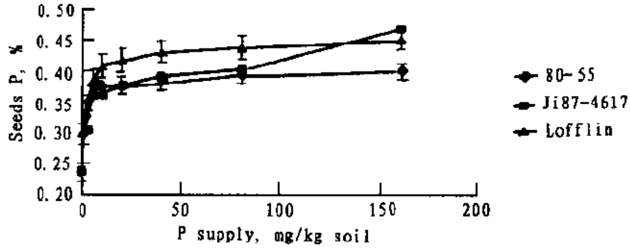


Fig. 3 Correlation between P concentration and P rates for various genotypes

Total amount of phosphorus uptake from soil or fertilizer by various phosphorus efficient genotypes indicated that, except for the highest rate (160 mg/kg), the total amount of phosphorus uptake by high efficient genotype was higher than that by low efficient ones(Table 2).

Yield production per gram of phosphorus in plants, which is called utilization rate, is an important indicator for phosphorus efficiency, especially at low or phosphorus stress conditions, the higher the utilization rate, the higher the phosphorus efficiency (Table 3).

**Table 2 Total amount of P uptake by wheat genotypes with different P efficiencies at various P supply (P mg/pot)**

| | $P_0$ | $P_{2.5}$ | $P_5$ | $P_{10}$ | $P_{20}$ | $P_{40}$ | $P_{80}$ | $P_{160}$ |
|---|---|---|---|---|---|---|---|---|
| 80-55 | 13.8 | 27.3 | 32.5 | 35.3 | 42.2 | 53.2 | 70.6 | 91.3 |
| Ji87-4617 | 16.3 | 28.5 | 40.0 | 47.5 | 63.1 | 74.7 | 80.2 | 94.6 |
| Lofflin | 25.1 | 40.3 | 56.2 | 67.1 | 80.6 | 88.1 | 93.0 | 97.2 |

**Table 3 Total output of wheat genotypes per gram P with various P rates**

| | $P_0$ | $P_{2.5}$ | $P_5$ | $P_{10}$ | $P_{20}$ | $P_{40}$ | $P_{80}$ | $P_{160}$ |
|---|---|---|---|---|---|---|---|---|
| | | | | DM of biomass, g/gP | | | | |
| 80-55 | 898.6 | 615.4 | 560.0 | 566.6 | 549.8 | 503.8 | 441.9 | 375.1 |
| Ji87-4617 | 962.0 | 747.4 | 620.0 | 581.1 | 491.3 | 436.4 | 423.9 | 361.5 |
| Lofflin | 737.8 | 630.3 | 533.8 | 482.9 | 436.7 | 413.4 | 408.6 | 390.9 |
| l.s.d. $p<0.05$ | 115.3 | 83.2 | 65.3 | 72.5 | 83.6 | 89.2 | 35.4 | 32.2 |
| | | | | Seed yield, g/gP | | | | |
| 80-55 | 250.0 | 153.8 | 141.5 | 136.0 | 142.2 | 149.2 | 153.0 | 157.7 |
| Ji87-4617 | 317.8 | 217.2 | 193.3 | 187.4 | 185.4 | 180.7 | 174.9 | 149.0 |
| Lofflin | 212.0 | 196.8 | 181.5 | 178.8 | 178.7 | 171.4 | 163.4 | 161.5 |
| l.s.d, $p<0.05$ | 89.9 | 58.3 | 48.4 | 35.5 | 39.8 | 35.4 | 32.6 | 28.8 |

Results in Table 3 implied that under low rates of phosphorus application (e.g. < 10 mg/kg), yield production of biomass per gram of phosphorus was in the following order: Ji87-4617 > 80-55 > Lofflin; under higher rates of phosphorus application (except for 160 mg/kg), 80-55 > Ji87-4617 > Lofflin. However, the utilization rate at the highest phosphorus rate(160 mg/kg for example) is meaningless because so high amount of phosphorus application is definitely not practical.

Seed yield produced by each gram of phosphorus in most cases is Ji87-4617 > Lofflin > 80-55, which has reflected the difference of phosphorus utilization rate by various efficient genotypes, the higher the utilization rate, the higher the seed yield. It implied that utilization rate of phosphorus by Ji87-4617 is definitely higher while the mobilization, absorption rates of phosphorus from soil or fertilizer are the main property of phosphorus efficiency(Table 2 and 3).

### 3.4 Critical phosphorus concentration

Correlation between phosphorus concentration and yields of biomass or seeds indicated that there was positive correlation between phosphorus concentration and dry matter of seeds or shoots for all the genotypes ($r = 0.73$—$0.86$). That is as phosphorus concentration increase, the dry matter increased but maintained constant when it reached a certain level (Fig.4—7).

Based on the relationship between dry matter of shoots or seed yields and phosphorus concentration, critical phosphorus values could be determined by taking 90% of maximum yield related to P% (Fig.4) which showed that it was higher for low efficient genotype than that for high efficient with their shoots. But on the contrary, for seeds, critical phosphorus concentration in high efficient genotypes was higher than that in low efficient(Table 4), which proved that more phosphorus uptake can be transported to seeds for high efficient genotypes but low efficient one usually accumulated more phosphorus in shoots and relatively smaller amount could be retransported to seeds. In other words, the efficient genotypes could be translocated more phosphorus for seed production and the amount left in the straw was much smaller so that high efficient genotypes of wheat belong to a phosphorus saving type.

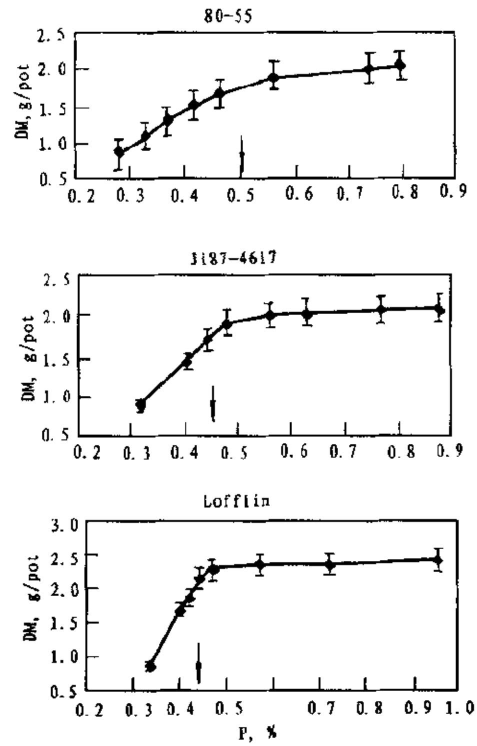


Fig.4 Relationship between tissue P concentration and dry matter of biomass at seedling stage

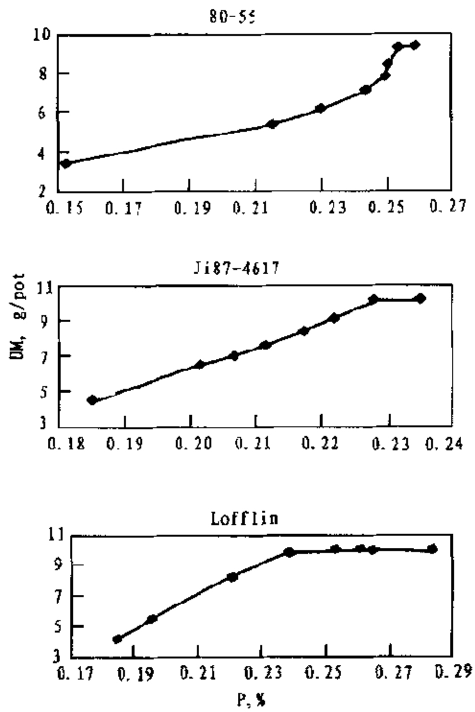


Fig.5 Relationship between tissue P concentration and dry matter of biomass at flower stage

**Table 4 Critical values of P in wheat genotypes with different P efficiencies at various growth stages, P%**

| | Seedling stage | Flower stage | Maturity stage | Seeds |
|---|---|---|---|---|
| 80-55 | 0.50 | 0.252 | 0.215 | 0.390 |
| Ji87-4617 | 0.46 | 0.225 | 0.205 | 0.405 |
| Lofflin | 0.45 | 0.230 | 0.196 | 0.410 |

# 4 Conclusion

Generally, wheat growth, development and phosphorus concentration were improved by increasing phosphorus supply but some differences existed between high efficient and low efficient genotypes. High efficient genotypes can produce more seed yield and biomass than low efficient one with low or without phosphorus application, and dramatically increase but maintain constant up to certain level by phosphorus supply. Low efficient one not only reduced less yield but also increase slowly with remuneration decrease by supplying certain amount or in the all extent of phosphorus levels.

There were close correlation between phosphorus concentration in shoots or seeds and phosphorus rates supplied so that the critical phosphorus concentration of various genotypes at crop

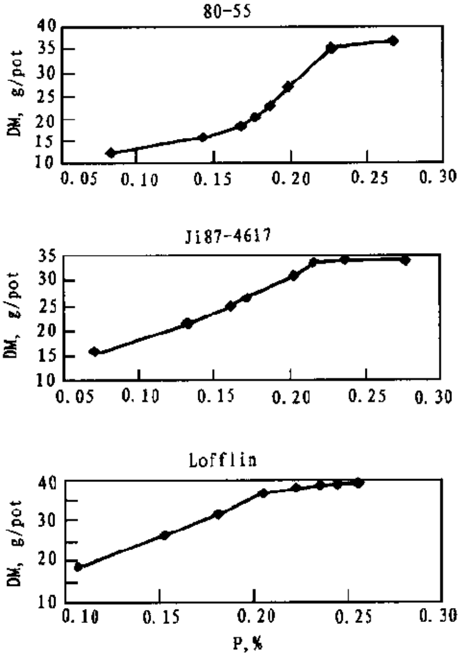


Fig. 6 Relationship between tissue P concentration and dry matter of biomass after maturity

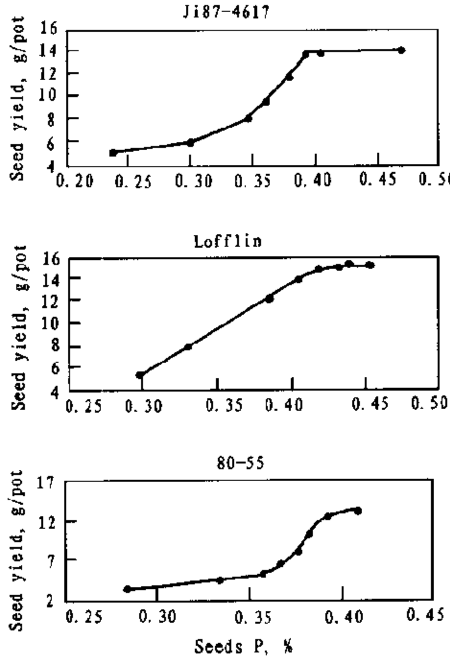


Fig. 7 Relationship between seed P concentration and seed yield after maturity

development stages could be obtained from the correlativity between dry matter of biomass or seed yield and phosphorus concentration in tissues or in seeds. This can be used to asses the requirements for phosphorus by various plant genotypes and to diagnose the phosphorus status. In normal phosphorus rates applied, the amount of phosphorus required by high efficient genotypes was lower but the metabolism or utilization rates were higher than that by low efficient genotype. Therefore, high phosphorus efficient genotypes require less phosphorus for their normal growth, development and yield production which implies that the high efficient genotypes do not need to supply as much phosphorus as low efficient one does. The high efficient phosphorus genotypes will be useful not only for saving phosphorus resource but also for preventing phosphorus pollution to waters in our environment through its control of amount applied.

## References

Li J Y, 1995. Science in China, Series B, 38(11): 1313—1320

L Q, 1986. Journal of Soil Sci, 2: 1—7

Marschner H, 1995. Mineral nutrition in higher plants. London: Academic Press

Pinkerton A, 1991. Australian Journal of Experimental Agriculture, 31: 107—115

Wang Q R, Li J Y, Li Z S, 1998. Journal of Plant Nutrition and Fertilization, 1998, 4(2): 107—116

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