Effect of Phosphorus Application on Morphological Characters of Root Under Drought Stress at Different Reproductive Stages in Soybean

SHEN Zhong-bao[1], QI Zhi-yong[2], JIN Jian[3]

(1. *Heilongjiang Academy of Agricultural Sciences*, *Harbin* 150086; 2. *Harbin Evaluation Center for Environmental Engineering*, *Harbin* 150076; 3. *Northeast Institute of Geography and Agro－ecology*, *Chinese Academy of Sciences*, *Harbin* 150040)

Abstract Application of phosphorus (P) fertilizer is an important factor for improving the tolerance to water deficit in many plants. A pot experiment was conducted to identify the effects of P application on soybean adaptability to water deficit at the R1 (initial flowering) and R4 (full pod) stages through the investigation of root morphological traits and resultant yield in a soybean (*Glycine max* L. Merrill) cultivar (Dongnong 434). The four levels of P application were 0, 7.3, 14.6 and 29.2 mg kg^{-1} soil, respectively. The three soil moisture treatments were (1) 65%～75% of field water capacity (FWC) as control, (2) 30%～40% of FWC at the R1 stage, and (3) 30%～40% of FWC at the R4 stage. Results showed that root traits and yield were significantly reduced by drought stress at different growth stages, especially at the R4 stage. Application of P enabled to alleviate the adverse effects of drought, to increase the root dry weight, root length, root surface area and consequently yield.

Key words Soybean; Water Stress; Phosphorus application; Root traits; Yield

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大豆不同生殖生长期干旱胁迫条件下施磷对根系形态性状的影响

申忠宝[1]，齐志勇[2]，金 剑[3]

(1. 黑龙江省农业科学院，哈尔滨 150086；2 哈尔滨市环境工程评估中心，哈尔滨 150076；3. 中国科学院东北地理与农业生态研究所，哈尔滨 150081)

摘要 磷素(P)是提高植物抗水分胁迫能力的重要因子。选取大豆(*Glycine max* L. Merrill)品种东农 434 进行盆栽试验，分别在大豆 R1 期(初花期)和 R4 期(盛荚期)进行干旱胁迫处理，解析 P 在干旱胁迫条件下对根系性状和产量的影响。试验设置 4 个施 P 水平，即 0、7.3、14.6 和 29.2 mg kg^{-1}。3 个水份处理，即(1)全生育期维持田间持水量(FWC)的 65%～75%为对照；(2)R1 期控水为 FWC 的 30%～40%；(3)R4 期控水为 FWC 的 30%～40%。结果表明，两个时期的干旱胁迫均

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作者简介：申忠宝(1973－)，男，助研，从事杂粮产品研发。E－mail：shzhbao@126.com

显著影响根系性状,降低产量,且 R4 期比 R1 期严重。磷素营养显著改善干旱胁迫所引起的不利影响,增加根干重、根长、根表面积,进而减少大豆产量的损失。

关键词 大豆;水分胁迫;施磷量;根系性状;产量

The annual rainfall arranges from 400 to 700 mm in Heilongjiang province, China, and the precipitation was not evenly distributed in twelve months. Season droughts often occur and irrigation was nearly impossible for crops in Heilongjiang. Fertilization, particularly the application of P can alleviate drought-stress effects on crop productivity[1]. Boem and Thomas[2] indicated that the ability of plants to cope with mild water stress was enhanced by adequate P nutrition.

Compared with almost all the other plant organ systems, the development of the plant root system is exceptionally plastic, and strongly influenced by the growth conditions, such as soil fertility and degree of moisture deficit[3]. Development of the root system was one of the key factors for interpreting the effects of many abiotic stresses because of its essential role as a soil-plant interface [4]. Root architecture was closely linked with the plant uptake of water and the nutrients that move with water, as well as immobile nutrients such as P. Therefore, the total root biomass, root length and surface area have been found to influence the nutrient uptake, whereas the development of the root system was considerably affected by drought stress [5,6]. Previous studies had been mostly focused on the effects of P and soil moisture availability on root development as isolated factors rather than their possible interaction in soybean [7~10].

Nevertheless, the analysis of the relationships among P shortage, water stress and root characteristics of soybean has had little attention. The purpose of the present study was to identify how and how much P nutrition enhanced the relative tolerance of soybean to water deficit stress at R1 and R4 periods from some root traits.

1 Materials and Methods

1.1 Crop Management and Experimental Design

The study was conducted at Northeast Institute of Geography and Agro-ecology, Chinese Academy of Sciences in 2002. The institute is located at 45°41.8′N, 126°38.1′E and 150 m above sea level. The early maturing cultivar Dongnong 434 was a recently developed soybean cultivar in Heilongjiang province, China. The soil was slight alkali with poor available phosphorus nutrient. Total phosphorus and available P of the soil were 0.12 $g \cdot kg^{-1}$ and 5.1 $mg \cdot kg^{-1}$, respectively. Soybean plants were grown in pots under a rain—shelter during the growing season. All of pots, 35 cm height and 28 cm diameter, were on movable plat vehicle that can be easily moved into rain shelter during raining and moved out during sunshine. Treatments consisted in the combination of two factors: P fertilizer addition (four levels) and soil water availability (three levels). The levels of added P (KH_2PO_4) were 0, 7.3, 14.6 and 29.2 mg P/kg soil, (P0, P1, P2 and P3, respectively). With 192 mg N/kg soil and 103 mg K_2O/kg soil, the fertilizer was thoroughly mixed within the first 20 cm of each pot. Field water capacity (FWC) was determined before sowing. The water deficit treatments were (1) 30%~40% of FWC at R1 stage (W1); and (2) 30%~40% of FWC at R4 stage (W2). During other stages, the water content in soil was supplied to maintain the 65%~75% of FWC as same as control (W0). And the water content was brought to requirement of experimental design by weighing and watering whenever it was needed. The experiment was arranged in a randomized complete block design with five replications per treatment. Six seeds in similar size were sown on May 8 and emerged after 8 days. Three plants per pot were determined on the 15th day after emergence. On June 10, the solution with micronutrients was applied: B = 0.1 μg/g soil as H_3BO_4; Mn = 0.1 μg/g soil as $MnCl_2 \cdot 4H_2O$; Cu = 0.004 μg/g soil as $CuSO_4 \cdot 5H_2O$; Zn = 0.001 μg/g soil as $ZnSO_4 \cdot 7H_2O$; Mo = 0.01 μg/g soil as H_2MoO_4

· H_2O.

1.2 **Measurements**

Since the root system of soybean had become fully developed by the R5 (initial pod filling) stage, the roots were sampled at this stage in three of the replications to determine the root dry weight, root surface area, and root length. Shoot mass was also determined at the same time. The entire root system was carefully removed by sliding it from its pot. The stem was cut off and the root system washed. The roots were first completely immersed in a water-filled container and then sprayed with water until it was almost free of soil and sand. Sieve with 74 μm of mesh size was used to prevent loss of fine roots. The method for determining root length was as followed [11]. An estimate of root length was given by: $R = \pi NA/(2H)$ where R was the total length of root, N was the number of intersection of between the root and the straight lines, A was the area of the rectangle, and H was the total length of the straight lines. Root surface (g $Ca(NO_3)_2$) was determined by immersing air-dried roots for 10 s in a saturated solution held on an analytical balance, suspending them out of solution for 30 s and recording the weight (g) of $Ca(NO_3)_2$ removed from solution that adhered to the root surface [12]. At maturity, residue plants were harvested; seeds were removed from the pods, dried and weighed. Seeds were counted and average weight per seed was calculated.

1.3 **Data Analysis**

Data collected on root traits, yield and yield components were analyzed by standard analysis of variance (ANOVA). The comparisons between treatments were evaluated by Fisher´s LSD using SAS (SAS Inst., 1990).

2 Results and Discussion

2.1 Root traits

Root dry mass varied among the applied P rates under water stress condition at different developmental stages (R1 and R4) and greater at P3 than at either of the other P fertilization rates (Fig. 1). At P3 fertilization rate, root mass was 1.45-, 1.34- and 1.41-fold greater than P0 for W0, W1 and W2 treatments, respectively. The positive effect of P on root dry mass has been previously reported [7]. But root/shoot ratio did not show great difference among P fertilization rates except for W2 (Fig. 1).

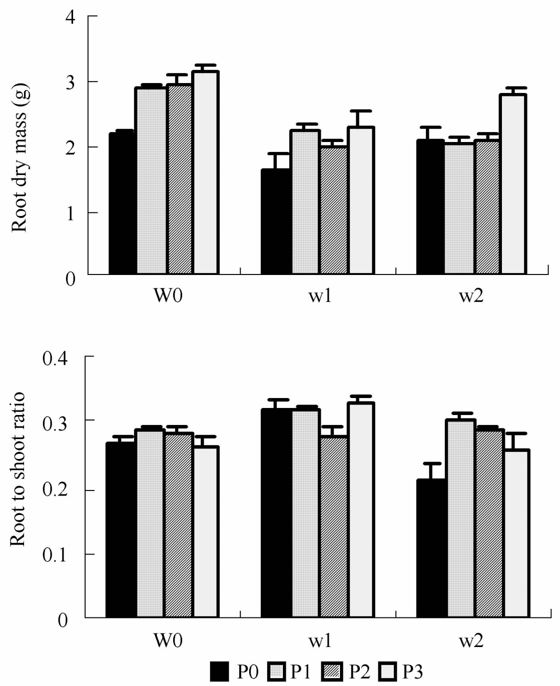

Fig. 1 Root dry mass and root/shoot ratio for different treatments of P and water

Total root mass alone cannot adequately describe many root functions involved in plant-soil relationship. However, total root length, surface area, and branching patterns have been shown to influence nutrient uptake [13]. And estimates of root length per unit of soil are sometimes used in quantitative studies of water and nutrient uptake [14]. In this study, because the volume of the containers in which soybean were grown was same, root length could represent root density. The responses of root traits across all of P treatments to water deficit at R1 or R4 were significant. Total root length of W0 was 1.7 and 1.6-fold higher than those of W1 and W2, and 1.4- and 1.2-fold for root surface (Fig. 2). Root length of P-limiting conditions was obviously lower than that of P added application

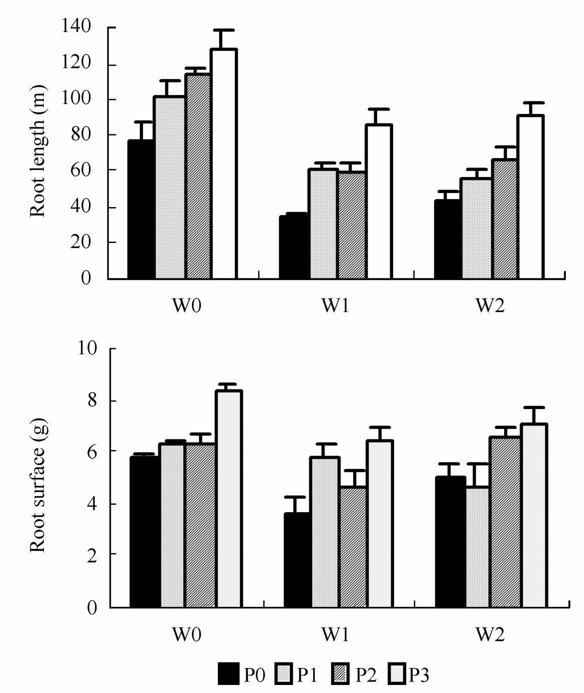

Fig. 2 Root length and surface of soybean for different treatments of P and water

whether W1 or W2 treatment. At R5 stage, root length of P3 during water stress at R1 or R4 stage was 2.50 — and 2.05 — fold, respectively, than those of P0. However, root length of P3 without water stress was just 1.67—fold higher than that of P0. Root surface was also higher when the P supply was increased(Fig. 2). Of course, many of the root characteristics, such as length, surface area, and mass, had been used to assess the quantity of roots and the functional size of the root system[3]. Root traits were important determinants of soil water extraction. High dose of P fertilizer, in our work, made root length, root surface and root dry mass greater than either no—P fertilizer or low P fertilizer treatments, which could enhance resistant capability to drought stress. This indicated that increased soybean root growth by P alleviated plant drought stress, especially in soil of low available P. Greater root surface increased the available volume of soil to be exploited, so enhanced rooting was an important mechanism for improving water—use efficiency in soybean [15].

2.2 Yield and yield components

Water stress at R1 or R4 reduced seed number and yield (Table 1). The reduction in seed number and yield was related to the amount of P application. P nutrient significantly increased seed number and yield per plant whether water stress or not. Moreover, the yield reduction by water stress at R4 was greater than that at R1 and P reduced yield loss caused by drought stress more effectively at this time. P nutrient also increased seed size significantly except water stress at R1. Generally, P application rates enhanced resistant ability of soybean to water stress at different reproductive stages by improving some morphological traits. It was worthy to mention that compared with yield loss by water stress at R4 more than R1, the root traits of water stress at R4 were similar with or even better than R1, so there would be other reasons for this phenomenon, such as root function, root activity to absorb nutrients and photosynthesis etc.

Table 1 Yield and yield components at final harvest

Treatment	Yield g/plant			Seed No. No./plant			Seed size mg/seed		
	W0	W1	W2	W0	W1	W2	W0	W1	W2
P0	5.33 b	5.24 b	2.67 c	26.7 ab	21.7 bc	14.8 b	198 ab	240 ns	180 c
P1	5.28 b	5.38 a	3.86 b	27.7 ab	21.5 c	20.8 a	191 b	249 ns	184 bc
P2	5.31 b	5.30 ab	4.06 ab	24.7 b	22.5 ab	20.8 a	213 a	236 ns	193 b
P3	6.02 a	5.50 a	4.51 a	28.5 a	23.2 a	20.4 a	210 ab	233 ns	215 a
Average	5.49	5.36	3.782	6.9	22.2	19.2	203	240	193
CV,%	6.5	2.1	20.8	6.1	3.5	15.3	5.1	3.0	8.1

* Different letters indicated significant differences ($p < 0.05$) by a LSD test

3 Conclusions

Phosphorus nutrient affected root characteristics of soybean. Compared with either the absence of fertilizer P or at low P rates, greater root mass, root length and root surface were obtained at high P application rate when water deficit occurred at R1 or R4 stage. Overall, P nutrient improved root traits to enhance the relative tolerance to water stress at two reproductive periods, reduced yield loss of soybean resulting from water stress. The results suggest that, in the region with degraded black soil with low P availability in Northeast China, where was also prone to drought stress occurring during the reproductive period, the improvement of root morphological traits by the application of an adequate amount of P fertilizer might offset the adverse effects of water deficit.

References

[1] Garg BK, Burman U, Kathju S. The influence of phosphorus nutrition on the physiological response of moth bean genotypes to drought [J]. Journal of Plant Nutrition and Soil Science, 2004, 167: 503－508.

[2] Boem FH, Thomas GW. Phosphorus nutrition affects wheat response to water deficit [J]. Agronomy Journal, 1998, 90: 166－171.

[3] Fitter AH, Graves JD, Self GK, et al. Root production, turnover and respiration under two grassland types along an altitude gradient: Influence of temperature and solar radiation [J]. Oecologia, 1998, 114: 20－30.

[4] Vamerali T, Saccomani M, Bona S, et al. A comparison of root characteristics in relation to nutrient and water stress in two maize hybrids [J]. Plant Soil, 2003, 255: 157－167.

[5] Morita S, Okuda H. Effects of soil water condition on root development of wheat seedling with special reference to branching of primary seminal root [J]. Japan Journal Crop Science, 1994, 63: 418－422 (in Japanese).

[6] Jin J, Liu XB, Wang GH. Advance in root research of soybean [*Glycine max* (L.) Merril][J]. Soybean Science, 2002, 21: 223－228.

[7] Liao H, Yan XL. Adaptive changes and genotypic variation for root architecture of common bean in response to phosphorus deficiency [J]. Acta Botanica Sinca, 2000, 42: 158－163 (in Chinese).

[8] Rodriguez D, Santa Maria GE, Pomar MC. Phosphorus deficiency affects the early development of wheat plants [J]. Crop Science, 1994, 173: 69－72.

[9] Rodriguez D, Goudriaan J. Effects of phosphorus and drought stresses on dry matter and phosphorus allocation in wheat [J]. Journal of Plant Nutrition, 1995, 18: 2501－2517.

[10] Wang, ML, Yan XL. Characteristics on root morphology and root exudation of soybean in relation to phosphorus efficiency [J]. Journal of South China Agricultural University, 2001, 22: 1－4 (in Chinese).

[11] Newman EI. A method of estimating the total root length in a sample [J]. Journal of Applied Ecology, 1966, 3: 139－145.

[12] Carley HE, Watson TW. A new gravimetric method for estimating root－surface areas [J]. Soil Science, 1966, 102: 289－291.

[13] Raper CDJ, Osmond DL, Wann M, Weeks WW. Interdependence of root and shoot activities in determining nitrogen uptake rate of roots [J]. Bot. Gaz. (Chicago). 1978, 139: 289－294.

[14] Cowan IR. Transport of water in the soil－plant－atmosphere system[J]. Journal of Applied Ecology, 1965, 2: 221－239.

[15] Hudak CM. Patterson RP. Vegetative growth analysis of soybean plant introduction [J]. Crop Science, 1995, 35: 464－471.