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Comparison of Rhizosphere Impacts of Wheat (*Triticum aestivum* L.) Genotypes Differing in Phosphorus Efficiency on Acidic and Alkaline Soils

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A glasshouse study was conducted to compare the rhizosphere characteristics of two wheat genotypes, Xiaoyan54 (XY54) and Jing411 (J411) on two soils. The results showed that supplying phosphorus (P) increased the biomass and P content of two wheat lines significantly on alkaline soil, but P fertilization altered their biomass and P content on acidic soil only slightly. XY54 decreased rhizosphere pH more significantly than J411 on Fluvo-aquic soil without P addition, but similar acidity ability was shown when P applied. On red soil, two wheat genotypes showed similar rhizosphere pH. Two wheat lines showed similar rhizoshphere phosphatase activity on alkaline soil, whereas XY54 demonstrated greater rhizoshphere phosphatase activity than J411 on acidic soil. Rhizoshphere phosphatase activities of two wheat lines on acidic soil were greater than alkaline soil. Therefore, stronger acidity on alkaline soil and greater phosphatase activity on acidic soil are principal rhizosphere mechanisms for XY54 to adapt to low-P soils.

Keywords Genotype, phosphatase activity, rhizosphere acidity, soil type, wheat

Introduction

Low soil phosphorus (P) is a major limitative factor for crop growth and yield in China, particularly for calcareous soils and acidic soils. It was estimated that about 51% of arable lands in China are deficient in available P (less than 5 mg kg^{-1}) (State Environmental Protection Administration of China 2007). Phosphorus inactivation and fixation by association with the cations of calcium (Ca) in calcareous soil and aluminum (Al) and iron (Fe) in acidic soil were the main reasons for the low bioavailability of soil P (Marschner, Solaiman, and Rengel 2005). In addition, large proportions of soil P was presented in

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forms of organic compounds (mainly phytate, inositol hexaphosphate, etc.) in some soils (Schachtman, Reid, and Ayling 1998), but they were released slowly for being strongly bound to soil particles (Turner et al. 2002). The mineralization rate of organic P depended on soil phosphatase activity of rhizosphere (Tarafdar and Claassen 1988). In agricultural production, although P fertilizer application could enhance the available P concentration in soil, the enhancement effect usually disappeared soon for rapid chemical fixation, particularly in calcareous soils and acidic soils. Furthermore, overuse of P fertilizers would not only lead to accumulation of more unavailable P in soil (Lu 2004) but also pose a great pollution threat to the quality of the surface water in the vicinity of the fields (Chambers, Gawood, and Unwin 2000; Butler and Coale 2005). Therefore, to develop methods to utilize the fixed phosphates and organic P already accumulated in soils is an efficient, sustainable avenue for conservation-orientated agriculture.

Intraspecific variations in P efficiency of many crop species have been well documented (Gahoonia, Nielsen, and Lyshede 1999; Valizadeh, Rengel, and Rate 2002), and some biochemical mechanisms in P activation and utilization have also been revealed (Marschner, Solaiman, and Rengel 2005). Selecting P-efficient genotypes and introducing them in the areas with low-P soils have received attention, and relevant studies on mechanisms performed by P-efficient genotypes were extensively conducted worldwide in the past decade. Phosphorus-efficient genotypes could increase inorganic P activation and organic P mineralization by biochemical mechanisms, such as rhizosphere acidity and improvement of rhizosphere phosphatase activity (Valizadeh, Rengel, and Rate 2002). Wheat is a principal crop in China that is widely planted nationwide. Some wheat genotypes differ in P requirements, and growth capacities had been identified (Valizadeh, Rengel, and Rate 2002; Li, Pang, and Zhang 2003; Qiu et al. 2004). Among them, Xiaoyan54 (XY54) and Jing411 (J411) are typical cultivars with contrasting P efficiency (Li, Tong, and Liu 2004). Our previous study showed that XY54's large root biomass and strong acidification ability were the main mechanisms that allowed it to acquire more P on P-deficient calcareous soil (Yan et al. 2010).

There are large areas of calcareous soil and acidic soil distribution in northern and southern China with huge variation in pH levels. However, few comparative studies have been conducted to determine the differences in growth responsiveness and rhizosphere impacts of the cultivars with contrasting P efficiency, including acidity, and phosphatase activity on alkaline and acidic soils. Furthermore, the effects of P fertilization on P-utilization mechanisms of wheat genotypes differing in P efficiency on alkaline and acidic soils were rarely investigated and little understood. In the present study, two wheat cultivars (XY54 and J411) with contrasting P efficiencies were grown in a Fluvo-aquic soil and a red soil to investigate the intraspecific differences in growth, P acquirement, rhizosphere pH, and phosphatase activity with or without P supply.

Materials and Methods

Soils and Plants

Two soils, one alkaline soil (Fluvo-aquic soil) and one acidic soil (red soil), were used in the experiment. The alkaline soil was sampled from Fengqiu (E 114.04°, N 34.03°) of Henan Province, and the acidic soil was collected from Qiyang (E 111.85°, N 26.59°), Hunan Province. Two soils were air-dried and sieved (<2 mm) for the pot experiment. The general physical and chemical properties of the soils are listed in Table 1. Two different

Table 1
Physical and chemical properties of the soils tested

Soils	pH	Total P (g/kg)	Total K (g/kg)	Total N (g/kg)	OM (g/kg)	Avail. P (mg/kg)
Fluvo-aquic soil	8.00	0.58	11.06	0.41	9.72	9.0
Red soil	4.94	0.58	9.05	0.97	15.41	30.0

wheat (*Triticum aestivum* L.) genotypes, XY54 (P-efficient) and J411 (P-inefficient), were used in this study and obtained from the Institute of Crop Sciences, Chinese Academy of Agricultural Sciences (CAAS).

Experimental Design

A three-factorial experiment was designed, including two soils, two P levels, and two wheat genotypes. Six treatments were included, and each treatment was replicated four times. Two P rates are 0 and 100 mg P (KH_2PO_4) per kg soil, and they are denoted by P0 and P1. In addition, uniform nitrogen [N, in the form of urea, $CO(NH_2)_2$, 150 mg N per kg soil] and potassium (K, in the form of potassium sulfate, K_2SO_4, 100 mg K per kg soil) fertilizer were applied to two soils as basic fertilizers. The configurations of the Plexiglass rhizobox are 20 cm × 7 cm × 20 cm (length × height × width). They were separated into three compartments separated by two-layer 25-μm nylon mesh that did not allow wheat roots to grow into the outer compartment but did allow nutrients, water, and root exudates to penetrate. Each box was packed with a total of 3 kg air-dried soil. The inner compartment was packed with 1.5 kg soil for wheat growth, and another 1.5 kg soil was packed in the outer compartments.

Wheat seeds were surface sterilized with 10% hydrogen peroxide (H_2O_2) for 20 min and geminated at 25°C for 24 h. Seeds were sown in the inner compartment of the growth box, and the wheat seedlings were thinned to 25 plants per pot after 10 days of growth. The pots were randomly arranged in a glasshouse of the Institute of Crop Sciences, CAAS. The temperature in the glasshouse ranged from 15°C to 25°C, with 8–10 h of light. Plants were irrigated with distilled water to maintain the soil water content at 80% field water capacity.

Wheat shoots and roots were harvested 50 days after seedling. The roots were carefully taken out of the soil. The soil adhered to the roots in the outer compartment was sampled, and rhizosphere soil layers were called R1 to R5 (0–5 mm from root surface, 1 mm rhizosphere soil made up a sample). In addition, soil 6 to 20 mm soil from the root surface was sampled and called R6. They were incrementally sliced by a sharp knife into 1-mm-wide sections. The sampling method was described in Yan et al. (2010). Subsamples of soil samples (fresh soil) were kept at –20 °C for soil phosphatase activity analysis, while the remaining soil was air dried for soil pH measurement.

Determination and Data Analysis

The wheat roots and shoots were dried at 65 °C for 48 h and weighed. Soil pH was determined using a deionized water solution (1:2.5 w/v, soil/water). The acid phosphatase activity of soils was examined according to the method of Hoffman as modified by Zhao

and Jiang (1986). Shoot and root P concentration was determined colorimetrically by the phosphomolybdate method. The significant differences between treatments were analyzed by the SAS software (6.12; SAS Institute, Cary, N.C.).

Results

Biomass and P Content

Wheat with high P treatment had significantly greater shoot, root, and total dry weight than low P treatment on Fluvo-aquic soil for two genotypes (Table 2). The biomass of J411 was similar or greater than XY54 on red soil, whereas biomass of XY54 was greater or similar than J411 on Fluvo-aquic soil. XY54 had greater P content than J411 on Fluvo-aquic soil, but the situation was altered on red soil. On red soil, XY54 absorbed slightly more P than J411 at low P supply, but contrary results were shown at high P supply.

Rhizosphere pH

XY54 decreased rhizosphere pH more significantly for R1 to R6 location soils than J411 on the Fluvo-aquic soil with low P addition, but XY54 showed the similar acidity as J411 at high P treatment (Table 3). On red soil, all wheat genotypes showed similar rhizosphere pH independent of soil location and P level.

Rhizoshphere Phosphatase Activity

On Fluvo-aquic soil, J411 and XY54 showed similar rhizoshphere phosphatase activity irrespectively of soil P level and rhizosphere site (Table 4). On Red soil, rhizosphere phosphatase activity of XY54 was greater than J411 independent of soil P level and rhizosphere site. Rhizoshphere phosphatase activity of Fluvo-aquic soil was greater than red soil at the $P < 0.01$ level.

Table 2
Wheat biomass and P content of XY54 and J411on Fluvo-aquic and red soil

			Biomass (g/pot)			P content (mg/pot)		
Soils	P level	Genotypes	Shoot	Root	Total	Shoot	Root	Total
Fluvo-aquic soil	P_0	XY54	8.29c	4.44bc	12.74b	0.13e	0.08a	0.21f
		J411	8.12c	3.48c	11.60b	0.12e	0.04b	0.16g
	P_1	XY54	10.49a	5.46ab	15.94a	0.31a	0.10a	0.40a
		J411	10.59a	4.99abc	15.58a	0.25b	0.08a	0.34b
Red soil	P_0	XY54	9.39b	6.57a	15.84a	0.17d	0.07ab	0.23ef
		J411	10.35a	6.38a	16.73a	0.18d	0.07ab	0.25de
	P_1	XY54	9.48b	5.73ab	15.21a	0.23bc	0.07ab	0.30bc
		J411	10.71a	5.14ab	15.96a	0.21c	0.06ab	0.28cd

Note. In the same column, the different letters following the averages indicated significantly differences between treatments at the $P < 0.05$ level.

Table 3
Rhizosphere pH values of the two wheat genotypes at two P levels on Fluvo-aquic and red soils

Soils	P level	Genotypes	Rhizosphere soils					
			R1	R2	R3	R4	R5	R6
Fluvo-aquic soil	P_0	XY54	8.23f	8.26ef	8.28def	8.27def	8.29def	8.30cdef
		J411	8.34abcd	8.38abc	8.40a	8.40a	8.40a	8.41a
	P_1	XY54	8.34abcd	8.38abc	8.41a	8.40a	8.40a	8.41a
		J411	8.31bcde	8.38abc	8.39ab	8.40a	8.39ab	8.40a
Red soil	P_0	XY54	4.79ijkl	4.77kl	4.75l	4.77jkl	4.79ijkl	4.84hijk
		J411	4.81hijkl	4.80ijkl	4.79ijkl	4.82hijkl	4.83hijkl	4.86ghij
	P_1	XY54	4.78jkl	4.80ijkl	4.81hijkl	4.86ghij	4.89gh	4.92g
		J411	4.79ijkl	4.82hijkl	4.82hijkl	4.81hijkl	4.87igh	4.92g

Note. In the same column, the different letters following the averages indicated significantly differences between treatments at the $P < 0.05$ level.

Table 4
Rhizosphere phosphatase activity of the two wheat genotypes at two P levels on Fluvo-aquic and red soils (mg phenol/kg soil)

Soils	P level	Genotypes	Rhizosphere soils					
			R1	R2	R3	R4	R5	R6
Fluvo-aquic soil	P_0	XY54	41.5j	40.5j	41.8j	39.5j	39.8j	39.3j
		J411	47.3j	41.8j	41.3j	42.0j	42.0j	40.3j
	P_1	XY54	48.8j	43.0j	47.5j	41.5j	41.0j	39.3j
		J411	45.5j	40.8j	40.5j	40.8j	41.0j	40.0j
Red soil	P_0	XY54	169.0a	143.8b	138.8bcd	144.0b	139.3bc	139.8bc
		J411	163.0a	123.8efgh	128.3defg	123.8efgh	119.0fgh	116.3h
	P_1	XY54	141.3b	137.8bcd	129.0cdef	138.3bcd	130.0cde	137.8bcd
		J411	127.0efg	117.9gh	119.0fgh	103.0i	116.0h	96.0i

Note. In the same column, the different letters following the averages indicated significantly differences between treatments at the $P < 0.05$ level.

Discussion

Two wheat genotypes could grow well in both alkaline and acidic soils, which indicated that they adapted to acidic and alkaline soils. However, two genotypes differed in rhizosphere pH reduction and phosphatase activity enhancement at low-P conditions. In addition, rhizosphere properties of two wheat genotypes were affected by P fertilization. On alkaline soil, P-efficient XY54 reduced rhizosphere pH of across a wide soil volume at low-P conditions compared with the P-inefficient J411. The results indicated that XY54 may be more efficient in activating rhizosphere-unavailable inorganic P (e.g., Ca P) than J411 for alkaline soil. In addition, greater root biomass of XY54 might facilitate soil P exploitation in low-P soil because morphological modification was a mechanisms to enhance P uptake (He, Liao, and Yan 2003). However, the situation changed when P fertilizer was applied into alkaline soil because two genotypes showed similar rhizosphere acidity ability. This suggested that two genotypes may have similar P activation ability

through rhizosphere pH reduction on alkaline soil at high soil P levels. On acidic soil, two wheat lines demonstrated no difference in rhizosphere pH reduction at two P levels, which indicated that two genotypes are unable to utilize inorganic fixed P by the pH reduction pathway. Our previous study showed that XY54's large root biomass and strong acidification ability were the main mechanisms contributing to high P uptake under P-deficient conditions on calcareous soil (Yan et al. 2010).

It was well documented that high rhizosphere phosphatase activity could increase the mineralization of organic P (Tarafdar and Claassen 1988). Irrespective of P fertilization and sampling site, XY54 showed similar rhizoshphere phosphatase activity on alkaline soil and demonstrated greater rhizoshphere phosphatase activity than J411 on acidic soil. Furthermore, rhizoshphere phosphatase activity of two wheat lines on alkaline soil was greater than on acidic soil. The data suggested that XY54 demonstrated more capacity to utilize organic P in acidic soil by increasing rhizoshphere phosphatase activity pathway. In addition, the results indicated that soil type and soil P level influenced rhizoshphere phosphatase activity of two wheat lines on acidic soil but not alkaline soil. It is well known that soils differ in organic P content and components. Therefore, it is necessary to investigate the response of J411 and XY54 to organic P components and levels. Furthermore, phosphatase activity on red soil was much greater than Fluvo-aquic soil for all wheat genotypes, which hinted that organic P activation by J411 is more effective on acidic soil than alkaline soil. It is concluded that P supply and soil type modified rhizosphere properties of two wheat genotypes. Stronger acidity on alkaline soil and greater phosphatase activity on acidic soil are principal rhizosphere mechanisms for XY54 to acquire more P in low-P soils.

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