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Genotypic differences in phosphorus efficiency of wheat

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Abstract

In an attempt to evaluate whether breeding and selection for high yielding capacity did change the P requirements of modern wheat cultivars, the response of two wheat cultivars to different levels of P supply was investigated. A traditional cultivar ("Peragis") and a modern cultivar ("Cosir") were cultivated in a C-loess low in available P and high in $CaCO_3$ in 120 cm high PVC pots. Shoot and root growth at different developmental stages was compared. The grain yield of the modern cultivar Cosir was higher at limiting and non-limiting P supply and, therefore, this cultivar can be considered as more P-efficient than the traditional cultivar. From the results it can be concluded that the main factors contributing to the higher P efficiency of the modern cultivar are (i) efficient use of assimilates for root growth characteristics which enhance P acquisition: smaller root diameter, and longer root hairs, (ii) efficient remobilization of P from vegetative plant organs to the grains, and (iii) lower P requirement for grain yield formation because of lower ear number per plant but higher grain number per ear.

Introduction

It is generally agreed and easily conceivable that for the expression of the high yielding capacity of modern wheat cultivars a higher P supply is necessary than for low yielding cultivars (Batten et al., 1984). However, concern has been expressed about the failure of such cultivars at low nutrient supply (Büchting and Elmshäuser, 1978) and the adjustment of higher available P levels in soils for high yielding cultivars has been advocated (Munk, 1976). One reason for a lower P efficiency of high yielding cultivars may be selection for less assimilate transport to the roots, a concern that was already expressed by Opitz (1904). Ruckenbauer (1969) found a decrease in root weight and root/shoot (w/w) ratio with increasing breeding intensity in wheat. The objective of the present study was to compare wheat cultivars with regard to their yield response to non-limiting and limiting P supply and their P acquisition and utilization efficiencies.

Materials and methods

Seeds of the spring wheat cultivars (*Triticum aestivum* L.) were originally supplied by FAL, Braunschweig, FRG. Among 10 cultivars Peragis I ("Peragis") and "Cosir" were selected representing tall traditional and short modern cultivars, respectively. A pot experiment was conducted in a screenhouse using 120 cm high PVC tubes covered with aluminium foil and filled with 13.8 kg of C-Loess (23% $CaCO_3$, 4.4 mg kg^{-1} Ca-acetate-lactate P,CAL-P) layerwise carefully compacted to 1.39 g cm^{-3} bulk density. P was supplied on the basis of 25 and 250% of the expected P requirement (167 and 825 mg P per pot giving 12 and 60 mg P kg^{-1}soil) as $Ca(H_2PO_4)_2$ and uniformely mixed with the soil. At the onset of the experiment CAL-P was 13 and 35 mg kg^{-1} and P concentration of the equilibrium soil solution (centrifugation) was 16 and 435 µg l^{-1}. Other nutrients were supplied as basal dressing (per pot): 1200 mg K, 200 mg Mg, 30 mg Zn, 15 mg Cu, and 2000 mg N in 4 dressings.

Soil moisture was controlled by applying deionized water to the bottom of the columns as required and to the soil surface to give tensiometer readings of pF 2.2 at 25 cm depth. Plants were seeded in early spring.. Harvests were taken at the cultivar-specific developmental stages (Zadoks et al., 1974) tillering (25), shooting (31), anthesis (61), and maturity (92). Length of soil-free washed roots was determined using the line intersection method (Tennant, 1975). P in plant tissues was determined using the molybdate-vanadate method. P uptake rate was calculated according to Williams (1948).

Results

Yield

At low P supply, yields of both cultivars were severely reduced. However, at both the non-limiting and at the limiting P supply, grain yields of the modern cultivar Cosir were higher whereas straw yields were lower than those of the cultivar Peragis (Tab. 1).

Grain yields at suboptimum P supply were reduced mainly because of lower number of ears per plant (Fig. 1)., whereas grain number per ear and grain weight were hardly affected. Clear differences in yield structure existed between the cultivars. While the traditional cultivar Peragis produced 15% more ears/pot with 10% heavier grains, it was outyielded by the modern cultivar Cosir which had 74-85% more grains per ear.

Table 1. Effect of P supply on grain and straw yields of 2 spring wheat cultivars

Cultivar	P supply [mg kg^{-1} soil]	Grain yield [g pot^{-1}]	Straw yield [g pot^{-1}]	Total yield [g pot^{-1}]
Peragis	12	27	63	90
	60	64	121	184
Cosir	12	34	44	78
	60	87	83	169

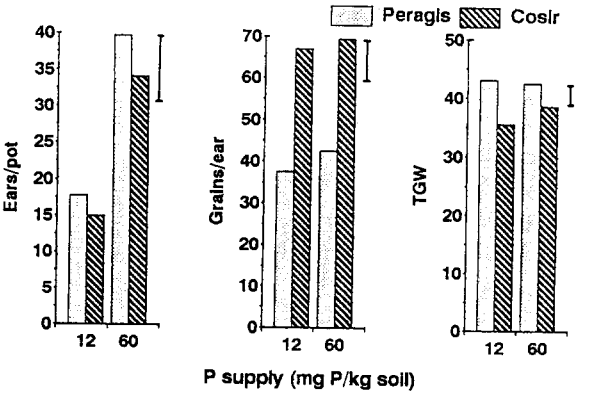

Fig. 1. Effect of P supply on yield structure of 2 spring wheat cultivars.

Root growth

At early developmental stages root growth, especially root length was hardly affected by P supply (Fig 2). There was even a tendency of increased root length of cultivar Cosir at low P supply. At anthesis, root growth of both cultivars was clearly depressed at low P supply. In

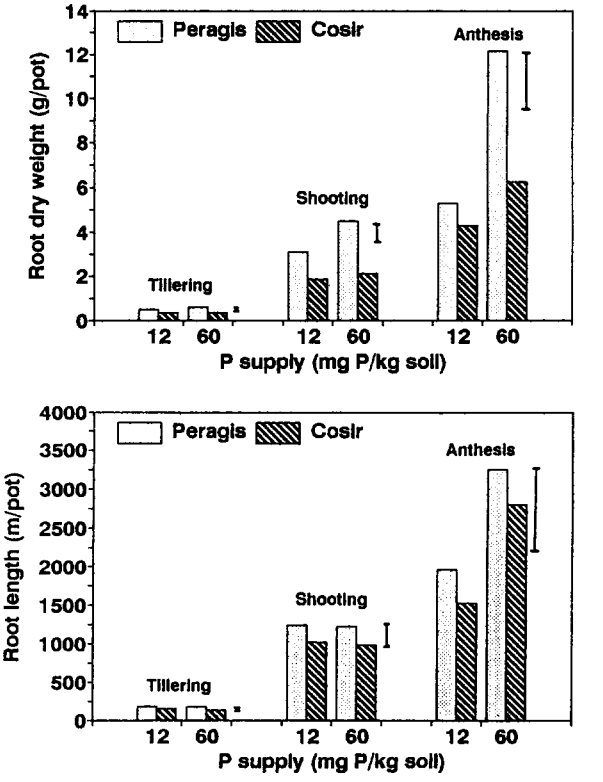

Fig. 2. Effect of P supply on root dry weight and root length of 2 spring wheat cultivars at 3 developmental stages.

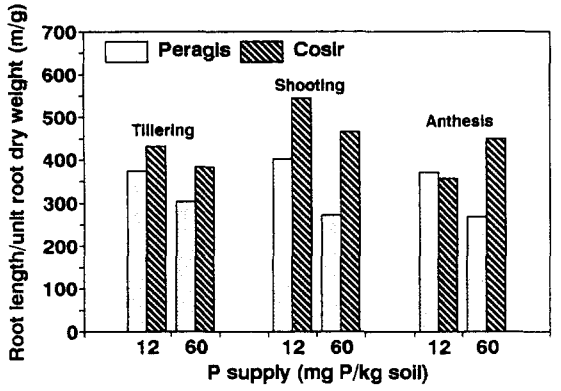

Fig. 3. Effect of P supply on specific root length of 2 spring wheat cultivars at 3 developmental stages.

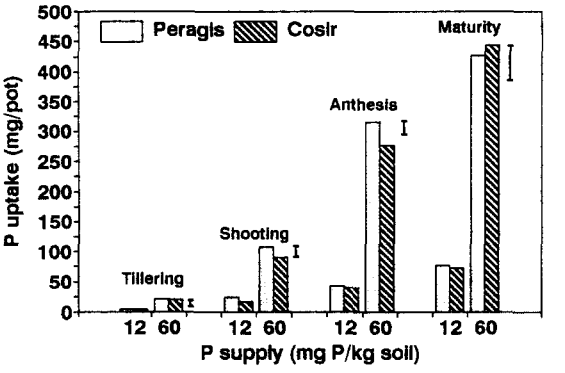

Fig. 4. Effect of P supply on cumulative P uptake (shoots) of 2 spring wheat cultivars at 4 developmental stages.

accordance with the higher shoot dry matter production, cultivar Peragis produced more root dry matter than Cosir. Differences in root length, however, were much less clearly expressed. This was due to finer roots of cultivar Cosir as can be derived from the specific root length (Fig. 3). Cultivar Cosir had longer root hairs than Peragis (not shown). Also, root-hair length tended to decrease at high P supply. The ratio of root elongation to shoot dry matter production was much higher at low P supply but comparable for both cultivars (Tab. 2).

P uptake and utilization

Total P uptake by the traditional cultivar Peragis was slightly higher, in agreement with its dry matter production (Fig.4). However, P uptake rate per unit of root length was higher for the modern cultivar Cosir at high but not at low P supply (Fig. 5). Retranslocation of P from vegetative plant organs to the grains was more efficient in Cosir (Tab.3). P utilization for total dry matter production was more efficient in Peragis, but P utilization for grain formation was more efficient in Cosir (Fig. 6).

Table 2. Ratio of root elongation to shoot growth-rate (cm mg^{-1}) at different developmental stages of 2 spring wheat cultivars as affected by P supply

Cultivar	P supply [mg P/kg^{-1} soil]	Developmental stage		
		Seeding-Tillering	Tillering-Shooting	Shooting-Anthesis
Peragis	12	14.6	5.0	1.8
	60	6.8	2.6	1.1
Cosir	12	15.7	4.6	1.6
	60	6.2	2.9	1.6

Table 3. Remobilization of P from halms and glumes between anthesis and maturity in 2 spring wheat cultivars as affected by P supply

Cultivar	P supply [mg P kg^{-1}soil]	Relative decrease of P concentration
Peragis	12	63
	60	64
Cosir	12	81
	60	73

Discussion

Grain yield reduction at suboptimum P supply was mainly due to inhibition of tillering leading to fewer ears per plant, whereas other yield components were hardly affected (Fig. 1) indicating a high P requirement for the expression of this yield component. This is in agreement with results of Sherchand and Paulsen (1985) and Römer and Schilling (1986) showing that grain yield is more affected by P nutrition before than after anthesis.

According to the agronomic definition of nutrient efficiency, the modern cultivar Cosir can be classified as more P-efficient than the

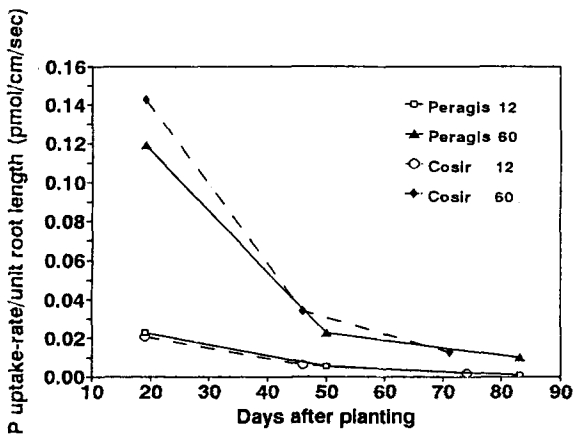

Fig. 5. Effect of P supply (12 and 60 mg kg^{-1}) on P uptake-rate of 2 spring wheat cultivars at 3 developmental stages.

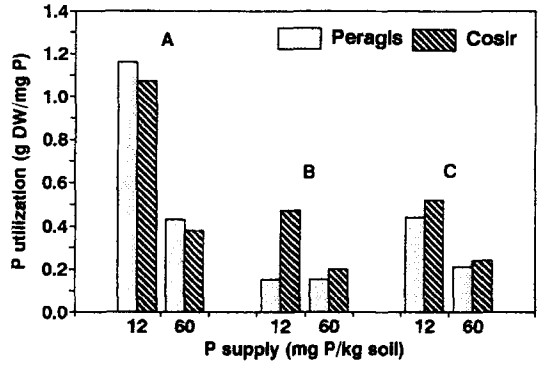

Fig. 6. Effect of P supply on P utilization efficiency at maturity of 2 spring wheat cultivars. A: Total dry weight per mg total P uptake. B: Grain dry weight per mg total P uptake. C: Grain dry weight per mg grain P.

traditional cultivar Peragis. Although the comparison of only one cultivar from each group does not allow generalization, these results support conclusions by Batten and Khan (1987) and Jones et al. (1989) that, in contrast to the suspicion expressed earlier (see Introduction), breeding for grain yield has not necessarily decreased P efficiency. These authors showed that this was mainly due to better P utilization for grain formation (higher P harvest index) a factor which was also important in this study (Fig. 6, Table 3).

The above and below-ground vegetative growth of the traditional cultivar Peragis was typically (Ruckenbauer, 1969) much more vigorous at all developmental stages (Table 1, Fig. 2). However, the modern cultivar Cosir made more-efficient use of the assimilates transported to the roots for the expression of root morphological characteristics which are decisive for efficient P acquisition from soil (Römer et al., 1991; Föhse et al., 1991) that is high specific root length, thin roots (Fig. 3) and longer root hairs. As a general adaptive mechanism to low P supply a higher ratio of root to shoot growth-rate (Föhse et al., 1988; Table 2), an absolute increase in root length at moderate P deficiency (Römer et al., 1988; Fig. 2) and an increased root-hair length (Föhse et al., 1983.) could be confirmed. However neither P remobilization and transport to the grains nor P uptake can satisfactory explain the differences in P efficiency between the cultivars. The results (and work in progress) indicate that yield structure is of foremost importance for P efficiency: cultivars with emphasis on grain number per ear as yield component are less reduced in grain yield at low P supply than cultivars more dependent on number of ears per plant.

Acknowledgements

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