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Screening Technique for Phosphorus Deficiency Stress Tolerance in Wheat Genotypes

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Abstract: Growth performance of wheat genotypes were found in close association in the two different growth media. Wheat grain and straw yields, harvest index and P use efficiency by wheat genotypes in soil were closely related to shoot and root growth and P uptake in solution culture experiment. Results concluded that wheat genotypes with larger root system performed better under P stress in both the growth media. Results also showed that similar plant genetic factors played major role in the adaptation of genotypes to P stress conditions in solution as well as in soil. The positive relationship between phosphorus physiological efficiency index (PPEI) and shoot growth provided a clue that wheat genotypes adapted to P deficiency stress were better able to tune and remobilize the absorbed P from root to straw and then grain under P stress conditions in the field. Therefore, the genotypes with greater PPEI values produced high grain yield per unit P absorbed. Negative relationship between PPEI and root growth was expected due to net translocation of photosynthates towards root.

Key Words: wheat, screening technique, phosphorus, deficiency, tolerance

Introduction

There is a controversy among the scientists about the validity and promise between the results obtained in solution culture/artificial growth medium and soil. Soil is a highly variable and complex medium with regard to phosphorus availability (Olsen and Khasawneh, 1980) which makes the selection of crop genotypes complex for low phosphorus tolerance, particularly for those genotypes better suited to artificial growth media. Moreover, detailed measurements of root characteristics are often difficult in soil (Gerloff, 1987; Mian et al., 1994). Therefore, heterogeneity and complexity of soils make the identification and study of genetically superior plant difficult (Whiteaker et al., 1976) because soil components restrict the movement of phosphorus to plants (Clarke et al., 1990; Tisdale et al., 1993). Coltman et al. (1985) compared the growth of tomato strains in sand-alumina culture and soil and reported that similar adaptive mechanisms were functional in both the media, however, some of the mechanisms involved in P uptake that differentiate lines under edaphic conditions may not occur in sand-alumina culture. Many physical, chemical and physiological processes of plant and soil are found associated with the adaptation of crop genotypes to P deficiency stress (Whiteaker et al., 1976; Lindgren et al., 1977; Vase, 1990; Fohse et al., 1991; Gahoonia and Nielsen, 1996).

In order to verify the validity of the results obtained in solution culture and soil under field conditions, the experimental data of nutrient solution and soil were compared. The main objective was to standardize the screening technique.

Materials and Methods

Seeds of fifteen wheat genotypes were sown in iron trays. Two week old seedlings were transplanted into the foam plugged holes in the thermopal sheets, floating on modified half strength Johnson's nutrient solution, contained in 200 L capacity tubs. Two seedlings per hole were repeated four times in completely randomized design. Two levels of phosphorus (P) were developed by adding powdered phosphate rock (at 100 g 200 L⁻¹ (deficient P level) and NH₄H₂PO₄ equal to 250 μ MP (adequate P level). Contents of each tub were stirred daily. Crop was raised for four weeks. At harvesting plants of each genotype were separated into roots and shoots for dry weight.

Same wheat genotypes were grown under field conditions of Soil Science research area at control (8 mg kg⁻¹ soil) and adequate (120 kg P_2O_5 ha⁻¹) P levels. Experiment was raised according to split plot design by placing P levels in the main plots and genotypes in the sub plots. Each treatment was repeated four

times. Recommended doses of nitrogen and potassium were also added. At harvesting, straw and grain yields were recorded. Dried plant material was digested in tri-acid mixture of HNO_3 , $HCIO_4$ and H_2SO_4 mixed in 2:1:1 ratio. The extract was used for P determination on spectrophotometer (Chapman and Partt, 1961). Results were statistically analyzed (Steel and Torrie, 1980). The estimates of genotypic and phenotypic correlation were calculated according to Kwon and Torrie (1964) and comparisons were made among the growth and phosphorus related parameters.

Results and Discussion

The correlation between grain yield in the field experiment and shoot dry matter yield in solution culture was negative and significant both at genotypic (-0.3682*) and phenotypic (-0.1428) levels. This type of relationship showed that grain yield was inversely related to shoot growth. However, high value of genetic than phenotypic correlation coefficient, indicated strong expression of plant genetic factors under different set of growth and environmental conditions (Table 1-5). The significantly positive and relatively higher value of genotypic correlation (0.3476*) suggested that root played an important role in phosphorus stress conditions. Results showed increased root growth in response to P deficiency stress (Table 1-4). Larger root growth in turn favoured the increase in P uptake and grain

Table 1: Highest and lowest dry matter weights, P concentration and P content for 15 wheat genotypes grown with rock-P and adequate levels of phosphorus

| Plant | P levels | | | |
|----------------------|-----------------------------|---------------------|--|--|
| part | | | | |
| | 250 µM Avg. (Range) | Rock-P Avg. (Range) | | |
| Dry matter | (g 2 plant ⁻¹) | | | |
| Shoot | 2.45 (1.75 - 3.59) | 1.74 (0.96 - 2.30) | | |
| Root | 0.28 (0.19 - 0.41) | 0.31 (0.14 - 0.46) | | |
| Total | 2.73 (1.97 - 4.00) | 2.05 (1.10 - 2.70) | | |
| (shoot + root) | | | | |
| Root:shoot ratio | 0.13 (0.08 - 0.17) | 0.20 (0.14 - 0.28) | | |
| P Concentration | (mg g ⁻¹) | | | |
| Shoot | 4.70 (3.09 - 6.22) | 2.49 (2.00 - 3.06) | | |
| Root | 4.92 (3.04 - 6.53) | 6.37 (4.02 - 9.76) | | |
| P content | (mg 2 plant ⁻¹) | | | |
| Shoot | 11.55 (7.17 - 20.49) | 4.38 (2.29 - 6.44) | | |
| Root | 1.38 (0.88 - 2.07) | 1.99 (0.90 - 4.27) | | |
| Total (shoot + root) | 12.92 (8.77 - 21.84) | 6.37 (3.19 - 8.60) | | |

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| Plant | P levels | | |
|---|-----------------------|----------------------|--|
| part | | | |
| | 250 µM Avg. (Range) | Rock-P Avg. (Range) | |
| Phosphorus | 0.56 (0.32 - 0.95) | 0.78 (0.41 - 1.17) | |
| utilization index | | | |
| in shoot (g ² mg ⁻¹ | P) | | |
| Phosphorus | 0.88 (0.79 - 0.94) | 0.67 (0.50 - 0.80) | |
| harvest index | | | |
| Phosphorus | 0.23 (0.16 - 0.38) | 0.45 (0.34 - 0.62) | |
| efficiency ratio | | | |
| (g shoot dry | | | |
| matter mg ⁻¹ P) | | | |
| Root efficiency | 45.35 (22.72 - 78.15) | 15.75 (9.68 - 23.57) | |
| ratio (mg shoot | | | |
| $P g^{-1}$ root dry we | eight) | | |

Table 2: Highest and lowest phosphorus efficiency related parameters for 15 wheat genotypes grown with rock-P and adequate levels of phosphorus

yield. The significantly positive correlation between straw yield in the field experiment and shoot growth in solution culture experiment showed an coherent agreement among the wheat genotypes for plant growth between the two different growth media and environmental conditions. Many times high value of genotypic correlation (0.0871*) than phenotypic correlation (0.0038) suggested that inherited plant characteristics were responsible for the adaptation of wheat genotype to P stress environment (Table 5). A strong positive genotypic correlation (0.6363*) between these two plant growth parameters in soil and solution culture indicated that most of the genotypes adapted to P stress conditions by increasing their root growth, which in turn increased the above ground plant growth by exploring more volume of soil for the absorption of phosphorus. The estimated variability attributed to straw yield was about 43 percent. Harvest index in the field experiment was found significantly and

negatively correlated with shoot growth in solution culture experiment at genotypic and phenotypic levels. Since harvest index decreased with the increase in biological yield, therefore this

Table 3: Highest and lowest yields, P concentrations and P contents of 15 wheat genotypes grown with control and adequate levels of phosphorus

| Plant part | P levels | | Phosphorus stress | |
|-----------------------------|--|-------------------------|----------------------|--|
| factor | | | | |
| | 120 kg P₂O₅ ha ⁻¹ Avg. (Range) | Control Avg. (Range) | | |
| Yield | | (kg ha ^{−1}) | | |
| Grain | 3752 (2915 - 4753) | 3474 (2636 - 4455) | 6.69 (-4.19 - 32.26) | |
| Straw | 7800 (6664 - 9017) | 6952 (6186 - 8022) | 9.85 (-7.37 - 22.62) | |
| P Concentration | | (mg g ⁻¹) | | |
| Grain | 3.18 (2.70 - 3.99) | 2.91 (2.47 - 3.27) | | |
| Straw | 0.25 (0.18 - 0.39) | 0.21 (0.15 - 0.31) | | |
| P content | | (kg ha ^{−1}) | | |
| Grain | 11.93 (8.34 - 17.22) | 10.00 (5.47 - 12.69) | | |
| Straw | 2.01 (1.25 - 3.53) | 1.48 (0.96 - 2.44) | | |
| Whole plant (Grain + Straw) | 13.93 (10.50 - 20.17) | 11.61 (8.43 - 14.05) | | |

Table 4: Highest and lowest phosphorus efficiency related parameters for 15 wheat genotypes grown with control and adequate levels of phosphorus

| Parameter | P levels | | |
|---|--------------------|-------------------------|--|
| | | Control Avg. (Range) | |
| Harvest Index | 0.32 (0.28 - 0.37) | 0.33 (0.26 - 0.38) | |
| Phosphorus harvest index | 0.85 (0.78 - 0.92) | 0.87 (0.82 - 0.92) | |
| Phosphorus efficiency ratio (kg grain g^{-1} P absorbed in grain) | 0.32 (0.26 - 0.38) | 0.35 (0.31 - 0.42) | |
| Phosphorus physiological efficiency index (kg grain g ⁻¹ P absorbed) | 0.28 (0.21 - 0.33) | 0.30 (0.27 - 0.38) | |
| Phosphorus physiological efficiency index (kg straw g^{-1} P absorbed) | 0.58 (0.40 - 0.71) | 0.63 (0.49 - 0.82) | |

Table 5: Genotypic and phenotypic correlation coefficients between grain yield and other P uptake parameters at phosphorus stress level in solution culture and soil under field conditions

| Plant parameters in siol | | Plant parameters in solution culture | | | |
|--------------------------|---|--------------------------------------|-----------------|----------------|----------------|
| | | Shoot dry matter | Root dry matter | Shoot P uptake | Total P uptake |
| Grain P uptake | G | -0.3682* | 0.3476* | -0.2850* | -0.1070* |
| | Р | -0.1428 | 0.2373 | -0.1180 | 0.0117 |
| Staw P uptake | G | 0.0871* | 0.6563* | -0.1050* | 0.0594* |
| | Р | 0.0038 | 0.3197* | -0.0730 | 0.0050 |
| Harvest index | G | -0.4100* | -0.0060 | -0.2440 | -0.1370 |
| | Р | -0.1367 | 0.0624 | -0.0880 | 0.0021 |
| grain PPEI | G | 0.2942 | -0.0730 | 0.3847 | 0.4472 |
| | Р | 0.0704 | -0.0900 | 0.1067 | 0.1336 |
| Staw PPEI | G | 0.4848 | 0.0528 | 0.3813 | 0.3109 |
| | Р | 0.1274 | -0.0620 | 0.1055 | 0.04226 |

relationship held true because increase in biomass is expected in solution culture experiment where nutrients are easily accessible to plant roots. The genotypic correlation between harvest index and root growth was negative and nonsignificant. This indicated minimum role of root growth in the harvest index. However, its positive relationship with grain and straw yields revealed increase in yield with the increase in root growth.

Phosphorus efficiency parameter i.e. Phosphorus Physiological Efficiency Index (PPEI) in grain and straw from field experiment had positive relationship with shoot growth in solution culture. The relationship also confirmed the validity of the results obtained from soil experiment and solution culture experiment because high PPEI is expected under phosphorus stress conditions. The genotypic correlation between grain PPEI in the field experiment and root growth in solution culture was negative while it was positive between straw PPEI and root growth.

Relatively high genotypic than phenotypic correlations indicated close agreement between growth parameters in soil under field conditions and in solution culture. It means that similar genetic mechanisms were operating in both the growth media. Genotypic relationship also indicated genetic purity and role of plant genetic factors in the adaptation of wheat genotypes to phosphorus stress condition. Coltman et al. (1982, 1985) and Yan et al. (1996) also reported close agreement of plant growth between two contrasting growth media and environment conditions. Growth parameters in soil experiment i.e. grain and straw yields were found strongly related to growth parameters (shoot and root) in the solution culture experiment. This relationship suggested that the genotypes with larger root dry matter weight in solution culture had high grain, straw and total (grain + straw) yields in the P deficient soil under field conditions. The larger root system helps to explore more volume of soil for P acquisition and absorption (Vase, 1990; Clark, 1990; Fohse et al., 1991; Gahoonia and Nielsen, 1996). Mian et al. (1994) reported that wheat genotypes producing larger roots in solution culture also produced larger roots under field conditions.

Phosphorus use efficiency measured by phosphorus physiological efficiency index (kg of grain or straw g^{-1} of P absorbed in the above growth plant parts) identified in soil experiment was found associated with shoot and root growth and shoot P uptake in the solution culture experiment. Increase in shoot and root growth was associated with increased P uptake. Similarly grain yield was also found associated with increased P uptake in phosphorus deficient soil. However, variation in the extent of P uptake in both the media indicated that different mechanisms were involved and these mechanisms in soil are not fully understood (Vase, 1990). Coltman et al. (1985) observed similar results in tomato strains. Results on genotypic correlation showed that genetic variation in solution was closely associated with that in soil under field conditions. These also indicated that genetic variation existed among the wheat genotypes and plant genetic factors played important role in the adaptation of P efficient wheat genotypes to P stress environment.

It is also obvious from the results on P use efficiency in both the media that the wheat genotypes exhibiting efficient use of P in solution culture experiment, also behaved similarly in soil. Wheat genotypes Inq-91, Pak-81, 4943 and 4072 utilized phosphorus efficiently from both the media and produced high yield per unit of P absorbed.

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