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Larger root system increases water – nitrogen uptake and grain yield in bread wheat

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ABSTRACT

The effect of root biomass on water – nitrogen (N) absorption, drainage, and grain yield was investigated in bread wheat 'Pavon 76' and its 3 1RS translocation lines, namely 1RS.1AL, 1RS.1BL, and 1RS. 1DL. These four isolines were grown at optimum (ON) and low (LN) levels of N solution in a sand-tube experiment in a glasshouse. The translocation lines had larger root biomass than Pavon 76 which confirmed previous studies. Root biomass per plant ranged from 1.563 to 2.566 g in LN and from 2,081 to 3.201 g in ON. Regression of N content in whole plant, in roots, in stems and leaves, and in grain; and grain yield on root biomass across genotypes and N levels was significant. For an increase of 1 g in root biomass per plant, solution uptake increased by 39 ml per day in five consecutive days during early grain filling period. Similarly, N content increased in whole plant by 148 mg, in roots by 8.6 mg, in stems and leaves by 44.0 mg, in grain by 95.4 mg; and grain yield increased by 3.1 g. In contrast, the amount of leachate during the same period was reduced by 32.4 ml per day and the amount of N in leachate was reduced, by 17.5 mg L^{-1} in LN and by 13.0 mg L^{-1} in ON. These results indicate that a larger root system in wheat may increase grain yield and grain protein content while reducing residual N in drain water, thus decreasing N pollution and increasing sustainability.

INTRODUCTION

Chemical fertilizers have had a substantial impact on food production in the past, and are today an indispensable part of modern agricultural practices. Nitrogen fertilizer is the most expensive and important nutrient to raise crop plants. The N-use efficiency (NUE, the ratio of grain N yield to supplied N) of wheats grown in California is about 51% (Ehdaie and Waines, 2001). The loss of supplied N fertilizer results from surface runoff, leaching, soil denitrification, volatilization, and gaseous plant emission. Thus, the use of high N input results in nitrate pollution of underground water and atmosphere, and in economic loss to farmers.

We identified wheat-rye translocation lines 1RS.1AL, 1RS.1BL, and 1RS.1DL in the genetic background of spring bread wheat cultivar Pavon 76 that increase root biomass by 29.6, 11.0, and 25.9%, respectively, without depressing shoot biomass or grain yield (Ehdaie et al., 2003). The main objectives of this study were to test the hypothesis that 1) increased root biomass will improve N uptake and reduce rates of N fertilizer input and 2) improved N uptake will reduce N content in leachate and thus soil residual N.

MATERIALS AND METHODS

Spring bread wheat Pavon 76 and its 1RS translocation lines (Lukaszewski, 1993), namely 1RS.1AL, 1RS.1BL, and 1RS.1DL were grown at optimum level (OL) and low level (LN) of N solution in a sand-tube experiment in a glasshouse at the University of California, Riverside, using a randomized complete block design with four replications (blocks). Seeds from each genotype were soaked in water for 24 hrs and germinated in Petri dishes on 10 March 2006. Five days later, seedlings with similar growth were transplanted in polyethylene tubing bags sleeved into polyvinyl chloride (PVC) tubes, 80 cm long and 10 cm in diameter. Two drainage holes made at the bottom of each bag were covered with a filter paper before being filled with 7.750 kg of dry silica sand # 30 with 24% field capacity (w/w). Each bag was well-irrigated with half-strength Hoagland solution provided in the glasshouse before transplantation and this solution was used during the experiment to irrigate tubes under the optimum level of N. This nutrient solution was diluted with tap water in the ratio of 1:1 to provide nutrient solution to irrigate tubes under the low level of N. The low N treatment was initiated after seedlings were grown under ON for 25 days. The amount of nutrient solution used for irrigation was recorded and samples of nutrient solution and tap water were taken regularly during the experiment to determine N content. During early grain filling (about 10 days after anthesis), leachate was collected for 5 consecutive days from each tube, measured, and samples were taken for N content. Each plant received 25 l of nutrient solution which supplied 2400 mg N to each plant in ON and 1500 mg N to each plant in LN. At maturity, the shoots were excised at the shoot/root interface. Shoot materials including stems, leaves and spikes were dried in a forced-air drier for 24 h at 80°C, and weighed. Grain yield per plant was determined. Each polyethylene bag was pulled from the PVC tube and was laid out on a screen frame in a tub half-filled with water and cut lengthwise without damaging the roots. The frame was moved gently in the tub to separate sand from the roots. Intact roots were floated to the water surface and washed by hand to remove attached sand. Washed roots were dried on a paper towel for a few days in the glasshouse before being put in a forced-air drier for 24 h at 80°C, and weighed. Stems, leaves, and chaff of each plant were chopped in small pieces together and were ground with a Wiley mill using a 0.4 mm screen for determination of N content. Similarly, grains and roots were ground. Nitrogen content in tap water was analysed at UC Riverside and N content in plant samples and leachate was analysed at ANR Analytical Laboratory at UC Davis. The data were subjected to regression analysis (Draper and Smith, 1981).

RESULTS

Root biomass in the translocation lines 1RS.1AL, 1RS.1BL, and 1RS.1DL was greater than that of Pavon 76 by 34, 35, and 64% under LN and by 54, 35, and 64% under ON, respectively. These observations confirm our earlier observations (Ehdaie et al., 2003; Ehdaie and Waines, 2006). Root biomass per plant ranged from 1.563 to 2.566 g in LN and from 2.081 to 3.201 g in ON (see Fig. 1, horizontal axis). Regression analysis of N content in whole plant, in roots, in stems, leaves, and chaff, and in grain; and grain yield on root biomass across genotypes and N levels was either significant or highly significant. Regression of nutrient solution uptake (Fig. 1) indicated that for an increase of 1 g in root biomass per plant, solution uptake increased by 39 ml per day during five consecutive days during early grain filling period.

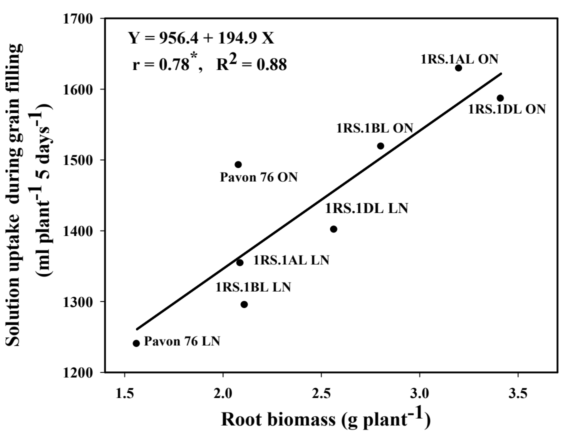

Fig.1. Relationship between the amount of nutrient solution uptake in five consecutive days during early grain filling and root biomass per plant for spring bread wheat Pavon 76 and its 1RS translocation lines grown in low level and optimum level of N.

Similarly, N content in whole plant increased by 148 mg (Fig. 2), in roots by 8.6 mg, in stems, leaves, and chaff by 44.0 mg, in grain by 95.3 mg (Fig. 3); and grain yield per plant increased by 3.1 g. (Fig. 4). In contrast, 1 g increase in root biomass reduced the amount of leachate during the same period by 32.4 ml per day (Fig. 5) and the amount of N in leachate was reduced by 17.5 mg L^{-1} in LN (Fig. 6) and by 13.0 mg L^{-1} in ON (Fig. 7).

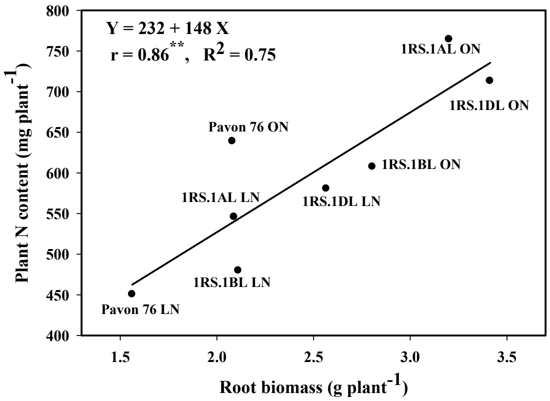

Fig.2. Relationship between plant N content and root biomass per plant for spring bread wheat Pavon 76 and its 1RS translocation lines in low level and optimum level of N.

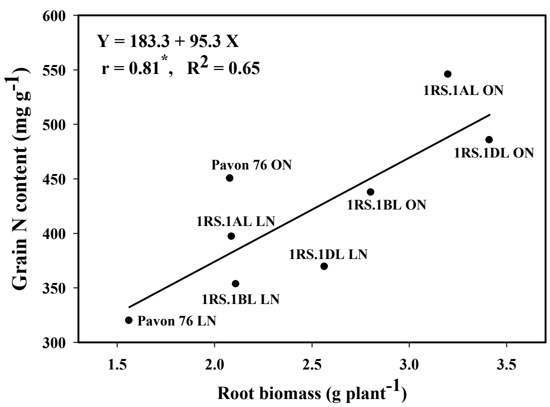

Fig.3. Relationship between grain N content and root biomass per plant for spring bread wheat Pavon 76 and its 1RS translocation lines in low level and optimum level of N.

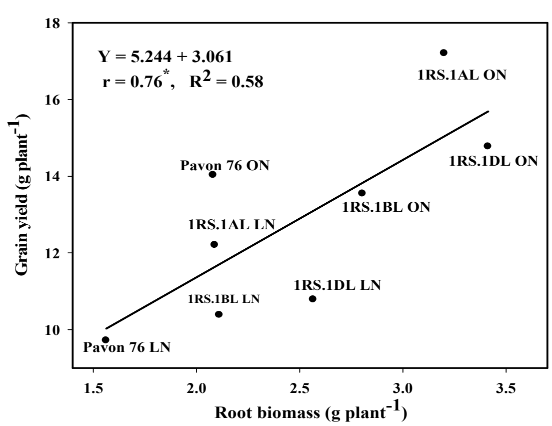

Fig.4. Relationship between grain yield per plant and root biomass per plant for spring bread wheat Pavon 76 and its 1RS translocation lines in low level and optimum level of N.

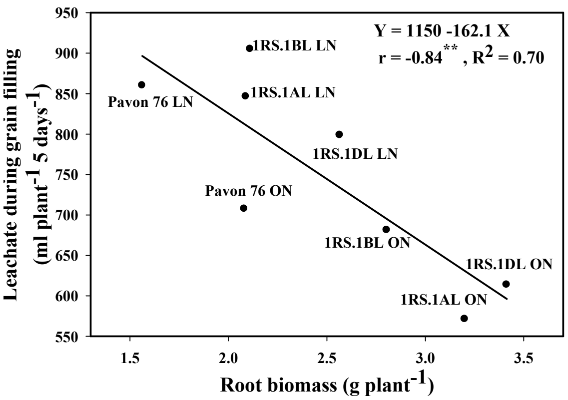

Fig.5. Relationship between the amount of leachate collected in five consecutive days during early grain filling and root biomass per plant for spring bread wheat Pavon 76 and its 1RS translocation lines grown in low level and optimum level of N.

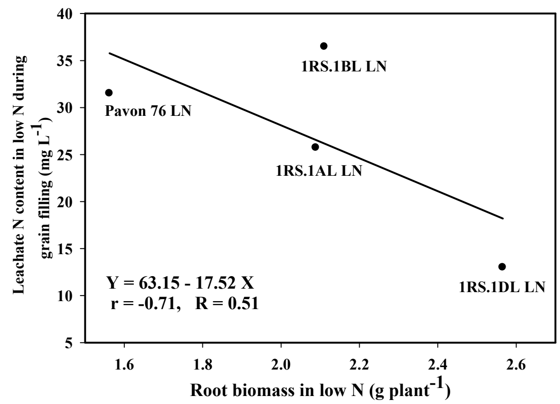

Fig. 6. Relationship between the amount of N in leachate and root biomass per plant during early grain filling for spring bread wheat Pavon 76 and its 1RS translocation lines in low level of N.

CONCLUSIONS

1- The Pavon 1RS translocation lines had larger root biomass than Pavon 76 bread wheat.

2- Trend analysis indicated lines with larger root biomass absorbed more water – nitrogen solution.

3- As root biomass per plant increased, N content in the plant and in the grain increased as well as grain yield; but the amount of leachate and leachate N content and concentration decreased.

4- The root size of Pavon 76 bread wheat and other CIMMYT-derived wheats with similar small root systems, may not be large enough for maximum N absorption and grain yield.

IMPLICATIONS

Increased N absorption and mobilization due to greater root biomass in wheat may result in:

1- increased grain yield and grain protein content,

2- reduced application of N,

3- less N leaching into ground water and air, thus decreasing N pollution, and

4- improved N sustainability.

ACKNOWLEDGEMENT

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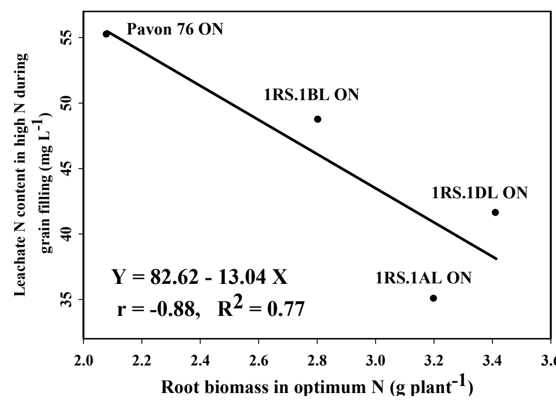

Fig. 7. Relationship between the amount of N in leachate and root biomass per plant during early grain filling for spring bread wheat Pavon 76 and its 1RS translocation lines in optimum level of N.

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