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Analysis of maize root traits in response to low nitrogen

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ABSTRACT

Abiotic stress such as low nitrogen content present in the soil is responsible for reduced yields throughout the world. Plant breeders aim to develop plants that can adapt to such environments. There is a need for more efficient root systems tolerant to an array of abiotic stresses. The objective of this study was to assess the root systems of 10 maize intermated B73-Mo17 (IBM) genotypes and their parents B73 and Mo17 for their growth and morphology and their response to low nitrogen. The aim was to test the hypothesis that published QTL regions related to root traits and nitrogen use efficiency could be used to select recombinant inbred lines (RILs) that would differ in their response to nitrogen stress based on which parental background predominated at these QTL regions. Ten IBM genotypes from the published Maize Genome Database were evaluated in this study along with their parents B73 and Mo17. Five IBM genotypes were chosen that carry predominantly B73 alleles at five quantitative trait loci (QTL) regions associated with root traits and nitrogen use efficiency and five genotypes were chosen that carried predominantly Mo17 alleles in these regions. Plants were grown in Guterman Green House of Cornell University, USA. Two nitrogen treatments (low and high) were given to note the effect of different nitrogen levels. Plants were grown and nitrogen stress symptoms were observed over time. Various root traits like root length, branching, adventitious roots, lateral roots, primary root length, and root dry weight were observed. Results showed that nitrogen treatment variation was significant for all traits measured except root length and numbers of adventitious, lateral, and primary roots. Genotype by nitrogen treatment interaction was significant for root dry weight. At high nitrogen, IBM189 showed the highest value of root dry weight and IBM337 had the lowest value. Based on the root dry weight under low nitrogen condition, the genotypes were classified into three categories: susceptible, moderate and resistant. Significant groupings from the most susceptible to most resistant were: Mo17, IBM337, IBM189, IBM248, IBM280=IBM153, IBM055=B73, IBM346, IBM284, IBM236, IBM056. A relationship between root length and nitrogen stress resistance was not found in this study. Genotype with high in B73 composition had relative advantage over Mo17 in dry weight of roots under low nitrogen condition. It is relatively difficult to measure the effect of nitrogen levels on various root traits.

Key words: IBM population, Nitrogen use efficiency, Root growth, Root dry weight, *Zea mays* L.

INTRODUCTION

Low fertility is reported to be one of the major causes of maize yield loss in the tropics [6]. Two basic approaches can be taken to obtain sustainable maize yield in areas with low nitrogen fertility. First, innovative agronomic practices can be developed to make better use of nitrogen from organic matter and nitrogen inputs from biological fixation and atmospheric deposition. The second approach would be to lower crop demand for nitrogen through breeding [17]. This approach could help address productivity limitations in nitrogen-poor areas, and may help

reduce reliance on synthetic nitrogen fertilizers. Breeding for high productivity under low nitrogen conditions will enable the cultivars to fit into the environments instead of altering the environment by adding more chemicals [3].
One strategy for improving the productivity of maize under suboptimal N fertility is to use the second approach of selecting for low N tolerance. The low N tolerant cultivars are superior in the utilization of available N, either due to enhanced uptake capacity or because of more efficient use of absorbed N in grain production [11]. N-use efficiency (NUE) is defined as grain production per unit of N available in the soil [14]. There are two primary components of NUE, the efficiency of absorption (uptake) and the efficiency with which the N absorbed is utilized to produce grain. Efficiency in uptake and utilization of N in the production of grain requires that those processes associated with absorption, translocation, assimilation, and redistribution of N operate effectively [14]. The relative contributions of these processes to genotypic differences in NUE vary among genetic populations and among environments. Past progress in selecting genotypes for NUE has been limited because of the complexity of the genetic network regulating plant N metabolism [15].

Among the morphological traits associated with the adaptation to N- depleted soils, the qualitative and quantitative importance of the root system in taking up N under N-limiting conditions has been pointed out in several studies [4, 9]. N enters through the root of the maize plant and rooting pattern and branching influence N uptake from the soil solution. Agricultural production in the twenty-first century is predicted to be more limited because of lower availability and increased cost of water and nutrient resources [13]. This emphasizes the need and urgency in improving the root system so that plants are better able to capture the essential resources more efficiently. N fertilization increases root length and root surface area and decreases root mass per unit length [5]. Pot experiments with maize have shown that maize roots are thinner and longer in ammonium rich zones [19]. It would be necessary to look into the system and genetic control of N uptake at different levels of N fertilization through the activity of different components of the N transport system in relation to root architecture [20]. So, in simple terms, selecting genotypes for better growth under low N levels and improving the root architecture for more efficient uptake of the nutrients present in the soil would open the door for the path of food-sufficiency and sustainability of agriculture.
Here, ten maize (IBM) inbred lines and their parents B73 and Mo17 were used to better understand the relationship between root system traits and nitrogen use efficiency.

MATERIALS AND METHODS

Root length

Root length of each plant was determined. The length from the base of the shoot to the tip of the longest root was measured and expressed in cm.

Number of root branches

Number of root branches was determined by counting the root branches from the base of the plant and expressed in numbers.

Adventitious roots

Adventitious roots originate from the stem, branches, leaves, or old woody roots. They commonly occur in monocots and pteridophytes. Adventitious roots of the plants were counted and the thickness was observed.

Lateral branching of roots

Root lateral branches which were attached to the primary root were counted on each plant.

Primary root length

The first root produced by a germinating seed, developing from the radical of the embryo, is known as the primary root. Primary root length was measured from the end point of the seed to the tip of the root and expressed in cm.

Root density

Root density was observed and rated using three categories – high, medium and low.

Root distribution

Root distribution was measured by dividing the root system into two parts and measuring the upper root length and lower root length.

Dry weight

Plants were separated into leaves, stems, and roots and dry weights of each part were measured after drying them in the oven for five days at 60ºC.

RESULTS

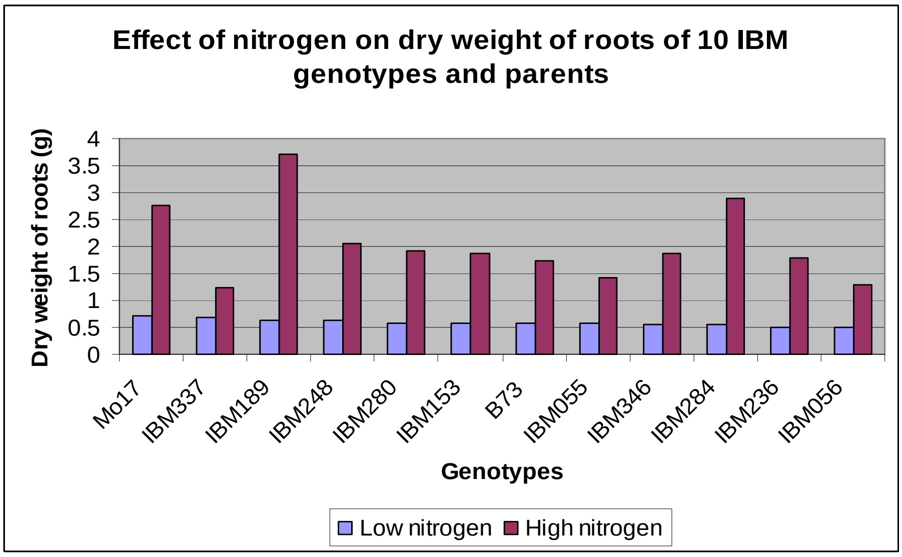
Nitrogen treatments did not have any significant effect on the root variables measured except for root branching and dry weight of roots (Table 1). N treatment X genotype interaction was significant for dry weight of roots (Table 1). Root branches were affected by different N treatments. Under low N branching was reduced. Genotype IBM189 (10 nos.) showed to have high branching under high N condition and under low N IBM055 and IBM337 had high root branches (7 nos.) (Table 2). Dry weight of roots was higher at high N (Figure 1). No significant genotype or genotype x N treatment interactions were observed for root traits except for dry weight of roots. The root length of the plants might have been restricted because of pot size since maize plants usually respond to low nitrogen by increasing root length [2]. Total soil depth of the pot was 23 cm and the IBM189 RIL had a deeper root system at low N, whereas root distribution of all the other genotypes was in the upper half of the soil profile.

Table 1: Sums of Squares from Analysis of Variance for root traits

Source	DF	Root Length	Branching	Adventitious Roots	Lateral Roots	Primary Roots	Dry Weight of Roots
Replication	4	1298	24	32	8	942	1.0
N Treatment	1	194	168**	63	2	103	63.5**
N x Rep (Error a)	4	319	27	37	12	325	1.4
Genotype	11	242	56	49	36	309	15.7**
Genotype x N	11	171	50	49	22	267	14.0**
Error b	88	1221	326	384	146	1725	19.5

*** Significant at P<0.05.*

Figure 1: Effect of N treatment on dry weight of roots for 12 maize inbreds evaluated at low and high N in five replications in the greenhouse.



At both low and high N, dry weight of roots was higher for Mo17 than for B73. Nonetheless, the IBM RILs with high B73 at the target QTL regions had higher dry root weight under low N conditions (0.60 g) compared to genotypes with high Mo17 (0.55 g). Maize inbred IBM236 grown under high N shows less root growth compared to shoot growth.

High N increased root dry weight in all the genotypes with highest root dry weight observed in IBM189 (Figure 2). IBM337 (Figure 2) had the lowest root dry weight in high N, yet had among the highest root dry weight in low N.

Table 2: Mean performance of root traits of genotypes with high B73 and Mo17 under low nitrogen

Genotypes	Root length (cm)	Branching (Number 1-9)	No. of Adventitious Roots	No. of Lateral Roots	Primary Root Length (cm)	Dry weight of roots (g)
IBM055	21.3	7	5	4	17.4	0.57
IBM056	20.1	5	2	5	17.8	0.49
IBM153	17.1	5	3	3	17	0.59
IBM189	23.9	6	4	3	21.3	0.64
IBM236	21.4	4	4	5	19.8	0.50
IBM248	19.7	6	2	4	15.9	0.62
IBM280	20.7	5	2	3	19.4	0.59
IBM284	20.5	6	5	4	18.1	0.54
IBM337	21.4	7	3	4	20.6	0.68
IBM346	22.2	5	3	4	21.6	0.55
B73	20.7	6	1	4	16.9	0.57
Mo17	19.6	5	3	4	21.1	0.72

Figure 2: Maize genotype IBM189 (left) and IBM337 (right) grown under low nitrogen condition

Finally, based on the root dry weight under low nitrogen condition, the genotypes were classified into three categories: susceptible, moderate and resistant. Significant groupings from the most susceptible to most resistant were: Mo17, IBM337, IBM189, IBM248, IBM280=IBM153, IBM055=B73, IBM346, IBM284, IBM236, IBM056. Also grouping was done based on the root dry weight under the high N treatment in order to compare the genotypic performance under two different N levels. Significant groupings from the most susceptible to most resistant under high N condition were: IBM337, IBM056, IBM055, B73, IBM236, IBM153 = IBM346, IBM280, IBM248, Mo17, IBM248, IBM189.

DISCUSSION

In the present study, attempts were made to pre-select IBM families based on their genetic constitution at five target regions identified in previous QTL studies as associated with root traits and NUE, and thus identify inbreds with better NUE and understand the relationship between maize root systems and NUE. The genetic variability for response to low and high N treatments among 10 maize IBM RILs and their parental inbreds B73 and Mo17 were determined using morphological and physiological traits [root length, number of root branches, adventitious roots, lateral branching of roots, primary root length, root density, root distribution and dry weight of roots.

There are conflicting results concerning whether or not a low N level will lead to an increase [7] or decrease [16, 18] in lateral root growth. Chun *et al*. [2] reported that increased N treatment in maize increased total root length and total lateral root length, but with a reduction in the number of axial roots. The present study showed no significant effect of N treatment on primary root length or number of lateral roots. Root branching was significantly affected by N treatments, with high N application increasing the number of root branches, which is also reported by Eghball *et al*. [8].

Chun *et al*. [2] reported that low N reduced root biomass in all the genotypes tested, which is in accordance with our results showing reduced root dry weight at low N. The absolute amount of roots is usually less for plants grown under low N conditions than under normal soil containing sufficient N [1], a pattern that is clearly confirmed by root dry weight data from the present study.

The differences in N-uptake, N utilization efficiency and NUE of the genotypes studied may be due to several factors. According to Jackson *et al*. [10], these factors may include root morphology and extension and biochemical and physiological mechanisms in nitrate assimilation and use. Kling *et al*. [12] also suggested that cultivar traits such as maximum rooting depth and the capacity of the roots to absorb nutrients enable plants to take up N from different soil layers.

CONCLUSION

Nitrogen-fixing maize may not be developed very soon but the development of low N tolerant genotypes will contribute towards a healthy environment. Further work is necessary to ascertain the role of root architecture in the expression of yield and its components.

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