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New maize hybrids had larger and deeper post-silking root than old ones

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ABSTRACT

Since new maize (*Zea mays* L.) varieties have higher grain yield, a larger root system with longer total root length and more deep roots is expected for more water and nutrient uptake and shoot biomass accumulation. To compare the differences in root dry weight (DW), total root length, vertical root distribution and post-silking root mortality in the 0–60 cm soil profile between old and new maize varieties with different leaf longevity, a two-year field experiment with six maize varieties with early-senescing (old varieties) and stay-green leaves (new varieties) was conducted. Although the new varieties had larger root DW at silking, which corresponded to their larger shoot biomass, the total root length and vertical root distribution of all six varieties were the same in the 0–60 cm soil profile at the same stage. At maturity, the difference in root DW between the old and the new varieties enlarged, and the total root length of the new varieties exceeded that of the old varieties, with more deep roots. Longer post-silking root length and more roots in deeper soil layers of the new varieties is beneficial for water acquisition in the deep soil layer and nutrient interception such as nitrate in leachate.

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1. Introduction

New maize varieties have longer duration of photosynthesis, delayed leaf senescence and higher rates of dry matter accumulation during grain-filling (Ma and Dwyer, 1998; Duvick and Cassman, 1999; Tollenaar and Wu, 1999; Borrell et al., 2001; Valentinuz and Tollenaar, 2004; Duvick, 2005; Echarte et al., 2008). To date, comparative studies between old and new maize varieties are focused on physiological and agronomic traits of the shoot, and less attention has been paid to the changes in root growth and distribution in the soil profile (Herder et al., 2010). Because soil is an opaque growing environment and roots are tangled underground, it is difficult to directly observe or study root growth in the soil, especially under the field conditions (Hirel et al., 2007; Gewin, 2010). However, roots play a vital role in anchoring plant and in water and nutrients uptake from the soil. Better root growth is beneficial for water and nutrient acquisition and grain yield increase (Lynch et al., 2013; White et al., 2013).

Newer maize hybrids are more lodging resistant at high density, which makes new hybrids higher yield (Duvick and Cassman, 1999; Duvick, 2005). In maize hybrid B73_Mo17 grain yield and the root size is positively correlated (Mackay and Barber, 1986). In the subsoil layer, maize root length densities are closely correlated with soil nitrate depletion (Wiesler and Horst, 1994; Peng et al., 2012). By using a modeling approach, Hammer et al. (2009) suggested that the change in the root architecture and water capture had a direct effect on biomass accumulation, which might be sufficient to explain maize yield trends in the US Corn Belt. Genetic analysis of root traits in a maize RIL population shows a weak but significant correlation between root traits, biomass production and yield under suboptimal N feeding conditions (Guingo et al., 1998). QTLs for maize root architecture, N uptake and leaf greenness coincided positively in eight clusters of 608 QTLs (Coque et al., 2008).

Since new maize varieties have higher grain yield (Duvick, 2005; Hirel et al., 2007), larger root system with steep root growth angle is expected to support shoot growth and more water and nutrient uptake, compared with the old varieties. Under field conditions, the maize total root length, primarily referring to lateral root length, reached the highest value at silking and then decreased rapidly during grain filling (Peng et al., 2010, 2012). Delayed leaf senescence in both maize and sorghum allows plants to have a longer duration of photosynthesis, which has a positive effect on N uptake (Borrell et al., 2001; Ma and Dwyer, 1998; Rajcan and Tollenaar, 1999). The root longevity of new maize varieties is expected to increase due to more assimilate translocation from

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shoots to roots during the reproductive growth stage. It is also interesting to clarify whether new maize varieties have more deep roots than old varieties. To address these essential issues, namely, whether the new varieties have larger root size, longer root longevity and deeper root distribution than the old ones during grain filling, a two-year field experiment was conducted, and six widely used maize varieties released from 1950s to now in China were employed. The differences of these varieties in root length, dry weight, and vertical root distribution in the 0–60 cm soil profile, as well as root longevity between silking and maturity were compared.

2. Materials and methods

2.1. Experimental design and fertilization

The field experiments were repeated in 2009 and 2010 in two adjacent experimental sites at the Shangzhuang Experimental Station of the China Agricultural University in Beijing. The soil type is a typical Ustochrept soil with silty loam texture, mesic soil temperature regime, and mixed mineralogy. The chemical properties of the 0–30 cm soil layer of the study site in 2009 and 2010 were as follows: extracted mineral N (N_{min}) 7.7 and 8.3 mg kg^{-1}, pH (H_2O) 7.9 and 7.7, Olsen-P 7.1 and 9.9 mg kg^{-1}, NH_4OAc extracted K 97.6 and 137.1 mg kg^{-1}, organic matter 7.3 and 14.8 g kg^{-1}, respectively. The field was irrigated with a sprinkler a few days before sowing and was plowed just before sowing.

Six widely used maize varieties in the last 60 years in China were used in both years: Baimaya (BMY) and Jinhuanghou (JHH), two open-pollinated, early senescing varieties in 1950s; Zhongdan 2 (ZD2) and Tangkang 5 (TK5), two moderate senescing hybrids in 1970s; Nongda 108 (ND108) and Zhengdan 958 (ZD958), two currently popular stay-green hybrids. The leaf senescence characteristics were distinguished as leaf longevity in our previous work (Ning et al., 2013). Seeds were sown on May 20, 2009 and April 29, 2010. The plots were over-seeded with hand planters and then thinned at the seedling stage to a stand of 60,000 plants ha^{-1}. Pre-sowing base fertilizers were 60 kg N ha^{-1} (urea), 135 kg P_2O_5 ha^{-1} (super phosphate), and 80 kg K_2O ha^{-1} (potassium chloride). Then 100 and 40 kg N ha^{-1} were banded as top dressing at the V8 (the eighth leaf emerged with ligule visible) and V12 stage, respectively; another 40 kg ha^{-1} of K_2O was banded at the V12 stage. The experiments used a randomized block design with four replicates, and each plot was 6 m long and 4.8 m wide. The distance between rows and plants was 60 cm and 28 cm, respectively. Border plots were included at the sides of the experimental field. Weed growth in plots was controlled by herbicides and hand cultivation. Total precipitation during maize growing season from May to September was 195 mm in 2009 and 308 mm in 2010. In addition, 43 mm of irrigation were applied on July 2, 2009, and 62 mm and 69 mm were applied on June 2 and August 2, 2010, respectively.

2.2. Harvest and sample analysis

Plants were harvested at silking (64–71 days after sowing, DAS, in 2009 and 69–79 DAS in 2010) and physiological maturity (111 DAS for BMY, JHH and ZD2, 116 DAS for TK5, 130 DAS for ND108 and ZD958 in 2009; 114 DAS for BMY and JHH, 130 DAS for ZD2 and TK5, 151 DAS for ND108 and ZD958 in 2010) when over 50% of the plants showed a visible black layer at the base of the kernel. At harvest, 5 consecutive plants were cut at the stem base, combined together, and chopped to a fine consistency, dried to a constant weight at 70 °C to determine aboveground dry weight.

In order to study the spatial distribution of maize roots at silking and maturity, one root was harvested in each plot at each harvest after shoot excision. A soil block of 28 cm × 60 cm area with the plant in the central position and total 60 cm depth with 10 cm increment was dug out. There were six subsoil blocks with 60 cm (length) × 28 cm (width) × 10 cm (depth) in each plot. The area of 28 cm × 60 cm was the soil surface occupied by each plant at the plant density of 60,000 plants ha^{-1}. All of the visible roots in each soil block were picked out in the field and placed in individually labeled plastic bags. These roots were washed free of soil after transfer to the laboratory and then frozen at −20 °C until further analyses.

2.3. Root length analysis

Root samples harvested from each soil layer at both harvests in two years were scanned as described by Peng et al. (2010). The obtained images were analyzed using the software WinRHIZO (version 5.0, Canada), and the root length in each soil layer and total root length of each plant were obtained. After root length analysis, the roots in each soil layer were dried at 70 °C to a constant weight and weighed, to obtain the DW of roots in each soil layer.

2.4. Statistical analysis

Analysis of variance for the data in all tables was performed using analysis of covariance with the GLM procedure of SAS 9.1

Table 1
Shoot (including the ear) and root dry weight (DW, g plant^{-1}) and root/shoot DW ratio (R/S) of six maize genotypes at silking and maturity in 2009 and 2010.

Year	Parameters	Harvest time	Genotypes					
			BMY	JHH	ZD2	TK5	ND108	ZD958
2009	Shoot DW	Silking	117.8 bc	108.6 c	126.6 bc	133.3 b	155.3 a	157.7 a
		Maturity	215.8 bc	179.0 c	228.5 b	293.8 a	339.5 a	334.3 a
	Root DW*	Silking	10.9 bc	8.5 c	10.4 bc	11.9 b	17.3 a	12.7 b
		Maturity	6.1 b	5.8 b	8.2 b	12.9 a	12.1 a	11.5 a
	R/S	Silking	0.09 b	0.08 b	0.08 b	0.09 b	0.11 a	0.08 b
		Maturity	0.03 b	0.03 b	0.04 ab	0.04 a	0.04 ab	0.03 ab
2010	Shoot DW	Silking	131.1 bc	120.1 c	139.8 abc	134.3 bc	152.7 ab	160.6 a
		Maturity	216.8 d	197.2 d	279.6 b	249.2 c	345.7 a	356.9 a
	Root DW*	Silking	12.6 b	10.1 c	12.0 b	12.2 b	18.3 a	12.8 b
		Maturity	7.0 b	8.1 b	12.1 a	12.2 a	14.4 a	12.0 a
	R/S	Silking	0.10 b	0.09 b	0.09 b	0.09 b	0.12 a	0.08 b
		Maturity	0.03 b	0.04 ab	0.04 ab	0.05 a	0.04 ab	0.03 b

* Root dry weight was the sum of roots collected from each of the six soil sublayers (60 × 28 cm^2 area with 60 cm depth). BMY and JHH were varieties in 1950s, ZD2 and TK5 in 1970s, ND108 and ZD958 in 1990s. Values are means of four replicates. Values followed by the different letters in row represent significant differences among genotypes within same harvest time in each year ($P < 0.05$).

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