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Effects of integrated agronomic practices management on root growth and development of summer maize

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ABSTRACT

Root growth and development of summer maize (*Zea mays* L.) is an important process in determining grain yield. In comparison to the information on above ground plant responses only limited knowledge exists on the response of root growth and development to integrated agronomic practices management (defined as a comprehensive management framework consisted of tillage method, plant density, seeding and harvest date, and fertilizer application) under field conditions. Two experiments, integrated agronomic practices management (IAPM) and nitrogen rate testing (NAT) were used to determine the effects on summer maize root system in the course of five years in North China. IAPM consisted of four treatments (CK: local conventional cultivation practices, Opt-1: an optimized combination of cropping system and fertilizer treatment, HY: treatment based on high-yield studies, and Opt-2: a further optimized combination of cropping system and fertilizer treatment). NAT had four treatments of nitrogen rate (0, 129.0, 184.5, and 300.0 kg N ha^{-1}).Individual/population root dry weight, individual/population absorption area, surface, volume, and length density of root and grain yield were measured. Roots were sampled per plot at six-leaf stage (V6), tasseling stage (VT), milk stage (R3) and physiological maturity stage (R6). The results from IAPM revealed that Opt-2 significantly increased dry weight, volume, superficial area, and length density of root across the 0–30 cm soil layer of whole growth period. Root active absorption area of Opt-2 exhibited a significant increase in the 0–30 cm soil layer of whole growth period except V6. In compare with root/shoot ratio of CK, this of Opt-2 increased by 14.5% at VT and 16.3% at R6. Results from NAT revealed that N with a range from 0 to 184.5 kg N ha^{-1} played a positive role in root growth and development. Dry weight, absorbing area of root, and the root/shoot ratio increased as N rate rise within certain limits and then decreased significantly. Dry weight, the proportion of deeply distributed, absorption area, length density of root, and root/shoot ratio increased due to appropriate population, reasonable fertilizer management, and suitable harvest date, which provided sufficient nutrients and moisture to aboveground parts for growth, development, and high grain yield of summer maize.

1. Introduction

Root system is the basis of maize growth, as robust roots provide sufficient nutrients and moisture for development, which is conducive to a high crop yield. Maize production is regulated and controlled by a range of factors, such as the seeding method, planting density, and nitrogen(N) application rate and time (Bian et al., 2016; Chen et al., 2011; Innocent and Leo, 2014; Ning et al., 2012). Agronomic practices always initially affect growth, distribution, and function of root, followed by the aboveground parts and yield (Guan et al., 2014; Hammer et al., 2009; Zhao et al., 2016). Therefore, it is very important to study the effects of integrated agronomic practices management (IAPM) on root growth and development of summer maize and verify the relationship between roots and aboveground parts. Ensuring environmental safety and food demand have become more and more urgent problems. People are increasingly concerned about realizing high-grain-yield, high-efficiency, and environmentally friendly production. N fertilizer has been the most important factor for improving maize yield, as it increases dry weight, length, and length density of root, which improves root activity (Belford et al., 1987; York et al., 2015). However, overuse of N fertilizer does not increase grain yield and results in loss of N through leaching, which could harm the environment and human health. Hence, it is imperative to reduce N application rates during agricultural production, particularly among small landholders engaged in traditional cultivation practices. In the Huang-huai-hai region of China, maize farmers generally apply one-off N fertilizer at the sixth extended leaf stage

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(V6), resulting in low N fertilizer use efficiency (about 10%) and not much benefit to root growth (Chen et al., 2014). Research suggests that delaying N application increases root activity in the upper soil layer, and weight and length density of root in the deep soil layer (Wang et al., 2003). Applying phosphorus and potassium fertilizers increases the number of roots and improves root activity in maize (Qiu et al., 2014; Xia et al., 2013). Increasing plant density is an important way to obtain high yield for summer maize. Group quality, length density, and absorption area of root increase in response to improved planting density, but competition for nutrients and water among individual roots increases, forcing roots to grow into deeper soil to maintain activity (Yang et al., 2012).

By the previous studies, IAPM have a significant impact on aboveground parts, including grain yield, plant dry matter weight, and N efficiency (Jin et al., 2012). However, few studies have explored the IAPM about affecting root system. Many studies have focused on the effect of a single factor on summer maize roots, such as the cultivation method, planting density, and N application management, but the effects of IAPM on root growth and development in summer maize should be a concern, since grain yield formation of summer maize is the result of combined action by various agronomic practices. Therefore, the objective of this study was to determine the effects of IAPM on root growth and development of summer maize, and the relationship between roots and aboveground parts. We hope the findings from this study could help to increase grain yield while harmonizing growth between root and aboveground parts through IAPM.

2. Materials and methods

2.1. Experiment design

This study was conducted from 2009 to 2013 at the Dawenkou research field (36°11′N, 117°06′E, 178 m a.s.l.), Shandong Province, China. This region is characterized by brown loam soils and a temperate continental monsoon climate. Organic matter, total N, available N, rapidly available phosphorus (P), and rapidly available potassium (K) in the upper 30 cm of the soil were 12.76 g kg^{-1}, 1.01 g kg^{-1}, 65.1 mg kg^{-1}, 70.36 mg kg^{-1}, and 96.15 mg kg^{-1} (measurement methods refer to Mulvaney and Bremner, 1979; Smith and Bain, 1982; Toth et al., 1948), respectively. The air temperature and rainfall during the study period growing seasons are listed in Table 1.

Two experiments, integrated agronomic practices management (IAPM) and nitrogen rate testing (NAT) were conducted. The summer maize hybrid ZhengDan958, which is the most common hybrid planted in China, was used as experimental material. The IAPM with four treatments were carried out in a randomized block design with four replications: (i) CK: local conventional cultivation practices; (ii) Opt-1: based on CK, change interplanting into direct seeding, decrease N application rate, and optimize fertilization date and harvest time; (iii) HY: based on Opt-1, increase fertilizer application and the ratio of phosphate to potassium fertilizer, split N fertilizers, and increase plant density; and (iv) Opt-2: based on HY, optimize fertilization date and decrease fertilizer application rate and planting density appropriately. Each plot was 6 × 40 m. A distance of 1 m was left between each block, and the total experimental area was 24 × 163 m. Each plot consisted of 10 rows of maize spaced 0.6 m apart. The combination details of tillage method, plant density, seeding and harvest date, and fertilizer application were shown in Table 2.

NAT was conducted to verify the root characteristics of a single variable N application rate. Four N rates (0, 129.0, 184.5, and 300.0 kg ha^{-1}) were designated as four treatments (N0, N1, N2, and N3, respectively) with four replications. The tillage method, plant density, seeding and harvest date, and P and K fertilizer application of NAT were identical to those of Opt-2. Each plot area was 3 × 40 m. A distance of 1 m was left between two blocks, and the total experimental area was 12 × 163 m. Each plot consisted of 5 rows of maize planted 0.6 m apart. The natural rainfall could satisfy the needs of maize growth. No irrigation was used during the whole growing season, except seeding. Disease, pest, and weed controls in each treatment were well controlled by managers.

2.2. Sampling and measurements

Grain yield was analyzed by harvesting the three central rows from each plot in from 2009 to 2013. At R6, thirty consecutive plants per row were harvested as a replication and used to measure grain yield (moisture content is approximately 14%).

Five plant roots were sampled per plot at six-leaf stage (V6), tasseling stage (VT), milk stage (R3) and physiological maturity stage (R6) in 2012 and 2013 using the soil profile method (Holanda et al., 1998): centering on the plant with line spacing of 60 cm, row spacing of 27.8 cm in CK, 24.7 cm in Opt-1, 19.2 cm in HY, and 22.2 cm in Opt-2, and depth of 0–30, 30–60, and 60–90 cm, respectively. The roots were washed and collected after the soil had been passed through a 0.5 mm sieve using a hose and nozzle attachment. The root samples were stored at 4 °C after drying surface moisture to determine various root indicators.

The root samples were oven-dried in an oven (DHG-9420A; Bilon Instruments Co. Ltd., Shanghai, China) at 85 ± 5 °C after heat-process at 105 °C for 30 min to a constant weight and then measured root dry weight. Root morphological parameters included root surface (cm^2 plant^{-1}), root volume (cm^3 plant^{-1}) and root length density (mm cm^{-3}). Roots in different soil layers were scanned using an HP Scanjet 8200 scanner and analyzed with software (Delta-T Area Meter Type AMB2; Delta-T Devices, Cambridge, UK) to measure root length and root surface area. Root volumes in different soil layers were determined by the drainage method. Root length density calculated by using the following formula:

Root length density = root length in different soil layers/soil volume

Total and active absorption area of fresh root samples were determined by methylene blue dyeing method (Zhang et al., 1994).

2.3. Date statistics and analysis

Comparisons among different treatments were performed with Duncan's multiple range tests. Data were analyzed statistically by analysis of variance (ANOVA) procedure using SPSS 17.0 software (SPSS Inc., Chicago, IL, USA). A P-value < 0.05 was considered significant.

3. Result

3.1. Analysis of variance, normality and homogeneity of variance

The analysis of variance, normality and homogeneity of variance were showed in Table 3. The changes in grain yield, root dry matter, root surface, root volume, root length density, root absorption area, root active absorption area and root vertical distribution followed normal distribution. It is no significant differences of the variances at the 0.05 probability level, namely variance is homogeneous.

3.2. Grain yield

IAPM had a significant effect on summer maize grain yield. The highest yield (mean, 13.66 Mg ha^{-1}) was obtained in HY during the 5 years, followed by that using Opt-2 (mean, 11.26 Mg ha^{-1}). Grain yields of Opt-1, HY, and Opt-2 increased by 22.10%, 22.10%,