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Effects of narrow plant spacing on root distribution and physiological nitrogen use efficiency in summer maize

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The objective of this study was to understand the effects of plant spacing on grain yield and root competition in summer maize (*Zea mays* L.). Maize cultivar Denghai 661 was planted in rectangular tanks (0.54 m × 0.27 m × 1.00 m) under 27 cm (normal) and 6 cm (narrow) plant spacing and treated with zero and 7.5 g nitrogen (N) per plant. Compared to normal plant spacing, narrow plant spacing generated less root biomass in the 0–20 cm zone under both N rates, slight reductions of dry root weight in the 20–40 cm and 40–70 cm zones at the mid-grain filling stage, and slight variation of dry root weights in the 70–100 cm zone during the whole growth period. Narrow plant spacing decreased root reductive activity in all root zones, especially at the grain-filling stage. Grain yield and above-ground biomass were 5.0% and 8.4% lower in the narrow plant spacing than with normal plant spacing, although narrow plant spacing significantly increased N harvest index and N use efficiency in both grain yield and biomass, and higher N translocation rates from vegetative organs. These results indicate that the reductive activity of maize roots in all soil layers and dry weights of shallow roots were significantly decreased under narrow plant spacing conditions, resulting in lower root biomass and yield reduction at maturity. Therefore, a moderately dense sowing is a basis for high yield in summer maize.

1. Introduction

Population structure is of great importance for maximizing yield in crops. Plant density acts as a key factor in regulating plant competition within the population and optimal plant densities are very important for efficient agronomic practice. Plant spacing varies with the growth of plants and the growing environments [1]. To date, diverse planting patterns, such as narrow spacing [2,3], wide–narrow rows [4–6], and multiple-plant hill plots [7], have been developed in maize (*Zea mays* L.) in pursuit of high grain yields under different growing conditions. Studies addressing the effects of plant spacing on yield have largely focused on improvement of above-ground canopy structure, resulting in photosynthetic rate increases via effective interception of solar radiation [3,6] or better photosynthetic performance of ear leaves [7]. These strategies often result in reduction in plant competition for light resources at high planting densities. However, individual plants always compete for nutrition, water and root space [8], and few reports are available regarding root nutrient absorption under different plant spacings.

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The fibrous root system of maize radiates outward and more than 90% of the dry root weight in soil is distributed in the top 20 cm, and 60% in the soil region within 10 cm from each plant [9]. Mineral nutrient absorption by roots results in the formation of a nutritional gradient zone around each individual. When the nutritional gradient zones of neighboring plants overlap, nutrient concentration in the overlapped area remarkably decreases because of interactions between adjacent roots, resulting in reduced root absorption efficiency [10]. It has been demonstrated that root nutrient absorption in the overlapped area varies under different plant spacing strategies.

Competing neighboring roots can deplete soil nutrient resources and thus inhibit root growth. With other things being equal, plants grow roots preferentially in areas free of other roots [11]. Plant roots do not interact solely through the depletion of soil resources but may also interact, causing profound consequences for plant growth and competition [12]. Schenk provided an excellent summary of direct interactions between roots, and distinguished between two classes of interaction [13]. First, roots may exude toxic substances that cause non-specific inhibitory effects on root development of neighboring plants. Second, genetically identical plants may use non-toxic chemical signals that specifically affect the roots of neighbors. Increasing numbers of studies have shown that plants produce more root mass when sharing rooting space with a genetically similar neighbor compared with plants growing alone [11,14]. This phenomenon has been described as a “tragedy of commons” [15]. However, Hess and Kroon hypothesized that root overproduction in the presence of other plants is consistent with the effects of available larger soil volumes on plants with competition than on those growing alone [12]. Earlier, McConnaughay and Loh showed that root mass is a function of the available rooting volume, independent of the available nutrients [16,17]. Furthermore, some of the observed root overproduction could not be immediately explained solely based on soil volume and nutrient availability [12]. The results observed with competing plants may be an overall effect of the existence of interplant root interactions within a larger space.

Therefore, a thorough understanding of the effects of overlapping roots on maize root growth and nitrogen absorption and utilization will help to explore the effects of plant spacing on maize yields. In recent years, it was proposed that increasing plant populations is a key factor for improvement of maize yields in China [7,18], but few reports are available on competition between above-ground and below-ground factors while increasing plant populations. In this study, the differences between root distribution, nutrient absorption and nitrogen utilization under different conditions of plant spacing and nitrogen availability were investigated to provide guidelines for optimizing plant densities in high yield maize production.

2. Materials and methods

2.1. Plant materials and experimental designs

The field experiment was carried out at the Experimental Farm of Shandong Agricultural University, Tai’an, China (36°18′ N, 117°13′ E) in 2007 and 2008. Only one maize hybrid, Denghai 661, was used because previous experiments confirmed increased grain yield of this cultivar at high plant densities [18].

A box-type soil column cultivation method was adopted. The soil column measuring 54 cm × 27 cm × 100 cm was made of a PVC plate with bottom sealing, and one side of the planter could be dismantled to facilitate removal of the soil and roots without damage to the study materials. The soil column was placed in an 80 cm deep square pit filled with soil both inside and outside the column and made soil compact by watering. The distance between soil columns was 11 cm, that is, the row width was 65 cm, and surrounded by the board rows (Fig. 1).

Two plants were grown in each soil column. Plants in one column were planted under normal spacing (NS, 27 cm), and the other under narrow spacing (CS, 6 cm). The columns were treated at two nitrogen levels, N0 (no N) and N1 (7.5 g N plant^{-1}), and for the N1 treatment, nitrogen fertilizer was applied by 20%, 50% and 30% at the seedling, male-tetrad and flowering stages, respectively. The experimental design included four treatments (N0 × NS, N0 × CS, N1 × NS and N1 × CS) and 30 separate soil columns were planted in each treatment.

Samples of the soil columns (top 40 cm) were mixed and screened with 20 mesh sieving. Then they were mixed with clean river sand in a ratio of 3:1 by volume of topsoil to sand.

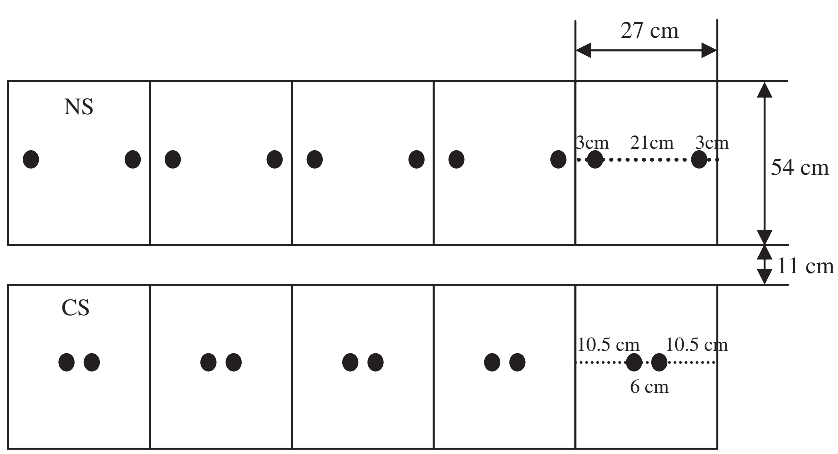

Fig. 1 – Field arrangement of different experiments.