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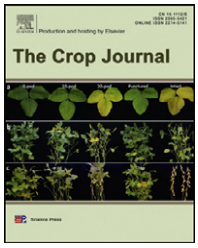

Response of grain yield to plant density and nitrogen rate in spring maize hybrids released from 1970 to 2010 in Northeast China

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ABSTRACT

The objective of this study was to identify the response of grain yield to plant density and nitrogen rate in spring maize hybrids released from 1970 to 2010 and grown extensively in Northeast China. Twenty-one hybrids were grown for 2 years in Northeast China at densities of 30,000, 52,500, 75,000, and 97,500 plants ha^{-1} and N application levels of 0, 150, 300, and 450 kg N ha^{-1}. Irrespective of density or nitrogen application rate, grain yields both per plant and per unit area were significantly higher for newer than older hybrids. As plant density increased from 30,000 to 97,500 plant ha^{-1}, yield per plant of 1970s, 1980s, 1990s, and 2000s hybrids decreased by 50%, 45%, 46%, and 52%, respectively. The response of grain yield per unit area to plant density was curvilinear. The estimated optimum plant densities were about 58,000, 49,000, 65,000, and 65,000 plants ha^{-1} for hybrids released in the 1970s, 1980s, 1990s, and 2000s, respectively. The theoretical optimum densities for the hybrids released from the 1970s to the 2000s increased by 1750 plants ha^{-1} $decade^{-1}$. Nitrogen fertilization significantly increased grain yields per plant and per unit area for all hybrids. The theoretical optimum N application rates for high yield for hybrids released in the 1970s and 1980s were about 280 and 360 kg ha^{-1}, and the hybrids from the 1990s and 2000s showed highest yield at 330 kg ha^{-1} N. No significant difference in the grain yields of 2000s hybrids between the N levels of 150 to 450 kg ha^{-1} was found. Significant yield gains per plant and per unit area were found, with average increases of 17.9 g $plant^{-1}$ $decade^{-1}$ and 936 kg ha^{-1} $decade^{-1}$ over the period 1970–2010, respectively. Yield gains were attributed mainly to increased yield per plant, contributed by increases in kernel number per ear and 1000-kernel weight. The rates of lodging and barren plants of newer hybrids were significantly lower than those of older ones, especially at high plant density.

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1. Introduction

Globally, maize (*Zea mays* L.) yield and total production increased by 168.5% and 311.8% during the period 1961–2010 [1]. The yield gain can be attributed mainly to variety improvement and cropping technique innovations, such as increases in plant density and fertilizer application [2]. Cardwell [3] reported that increased plant density contributed 21% of the gain in maize yield in Minnesota from 1930 to 1970. Wu et al. [4] stated that fertilizer inputs contributed 50% of the gain in maize yield in China during the period 1985–1994. Thus, the yield superiority of newer over older varieties is attributed to their productivity improvement and their better adaptation to changes in cropping techniques, such as dense cropping and nitrogen (N) fertilization [2,5]. Characterizing trends in yield change and response to plant density and N application among maize hybrids released in different eras can guide future breeding of new varieties and cropping technique innovation [6,7].

Many experiments have been conducted to study the changes in maize hybrids during the past decades [8–11]. Most have focused on changes in plant productivity and morphological characteristics among different eras [12–14], and have greatly advanced our understanding of the improvement potential of maize hybrid productivity and accelerated the progress of new variety breeding [15–17]. With respect to response to density and N rate, some studies have confirmed that older hybrids gave their highest yields at lower densities typical of their era of release, whereas newer hybrids yielded most at higher densities typical of recent years [2,18–20]. N application rates with the highest yields were lower for newer than for older hybrids [21] and older hybrids were more sensitive than newer ones to low soil N [22,23]. However, fewer studies have focused on plant density × N rate × decade interaction. Moreover, most previous studies have been conducted in the European and American continents, with few conducted in Asia. Although it is well known that increased plant density and N application have contributed much to the yield gains of maize hybrids during the past eras [2,21,24], this knowledge is not well documented. It is desirable to investigate further the response of grain yield to plant density and N application in maize hybrids released from different eras, especially in Asia.

Northeast China is the major maize cropping area in Asia and accounts for more than one third of the total maize-sown area in China. Approximately 1200 maize cultivars were released during the period 1970–2010; however, few studies of the change of these cultivars, especially with respect to their responses to plant density and N application under field conditions, have been performed. This lack of knowledge hinders the progress of new variety breeding and cropping technique innovation in Northeast China. We accordingly conducted a field experiment to investigate the responses of grain yield, morphological characteristics, and yield components to plant density and N application, using 21 leading hybrids released during 1970–2010 in Northeast China.

2. Materials and methods

2.1. Study site

This study was conducted in three locations: Shuangcheng (45°25′ N, 126°24′ E), Heilongjiang province; Liuhe (42°05′ N, 125°50′ E), Jilin province; and Tai'an (41°24′ N, 122°26′ E), Liaoning province, China in 2009 and 2010. The rainfall and mean daily air temperature during the growing season in 2009 and 2010 and the soil chemical characteristics at the experimental sites are described in Tables 1 and 2.

2.2. Plant materials and experimental design

Twenty-one maize hybrids, spanning four decades from the 1970s to 2000s and representing the most popular hybrids of their time in the main maize-growing areas in Northeast China, were used. All tested cultivars were the top 10 cultivars in their era of approval with a sown area of more than one million hectares per year in each province. All the parental seeds of the tested hybrids except for those of the 2000s were obtained from the State Bank of Crop Germplasm Sources in Chinese Academy of Agricultural Sciences, China. The seeds of hybrids from the 1970s to 1990s were reproduced hybridization of their parents in Shanya city, Hainan province, China in 2008 and 2009, respectively. The seeds of the 2000s hybrids were purchased from local seed companies. Detailed information about the hybrids tested at each experimental site is presented in Table 3.

Three treatments (hybrid variety, plant density, and N application rate) with three replicates were applied. In view of the changes in plant density and N application adopted by farmers during 1970–2010 in Northeast China, eight hybrids (Table 3) with three densities (30,000, 52,500, and 75,000 plants ha^{-1}) and three N application rates (0, 150, and 300 kg ha^{-1}) were assigned to each experimental site in 2009. Based on the results in 2009 and considering the density and N rate used in yield contests, a density (97,500 plants ha^{-1}) and N application rate (450 kg ha^{-1}) were added in 2010. The plots were arranged in a split-split design, in which plant density was the main plot, N treatment the split plot, and the hybrid variety the sub-split plot. Each sub-split plot comprised five rows 5 m in length.

Total fertilizer P_2O_5, K_2O and one third of N were applied pre-planting and the remaining N (as urea) was applied at the six-leaf collar stage [25] based on each treatment's

Table 1 – Growing season rainfall and mean daily air temperature in 2009 and 2010 at study sites.

Experimental site	Precipitation (mm)		Mean daily air temperature (°C)	
	2009	2010	2009	2010
Shuangcheng	403.3	371	18.9	21.4
Liuhe	328.9	817	18.8	20.1
Tai'an	323.5	635.9	21.1	21.5