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Maize response to elevated plant density combined with lowered N-fertilizer rate is genotype-dependent

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ABSTRACT

Increasing plant density and improving N fertilizer rate along with the use of high density-tolerant genotypes would lead to maximizing maize (*Zea mays* L.) grain productivity per unit land area. The objective of this investigation was to match the functions of optimum plant density and adequate nitrogen fertilizer application to produce the highest possible yields per unit area with the greatest maize genotype efficiency. Six maize inbred lines differing in tolerance to low N and high density (D) [three tolerant (T); L-17, L-18, L-53, and three sensitive (S); L-29, L-54, L-55] were chosen for diallel crosses. Parents and crosses were evaluated in the 2012 and 2013 seasons under three plant densities: low (47,600), medium (71,400), and high (95,200) plants ha^{-1} and three N fertilization rates: low (no N addition), medium (285 kg N ha^{-1}) and high (570 kg N ha^{-1}). The T × T crosses were superior to the S × S and T × S crosses under the low N–high D environment in most studied traits across seasons. The relationships between the nine environments and grain yield per hectare (GYPH) showed near-linear regression functions for inbreds L54, L29, and L55 and hybrids L18 × L53 and L18 × L55 with the highest GYPH at a density of 47,600 plants ha^{-1} and N rate of 570 kg N ha^{-1} and a curvilinear relationship for inbreds L17, L18, and L53 and the rest of the hybrids with the highest GYPH at a density of 95,200 plants ha^{-1} combined with an N rate of 570 kg N ha^{-1}. Cross L17 × L54 gave the highest grain yield in this study under both high N–high-D (19.9 t ha^{-1}) and medium N–high-D environments (17.6 t ha^{-1}).

1. Introduction

Hybrid varieties currently released in Egypt by the National Maize Breeding Program (NMBP) are bred and grown at low plant density (57,000 plants ha^{-1}) around half the density used in developed countries [1]. This lower plant density may be one of the main reasons for lower grain yield per unit land area planted in maize than that in the developed countries. A potential method for maximizing total maize production in Egypt is raising productivity per unit of land area and thus upgrading our global rank in average productivity, especially with the irrigation system used in Egypt and weather and soil conditions better suited to maize cultivation than those of other regions in the world. Grain yield per unit land area is the product of grain yield $plant^{-1}$ and number of plants per unit area [2]. Maximum yield per unit area may be obtained by

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growing maize hybrids that can withstand high plant density, up to 100,000 plants ha^{-1} [3]. Average maize grain yield per unit area in the USA increased dramatically during the second half of the 20th century, owing to improvements in crop management practices and greater tolerance by modern hybrids of high plant densities [4,5].

Growing hybrid varieties released by the NMBP at high plant densities causes a drastic reduction in grain yield per unit area. The reason is probably that these varieties are not tolerant of high plant densities, because of their height, one-eared bearing habit, decumbent leaf, and large-type plants. In contrast, modern maize hybrids in developed countries are characterized by high yielding ability per unit area under high plant densities, owing to morphological and phenological adaptations such as early silking, short anthesis-to-silking interval (ASI), few barren stalks, and prolificacy [6]. Radenovic et al. [7] pointed out that maize genotypes with erect leaves are very desirable for increased population densities, owing to their better light interception.

Maize grain yield per plant decreases as the density per unit area increases [2]. The yield decreases as a response to decreasing light and other environmental resources available to each plant [8]. Reduction in yield is due mainly to fewer cobs (barrenness) [9], fewer grains per cob [10], lower grain weight [11], or a combination of these components [12]. At high densities, many kernels may not develop, an event that occurs in some hybrids following poor pollination resulting from a silking period that is delayed relative to tassel emergence [13] and/or owing to a limitation in assimilate supply that causes grain and cob abortion [14]. However, under optimum water and nutrient supply, high plant density can result in an increased number of cobs per unit area, with an eventual increase in grain yield [15]. Liu et al. [16] reported that maize yield differed significantly at varying plant density levels, owing to differences in genetic potential.

Nitrogen is an essential nutrient for maize crop growth [17]. It is the principal raw material required for the growth of plants and is an essential constituent of metabolically active compounds such as amino acids, proteins, enzymes, coenzymes, and some non-proteinaceous compounds [17,18]. Low N stress is one of the factors most frequently occurring under high plant density and limits maize production. Low N availability in soils is an important yield-limiting factor frequently found in farmers' fields where fertilization is not commonly used and organic matter is rapidly mineralized [19]. Ears $plant^{-1}$ and anthesis-to-silking interval are considered the most important low-N adaptive traits [20]. Under these circumstances, given that smallholder farmers cannot afford additional inputs, it is desirable to increase the tolerance of the crop to stresses that occur in their fields [21].

Matching the functions of optimum plant density and adequate nitrogen fertilizer application to produce the highest possible yields with the greatest maize hybrid efficiency has been the aim of many researchers [22–24]. Modern hybrids have shown tendencies to withstand higher levels of stresses (such as low N and high plant densities), allowing them to better sustain suitable photosynthetic rates and sufficient assimilate supplies and to maintain plant growth rates attributable to enhanced nitrogen use efficiency [25]. Along with the prevailing belief that high yields require more plants and that more plants require more N, the idea that different hybrids respond differently to both N and plant density should be considered [26]. Moreover, different hybrids may behave differently in their tolerance to both low N and high-density stresses [26]. The objectives of the present investigation were (i) to evaluate the effects of stresses resulting from elevating plant density combined with lowering N application rate on traits of six inbreds and their diallel F_1 crosses, and (ii) to match the functions of appropriate plant density and adequate nitrogen fertilizer application with greatest maize inbred or hybrid efficiency to produce the highest possible yields per unit area.

2. Materials and methods

This study was performed in the 2011, 2012, and 2013 seasons at the Agricultural Experiment and Research Station of the Faculty of Agriculture, Cairo University, Giza, Egypt. Six maize inbred lines (Table 1) in the sixth selfing generation (S_6), showing clear differences in performance and general combining ability for grain yield per hectare under high plant density were chosen as parents of diallel crosses. In the 2011 season, all possible diallel crosses (except reciprocals) were made among the six parents, so that seeds of 15 direct F_1 progenies were obtained. Two field evaluation experiments were performed in the 2012 and 2013 seasons. The climatic differences over experimental years are shown in Table 2. Each experiment included the 15 F_1 crosses, their six parents, and two check cultivars: SC 10 (with white grains) obtained from the Agricultural Research Center (ARC) and SC 2066 (with yellow grains) obtained from Hi-Tech Company-Egypt.

Evaluation in each season was performed under nine environments (from E1 to E9): three nitrogen levels: high (HN), medium (MN), and low N (LN) by addition of 570, 285, and 0 kg N ha^{-1}, respectively, in two equal doses of urea

Table 1 – Designation, origin, and most important traits of six inbred lines (L) used for making diallel crosses in this study.

Entry designation	Origin	Institution (country)	Prolificacy	Productivity under high density and/or low-N
L17-Y	SC 30 N11	Pioneer	Prolific	High
L18-Y	SC 30 N11	Pioneer	Prolific	High
L53-W	SC 30 K8	Pioneer	Prolific	High
L29-Y	Pop 59	ARC-Thailand	One-eared	Low
L54-W	SC 30 K8	Pioneer	One-eared	Low
L55-W	SC 30 K8	Pioneer	One-eared	Low

ARC: Agricultural Research Center; Pioneer: Pioneer International Company in Egypt; SC: Single cross; W: White grains; Y: Yellow grains.