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Phenotypic responses to 75 years of recurrent selection for yield in the Iowa State Stiff Stalk synthetic maize population.

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Abstract

Modern era hybrid maize yield increases and tolerance of these hybrids to increased plant density could perhaps be facilitated by understanding the physiological and genetic bases for phenotypic changes in response to recurrent selection for yield. Phenotypic changes in hybrids across decades include upright leaves, fewer tassel branches, and reduced silking-anthesis interval. These changes have also been observed in the Iowa Stiff Stalk Synthetic, but have not been studied as indirect responses to recurrent selection. Nor has it been determined which of these phenotypes may result from changes in functionally related genes. Our objectives were to identify and quantify indirect selection responses for several morphological phenotypes and their interactions with plant density in the Iowa Stiff Stalk synthetic population. The Iowa Stiff Stalk Synthetic (BSSS), was compared to the most advanced cycles of selection from three different recurrent selection programs derived from BSSS at four densities. Phenotypes measured include leaf angle, tassel branch number, plant height, silk delay (ASI), and yield. Plant density significantly affected ASI, plant height and yield. All phenotypes changed significantly from the base population to advanced cycles. These results demonstrate that selection for high yield led to significant changes in several phenotypes.

Introduction

Since the 1930's average maize yields in the United States have increased nearly 5 times from 1.5 mg/ha^{-1} to an average of 8.5 mg/ha^{-1} today(Duvick, 2005). During the same time period average plant density has increased by an average of 700 plants/ha annually from an average 30,000 plants/ha to over 80,000 plants/ha (Duvick, 2005). Russell (1984) also reported large increases in yield when comparing varieties from the 1980's to varieties from older open pollinated varieties. They noted an increase in yield of nearly 56%.

Studies by Cardwell (1982) indicated that over a 50 year period prior to the 1980's, increases in plant densities were responsible for 21% of the total yield increase in Minnesota. Over this time, plant productivity at high density has increased. In the 1960's increases in yield leveled off at densities as low as 3 plants/meter^2 while today's hybrids have the ability to increase yields at densities as high as 6 plants/meter^2 (Hammer et. al., 2009).

Our objectives were to identify and quantify indirect selection responses for several morphological phenotypes and their interactions with plant density in the Iowa Stiff Stalk synthetic population.

BSSS

BSSS(R)C17

Materials and Methods

•Field experiments were conducted in Ames, IA and Carroll, IA in 2008 and 2009.
•The experiment was a split-plot design with plant density was the main effect and population as the sub-plot effect.
•Material from an unselected base population, Iowa State Stiff Stalk, was compared to the most advanced cycles of selection from three different recurrent selection programs initiated from the same base population.
•Selection for cycle advancement was based on an index of root lodging, stalk lodging, grain moisture, and grain yield, with primary emphasis on grain yield.
•Plants were compared at four densities: 38,000, 57,000, 77,000, and 97,000 plants/ha.

Populations
•BSSS - The original base population, Iowa Stiff Stalk Synthetic.
•BSSS(HT)C7 – Seven cycles of half-sib selection with double cross hybrid IA13 as tester.
•BS13(S)C0 – Derived by intermating selected lines from BSSS(HT)C7.
•BS13(HI)C5 – Five cycles of selection with inbred B97 as tester (beginning with BS13(S)C0 as base population).
•BSSS(R)17 – Seventeen cycles of reciprocal selection with BSCB1 (Iowa Corn Borer Synthetic Number 1).

ASI
Anthesis to silking intervals were established by taking daily recordings of the number of plants with one or more visible silks and the number of pollen shedding tassels per plot. The percent of plants with pollen shedding or available silks was figured as the percent of daily shedding or silking over final plot stand count. The point at which this reached 50% for each plot was noted and used to determine the date of 50% silk/pollen shed for that plot. ASI was figured as number of days to silking – number of days to pollen shed (Bolanos and Edmeades, 1996).

Tassel Branch Number
Tassel branch numbers were determined by removing the tassels from each plant and counting the number of branches. Only branches directly attached to the main branch were counted (Bolanos and Edmeades, 1996).

Leaf Angle
Leaf angle of the flag leaf was recorded using the Pro 3600 digital protractor. Vertical (0°) was set by placing the protractor against the stalk. The protractor was then placed against the midrib on the underside of the leaf and the digital reading was recorded.

Plant Height
Plant height was recorded as the height of the flag leaf collar (Maddonni et. al., 2001, Bolanos and Edmeades, 1996).

Yield
Yield was measured and recorded in megagrams/hectare (Mg Ha^{-1}).

References

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Population	Flag Leaf Angle	Tassel Branch Number
BSSS	47.4	18
BSSS(HT)C7	30.3	13
BS13(S)C0	34.6	13
BS13(HI)C5	37.8	11
BSSS(R)C17	24.9	7

Table 1. Flag Leaf Angle (Degrees from Vertical) and Tassel Branch Number

Results

•All population effects were significant. Density and density*population interactions were significant for ASI, plant height, and yield.
•ASI: High plant density increased ASI for the unselected population, did not affect ASI of the most advanced population, and had an intermediate effect on the other populations (fig 1).
•Plant height: High plant density increased plant height of selected populations but did not affect the unselected base population BSSS (fig 2).
•Grain yield: BSSS (base population) had maximum yield at lowest density while BSSS(R)C17 (most advanced population) had highest yield at the highest density (fig 3).
•Flag leaf angle: Selection led to more erect flag leaves (table 1).
•Tassel branch number: Selection reduced the number of tassel branches (table 1).

Conclusions

•Improvement in grain yield and agronomic performance with recurrent selection was accompanied by increasingly erect flag leaves and reductions in plant height, ASI, and tassel branch number.
•Increased plant density impacted ASI, plant height, and yield.
•Our findings indicate that there is a strong relationship between changes in these phenotypes and increases in yield that have occurred over the past 75 years as plants have adapted to higher densities.
•Further investigations into the physiological and genetic basis of these and other phenotypes should be conducted.

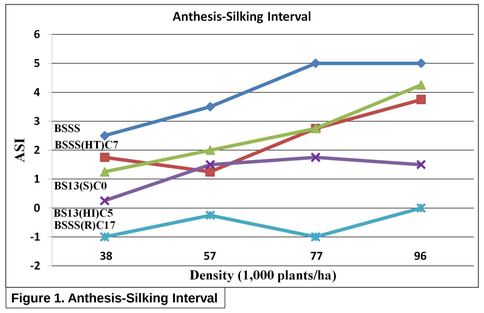

Figure 1. Anthesis-Silking Interval

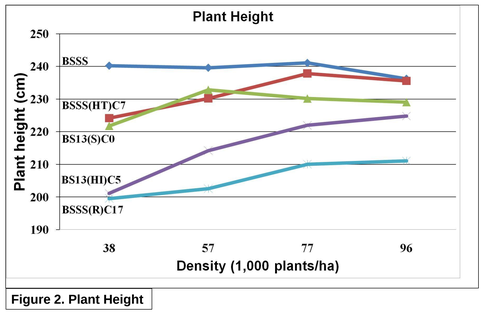

Figure 2. Plant Height

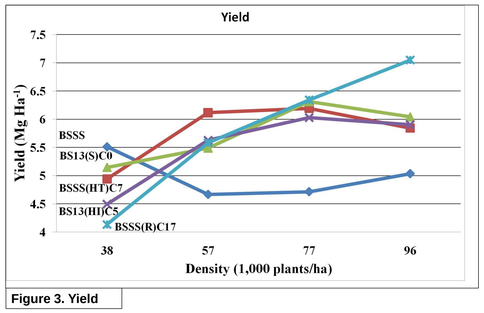

Figure 3. Yield