OPTIMUM DENSITY AND STAND UNIFORMITY AS DETERMINANT PARAMETERS OF YIELD POTENTIAL AND PRODUCTIVITY IN EARLY MAIZE HYBRIDS

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ABSTRACT

A generally held view is that maize yield per unit area responds to plant density changes in a curvilinear pattern. Non-uniform stand in the field has been reported to be negatively associated with productivity. The objective of this study was to assess how hybrids' yield respond to density changes, and to estimate their optimum density for maximum grain yield per unit area. The impact of density on stand uniformity was also evaluated. Seven single-cross hybrids were grown at densities of 2.5, 4.2 and 8.3 plants/m^2 at the Agricultural Research Station Turda, Romania. Experimental design was split-plot RCB with density as main plot and hybrids as subplots. Each block was replicated three times. In all hybrids except one, maximum yield per hectare was obtained at the medium density of 4.2 plants/m^2. Calculated optimum density was found to be 4.7 plants/m^2 in four out of the seven hybrids, and 4.2, 4.8 and 5.0 plants/m^2 for the other three hybrids. Optimum density was too narrow, only one hybrid showing considerably lower yield losses at lower and higher density, compared to the rest of the hybrids. CV values for three agronomic traits (yield per plant, ear length, and ear kernel row number) considerably increased as density increased. In breeding programs, selection of superior genotypes is expected to be more effective under lower densities, where lower CV values reflect lower environmental impact on phenotypic expression. Comparative evaluation of different hybrids under a single density to estimate crop yield potential may lead to biased judgment, due to strong hybrid by density interaction. Alternative models to predict crop yield potential are needed and these preliminary data constitute part of such a project under way. Maize breeding should aim to hybrids that are less affected by density changes (i.e., density-independent hybrids) to avoid adverse effects of high densities on stand uniformity. As far maize cultivation in the field is concerned, producers should take the necessary measures to achieve both optimum density for the hybrid they choose and most uniform stand.

Key words: honeycomb design, maize hybrids, yield components, yield determinant parameters.

INTRODUCTION

Differences in grain yield between older and newer maize hybrids were shown to be a function of plant population density (Duvick, 1992). At lower plant densities, the differences between older and modern hybrids were smaller, becoming greater as plant density increased (Tollenaar 1989, 1991, 1992). Fasoula and Fasoula (2000) explained the causes of tolerance to higher and lower plant densities and the ways of overcoming the density barriers. This was made possible through partitioning of crop yield into three components (yield per plant, tolerance to stresses, and responsiveness to inputs), all assessed in the absence of competition. It was shown that tolerance to higher plant densities was mainly the result of the incorporation of genes conferring tolerance to various biotic and abiotic stresses, due to screening under a wide range of environmental conditions.

Optimum plant density for maximum grain yield per unit area may differ from hybrid to hybrid on account of significant interactions between hybrids and densities (Farnham, 2001; Widdicombe and Thelen, 2002; Tokatlidis et al., 2005). Optimum density could be approached from the slope of the linear regression of the natural logarithm of yield per plant on plant density (Duncan, 1958; Tollenaar, 1989).

Density also influences plant-to-plant uniformity in the stand (Tokatlidis et al., 2005). Non-uniform stand in the field has been reported to be negatively associated with productivity (Tollenaar and Wu, 1999; Troyer, 2001), and to reflect greater environmental impact on phenotypic expression of genotypes (Fasoula and Fasoula, 2002).

The objective of the present paper was to determine the optimum density for maximum grain yield per unit area in several maize hybrids, and to estimate how densities affect stand uniformity for three agronomic traits. This paper is a short presentation of the main results obtained in plant breeding at Turda so far.

MATERIAL AND METHODS

Experimentation was conducted under natural conditions, without irrigation, at the Agricultural Research Station Turda, Romania, during the 2006 season. Seven single-cross hybrids (FAO 320-450) were grown at three densities. The experimental design was a split-

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plot RCB, with densities as main plots, and hybrids as subplots. Each block was replicated three times. Subplots consisted of four rows, 5 m long with 70 cm between rows. Distances among plants within rows were 57, 34 and 17 cm, to obtain the densities of 2.5, 4.2 and 8.4 plants/m^2, respectively. Twenty plants from the two central rows of each subplot, at the desired density (no adjacent missing plants), were collected to measure grain yield per plant, main ear length and kernel row number. Comparison of means was conducted by least significance difference (LSD) after analysis of variance for a two-factor split-plot design.

The optimum plant density for maximum crop yield of each hybrid was calculated through the slope b of a linear regression of natural logarithm of yield per plant in grams on plant density in plants/m^2 $\{\ln(Y_p) = \alpha\text{-}bD\}$, with the optimum plant density being equal to 1/b (Duncan, 1958; Tollenaar, 1989).

RESULTS AND DISCUSSION

Decreasing plant density resulted in higher grain yield per plant, an expected result on account of more environmental resources available for each plant (Table 1). At each density, significant differences among hybrids for grain yield per plant were found. However, differentiation between hybrids increased as density decreased (Table 1). So, the first conclusion of this study is that phenotypic expression and differentiation increase as density decreases, highlighting the importance of low densities for isolating superior genotypes via phenotype during a selection process.

When grain yield per plant was adjusted to grain yield per hectare (ha), it was found that maximum yield was obtained at the medium density of 4.2 plants/m^2. An exception existed for a single hybrid (H5), which gave the highest yield at the lowest density. Nevertheless, data from Table 1 shows that optimum densities were different for the seven hybrids, ranging from 4.13 to 5.02 plants/m^2, with four of the hybrids having similar optimum density (≈4.7 plants/m^2). Parabolic responses of grain yield per ha to density changes, shown in figure 1 for four out of the seven hybrids, also illustrate the differences among hybrids regarding optimum densities.

Table 1. Yield per plant, in grams, at three densities and optimum density (D_{opt}) in plants/m^2 calculated from linear regression analysis of natural logarithm of yield per plant on density (D_{opt} = 1/b).

Hybrids	Density (plants/m^2)			D_{opt}
	2.5	4.2	8.4	
H1 : TC316 x TA419	210 c	132 cd	50.7 b	4.13 ± 0.15
H2 : TD268 x TA426	228 b	147 ab	69.9 a	5.02 ± 0.44
H3 : TC243 x TC399	184 d	130 d	53.5 b	4.69 ± 0.05
H4 : TA428 x TC385A	247 a	158 a	70.8 a	4.72 ± 0.33
H5 : Lo3Berg x TC344	198 c	116 e	55.0 b	4.67 ± 0.65
H6 : TC365 x P1940	205 c	145 abc	59.3 ab	4.67 ± 0.06
H7 : TA367 x TB329	199 c	137 bcd	59.2 ab	4.80 ± 0.06

Means followed by the same letter do not differ significantly at P<5% ($LSD_{0.05}$ = 13.5).

Consequently, a question arises: „under which density should one carry out comparative estimation of crop yield potential for the seven hybrids?" It seems that evaluation of different hybrids under a single plant density might lead to biased judgment.

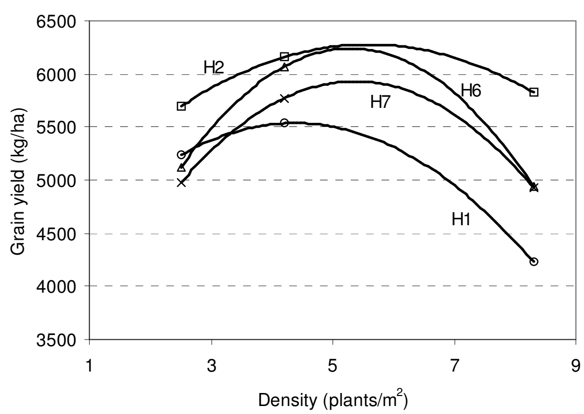

Figure 1. The response of grain yield per unit area to plant density in four hybrids

Figure 1 also depicts that for each hybrid a narrow range of densities exist under which maximum grain yield per unit area could be achieved. In other words hybrids could be characterized as density-dependent on account of their relative low yield potential per plant.

The impact is stronger in modern long-season hybrids because breeding so far did not essentially improve this particular parameter of crop yield potential (Tokatlidis and Koutroubas, 2004). For this reason, Tokatlidis and Koutroubas (2004) suggested improvement of yield potential per plant as a determinant parameter for stability, since missing plants in the field is a common problem, and neighboring plants better compensate for yield of missing plants in hybrids with improved yield potential per plant. Comparison of hybrids H2 and H6 in figure 1 is instructive showing that, although both hybrids seem to achieve the same level of yield per unit area, when density deviates from their optimum density, yield loss is less in hybrid H2, which yielded significantly higher at the lowest density, of 2.5 plants/m^2.

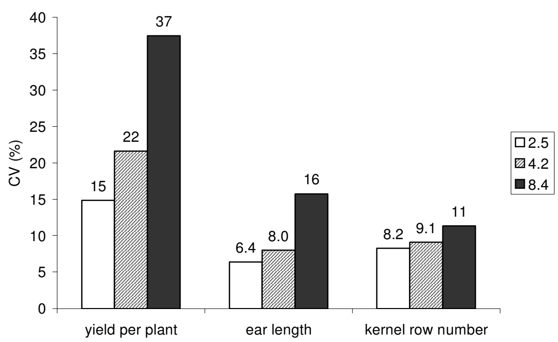

Figure 2. Average hybrids' CV values for three traits at the densities of 2.5, 4.2 and 8.4 plants/m^2

According to figure 2, as density decreases, CV values for three agronomic traits (i.e., yield per plant, ear length and ear kernel row number) also decrease, illustrating that higher densities deteriorate stand uniformity. Stand uniformity, however, is associated with high productivity (Tollenaar and Wu, 1999). This effect emphasizes the importance of density-independent hybrids which could be cultivated under lower densities, and thus better stand uniformity could be attained (Tokatlidis et al., 2005).

In conclusion, as far as maize cultivation in the field is concerned, producers should take the necessary measures to achieve both optimum density for the hybrid they choose and the most uniform stand possible. Regarding maize breeding, selection of superior genotypes is expected to be more effective under lower densities where lower CV values reflect lower environmental impact on phenotypic expression. Comparative evaluation of different hybrids under a single dense stand to estimate crop yield potential might lead to biased judgment, due to strong hybrid by density interaction. Alternative models to predict crop yield potential are needed. Yan and Wallace (1995) suggested testing of hybrids across a range of densities to evaluate their crop yield potential. They distinguished two components of crop yield potential: yield potential per plant and tolerance to density. On the other hand, Fasoula and Fasoula (2002) suggested a model of crop yield potential assessment under a single ultra-low density that approaches total absence of competition. According this model, crop yield potential is determined by three components: yield potential per plant, tolerance to biotic and abiotic stresses and responsiveness to inputs. Hybrids improved for these three components are expected to be less density-dependent and to express their crop yield potential at a wider range of plant densities.

CONCLUSIONS

Maize breeding should aim to hybrids that are less affected by density changes („density-independent hybrids"), in order to avoid adverse effects of high densities on stand uniformity, and to reduce grain yield loss due to missing plants (Tokatlidis and Koutroubas, 2004). Preliminary data of the present study constitute part of a project aiming to investigate the efficiency of this approach.

A combination of higher potential yield per plant with tolerance to stresses is the key to future improvement of maize hybrids performance.

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