WHAT IS YIELD?

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ABSTRACT

During the past 70 years, genetic yielding ability of maize hybrids adapted to central Iowa (USA) has increased at a linear rate of about 74 kg/ha/yr, according to trials conducted during the four-year period, 1991-1994. Comparisons of 36 widely grown successful hybrids released at intervals from 1934 to 1991 show continuing improvements in tolerance to abiotic and biotic stresses such as heat and drought, excessively cool and wet weather, low soil fertility, high density planting, root and stalk rot, and European corn borer (*Ostrinia nublalis*). The hybrid series also exhibited linear increases in erect leaf habit and grain starch percent, and a linear decrease in grain protein percent; these continuing changes in plant architecture and grain composition conceivably can increase efficiency of grain production under stresses of high density planting, unfavorable weather, or low soil fertility. Maximum yield potential per plant has neither increased nor decreased during the past 70 years, as measured on non-stressed plants grown at very low densities (1 plant/m^2). Results of the 1991-1994 trials agree with the hypothesis that increased grain yielding ability of widely successful maize hybrids for central Iowa is due primarily to improved tolerance of abiotic and biotic stresses, coupled with maintenance of ability to maximize yield per plant under non-stress growing conditions.

INTRODUCTION

During the past 70 years Pioneer Hi-Bred International, Inc. maize breeders have continually altered hybrid genotypes for better adaptation to central Iowa soils and climate and to changing farming practices. Breeding started in the mid-1920s, and continues today. Since the beginning, the goal of the breeders has been to produce hybrids with more grain yield potential, greater stability of yield, and with plant and grain traits desired by farmers and end-users.

The goal of the experiment reported herein is to measure the rates of improvement (if any) in traits the breeders intended to change, and to look for changes that also may have occurred in other traits. Measuring and characterizing the changes can help breeders understand in detail how they have changed the genetic yield potential of the maize plant during the past seventy years, and may help them as they plan future courses of action to increase yield and dependability of hybrid maize. This experiment is one of a continuing series. It complements similar experiments on hybrid maize conducted by other researchers in Iowa and elsewhere (Castleberry, et al., 1983, Derieux, et al., 1987, Duvick, 1977, Duvick, 1984, Duvick, 1992, Eyhérabide, et al., 1994, Russell, 1991, Tollenaar, 1991).

MATERIALS AND METHODS

Performance trials of 36 hybrids released consecutively during the years 1934-1991 and one open-pollinated variety typical of farm use in 1930 (Table 1) were conducted in central Iowa in 1991-1994. All hybrids were developed and released by Pioneer Hi-Bred International, Inc. Each hybrid was a widely grown successful hybrid in central Iowa in its time. In each season, trials were planted in 3 locations in central Iowa, at 3 densities (30, 54 and 79 thousand plants/ha), one replication per density. The lowest density was typical for central Iowa in the 1930s, the middle density was typical of the 1960s, and the highest density was typical for maize grown on the best land in the 1990s. Plots consisted of 2 rows 631 cm long and 76 cm wide. Scores and counts were taken for several agronomically important traits, as well as for other traits of interest. In 1992, grain samples were saved for chemical analysis. Additional locations were planted in 1993 to provide plants for measurement of harvest index, and in 1992 and 1994 for artificial inoculation or infestation to provide special disease and insect ratings. Data also are presented for trials of a subset of the 36 hybrids in this experiment, grown in several midwestern states in 1978. They compared performance of the hybrids at two levels of nitrogen fertilization: 90 and 269 kg/N/ha.

RESULTS

Trial results show that during the past 70 years, genetic yielding ability of hybrids adapted to central Iowa has improved at a linear rate of about 74 kg/ha/yr (Table 2, Fig. 1). Linear improvements in yield were exhibited in each year of the test (Fig. 2). Growing conditions varied markedly among seasons: 1991 was too hot and dry, 1993 was too cold and wet, and 1992 and 1994 were nearly ideal for high grain yield. Rate of improvement in yield was greatest in high yield seasons and least in low yield seasons (Table 2, Fig. 2), and greatest at the high density and least at the low density (Table 2, Fig. 3). The hybrids showed linear improvement in grain yield when subjected to drought, to water-logged soils, to soils deficient in nitrogen, or to conditions promoting maximum yields. They showed linear improvements in resistance to root lodging, premature death and stalk rot, second generation European corn borer (*Ostrinia nublalis*), the stresses of high density planting, and stress-induced silk delay and barrenness. The hybrids have shown linear reductions in tassel size. Since about 1960 they have shown a linear reduction in grain protein percentage and linear increases in leaf erectness, harvest index and grain starch percentage. There was little or no change over time in growing degree units to anthesis, grain moisture percent at harvest, plant and ear height, leaf number per plant, leaf area per plant, fodder weight per plant, grain test weight, grain oil percent, resistance to leaf feeding by first generation of European corn borer, or resistance to Northern Corn Leaf Blight (*Helminthosporium turcicum*). There was no increase in grain yield over time when hybrids were grown at very low densities (1 plant/m^2). Hybrids differed significantly in yielding ability at the very low density, but yield differences were not associated with year of hybrid release (Fig. 3). Planting at very low density reduces stress to a minimum and allows maximum grain production per plant.

DISCUSSION

Results of this experiment agree with the hypothesis that increased stress resistance is the primary cause of increased yielding ability of hybrids developed for central Iowa during the past 70 years. A secondary cause of increased yielding ability appears to be changes that increase efficiency of grain production, e.g. smaller tassels and reduced grain protein percent. Maximum grain production per plant in absence of stress is unchanged, therefore the newer hybrids can still produce increased amounts of grain per plant when growing conditions are better than average; i.e., breeding for stress tolerance has not reduced ability to maximize yield in absence of stress. Many or most of the measured changes were for traits that were not subject to direct selection by breeders; the changes seem to have been produced by indirect selection. They probably are a consequence of intense selection for superior yielding ability over a broad spectrum of on-farm growing conditions, i.e., for dependable high yield.

(It probably is important to note that each hybrid in this experiment proved its worth in its time on thousands of farms during a period of several years, each year with different kinds of stress. This is why each of them was a sales leader. Many other hybrids with equally good records in the breeders' yield trials were released at the same time as these successful hybrids, but they failed to stand up to the ensuing large scale, rigorous, multiple-season test.)

Several traits did not change over time. They are of two kinds: those which the breeders intentionally held constant, such as plant height and grain moisture at harvest, and those which stayed constant in absence of breeder attention, such as grain oil percent and resistance to leaf feeding by first generation European corn borer. One can speculate that grain oil percent stayed constant because of a baseline requirement for kernel germination, and first generation corn borer resistance stayed constant because first generation borer damage in Iowa during the past 70 years caused little or no reduction in grain yield, on average.

Future breeding plans should take into account the high probability that little or no additional reduction can be tolerated in such traits as grain protein percent or reduced tassel size, and little more progress can be made in the upright leaf habit; thus it seems likely that no further help in increasing grain yield can be expected from continued change in these traits. The best way to effect future gains in yielding ability may be to make further improvements in tolerance to high plant densities, in combination with improvements in potential yield per plant under low stress environments. Continuing yield gains also can be expected by selecting for better resistance to second (and perhaps first) generation European corn borer, and by making improvements in internal physiological traits conferring heat and drought tolerance.

Results of this retrospective experiment agree with the generally accepted premise that widespread yield testing over several years in the intended area of adaptation appears to be the best way to select for hybrids with multiple-stress resistance and therefore higher yield and greater dependability (Baker, 1955). Breeder trials and farmer trials (on-farm “strip tests”) are equally essential for achieving this end. But trials conducted at multiple plant densities (e.g., high, low, and normal densities), or in specially chosen environments such as low fertility, drought, insect infestation, or disease inoculation are also very useful and sometimes essential. They will help the breeder to characterize hybrids and identify breeding stocks with specific desirable or undesirable traits.

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Fig. 1. Grain yield per hybrid regressed on year of hybrid introduction. Averages of 4 years, 3 locations and 3 densities per year. Yield per hybrid is plotted for the density with highest average yield. The 1930 entry is Reid Yellow Dent (RYD).

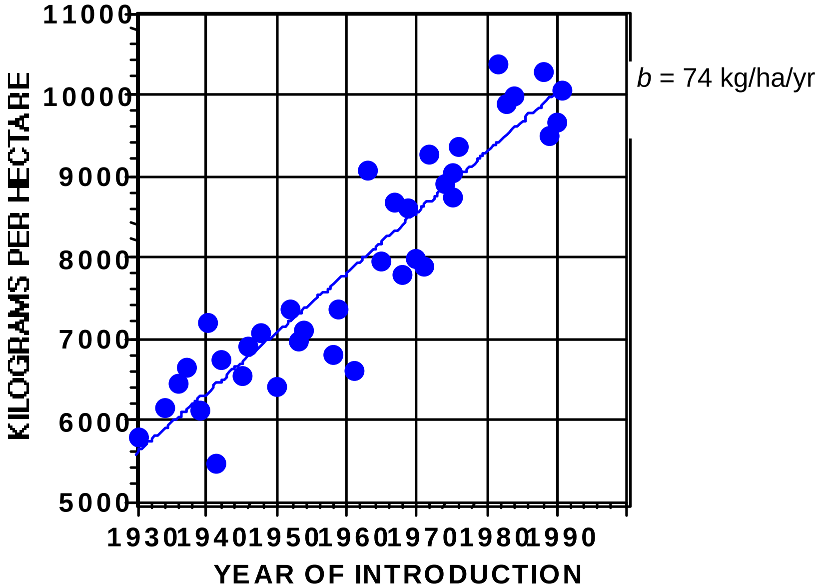

Fig. 2. Grain yield per hybrid regressed on year of hybrid introduction in four years, 1991-1994. Averages of three densities: 30, 54, and 79 K/ha. Yield per hybrid is plotted for the density with highest average yield.

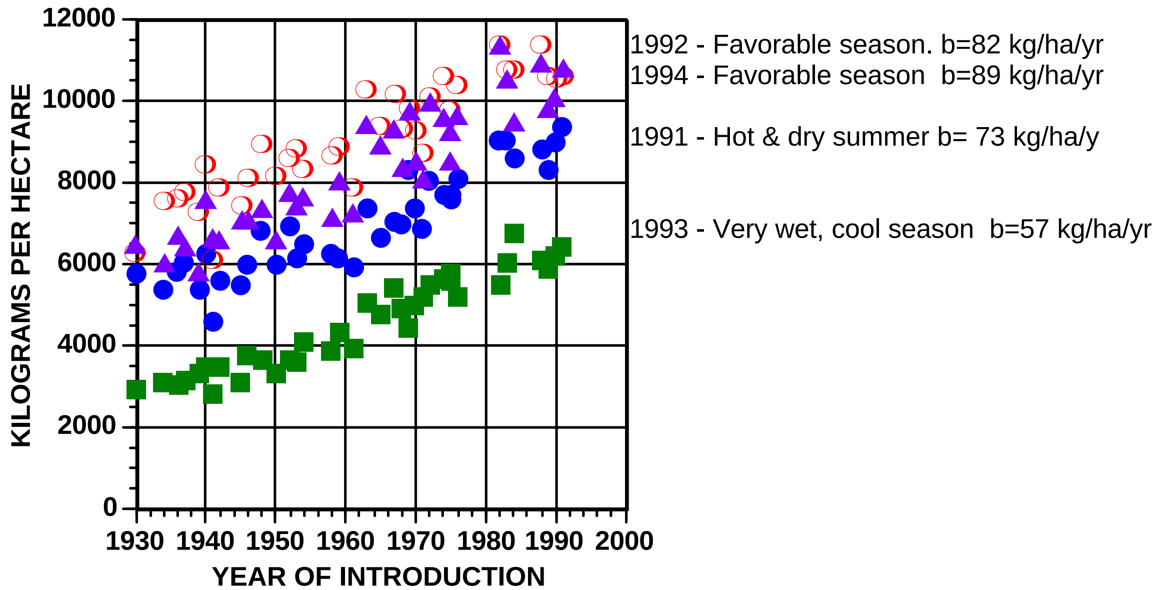

Fig. 3. Grain yield per hybrid regressed on year of hybrid introduction at 4 densities: 10, 30, 54 and 79 K/ha. Data from 3 locations, 1994.

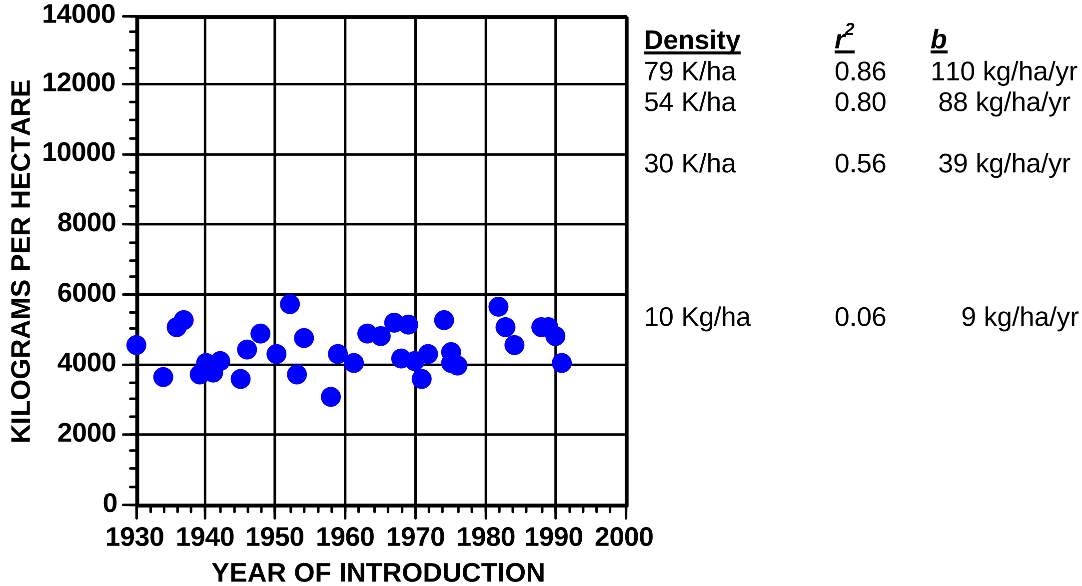

Table 1. List of hybrids and year of release. RYD = Reid Yellow Dent, open pollinated variety.

HYBRID	YEAR	HYBRID	YEAR	HYBRID	YEAR
RYD	1930	301B	1952	3517	1971
351	1934	354	1953	3366	1972
307	1936	329	1954	3301A	1974
317	1937	354A	1958	3529	1975
330	1939	328	1959	3541	1975
336	1940	3618	1961	3382	1976
340	1941	3306	1963	3377	1982
339	1942	3376	1965	3378	1983
344	1945	3390	1967	3475	1984
352	1946	3571	1968	3379	1988
350B	1948	3334	1969	3362	1989
347	1950	3388	1970	3417	1990
				3394	1991

Table 2. ERA hybrids, 1991-1994 trials. Regressions of trait on year of introduction; 36 hybrids, 1 open pollinated variety.

TRAIT	YEARS	DENSITY	*b*	r^2
Grain yield	1991-4	30, 54, 79 K/ha	+74 kg/ha/yr#	0.86
Grain yield	1991	30, 54, 79 K/ha	+73 kg/ha/yr#	0.78
Grain yield	1992	30, 54, 79 K/ha	+82 kg/ha/yr#	0.84
Grain yield	1993	30, 54, 79 K/ha	+57 kg/ha/yr#	0.87
Grain yield	1994	30, 54, 79 K/ha	+89 kg/ha/yr#	0.81
Grain yield	1991-4	79 K/ha	+93 kg/ha/yr	0.91
Grain yield	1991-4	54 K/ha	+71 kg/ha/yr	0.87
Grain yield	1991-4	30 K/ha	+33 kg/ha/yr	0.64
Grain yield	1991-4	10 K/ha	+ 8 kg/ha/yr	0.10
Grain yield	1978	{269 kg N}	+53 kg/ha/yr	0.59
Grain yield	1978	{90 kg N}	+66 kg/ha/yr	0.84
Leaf angle score	1991-4	30, 54, 79 K/ha	+1.0 score/10 yr	0.65
Not-tillered plts %	1992&4	30, 54, 79 K/ha	+4%/10 yr	0.48
Tassel weight	1992	30, 54, 79 K/ha	-0.5 gm/10 yr	0.70
Tassel branch no.	1992	30, 54, 79 K/ha	-2.5 brnch/10 yr	0.66
Staygreen score	1991-4	30, 54, 79 K/ha	+0.6 score/10 yr	0.66
Not stalk-lodged %	1991-4	30, 54, 79 K/ha	+3%/10 yr	0.68
Not root-lodged %	1991-2	30, 54, 79 K/ha	+9%/10 yr	0.66
ECB2 damage score	1992&4	30, 54, 79 K/ha	+0.5 score/10 yr	0.58
ECB2 tunnel length	1992	30, 54, 79 K/ha	-0.6 in./10 yr	0.46
Silk delay GDU##	1991-4	30, 54, 79 K/ha	-6 GDU/10 yr	0.61
Ears per 100 plants	1992&4	30, 54, 79 K/ha	+2 ears/10 yr	0.74
Rows per ear	1992	30, 54, 79 K/ha	-0.5 row/10 yr	0.36
Kernels per row	1992	30, 54, 79 K/ha	+0.4 kernels/10 yr	0.06
Kernels per ear	1992	30, 54, 79 K/ha	-11 kernels/10 yr	0.11
100 Kernel weight	1992	30, 54, 79 K/ha	+0.7 g/10 yr	0.31
Grain protein %	1992	30, 54, 79 K/ha	-0.3%/10 yr	0.68
Grain starch %	1992	30, 54, 79 K/ha	+0.3%/10 yr	0.56
Harvest index %	1993	10&54 K/ha	+1%/10 yr	0.42
50% silk GDU	1991-4	30, 54, 79K/ha	-5 GDU/10 yr	0.16
50% anthesis GDU	1991-4	30, 54, 79K/ha	+1 GDU/10 yr	0.01
Plant height	1991-4	30, 54, 79K/ha	-2 cm/10 yr	0.23
Ear height	1991-4	30, 54, 79K/ha	-3 cm/10 yr	0.33
Ear node	1992	30, 54, 79K/ha	+0.1 node/10 yr	0.05
Leaf area/plant	1992	30, 54, 79 K/ha	-16 cm^2 /10 yr	0.00
Fodder weight/plant	1993	10&54 K/ha	+12 gm/10 yr	0.00
NLB score	1994	30, 54, 79K/ha	+0.7 score/10 yr	0.34
ECB1 leaf feed score	1994	30, 54, 79K/ha	+0.3 score/10 yr	0.19
Grain oil %	1992	30, 54, 79K/ha	-0.0 %/10 yr	0.07
Test weight	1991-4	30, 54, 79K/ha	+0.2 lb/10 yr	0.10

regression calculation used density with highest yield, per hybrid.
GDU = growing degree units, Celsius