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Differential Response of Maize (*Zea mays* L.) to Mass Selection in Diverse Selection Environments[1]

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Summary. The present study was designed to find what seasonal effect mass selection would render when practiced within a maize (*Zea mays* L.) population. Three subpopulations of "Mezcla Varietales Amarillos" population (MVA) were selected for prolificacy and grain yield in three different seasonal conditions: (*i*) MVA-A selected in rainy seasons (A); (*ii*) MVA-B selected in dry seasons (B); (*iii*) MVA-AB selected under both seasonal conditions each year. Three cycles in MVA-A and MVA-B, and six in MVA-AB were tested during three A and three B growing seasons for evaluation of progress.

Mass selection in MVA-A resulted in an increase in grain yield of 10.5% per cycle when tested in the A seasons (direct response) and only 0.8% when tested in the B seasons (indirect response). For ears per plant the corresponding responses were 8.8 and 1.0%. The direct response in grain yield in MVA-B was only 2.5% per cycle whereas it was 7.6% when tested in the A seasons. The gain in ears per plant was 11.4% in the tests in the A seasons, but the direct response was 4.4% per cycle. In MVA-AB, there was a gain in grain yield of 5.3 and 1.1% per cycle in the tests in A and B seasons. For prolificacy, the respective gains were 7.0 and 3.3% per cycle.

Introduction

Mass selection has been practiced successfully in maize (*Zea mays* L.) by several breeders (Gardner 1961, 1969, Harpstead et al. 1967, Lonnquist 1964, 1967, Lonnquist et al. 1966, Torregroza and Harpstead 1967). All the reports deal with selection in only one selection environment. The authors are not aware of reports in the literature on mass selection for prolificacy and grain yield in maize in different selection environments beginning with the same original population. Such studies have been done in some animal species (Cockrem 1963, Falconer and Latyszewski 1952, Frahm and Kojima 1966, Hammond 1947), under good and poor diets and high and low temperature conditions. The question is whether environmental conditions that enhance the expression of a desired character will result in more gain from selection than will unfavorable conditions. A large genotype × environment interaction necessitates the development of varieties highly adapted to specific environments, and a small interaction permits the development of varieties that will perform well in a broad spectrum of environments (Allard and Bradshaw 1968, Cockrem 1963).

There are two planting seasons in the intermediate altitudes and in the lowlands of Colombia. At the Turipana Experimental Center, these two planting seasons have very different weather conditions. The Maize Breeding Program of the Instituto Colombiano Agropecuario has found limited progress from mass selection in many populations when cycles are obtained continuously in every season. However, in the highlands, where corn can be grown only in one season, mass selection has resulted in rapid progress in increasing number of ears per plant and grain yield. No information is available on genotype × season interaction in this two-season selection system.

The purpose of this paper is to report the results of several cycles obtained by mass selection for prolificacy and grain yield in a tropical variety of maize in different selection environments.

Materials and Methods

This study was carried out at Turipana Agriculture Experimental Center of the Instituto Colombiano Agropecuario (ICA). It is located at 12 meters above sea level, 12 kilometers northeast of Monteria, about 80 kilometers from the Atlantic coast of Colombia. For this paper, the two planting seasons each year at that location are called A and B seasons. The A season extends from April to September and has an average rainfall of about 600 mm. It is considered to be the more favorable cropping season. The B season extends from October to March and has an average rainfall of about 300 mm. Little or no rain usually occurs in the latter part of this season and there is less cloudiness than in the A season. There also is a larger difference between day and night temperatures in the B season, but the average temperature is about the same as for the A season (29 °C).

The population "Mezcla Varietales Amarillos" (MVA) was chosen for the present study due to its great diversity in genetic and geographic origin. In 1961 A (season A in

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the year 1961) a diallel cross was made among 10 yellow flint varieties adapted to Turipana. Those varieties were:

Venezuela 1, *Ven.* 400 and *Ven.* 471. Varieties representative of the race *Costeño* grown in the Caribbean coast of Venezuela and Colombia.

Cuba 2 and *Cuba* 345. Collections from the *Cuba flint* type from the Caribbean zone.

ETO. A Colombia composite adapted to almost all the tropical areas around the world.

Amarillo Theobromina. A collection from the Colombian race *Costeño*.

Nariño 330. Representative of the corn planted in the middle lands in southern Colombia.

Ecuador 542. From the lowlands of the coast of Ecuador.

Perú 330. From the lowlands of the coast of Perú.

Fifteen to twenty disease free ears from 50—60 healthy cross-pollinated plants were selected from each of the 45 F_1's. All ears from each cross were shelled and bulked. Two hundred seeds from each F_1 were mixed and the composite was planted in a 1/4 hectare isolation in 1962A on three dates to assure crossing of different maturity groups. Seeds from all ear-bearing plants were bulked. The population was then random mated for four generations. The seed of each generation was randomly picked from square isolated plots, 60×60 hills; the hills had two plants and each hill was separated 92 cm in either direction. In 1966A three samples of three kilos each were separated from the bulked sample of the fifth random-mated generation. They were called subpopulations MVA-A to be mass selected only in season A, MVA-B to be selected only in season B, and MVA-AB to be selected continuously in both seasons.

The selection criteria were *prolificacy* (two or more ears per plant) and *grain yield* for all three subpopulations. Each isolation had 42×52 hills separated 92 cm in either direction with 2 plants per hill at harvest. The selection intensity was 5%. Each grid consisted of 4 rows of 5 hills each (40 plants). At harvest the ears of 6—10 prolific plants per grid were dried to constant moisture and the two highest yielding plants were selected to be included in the composite for planting the next cycle. Forty-three seeds from each of the 200 selected plants were bulked together. Three composites were made in each cycle; one of these was for planting the next cycle, one for testing purposes and one for reserve which was stored in a cold room.

Yield trials were planted in seasons 1968B, 1969A, 1970A, 1970B, 1971A, and 1971B. The first three consisted of MVA-IA and IIA, MVA-IB and IIB, MVA-IAB to MVA-IVAB, MVA original, ICA V.105 and DH.104. ICA V.105 is a commercial variety released after two random mating generations of MVA-IIB. This cycle showed very good adaptability and yield performance throughout the Atlantic Coast in Colombia, based on 90 replications in ten environments. The last three seasonal tests consisted of MVA-IA to MVA-IIIA (obtained in 1967A, 1968A, and 1969A, respectively), MVA-IB, to MVA-IIIB (obtained in 1966B, 1967B, and 1968B, respectively), and MVA-IAB to MVA-VI AB (obtained in 1966B, 1967A, 1967B, 1968A, 1968B, and 1969A, respectively). The design used in each test was a randomized complete block with ten replications. Plots were two rows with 10 hills each, with hills and rows separated 92 cms in either direction. Five seeds were planted per hill and later thinned to three plants per hill. At harvest ear yields were recorded to the nearest tenth of a kilogram. The ear yields were corrected for missing hills by the method given by Jugenheimer and Williams (1957). Grain yields, adjusted to 15.5% moisture, were obtained by the method of Gorsline and Thomas (1963).

Table 1. *Yield of grain of the original maize population MVA and estimates of average gain per cycle in grain yield in three of its selected subpopulations tested during six seasons at Turipana, Colombia*

Population	Season tested						Weighted Regression ‡ in		
	1968B	1969A	1970A	1970B	1971A	1971B	„A"	„B"	„Both seasons"
MVA (Original)	17.0 q/ha	31.9 q/ha	30.2 q/ha	45.3 q/ha	15.4 q/ha	21.6 q/ha			
MVA-A ‡‡	9.1* ±.64 (2)+	13.9±3.72 (2)	−2.5±2.02 (3)	3.9±1.67 (3)	14.0*±2.94 (3)	−3.1±1.31 (3)	10.5*±3.13	0.8±2.17	4.9*±2.18
MVA-B	19.1±1.76 (2)	0.4±1.66 (2)	−2.1±2.84 (2)	1.5±1.71 (3)	13.7±4.14 (3)	−2.4±3.91 (3)	7.6±3.5	2.5±3.12	4.7*±2.34
MVA-AB	8.4*±2.90 (4)	3.2*±.86 (4)	−0.7±.35 (4)	1.3*±.34 (6)	8.0*±2.15 (6)	−1.5±.62 (6)	5.3**±1.44	1.1±1.0	2.9**±.92

* Significantly different from zero at $P = .05$
** Significantly different from zero at $P = .01$
+ Figures in parentheses = number of cycles tested
‡ Regression of grain yield in percent of the original variety on cycles of selection weighted by the number of tests of each cycle.
‡‡ *Gains* of the subpopulations are given in percent of the original population

Gain from selection was estimated for each subpopulation for each season and over both seasons by the weighted regression of each trait obtained from all individual observations (in percent of the original population), on cycles of selection.

Results

Yield

The results of the test conducted for grain yield in six seasons are summarized in Table 1. The 1970B season was the highest-yielding one. Unusually well distributed rainfall was present during that particular growing season. The lowest-yielding seasons were 1970A and 1971B; there was an unusual lack of rainfall for an A season in the former and an extreme drought in the latter. As a consequence, the MVA-A selections performed better in 1970B and the original MVA population outyielded the selected generations in 1970A and 1971B. For a clearer picture of the performance of the three subpopulations, the data from the tests in the A and B seasons, and overall seasons are presented in Fig. 1, 2, and 3.

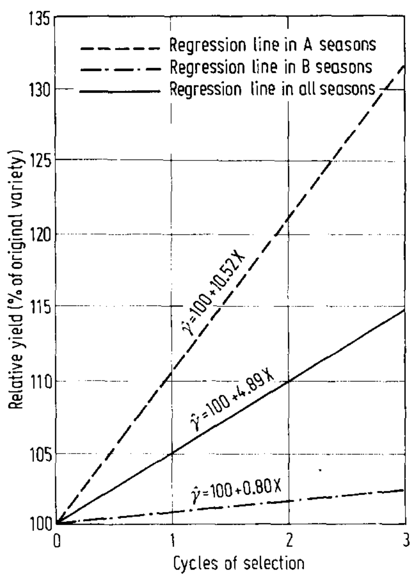

Fig. 1. Linear regressions of relative yield on cycles of selection in MVA-A subpopulation in tests in varying seasons at Turipana, Colombia

As shown in Fig. 1, a substantial gain of 10.5% per cycle (direct response) was obtained in the MVA-A selections when tested over three A seasons, but only 0.8% per cycle (indirect response) when tested in three B seasons. On the other hand, the selections made in the B season (MVA-B), Fig. 2, showed gains of 7.6% per cycle when tested in the A seasons (indirect response), but only 2.5% per cycle in the B seasons (direct response). The observed progress in the continuous selection scheme (MVA-AB), Fig. 3, was 5.3% per cycle in the A seasons and 1.1% per cycle in the B season tests.

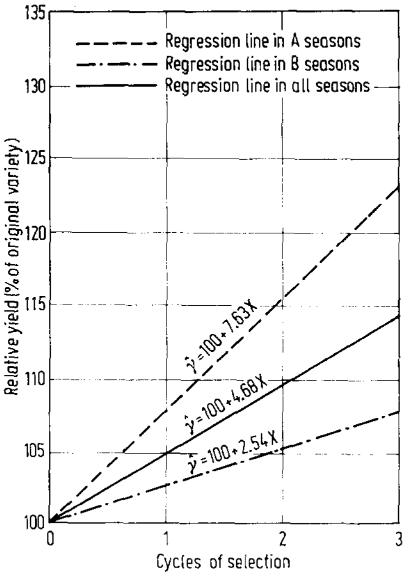

Fig. 2. Linear regressions of relative yield on cycles of selection in MVA-B subpopulation in tests in varying seasons at Turipana, Colombia

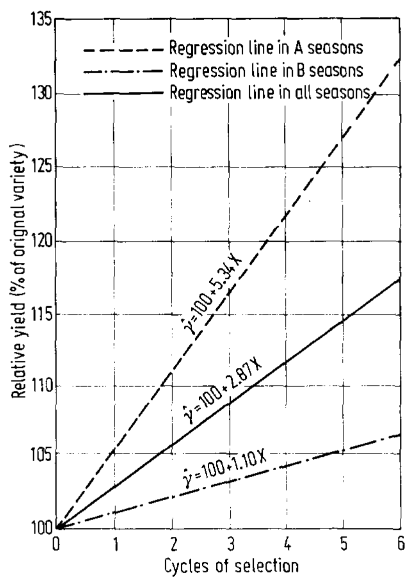

Fig. 3. Linear regressions of relative yield on cycles of selection in MVA-AB subpopulation in tests in varying seasons at Turipana, Colombia

The gains per cycle based on both seasons (a total of six) were 4.9% for MVA-A, 4.7% for MVA-B, and 2.9% for MVA-AB. Total gains as estimated from the above rates were 3 (4.9%) = 14.7% for MVA-A, 3(4.7%) = 14.1% for MVA-B, and 6(2.9%) = 17.4% for MVA-AB.

From a combined analysis of variance, the MVA-A cycles by A season interaction showed significance (P = .01) whereas the MVA-A cycles by B season interaction showed no significance. Also the MVA-B by A season interaction was significant (P = .05) while no significance was shown by the MVA-B by B season interaction. The interaction of MVA-AB subpopulation was non-significant in either season.

Prolificacy

The results of seasonal mass selection on prolificacy are summarized in Table 2. The MVA-A subpopulation showed an increase of 8.8% per cycle when tested in the A seasons but only 1.0% in the B season tests. The MVA-B subpopulation showed a substantial increase per cycle of 11.4% when tested in the A and 4.4% when tested in the B seasons. In the MVA-AB selections a gain of 7.0% and 3.3% per cycle were obtained when tested in A and B seasons, respectively. Based on the overall means, the gain per cycle in ears per plant was larger in the MVA-B selections (7.4%) than in the other two selected sub-populations (4.3% for MVA-A and 4.9% for MVA-AB). Total gains after three cycles in MVA-A and MVA-B, and six cycles in MVA-AB were 12.9%, 22.2%, and 29.4% over the original MVA population, respectively.

The MVA-B selection cycles by A season interaction was significant ($P = .01$) for prolificacy whereas no other interactions were significant for the other subpopulations when tested in either season.

Discussion

The results reported in this paper are in agreement with other studies in different populations of maize when mass selection either for prolificacy or for yield was made within each subpopulation in only one selection environment (Gardner 1961, 1969, Harpstead et al. 1967, Lonnquist 1964, 1967, Lonnquist et al. 1966, Torregroza and Harpstead 1967). Although genetic variance studies have not been performed in the MVA population and its subpopulations, the data suggest that, because of the upward linear trend in both traits, the seasonal mass selection practiced had successfully increased the frequency of favorable genes.

In a two-season per year breeding program, such as the one in Colombia, the results obtained in this study are of importance. It appears that more gain *per cycle* is achieved by selecting for grain yield in either the A or in the B seasons under similar environmental conditions, than when selecting in both seasons continuously. It is not clear why the indirect response (in the A seasons) was larger than the direct response for the MVA-B selections, or why more gain was observed for MVA-B than for MVA-AB selections when tested in the A seasons. Since the confidence intervals overlap, the authors have chosen to simply ignore these particular issues for the moment. However, if the trends continue, explanations will have to be developed in the future.

It would appear from these results that almost as much gain per year in grain yield could be achieved

Table 2. *Ears per plant of the original maize population MVA and estimates of average gain per cycle in ears/plant in three of its selected subpopulations tested during six seasons at Turipana, Colombia*

Population	Season tested						Weighted Regression ‡ in		
	1968 B	1969 A	1970 A	1970 B	1971 A	1971 B	„A"	„B"	„overall"
MVA (Original)	0.84⁺⁺	0.78	0.88	0.96	0.59	0.82			
MVA-A	3.8 ± .50 (2)⁺	11.3 ± 4.62 (2)	2.1 ± 1.82 (2)	1.7 ± .68 (3)	10.4* ± 1.55 (3)	−0.8 ± 2.43 (3)	8.8** ± 1.83	1.0 ± 1.08	4.3** ± 1.42
MVA-B	8.1 ± 1.66 (2)	19.5 ± 14.60 (2)	1.6 ± 2.06 (2)	4.7 ± 1.83 (3)	12.1 ± 5.62 (3)	2.8 ± 2.04 (3)	11.4* ± 4.40	4.4** ± 1.20	7.4** ± 2.18
MVA-AB	2.7* ± .68 (4)	10.8* ± 2.69 (4)	3.1** ± .16 (4)	3.6** ± .40 (6)	7.1* ± 1.78 (2)	3.2** ± .52 (6)	7.0** ± 1.23	3.3** ± .29	4.9** ± .93

* Significantly different from zero at $P = .05$
** Significantly different from zero at $P = .01$
⁺ Figures in parentheses = number of cycles tested
⁺⁺ Obtained from all individual observations
‡ *Ears per plant* of the original population are given in the actual mean of ten replications, *gains* of the subpopulations are given in percent of the original population.

by selection in the individual seasons (A or B) as one would achieve by continuous selection (AB). From a short term point of view one might still choose the continuous selection approach on the grounds that the additional gains per year were worth whatever additional costs would be involved. From a long term point of view, the authors feel that there is a substantial probability that higher selection limits could be reached in the more restrictive selection environments (either A or B instead of AB).

It appears that selection for prolificacy is more successful when performed under weather stress (MVA-B subpopulation). At Nebraska, much of the increase in prolificacy with mass selection for yield has not been expressed when the populations were grown under drought stress (Gardner 1969). Data from the present report suggest that selection for prolificacy under severe conditions may result in increases under "good" conditions as well, while selection for prolificacy under "good" conditions may not carry through when the material is placed under drought stress.

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