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Analysing yield stability of maize genotypes using a spatial model

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Summary. The yield stability of some CIMMYT tropical maize (*Zea mays* L.) populations of early and intermediate maturity, measured by the performance of varieties derived from them, was determined. Results of the stability analyses, conducted over international environments from 1980 to 1983, indicated that selections from Mezcla Amarilla exhibited good stability in high yielding sites. Varieties derived from Antigua-Republica Dominicana tended to be more stable in unfavourable environments, whereas selections from Blanco Cristalino-1 and Blanco Dentado-2 were stable in both low and high production sites. The combination of enviromental factors in the specific test locations, namely Poza Rica (Mexico), Tocumen (Panama), Islamabad (Pakistan), and Ferkessedougou (Ivory Coast), allowed selection of varieties that are very stable in other regions of the world. The varieties formed on the basis of multilocational data do not seem to be any more stable than those formed using data from a single location.

Key words: Spatial model – Stability – Maize

Introduction

Most of the maize (*Zea mays* L.) produced in tropical countries is grown as a subsistence crop in difficult production environments. Subsistence farmers are concerned about factors such as grain color, grain texture, taste, and yield stability as well as the yield potential of the variety. The CIMMYT Maize Program is primarily oriented towards the needs and problems of developing countries, for which it is developing and improving broad-based gene pools and populations in conjunction with international distribution and testing of varieties derived from this germplasm. CIMMYT's maize populations, improved by full-sib selection (Pandey et al. 1986), are selected for yield potential, stress tolerance, plant type, and pest resistance. Varieties are derived from those populations and tested in a wide range of environments in international trials. The maize breeding programme promotes yield stability in the populations and varieties distributed to national agriculture researchers around the world. This maize germplasm should offer, not only yield potential, but also yield stability across the range of environmental conditions that farmers expect to encounter.

Multivariate methods have been used for analysing a genotype-by-environment data matrix (Westcott 1986). The multidimensional scaling or ordination technique used in this analysis attempt to represent the structure or pattern that may be present in the observed data matrix in a low-dimensional space by mean of a simple spatial model or diagram (Everitt and Dunn 1983). The distance between points in the low-dimensional diagram will reflect the relationship between items in the original observed matrix. Similar items are, therefore, represented by points which are close together and dissimilar items are represented by points far from each other.

This study uses a spatial model (Westcott 1987) (i) to determine the yield stability of some short, intermediate season, tropical maize populations as measured by the performance of the varieties derived from them, and (ii) to identify specific locations where stable varieties have been formed.

Materials and methods

Details of the CIMMYT maize population improvement programme and its international testing system are given in

Johnson (1974), and Vasal et al. (1982). This study focused on two sets of varieties tested at 20 to 80 locations in Experimental Variety Trials (EVTs): (1) EVT 14A, which includes yellow flint-grained varieties selected from populations 26, 31 and 35, and (2) EVT 14B, which includes white flint and dent-grained varieties derived from populations 23, 30, 32, and 49. These tropical populations are of early to intermediate maturity and were described in various CIMMYT publications (CIMMYT 1982 and 1984). All trials were conducted in 1980, 1982, and 1983. The trait under consideration was grain yield (t/ha). In 1980 EVT 14B included only selections from Population 30. Each entry (variety) in each of the trials is identified by the number of the population from which the variety was derived and the year, country, and site where selection was performed. When the name of the variety is followed by a number in brackets, the selection was made by breeders in the national program. The "across" varieties are formed from the 10 families which performed best across test sites.

Statistical analysis

The spatial method used was described by Westcott (1987) and its advantages over the traditional regression method for analysing yield stability were discussed by Crossa (1988).

Sites were separated into high and low yielding classes (HYS and LYS, respectively) based on the mean site yield. The two sets of sites outside the lower (LYS) and upper (HYS) quartiles were examined in turn.

Principal coordinates analysis was performed in cycles with L1 corresponding to the analysis for the lowest yielding site, L2 for the two lowest yielding sites, and so on. The same procedure was carried out on the high yielding sites (H1, H2, etc.). For each cycle a two-dimensional diagram was generated that shows the original relationship among the genotypes. The measure of similarity between any pair of genotypes proposed by Westcott (1987) compares its average mean yield with the best yield performer in a given environment. This measure of similarity allows the high yielding genotypes to be represented by points located further away from genotypes that yield below the average mean. Varieties that consistently appear further away from the centre of the scatter points diagram are the best performers and the most stable. In this study the successive two-dimensional plots associated with principal coordinates analysis over a particular set of environments are described, and four diagrams (Figs. 1–4), corresponding to L3, L12, H3 and H12 of EVT 14A in 1980, are presented as typical examples.

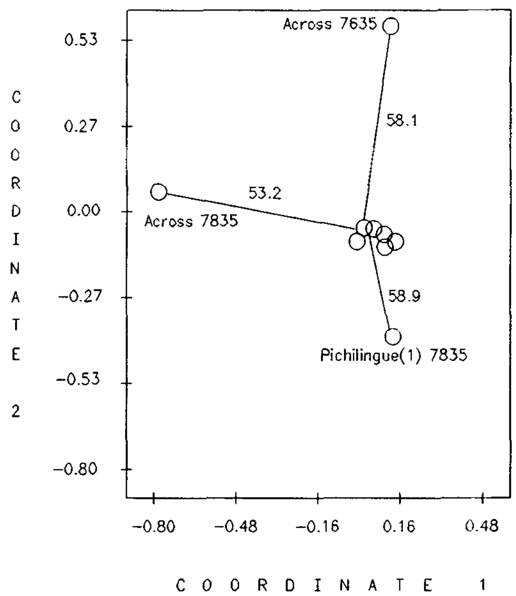

Fig. 1. Plot of similarities distances (expressed as percentages) among varieties relative to the first two principal coordinates in cycle L3 of the analysis of the EVT 14A in 1980

Table 1. Varieties in EVT 14A in 1980 ranked in descending order by their mean yields (t/ha) over all sites

Rank	Variety no.	Variety name	Country of origin	Mean
1	2	Tocumen (1) 7926	Panama	4.82
2	1	Poza Rica 7926	Mexico	4.65
3	11	Across 7726		4.29
4	3	Poza Rica 7931	Mexico	4.28
5	9	Across 7835		4.25
6	8	Bahia 7835	Brasil	4.25
7	7	Pichilingue 7835	Ecuador	4.23
8	4	Tocumen (1) 7931	Panama	4.22
9	6	Pichilingue (1) 7835	Ecuador	4.21
10	12	Across 7635		4.16
11	5	Levy 7835	Haiti	4.13
12	10	Amarillo cristalino-2	Mexico	4.06

Results

Stability analysis of EVTs in 1980

Three varieties from Mezcla Amarilla (Population 26), two from Amarillo Cristalino-2 (Population 31), six from Antigua-Republica Dominicana (Population 35), and a random sample of seeds representing Amarillo Cristalino-2 were evaluated in EVT 14A at 49 locations (their mean yield and rank are given in Table 1). Principal coordinates analyses of 12 low yielding locations of EVT 14A have shown a clear pattern of stability for Pichilingue (1) 7835 and Across 7635 (ranked 9th and 10th overall, respectively). The latter variety appeared closer to the centre in L7–L12. Across 7835, Tocumen (1) 7926, and Poza Rica 7926 (ranked 5th, 1st, and 2nd, repectively) were outlying points in just a few L cycles. A two-dimensional plot associated with the analysis for the three lowest yielding sites (L3) is presented in Fig. 1. Across 7835 was an outlying point only in L2–L6. The diagram in Fig. 2 shows the principal coordinates analysis for the 12 lowest yielding sites (L12). As mentioned previously, while Across 7635 was closer to the centre in L7 onwards, Tocumen (1) 7926 and Poza Rica 7926 showed signs of stability (being represented by remote points) only in L8–L12. Results of the analysis for the high yielding sites

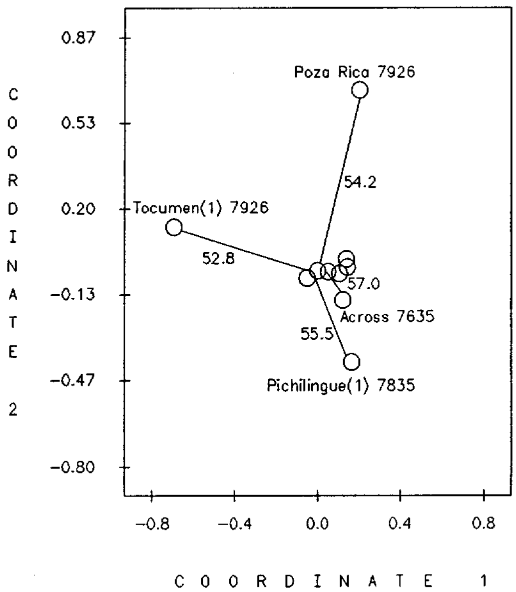

Fig. 2. Plot of similarities distances (expressed as percentages) among varieties relative to the first two principal coordinates in cycle L12 of the analysis of the EVT 14A in 1980

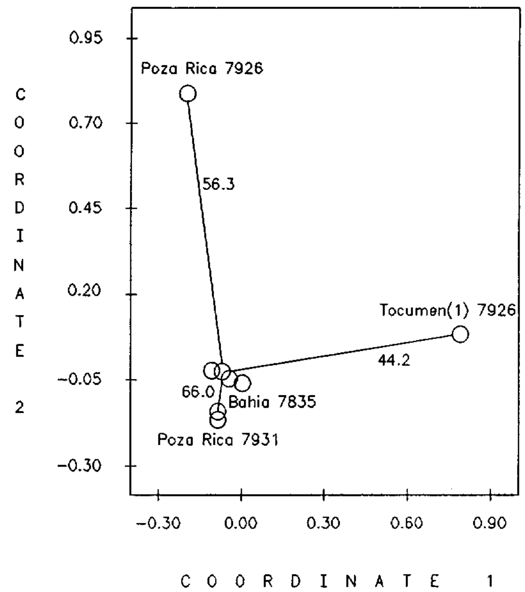

Fig. 4. Plot of similarities distances (expressed as percentages) among varieties relative to the first two principal coordinates in cycle H12 of the analysis of the EVT 14A in 1980

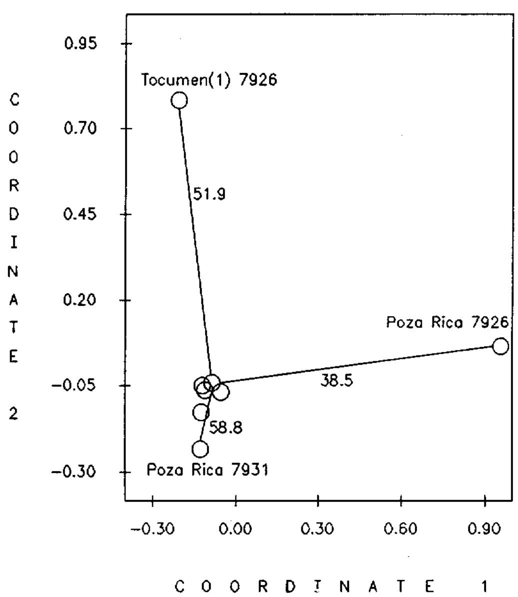

Fig. 3. Plot of similarities distances (expressed as percentages) among varieties relative to the first two principal coordinates in cycle H3 of the analysis of the EVT 14A in 1980

showed that Poza Rica 7926 and Tocumen (1) 7926 were the remotest points in all the H cycles (representing the most stable varieties), followed by Poza Rica 7931 (ranked 4th overall), which appeared closer to the centre in H3 and H7–H12. A typical two-dimensional diagram of the analysis for the three highest yielding sites (H3) is given in Fig. 3. The scatter points diagram associated with the analysis for the 12 highest yielding sites (H12) is given in Fig. 4. Bahia 7835 cannot be considered a stable variety because it was closer to the centre in H7–H10 and coincided with Poza Rica 7931 in H11 and H12. In summary, for LYS only Pichilingue (1) 7835 and Across 7635 can be considered stable, although the latter was closer to the centre in L7 onwards. Across 7835, Tocumen (1) 7926, and Poza Rica 7926 are not stable in LYS since they were remote points in just a few L cycles. Tocumen (1) 7926, Poza Rica 7926, and Poza Rica 7931 were consistently the remotest points in the analyses for HYS and are therefore the most stable varieties in favourable environments.

In EVT 14B, six varieties derived from Blanco Cristalino-2 (Population 30) in 1979, plus a random sample of seeds representing Blanco Cristalino-2, were evaluated at 42 locations (Table 2), 11 of which were classified as being low yielding. In the analyses for the LYS and HYS, Pirsabak (1) 7930 (ranked 1st overall) shows a clear pattern of stability in all L and H cycles. While Poza Rica 7930 was an outlying point in all the L cycles, Santa Cruz 7930 and Pirsabak (2) 7930 (ranked 3rd and 2nd overall, respectively) performed well in most of the H cycles. Jutiapa 7930 was stable in the first three and last three L cycles and Jutiapa (1) 7930 featured in L5–L11. Santa Cruz 7930 showed an erratic stability pattern in the L cycles; it was a remote point in L3 and L8 but was closer to the centre of the diagram in L1, L9, and L10.

Table 2. Varieties in EVT 14B in 1980 ranked in descending order by their mean yield (t/ha) over all sites

Rank	Variety no.	Variety name	Country of origin	Mean
1	5	Pirsabak (1) 7930	Pakistan	3.83
2	6	Pirsabak (2) 7930	Pakistan	3.77
3	4	Santa Cruz 7930	El Salvador	3.73
4	3	Poza Rica 7930	Mexico	3.68
5	1	Jutiapa (1) 7930	Guatemala	3.67
6	7	Blanco cristalino-2	Mexico	3.65
7	2	Jutiapa 7930	Guatemala	3.65

Table 3. Varieties in EVT 14A in 1982 ranked in descending order by their mean yields (t/ha) over all sites

Rank	Variety no.	Variety name	Countries of origin	Mean
1	4	Across 7926		4.55
2	1	Piura (1) 7926	Peru	4.40
3	2	Islamabad (1) 7926	Pakistan	4.35
4	11	Poza Rica 8035	Mexico	4.28
5	3	Gral. Saavedra 7926	Bolivia	4.20
6	10	Islamabad 8035	Pakistan	4.20
7	12	Suwan 8035	Thailand	4.17
8	9	Across 7931		4.15
9	5	Sete Lagoas 7931	Brasil	4.09
10	6	Pichilingue 7931	Ecuador	4.03
11	7	Satipo (1) 7931	Peru	4.00
12	13	Across 7726		3.98
13	8	Satipo (2) 7931	Peru	3.84
14	14	Across 7635		3.78

Stability analysis of EVTs in 1982

Fourteen selections were evaluated at 55 locations in EVT 14A (Table 3), and the relationships between varieties at the 14 lowest and highest yielding sites were studied. Poza Rica 8035 (ranked 4th overall) was clearly the most stable in all of the L cycles, followed closely by Islamabad 8035, which appeared closer to the centre in L7–L14. The best yielding variety overall, Across 7926, did well in all of the L and H cycles, except L1, H1, and H2. Across 7931 was stable in L2 and L3 and performed similarly to Islamabad 8035 in L8–L14. Islamabad (1) 7926 (ranked 3rd) showed good stability in all of the H cycles; Piura (1) 7926 (ranked 2nd) was stable only from H6 to H14. Poza Rica 8035 and Across 7726 also showed signs of stability, the former performing well in H6, H7, and H9 to H14 and the latter in H4–H10.

Table 4 gives the mean grain yield and rank of 14 varieties included in EVT 14B and evaluated at 58 locations. In analyses of the fifteen lowest yielding environments, Ferkessedougou (1) 8023, Across 8023, and Los Diamantes 7823 (ranked 2nd, 1st, and 6th,

Table 4. Varieties in EVT 14B in 1982 ranked in descending order by their mean yield (t/ha) over all sites

Rank	Variety no.	Variety name	Country of origin	Mean
1	5	Across 8023		4.43
2	2	Ferkessedougou (1) 8023	Ivory Coast	4.36
3	4	Maracay 8023	Venezuela	4.33
4	9	Poza Rica 8032	Mexico	4.33
5	1	Poza Rica 8023	Mexico	4.29
6	14	Los Diamantes 7823	Costa Rica	4.22
7	3	Pirsabak 8023	Pakistan	4.21
8	11	Cotaxtla 8032	Mexico	4.15
9	10	Alajuela 8032	Costa Rica	4.13
10	12	Across 8049		4.07
11	8	Across 7930		3.80
12	13	Pirsabak (1) 7930	Pakistan	3.70
13	6	Ilonga (1) 7930	Tanzania	3.67
14	7	Kisanga 7930	Zaire	3.62

repectively) were the most remote points in most of the L cycles. However, while Ferkessedougou (1) 8023 started to show a trend toward stability in L5 and remained stable until the last analysis, the other two varieties were stable from L4 onwards (except L9, in which Across 8023 did not feature). Similar stability patterns were detected for Ferkessedougou (1) 8023 and Maracay 8023 when the favourable environments were analyzed. Both varieties were remote points from H2 to H15, the former being closer to the centre in H3 and H4 and the latter in H2. Poza Rica 8032 and Alajuela 8032 (ranked 4th and 9th overall, respectively) showed different stability patterns: while the former was remarkably stable from H7 onwards, the latter performed well in H1–H7. Poza Rica 8023 did not do badly in H4–H10 and also showed signs of stability in H13 and H14.

Stability analysis of EVTs in 1983

EVT 14A was conducted at 46 locations (Table 5), and a total of twelve low and high yielding sites were used for assessing the yield stability of 11 varieties. Results of the principal coordinates analyses indicate that La Molina 8131 and Across 7635, both of which performed relatively poorly over all sites (ranked 10th and 7th, respectively), were outlying points in all L cycles, indicating good stability in unfavourable environments. Islamabad (1) 8131 performed well in low yielding sites. It appeared closer to the centre in most of the L cycles and did not feature in L11 and L12. Different patterns of stability were found for the four highest yielding varieties (Poza Rica 8126, Suwan 8126, Suwan (1) 8131 and Across 7726) through principal coordinates analyses on 12 HYS. The first two were consistently the remotest points in each of the H cycles. These materials

Table 5. Varieties in EVT 14A in 1983 ranked in descending order by their mean yields (t/ha) over all sites

Rank	Variety no.	Variety name	Country of origin	Mean
1	2	Suwan 8126	Thailand	4.13
2	1	Poza Rica 8126	Mexico	3.99
3	10	Across 7726		3.89
4	6	Suwan (1) 8131	Thailand	3.85
5	9	Across 8035		3.83
6	4	Islamabad (1) 8131	Pakistan	3.81
7	11	Across 7635		3.80
8	5	Suwan 8131	Thailand	3.75
9	8	Iboperenda 8035	Bolivia	3.75
10	3	La Molina 8131	Peru	3.74
11	7	Across 8131		3.72

Table 6. Varieties in EVT 14B in 1983 ranked in descending order by their mean yield (t/ha) over all sites

Rank	Variety no.	Variety name	Country of origin	Mean
1	9	Rattray-Arnold (1) 8149	Zimbabwe	4.16
2	12	Los Diamantes (1) 7823	Costa Rica	4.14
3	7	Poza Rica 8149	Mexico	4.14
4	8	Ikenne 8149	Nigeria	4.12
5	10	Across 8149		4.09
6	6	Across 8032		3.99
7	5	Ilonga 8032	Tanzania	3.97
8	1	CIAT 8130	Colombia	3.72
9	2	Comayagua 8130	Honduras	3.60
10	4	Poza Rica 8130	Mexico	3.60
11	11	Pirsabak (1) 7930	Pakistan	3.54
12	3	Comayagua (1) 8130	Honduras	3.46

were followed by Across 7726, which appeared closer to the centre in H11 and H12, and by Suwan (1) 8131 which was closer to the centre in H1–H4.

In EVT 14B twelve varieties derived from Blanco Cristalino-1 (Population 23), Blanco Cristalino-2 (Population 30), ETO Blanco (Population 32), and Blanco Dentado-2 (Population 49) were evaluated at 38 sites (Table 6). In principal coordinates analysis of the ten lowest yielding sites, Poza Rica 8149 (ranked 3rd overall) was the remotest point in all of the L cycles, followed by Los Diamantes (1) 7823 (ranked 2nd), which appeared closer to the centre in L3, L7, and L8. Ikenne 8149 and Rattray-Arnold (1) 8149 (ranked 4th and 1st, respectively) were stable under favourable and unfavourable environmental conditions; the former did not show up in L5 and L6 and was closer to the centre in H1, H2, and L8–L10. The latter did not appear as a remote point in L1, H1, and L2. Ilonga 8032 did less well over all sites (ranked 7th) but showed good yield stability over the ten highest yielding sites (it appeared closer to the centre in H3, H5, and H7–H9). Los Diamantes (1) 7823, which showed excellent stability in the L cycles, also showed positive responses under favourable conditions since it was an outlying point in H1–H4 and H8–H10.

Discussion and conclusions

Stability analyses performed to study relationships among varieties and examine changes in their responses under different environmental conditions indicate that eight selections from Mezcla Amarilla (Population 26) were stable in EVT 14A from 1980 to 1983; seven of them showed a good stability in high yielding environments. Antigua-Republica Dominicana (Population 35) produced six stable varieties; four of them (Pichilingue (1) 7835, Across 7835, Islamabad 8035 and Across 7635) were stable in unfavourable environments. Some varieties included in EVT 14B (1982 and 1983) showed good stability across both low and high yielding environments. Those were Ferkessedougou (1) 8023, Los Diamantes (1) 7823, Ikenne 8149, and Rattray-Arnold 8149 which were derived from Blanco Cristalino-1 (Population 23) and from Blanco Dentado-2 (Population 49, from initial selection of full-sib families in Tuxpeno).

Results indicate that Mezcla Amarilla has produced the most stable genotypes for high yielding sites, while Antigua-Republica Dominicana gave rise to varieties that show good stability patterns under low yielding conditions. Population Mezcla Amarilla includes Tuxpeno, Cuban flints, and Corn Belt Dents and is considered to have very high yield potential. Antigua-Republica Dominicana has produced selections that perform well under low yielding conditions.

Only four across-location varieties (developed from multilocational data) were stable from 1980 to 1983: Across 7926 was stable in both low and high yielding sites (1982); Across 7635 showed good stability in LYS (1980 and 1983); Across 7726 was stable at HYS (1982 and 1983); and Across 7931 did well in LYS (1982). These results indicate that across-site selections are not consistently more stable than varieties formed on the basis of data from a single site. This finding is in agreement with the results of Crossa et al. (1988), who analyzed the yield stability of varieties selected from tropical full season maize populations.

One pattern that seems evident from the analysis is that environmental factors prevailing in some locations have allowed selection of varieties that have been more stable than materials based on data from some other sites. Among the sites where stable varieties are consistently selected are Poza Rica (Mexico), Tocumen (Panama), Islamabad (Pakistan), and Ferkessedougou

(Ivory Coast). Paliwal and Sprague (1982) also cited Poza Rica, Tocumen, and Ferkessedougou among locations which have given rise to varieties with top performance at several other locations. However, further collection and interpretation of data (on climate and soils, for example) which characterise these specific sites is needed to allow identification of more specific sites that give rise to stable varieties. These data would also give a better understanding of the influence of environmental factors on physiological processes that determine the phenology and yield of genotypes.

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