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CLASSIFICATION OF MAIZE TESTING LOCATIONS IN SUB-SAHARAN AFRICA BY USING AGROCLIMATIC DATA[1]

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ABSTRACT - Classification of locations in CIMMYT's International Maize Testing Program in Sub-Saharan Africa into regions was done by using agroclimatic variables. The study was undertaken to improve the efficiency of the testing program. Agroclimatic variables used to classify locations included altitude, average monthly and total yearly rainfall, average monthly temperatures, average monthly minimum temperatures, average monthly maximum temperatures, and average yearly minimum and maximum temperatures. Averages were calculated over a minimum of 10 years' data. The classification procedures used were Ward's method of cluster analysis and canonical discriminant analysis. Good discrimination of regions of maize testing locations was achieved by using all the variables, and cluster analysis resulted in groups that can be defined as two areas of West Africa with different rainfall patterns, and three areas of East and South Africa with different temperature patterns. Final determination of the efficiency and use of these regions and whether all locations were correctly classified will be determined by using input of collaborators with personal experience at the locations and actual practice in the International Maize Testing Program.

KEY WORDS: *Zea mays* L.; Cluster analysis; Variety testing; Canonical discriminant analysis.

INTRODUCTION

The identification of appropriate geographical regions for testing performance of maize (*Zea mays* L.) genotypes is an important component of a breeding program. There is little published data on the methodology for determining testing regions. Ford and Nielsen (1982) identified agricultural regions similar to existing research stations in the Montana Agricultural Experiment Station System by using several agroclimatologic variables. Russell and Moore (1970) used numerical analysis on agroclimatologic data to identify homoclimes in various parts of the world with stations in Australia. They found numerical analysis to be an acceptable technique to use for this problem but that data choice could be a limiting factor. Russell (1982) later determined homoclimes in Mexico and Central America with similar stations in Australia, which assisted him in a collection trip for tropical legumes suitable for Australia. A study in the State of Iowa, U.S.A.,

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combined counties into agroclimatic regions though the use of cluster analysis based on environmental variables (Ortiz-Valdez, 1985).

Yield and genotype x environment interaction have also been used to group environments for soybean [*Glycine max* (L.) Merr.] (Nieto *et al.*, 1983), cotton (*Gossypium hirsutum* L.) (Abou-El-Fittouh et al., 1969), and oats (*Avena sativa* L.) (Horner and Frey, 1957). Using principal component analysis, Boyd *et al.* (1976) found that yield differences between regions in the Western Australian wheat (*Triticum aestivum* L.) belt were not explained by other agroclimatic parameters. In general, however, plant breeders do not consider climate variables when selecting genotypes (Boyd *et al.*, 1976).

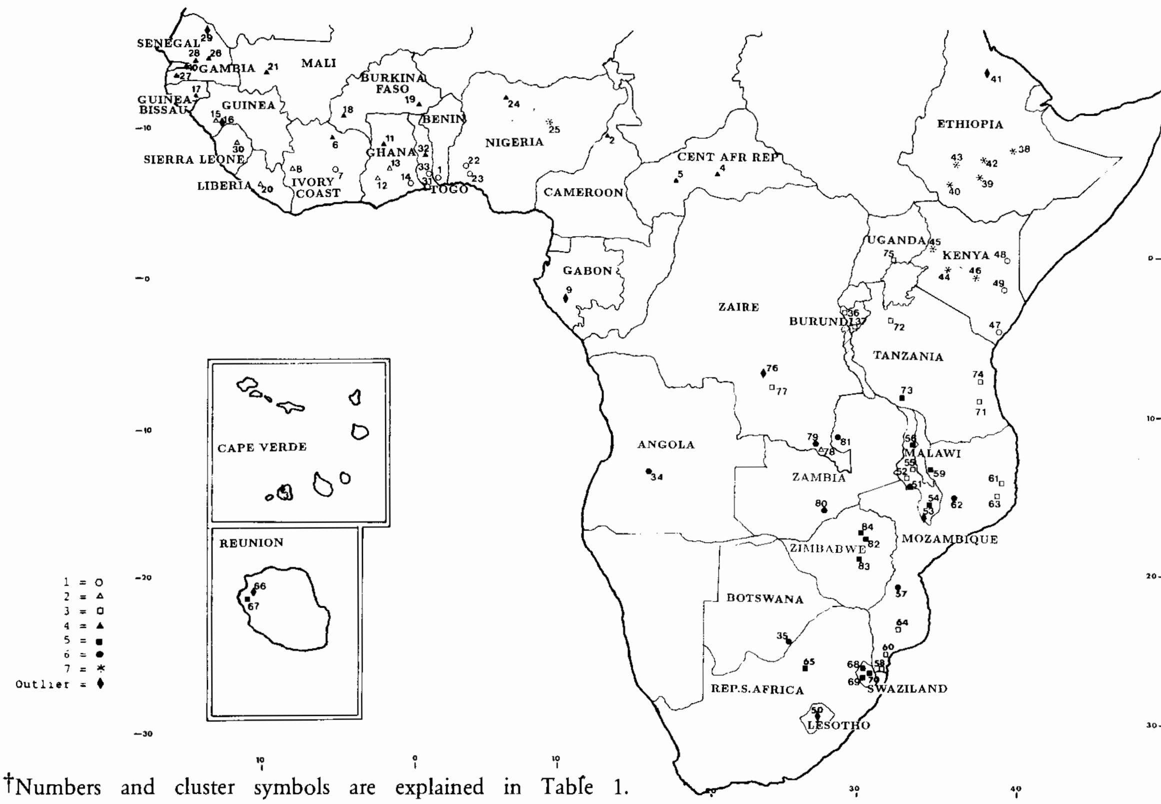
The present study was undertaken to improve the efficiency of the International Maize and Wheat Improvement Center's (CIMMYT) International Maize Testing Program. Currently, cooperators (maize breeders in national maize breeding programs) yearly request progeny for testing from cycles of improvement in CIMMYT populations. These progeny can be either full sibs or experimental populations, depending upon the particular international trial requested by the cooperator. This is an effective means of disseminating germplasm to the cooperators. However, testing environments and data quality change each year because different groups of cooperators offer to grow trials each year. Thus, this program is less effective for progeny testing and subsequent germplasm improvement by CIMMYT. Selection of a few reliable testing locations in national programs to use every year would made testing and germplasm improvement more efficient but would place an unfair burden on those cooperators chosen unless adequate financial compensation was given. Stable, reliable sites would, however, certainly improve the whole testing system. The classification of research stations that are similar for maize production would allow choosing reliable testing locations within appropriate production regions for progeny testing among the set of cooperators who requested the particular year's trial. This would allow more efficient progeny testing because, each year, the same number of locations of known production regions would be analyzed. All cooperators requesting the trial could still grow it, have the data analyzed by CIMMYT for their own use, and keep the germplasm that would fit in their own breeding program. But only the chosen testing sites' data would be analyzed for CIMMYT's use in determining breeding materials' performance in the International Maize Testing Program.

The objective of this study was to classify research sites in sub-Saharan Africa into similar groups suitable for maize production on the basis of agroclimatologic variables. Agroclimatic variables were chosen for analysis because they are easily available in Africa and are important in defining maize production areas. Yield was not used because yield varies according to the particular year's climate and genotypes included in that year's trial. For most locations, only sporadic and discontinuous yield data are available for relatively few years. Climatic data are collected daily, and long-term records are often available and accurate. Monthly mean weather data are good measures of the location. Sub-Saharan African environments were analyzed as a first step to an eventual classification of all CIMMYT testing sites, including Latin America and Asia. This African group of maize production areas was analyzed first inasmuch as it is considered one of the most critical locations for using the classification because of the importance of maize in human diets in the area, the scarce research resources available in many countries in the region, and the need to use the available resources efficiently.

MATERIALS AND METHODS

The research station locations used in the analysis are shown in Figure 1, with the corresponding station names and altitudes in meters given in Table 1. All locations have been used for CIMMYT's international progeny trials in the past. A total of 84 locations was selected from: (1) past cooperators at locations in sub-Saharan Africa who responded to a

FIG. 1: Locations and Clusters of Sub-Saharan African Maize Experiment Stations†



†Numbers and cluster symbols are explained in Table 1.

TABLE 1 - *Altitudes and clustered groups of maize research and testing sites in sub-Saharan Africa.*

No	Country	Station	Altitude	Cluster (=7)	Cluster (=5)	No	Country	Station	Altitude	Cluster (=7)	Cluster (=5)
1	BENIN	SEKOU	105	1	A	43	ETIOPIA	JIMMA	1700	7	E
2	CAMEROON	SANGUERE	190	4	C	44	KENYA	NAKURU	1872	7	E
3	CAPE VERDE	SAN JORGE	325	–	–	45		KITALE	1860	7	E
4	CENTAFRREP	BAMBARI	435	4	C	46		EMBU	1460	7	E
5		SOUMBE	465	4	C	47		MOMBASA	17	1	A
6	IVORY COAST	FERKE	330	4	C	48		H.I.R.S.	100	1	A
7		BOUAKE	360	1	A	49		HOLA	90	1	A
8		MAN	350	2	A	50	LESOTHO	THABA	2250	–	–
9	GABON	LEBAMBA	200	–	–	51	MALAWI	CHITEDZE	1000	6	D
10	GAMBIA	SAPU	17	4	C	52		KASINTHULA	70	3	B
11	GHANA	NYANKPALA	185	4	C	53		NGABU	91	–	–
12		KWADASO	270	2	A	54		BVUNMBWE	1138	5	D
13		EJURA	232	2	A	55		CHITALA	500	3	B
14		KPEVE	153	1	A	56		MBAWA	1243	5	D
15	GUINEA	FOULAYA	380	2	A	57	MOZAMB.	SUSSENDENGA	635	6	D
16		KINDIA	95	–	–	58		UMBELUZI	12	3	B
17	GUINEA-BISSAU	CONTUBOEL	9	4	C	59		LICHINGA	1356	5	D
18	BURKINA FASO	FARAKO-BA	420	4	C	60		GUIJA	33	3	B

Table 1 (continued)

No	Country	Station	Altitude	Cluster (=7)	Cluster (=5)	No	Country	Station	Altitude	Cluster (=7)	Cluster (=5)
19	BURKINAFASO	MOGTEGO	270	4	C	61	MOZAMB.	NAMAPA	230	3	B
20	LIBERIA	SUAKOKO	150	2	A	62		LIOMA	670	6	D
21	MALI	KITA	320	4	C	63		NAMPULA	432	3	B
22	NIGERIA	IBADAN	220	1	A	64		CHOCWE	33	3	B
23		IKENNE	53	1	A	65	REP. S. AFRICA	POTCHEFSTROOM	1345	5	D
24		GUSAU	400	4	C	66	REUNION	PETITEFRANCE	1380	–	–
25		JOS	1318	7	E	67		CALIMACOS	800	5	D
26	SENEGAL	SINTHION	38	4	C	68	SWAZILAND	MALKERNS	750	5	D
27		SEFA	40	4	C	69		LUVE	500	5	D
28		NIORO	15	4	C	70		HEBRON	1375	5	D
29		FANAYE	10	–	–	71	TANZANIA	ILONGA	500	3	B
30	SIERRALEONE	NJALA	57	2	A	72		UKIRIGURU	923	3	B
31	TOGO	LOME	300	1	A	73		NJOMBE	1800	5	D
32		SOTOUBOUA	380	4	C	74		LYAMUNGU	1020	3	B
33		KAMINA	400	1	A	75	UGANDA	KAWANDA	1200	3	B
34	ANGOLA	CHIANGA	1700	6	D	76	ZAIRE	GANDAJIKA	780	–	–
35	BOTSWANA	GABORONE	900	6	D	77		KANIAMA	949	3	B
36	BURUNDI	IMBO	830	3	B	78		KISANGA	1187	2	A
37		MOSSO	1260	3	B	79		KANIAMESHI	1200	6	D
38	ETHIOPIA	ALEMAYA	1980	7	E	80	ZAMBIA	MOUNT MAKULU	1230	6	D
39		AWASSA	1650	7	E	81		MANSA	1259	6	D
40		BAKO	1650	7	E	82	ZIMBABWE	HARARE	1506	5	D
41		MEKELE	1970	–	–	83		KADOMA	1155	5	D
42		NAZARETH	1550	7	E	84		GWEBI	1500	5	D

climatological questionnaire sent in 1986 and (2) other locations of similar longitude, latitude, and altitude as based on a data set of climate variables published by the Food and Agriculture Organization (FAO) of the United Nations (1984). The survey sent to all past cooperators asked for mean climatic variables over 5 to 10 years and included questions relating to factors affecting maize production, such as the growing season, soil characteristics, daily hours of bright sunlight, and disease and insect problems. Too few responses were received to make a data set that adequately represented sub-Saharan Africa, so these additional variables could not be used in this analysis. Locations that could be matched by altitude, latitude, and longitude to those in the FAO data set (1984) were used to supplement the survey data so that a data set with good representations of the area of interest could be obtained for this analysis. The FAO data set was based on averages of 10 to 30 years. Ideally, of course, averages should be over the same number of years, but a data set of this type was not available.

The agroclimatologic variables selected to define the climatic regions for maize production are presented in Table 2. These variables were selected because they could be obtained from both of our source data sets (servey data and FAO data set). Maximum and minimum temperatures were included because they are influenced by altitude differences, which were quite prevalent among locations in East Africa. Environmental characteristics over the entire year, rather than over the growing season, were used in the initial location grouping because interest was in grouping the sites by general climate characteristics as our initial step. Although several of the variables, such as maximum, minimum, and average tempera-

TABLE 2 - *Variables used to define the climatic regions for maize production in sub-Saharan Africa.*

VARIABLES No.	VARIABLE	ABBREVIATION	UNIT
1	Altitude	ALT	meters
2-13	Average monthly rainfall	RJAN....RDEC	mm
14	Average total rainfall	RTOT	mm
15-26	Average monthly temperature	TJAN....TDEC	degree C
27-38	Average monthly maximum temperature	MXJAN...MXDEC	degree C
39	Average yearly maximum temperature	MAXY	degree C
40-51	Average monthly minimum temperature	MNJAN....MNDEC	degree C
52	Average yearly minimum temperature	MINY	degree C

tures and altitude are undoubtedly correlated and might possibly represent redundant information, they were included in the initial cluster analyses because it was not known which variables would be better at defining the location grouping, and these variables are not perfectly correlated. As the survey data become more complete, variables such as solar radiation, distribution of rainfall, and heat units over the growing season can become additional location-defining variables. At present, such variables are difficult to obtain without input from the cooperators at the location.

Hierarchical cluster analysis using Ward's method (WARD, 1963) was used on the agroclimatologic variables to classify the research locations into regions. This cluster analysis groups research locations so that locations within a cluster are more similar than locations belonging to different clusters. Similarity between two locations is evaluated by squared Euclidean distance, which is

$$d^2(A,B) = \sum_{i=1}^{p} (X_{ia} - X_{ib})^2$$

where d^2 (A,B) is the squared Euclidean distance between locations A and B, p is the number of variables considered, X_{ia} is the vector for location A, and X_{ib} is the vector for location B (KENDALL, 1980). The algorithm begins by computing a matrix of squared Euclidean distances between every possible pair of locations for a group of variables. For purposes of analysis, each location is initially considered a cluster. Based on the analysis, clusters with similar characteristics are merged into the same cluster in a stepwise fashion. At each step, the two most similar clusters are merged, until the last step when all locations belong to one cluster. For this report, the clusters will refer to geographical regions. Ward's minimum variance method computes distance between clusters, added over the variables. Within-cluster sums of squares, when divided by the total sum of squares, give proportions of variance. At each step, the within-cluster sums of squares are minimized by merging two clusters (SAS, 1985).

Ward's method has a tendency to join clusters with few members, produces nearly equal-sized clusters, and is sensitive to outliers (MILLIGAN, 1980). To reduce the sensitivity to outliers, 10% of the outlying sites were trimmed from the analysis on the basis of low estimated probability densities (SAS, 1985).

The results from six cluster analyses will be presented. Three analyses used all the variables, stopping at the step at which 7, 6, and 5 clusters remained. Two analyses used either rainfall or temperature variables but not both. The final analysis used only altitude plus total rainfall and yearly mean maximum and yearly mean minimum temperatures. These analyses were done to determine if a smaller data set contained as much information as the larger data set because some variables were undoubtedly correlated.

Canonical discriminant analysis was performed after each cluster analysis, except the final one, to derive linear combinations of the quantitative variables that could best identify the differences between clusters. Canonical discriminant analysis is related to principal component analysis and canonical correlation and is, like them, a dimension-reduction technique (SAS, 1985). The linear combinations of the quantitative variables give rise to canonical variables that summarize between-cluster variation similarly to the way principal components summarize total variation. When large numbers of variables are involved, the analysis allows observation of the data graphically by plotting the canonical variables. The graphs allow one to observe how well the cluster analysis grouped individual locations into distinct regions. These graphs are especially valuable when comparing cluster analyses using different sets of variables to determine which set of variables is best in defining groups of locations.

RESULTS

Cluster analysis using all variables and resulting in seven clusters grouped the experiment station locations as shown in Table 1 and Figure 1. Table 3 gives the means and standard deviations for selected variables for the locations grouped into seven clusters. The regions indentified by cluster analysis are not contiguous (Figure 1).

Determining the appropriate number of clusters is one of the most difficult problems when using cluster analysis because there are no statistical tests to give a definitive answer. It was decided *a priori* to use 5 to 7 clusters based on the number of regions that could be handled practically by the International Maize Testing Program and on pior knowledge of climate patterns of ecological zones in Africa (DEVRED, 1973).

Locations in Regions One through Four are all at low altitude; Five and Six, mid-altitude; and Seven is high altitude (Table 3). Regions One includes locations in a contiguous band in West Africa, near the Atlantic Coast, from Ivory Coast to Nigeria (Figure 1), and the lowland stations in Kenya. Except for Kamina, Togo, the locations have two yearly periods of high rainfall. Kamina has a slight bimodal rainfall tendency also; two months of high average rainfall (July = 216 mm, September = 201 mm) are separated by a lower rainfall month (August = 166 mm). Two locations in Kenya, H.I.R.S. and Hola, are unusual in that they have much lower rainfalls (470 and 521 mm average yearly total, respectively) than the other locations in the region. These two locations are included in Region One because of their high minimum (yearly minimum = 21.4 C), maximum (yearly average = 33 C), and average temperatures (monthly averages range from 25 C to 30 C). The average yearly maximum and minimum temperatures for Region One are 31.4 and 21.9 C, respectively (Table 3).

TABLE 3 - *Means (X) and standard deviations (sd) for variables of maize testing locations in Sub-Saharan Africa, grouped into seven clusters. Only the months of January, April, July, and October are shown for the average monthly variables.*

	CLUSTERS													
	1		2		3		4		5		6		7	
Variable	X	sd	X	sd	X	sd	X	sd	X	sd	X	sd	X	sd
ALT	160.1	138.3	336.1	230.6	576.1	454.9	255.1	181.8	1255.3	378.7	1082.5	339.8	1676.0	218.7
RJAN	21.0	12.5	20.1	24.3	127.5	57.6	1.9	2.7	212.9	68.3	197.5	51.2	20.3	13.8
RAPR	122.9	34.5	142.4	33.7	117.1	71.7	39.2	40.9	86.6	60.3	69.0	39.4	123.9	81.1
RJUL	118.5	76.7	205.3	125.3	14.4	16.5	213.6	39.8	12.5	12.7	4.6	5.7	159.8	90.1
ROCT	123.2	53.9	230.7	56.2	51.9	41.8	100.8	56.6	44.1	35.0	41.9	36.7	86.3	58.0
RTOT	1099.1	389.4	1797.0	400.3	910.4	263.9	1128.7	236.0	1026.0	287.1	1026.1	258.5	1114.1	260.6
TJAN	27.4	0.8	24.8	0.6	25.5	2.3	25.2	1.4	20.5	2.4	22.6	2.2	19.3	1.4
TAPR	27.6	0.8	26.6	1.2	24.2	1.5	30.1	1.8	18.3	1.2	20.4	1.4	21.5	2.4

Table 3 (continued)

	CLUSTERS													
	1		2		3		4		5		6		7	
Variable	X	sd	X	sd	X	sd	X	sd	X	sd	X	sd	X	sd
TJUL	24.7	0.6	24.0	1.1	20.9	2.4	26.2	1.3	13.5	1.7	15.9	1.9	18.6	2.1
TOCT	26.1	0.8	25.4	2.2	25.0	1.6	26.9	1.1	19.5	2.0	22.0	3.5	19.8	2.2
MXJAN	32.8	1.3	31.2	0.8	30.4	2.3	33.8	1.2	25.5	1.5	27.9	2.3	27.4	0.9
MXAPR	32.7	1.1	31.7	0.5	29.1	1.1	36.7	2.4	24.1	1.5	26.8	0.7	28.0	1.9
MXJUL	28.8	1.4	27.6	1.0	27.0	1.5	30.7	1.5	20.3	1.2	24.0	1.3	23.4	2.0
MXOCT	30.7	1.3	29.1	1.2	30.7	1.5	33.0	1.6	26.3	2.4	30.6	1.7	26.6	1.4
MAXY	31.4	1.1	29.9	0.6	29.3	1.1	33.6	1.1	24.0	1.3	27.3	0.9	26.5	1.2
MNJAN	22.0	1.1	18.9	2.4	19.6	2.1	16.1	2.0	15.9	1.6	17.3	1.9	26.5	2.2
MNAPR	22.8	1.0	21.4	1.6	18.7	1.4	22.6	2.8	13.3	2.5	14.3	1.9	13.7	2.4
MNJUL	20.9	1.2	20.4	1.1	14.0	2.6	21.7	1.1	7.3	3.2	7.1	3.6	13.0	2.5
MNOCT	21.5	1.0	20.6	1.1	17.9	1.2	21.1	1.1	13.5	1.7	15.1	1.9	11.8	2.3
MINY	21.9	0.9	20.4	1.4	17.6	1.3	20.4	1.2	12.4	2.1	13.4	2.0	12.2	2.3
No. of locations	10		7		14		15		12		8		9	

Region Two is a lowland group of locations with warm temperatures (Table 3). Region Two also includes locations that are mainly in West Africa. The only exception is Kisanga, Zaire, which has more precipitation than other sites in Zaire. The West African sites are located within 200-300 km of the Atlantic Coast from the countries of Guinea through Ghana (Figure 1). This cluster is characterized by high precipitation, with total rainfall ranging from 1338 mm (Ejura, Ghana) to 2558 mm (Njala, Sierra Leone). All locations except two in Region Two have a bimodal period of high rainfall.

All locations in Region Three are in East Africa. Most locations are low altitude, although altitude reaches as high as 1200 m (Kawanda, Uganda) and 1260 m (Mosso, Burundi). Minimum temperatures are lower than in Regions One and Two (Table 3), although maximum temperatures are warmer.

Region Four's locations are all lowland sites in West Africa (Figure 1). These locations are located north of the sites in Regions One and Two and are located from the countries of Senegal through Central African Republic. Total rainfall ranges from 819 mm (Sinthion, Senegal) to 1502 mm (Contuboel, Guinea-Bissau). All locations have a 5- to 9-month interval of low rainfall, and the months of October through June have less than 100 mm of rainfall. December through February is very dry at all sites (30 mm monthly rainfall). These sites also have the hottest temperatures, on the average, of sites in any other region (Table 3).

Both Regions Five and Six contain sites in East Africa, which are mainly mid-altitude, or lower altitudes characterized by lower maximum and minimum temperatures. Both clusters are characrized by a cooler, drier period in June, July, and August.

Locations in Region Seven have altitudes ranging from 1295 m (Jos, Nigeria) to 1980 m (Alemaya, Ethiopia). All locations are in Ethiopia and Kenya, except for Jos, Nigeria (Figure 1). All temperatures are cool, with the rainiest season occurring in April through September (Table 3). Temperatures do not vary greatly in any season.

Ward's method of cluster analysis is very sensitive to outlying points (Milligan, 1980) so 10%, or nine locations, were trimmed from the analysis (represented by a diamond symbol in Figure 1). These locations were deleted because of unusual rainfall patterns, including very low rainfall (San Jorge, Cape Verde) and very variable rainfall (Kindia, Guinea). Kindia has a monthly average rainfall range of 122 to 1321 mm for 7 months (May through November), and a range of 1 to 17 mm in the months of December through April.

The plot of the first canonical variable versus the second canonical variable, which is uncorrelated with the first, is shown in Figure 2. The canonical variables were obtained from canonical discriminant analysis after cluster analysis, with the number of clusters equalling seven. Figure 2 shows that the clusters identified by the cluster analysis are actually seven distinct groups of locations.

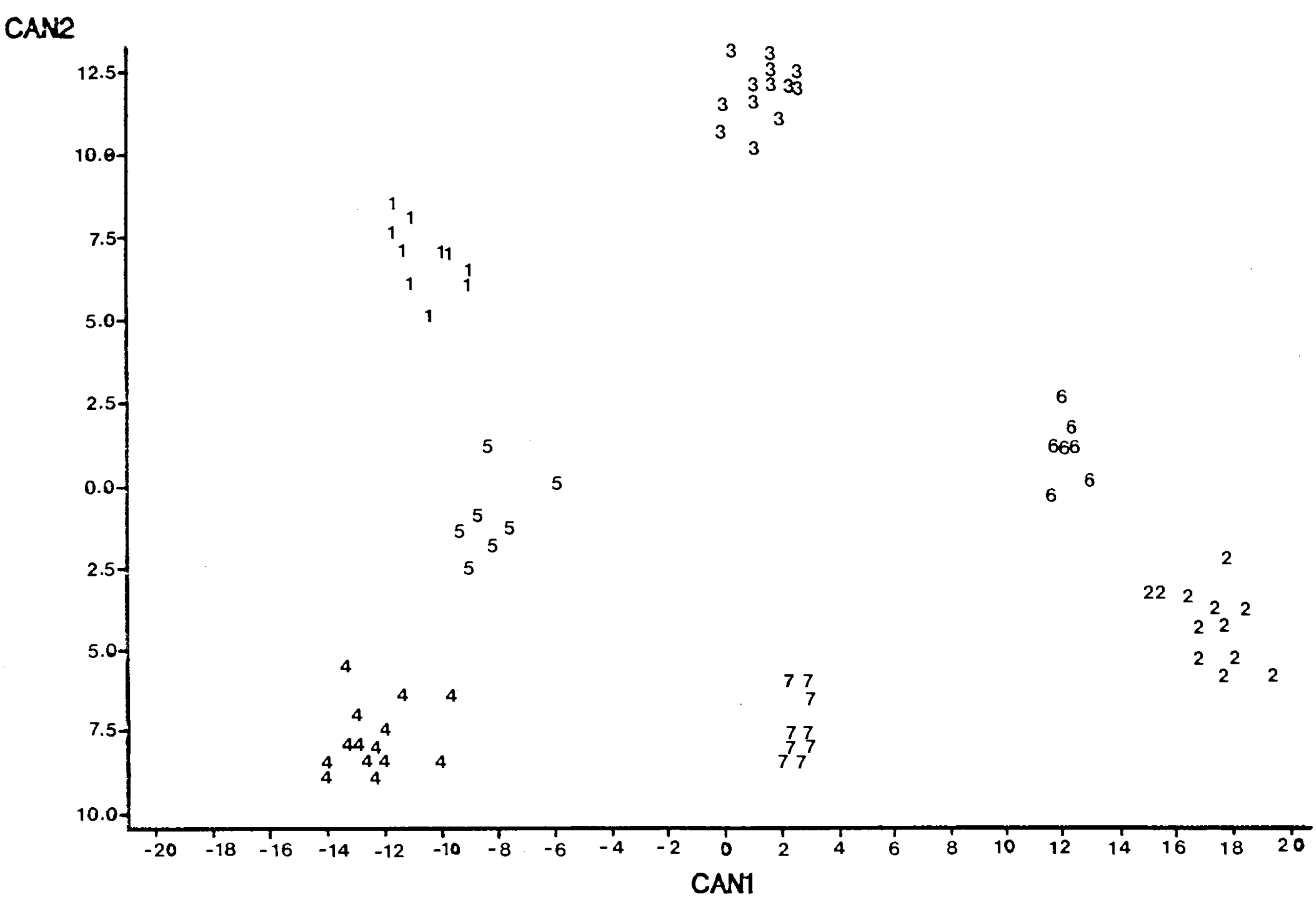


Fig. 2: First canonical variable plotted against the second canonical variable using seven clusters, for altitude, temperature and precipitation variables for maize testing sites in Sub-Saharan Africa.

Continuing the previous cluster analysis until six clusters remain merges Regions One and Two to become a single group. This leaves West Africa with only two clusters, one along the coast with high rainfall, and the other farther north with a dry season and hot temperatures. When the number of clusters equals five, Regions Five and Six are joined into one group. There was little difference between these two clusters, and joining them leaves East Africa with three main groups of locations. These groups can be defined very loosely as low, mid, and high altitude, or as groups with different temperature (especially maximum and minimum) patterns. Whether 5 or 7 clusters are used depends on how important it is to have the three rainfall divisions in West Africa because having three regions in East Africa seems to be adequate.

Fifty-two variables were used in this analysis. It would be interesting to know if fewer variables could be used to obtain good groupings of maize-growing locations or whether temperature or precipitation variables are more important in classification. Several additional cluster analyses using various sub-sets of data were done to see if the same clusters resulted and if separation between clusters was achieved in plots of canonical variables. These sub-sets included only altitude, total rainfall, and average maximum and minimum temperatures. In all cases, many locations were associated with the same original cluster, although there were also several classified into other groups. In no case, did the plots of first canonical variable versus the second canonical variable show the same clear differences between clusters as Figure 2 shows when all variables were used. The conclusion is that, although many variables were used, deleting some leads to a loss of information.

Cluster analysis using agroclimatic variables collected at maize testing locations identified 5 to 7 regions. The research station classification in this study in general agrees with a recent CIMMYT study using several biotic and abiotic parameters to delineate maize growing regions in West Africa (Pham and Edmeades, 1987). For example, Region One of the present study contains test locations situated in the areas defined as mega-environments 4 to 6 (lowland tropics with extra early to late-maturing maize) in Pham and Edmeades's study for the West African countries of Ivory Coast, Ghana, Benin, Togo, and Nigeria. Region Two has testing sites in the mega-environment 6 (lowland tropics with late-maturing maize) for Ivory Coast and Ghana. Region Seven, on the other hand, has one site in Nigeria that is defined as belonging to mega-environments 3A (subtropics with late-maturing maize). However, yield data, observations of collaborators familiar with the sites, additional traits more relevant to maize growing conditions through the growing season, and actual practice with the CIMMYT's International Maize Testing Program will be necessary to determine the usefulness of the groups and the classifications of the sites within groups.

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REFERENCES

Abou-El-Fittouh H.A., J.O. Rawlings, P.A. Miller, 1969 Classification of environments to control genotype by environment interactions with an application to cotton. Crop Sci. **9:** 135-140.

Boyd W.J.R., N.A. Goodchild, W.K. Waterhouse, B.B. Singh, 1976 An analysis of climatic environments for plant breeding purposes. Aust. J. Agric. Res. **27:** 19-33.

Devred R.F.E., 1973 Agricultural research centres and stations in Africa south of Sahara. (Map inside back cover.) *In* National Research Council, Committee on African Agricultural Research Capabilities. 1974. National Academy of Sciences, Washington, D.C.

Food and Agriculture Organization (FAO), 1984 Agroclimatological data for Africa. Volume 1. Countries north of the equator and Volume 2, Countries south of the equator. FAO No. 22, Rome.

FORD G.L., G.A. NIELSEN, 1982 Selecting environmentally analogous areas for agronomic research using computer graphics. Agron. J. **74:** 261-265.

HORNER F.W., K.J. FREY, 1957 Methods of determining natural areas for oat varietal recommendations. Agron. J. **49:** 313-315.

KENDALL M., 1980 Multivariate analysis. 2nd ed. MacMillan Publishing Co. Inc., New York. 210 p.

MILLIGAN G.W., 1980 An examination of the effect of six types of error perturbation on fifteen clustering algorithms. Psychometrika **45:** 325-342.

NIETO J.H., R. DE L. MARIO, S.J. DE JESUS, 1983 Agrupacion de ambientes en al tropico mexicano de acuerdo al desarrollo fenologico de 10 cultivares de soya. Agric. Tec. Mex. **9:** 45-63.

ORIZ-VALDEZ M., 1985 Climatic delineation of maize production areas in Iowa: A multivariate statistical analysis. Unpublished Ph.D. Diss. Iowa State University, Ames, IA. (Diss. Abst. 85-24684).

PHAM H.N., G.O. EDMEADES, 1987 Delineating maize production environments in developing countries, pp. 3-11. *In* CIMMYT Research Highlinghts 1986. CIMMYT, Mexico, D.F.

RUSSELL, J.S., 1982 Selection of homoclimates based on comparisons with single stations and using monthly rainfall and temperature data. Agric. Meteorol. **26:** 179-194.

RUSSELL J.S., A.W. MOORE, 1970 Detection of homoclimates by numerical analysis with reference to the Brigalon region (Eastern Australia). Agric. Meteorol. **7:** 455-479.

SAS , 1985 SAS user's guide. Statistics, Version 5 Edition. SAS Institute, Inc., Cary, North Carolina. 956 p.

WARD J.H., 1963 Hierarchical grouping to optimize an objective function. J. Am. Stat. Assoc. **58:** 236-244.