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MAPPING AGRICULTURAL ENVIRONMENTS: A FIRST APPROXIMATION FOR FIELD USE IN CASSAVA TRIALS FOR NIGERIA

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Abstract

The large genotype x environment interactions of cassava clones constitute a challenge for cassava breeders. The theory of site selection is not yet fully developed to incorporate as many site variables as possible to form a more stable basis for choosing trial sites. We mapped the agricultural environments of Nigeria to enable cassava breeders to select representative sites for the agro-ecological evaluation of candidate genotypes. First, we divided Nigeria into 337 land units or ecozones that measured 30' latitude x 30' longitude (i.e., almost 56 km^2). Each ecozone was described by 100 variables, which covered aspects of relief, rainfall, geology, meteorology, vegetation, soils, population, ground-water potential, and other related statistics. Data were coded for computer analyses of principal components and for clustering ecozones. The number of groups formed depended on level of resemblance among ecozones in each group. Our study is the first to classify the ecozones of Nigeria to facilitate selection of trial sites for cassava multilocational trials according to a broad-based list of variables and thus generate a practical map for field use. Any ecozone in a selected group may be a trial site if it is near, secure, and has other infrastructure.

Introduction

The presence of genotype x environment (G x E) interactions poses great difficulties for breeders to determine true genotype performance in cassava. An environment is everything that occurs around an object or living thing; thus, we may define an agricultural environment as a set of conditions, the variables of which, in their totality, influence crop growth and development; these variables include light, water, nutrients, and temperature regimes. The environments in which we test genotypes are not in steady state, but continually change, although they may exhibit temporary stationary states (Kay 1993). Weather changes often but climate only after about 35 years.

The predictable generalized pattern of weather of a place is regarded as its climate, as Ayoade's (1974) statistical analysis of rainfall in Nigeria showed. Climate should be used to classify environments, each of which is the result of a combination of biological, chemical, and physical variables that vary with space and time. Brinkman (1987) suggests these variables can be classified according to (1) the relatively more stable environmental aspects (e.g., altitudes,

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latitudes); (2) aspects that vary with time within one year (e.g., temperatures, monthly rainfall); or (3) actual incidence, severity, or timing, which fluctuate from year to year (e.g., rainfall totals, disease and pest attacks).

For cassava breeding, multisite trials are needed to generate new cultivars for use by farmers. As resources and time to conduct multisite trials are limited, a minimum set of trial sites must be determined. The number and locations of these sites depend on (1) available research funds; (2) representativeness of the sites across the area of cultivation of the targeted crop; (3) the wide range of biological, chemical, and physical conditions that are expected to represent the range of bad and good years at one or some sites; and (4) access to and from the site during the crop cycle.

Given the high cost of trials, some information must be sacrificed. If site A is similar to site B, then either site will provide sufficient information on genotype response to the prevailing environmental conditions. However, a breeder must decide on a certain degree of similarity such as 50%, 70%, or 90%. In this paper, I adopted 85% similarity as sufficient to declare any two sites, or ecozones in this case, as being similar. That is, a given trial site has an 85% similarity with other potential sites and is, therefore, considered as sufficiently representative for field testing genotypes developed for use in all ‘similar’ sites.

Whether villages should be treated as sites should not a major issue for multisite trials. Instead, an entire area with many villages should be classified in the hope that any one village will be a trial site. Nigeria, which covers 923,768 km^2, has 100,000 villages (Ene 1992), which can be incorporated into larger units of land to represent agricultural environments.

When breeders conduct multisite trials, they are evaluating the ecological adaptability of genotypes, whereas in on-farm trials, they are testing farmer acceptability. These two types of trials differ in that the former captures the effect of the biological, chemical, and physical aspects of the environment, whereas the latter may also capture the socio-economic environment of farmers, processors, and consumers.

As cassava yield is greatly affected by the growing environment, clones must be tested in the ecozones where they will be released to farmers. The importance of cassava in African food culture is well known. Its increasing spread into dry and marginal areas with very low rainfall has helped reduce famine in the worst years. For this reason, cassava improvement programmes seek to test emerging elite genotypes across wide and diverse locations.

Carter (1987), for example, proposed the trial of Brazilian cassava types in African ecologies that are homologues to those in Brazil. Along these lines, Porto et al. (1994) tested Latin American germ plasm in the dry areas of Nigeria and identified seedlings from crosses that involved cassava germ plasm adapted to the dry areas of Latin America, and which survived a 6-month dry season that started 2 months after planting. If such transcontinental matching of ecozones speeds the pace of technology transfer, then it can also be exploited by national cassava improvement programmes.

This study seeks to develop a reliable basis for:

(1) Matching ecozones in any one country, thus optimizing research resources used to conduct multisite trials across wide geographical areas that contain fewer, but distinct, ecological zones.

(2) Identifying domains where full selection from the earliest breeding stages can be undertaken.

Materials and Methods

In Nigeria, cassava is grown across all longitudes and from the Atlantic Coast to the northern border with the Niger Republic (Agboola 1979). Consequently, every ecozone in Nigeria can grow cassava and is a potential trial site for cassava improvement, despite the varied suitability of soils. The map of each selected variable was overlaid with a grid measuring 30' latitude by 30' longitude (i.e., 55.5 km^2 on the land). Of the 343 resulting grid cells, six were rejected because the land area was less than one-tenth the area of the ecozone.

A sufficiently large number of variables was used so not to omit any important environmental variables, and thereby eliminating, a priori, grounds for grouping the ecozones. Of the 100 variables used (Table 1), longitude of the ecozone and the 10 vegetation class variables affect several crop growth factors. The other 89 variables relate to water availability (44), sunlight conditions (21), nutrient supply (21) and ambient temperatures during crop growth (3).

As a first approximation, data on variables and for each ecozone are of unequal detail, completeness, age, period covered, as well as quality. Data for these variables were obtained from already published maps or data. Data available for variable 97 were put on the position of towns and then interpolated to obtain estimates for interlying areas. Data for each ecozone were as specific as possible. Data based on administrative units (states) were applied to all ecozones of that unit and similarly pro-rated for zones traversing two such units. Super Calc 4 spreadsheet computer software was used to input variable data, with grid cell rows representing ecozones and columns representing each variable. The 100 x 337 data matrix was then used to run correlations between the variables, as well as for principal component and cluster analyses. Later, factor analysis will be used to determine a minimum set of variables.

Each map containing some information judged to be useful for discriminating among ecozones was proportionately zoomed to a size that fit the grid snugly. Thereafter, the values on maps were coded to reflect the average value for each grid cell. Varied computations were made to digitize the information on the maps. Each ecozone was given the value of the isoline enclosing it or pro-rated in proportion of the area of the ecozone under different isolines or quantities. By such weighted allotments of the value of parts of the ecozone, the final value for an ecozone differed slightly from that of its neighbouring ecozone.

Groups of ecozones were formed by using two clustering techniques that were space-conserving, sequential, agglomerative, hierarchical, and non-overlapping. The first technique, the group-average method, was an unweighted pair-group method, which used the arithmetic average. The second, the average-linkage method, was a weighted pair-group method, which used the arithmetic average, as in the first method, but differed in that the member most recently admitted to a cluster was weighted equally with all previous members (Sneath and Sokal 1973). This increased the average distance between the clusters. To adopt an optimal number of groups, a similarity level of 85% was used.

Results

The two clustering techniques gave slightly differing numbers of groups for each level of similarity between any two ecozones in one group (Table 2).

The 12 and 10 groups formed by the two methods at the 85% level of similarity were combined to show the intermediate nature of some of the ecozones that were differently grouped by both methods. The group-average method placed 269 of the 337 ecozones (79.82%) in the same group as did the average-linkage method. In both techniques, four groups remained unchanged (5, 7, 11, and 12); whereas three groups merged with adjacent ones (2 with 1; 8 with 9; and Group 10 was split into two parts that joined groups 7 and 9). The group-average method formed one new small group of four ecozones around Lagos, which was not separated by the average-linkage method; the group was removed from Group 9 of the average-linkage method.

Of the 28 principal component axes that explain all variations among the 337 ecozones, the first three accounted for 91.31% (57.83%, 27.06%, and 6.42%, respectively, for principal components 1, 2, and 3). The 14 major variables with $\pm$ 0.10 or more loadings on the first three principal components were used to describe the groups. Of these variables, 10 were related to quantity of water supply to plants; its distribution throughout crop growth; and the magnitude and rate of water loss from the crop's environment through solar and wind action (Table 3).

Population density was the most important variable in both principal components 1 and 2 (accounting for 84.89% of the overall variation among ecozones). Also important were longitude with its contribution along the third principal component axis and the frequency of calm winds as fewer and weaker winds would imply reduced evapotranspiration from fields, thereby affecting water loss from soil and crop surfaces.

Another study is being conducted to examine both the partial logical and empirical correlations between the 100 variables. In a preliminary trial, variables with high coefficients of linear determination (r^2 = 0.90, n = 337) were regarded as sufficiently similar so that one of the pair could be considered redundant. This information is obtained, however, only after data collection and correlation analyses have been completed. The set of redundant variables will differ for each country; therefore, a reduced list excluding the redundant variables will not improve the clustering of ecozones, reducing only slightly the amount of information available for discriminating the ecozones by ($1-r^2$) for each correlated pair of variables. That amount of information is then sacrificed in lieu of the reduced work of handling fewer variables. Such a study on the admissibility and choice of variables requires a careful search for reasons for each selection, while maximizing the likelihood of obtaining any new information for differentiating the ecozones.

Although the map produced in this study is crop neutral, its practical utility for cassava trials will now be discussed.

Discussion

The ecozone groups formed appear natural, fairly compact, and easy to identify. A researcher can pick any ecozone within a group after considering factors such as nearness of location; availability of other infrastructure for conducting trials; security for humans, materials, and trials; and closeness to other collaborators. The researcher can then identify similar ecozones where clones that perform well in one ecozone are likely to be adopted after minimum testing. Stratification of the area enables the execution of probe trials across several representative sites. The bases of such stratification and how statistically sufficient and efficient representation can be obtained are addressed here.

Carter (1987) and Carter et al. (1992) proposed five climatic zones for cassava in Nigeria. These zones merge the groups formed in this study, probably because they were based on only a few variables: (1) mean growing season temperature (< or > 22 ^{o}C), (2) dry season (months with <60 mm rainfall), (3) daily temperature range (< or > 10 ^{o}C), and (4) seasonality (mean monthly range of temperatures < or > 5 ^{o}C). These variables relate specifically to their suitability for growing cassava. In this paper, variables were not coded with reference to any crop, the aim being to group all similar environments, irrespective of their suitability for cassava production.

FAO (1978) identified four generalized agro-climatic zones for rainfed production of cassava in Nigeria, according to which most ecozones of Group 1 in this study are unsuitable. Cassava is, however, increasingly being grown in those areas. These broad zones are not useful for planning multisite trials of new genotypes in cassava breeding schemes.

An earlier work by Papadakis (1965) identified eight agro-ecological zones for cassava in Nigeria. These match only partly with the groups found in this study. Group 10 agrees with his Zone 7; Groups 1 and 2 are combined into Zone 4 (but the shore area of Lake Chad is separated into a Zone 6). His Zone 3 combines all of Groups 5-8 and parts of Group 10. This type of broad regional division of the agricultural environment is inadequate for planning multisite trials. The zones essentially follow the pattern of the rainfall belts, which generally run from east to west.

Fagbami (1985) identified 10 agro-ecological zones in Nigeria based on a computer-aided overlay of maps of vegetation and mean annual rainfall, for use in resource surveys of soils and for land-use planning. Although his grid cells were small (1,296 ha), compared with those used in this study (308,025 ha), the zones formed do not match those formed in this study. Fagbami employed three rainfall classes and five vegetational zones, compared with the 11 rainfall and 10 vegetational classes used in this study. Also crop neutral, Fagbami's map seems to have oversimplified the ecological variation, *ab initio*; thus, grouping too many ecozones, and creating clusters with low in-group similarity.

Recently, IITA (1992) produced an 8-zone agro-ecological map for Africa, based on length of the growing period (30-150, 151-270, and >270 days), temperatures (< or > 20 ^{o}C), and altitudes (< or > 800 m). The four zones shown for Nigeria are broad, merging the 12 groups identified in this study. Consequently, the broad zones need to be re-divided to minimize the G x E interactions that result from treating these broad zones as homogeneous.

Most previous attempts to map Nigeria's agro-ecological areas into agricultural environments have yielded divisions that are too broad and thus inadequate for the more environmentally specific targeting of multisite trials needed for cassava breeding work. Chopra (1994) has expressed similar concerns about the low utility of large-scale, ecoregional zonings for national agricultural research systems who need to devise solutions to problems prevailing in the heterogeneous habitats within any large region.

Researchers also need multisite trials of genotypes across similar ecozones to test for pests and diseases that occur together on crops at unequal intensities and at different stages of growth. Disease (or pest) pressure across similar ecozones will not be even, and tests for tolerance will need to be done in areas with appropriate levels of infection. Disease intensity may also be more transient, compared with the other elements that define an ecozone's environment. Another characteristic of a crop's genotypes that is evaluated across similar ecozones is their performance, or response, under conditions of similar plant spacing and cultural practices (e.g., weeding, planting date, planting techniques, and intercropping).

Environmental factors that affect plant growth are found either above or below the ground. Although both groups are equally important, they are not equally easy to study. At present, we know more about the aboveground factors: rainfall translates into root or soil water status, regarded by Jones and Corlett (1992) as the most important constraint to crop production worldwide; soil water-holding capacity depends on the type and quantity of soil minerals and soil organic matter (OM), the status of which declines significantly under continuous intense land use, especially in densely populated areas where soil is not augmented with organic materials or mulch.

The essential role of water in the form of root or soil water status and its relation to drought-stress physiology of crops (Jones and Corlett 1992) is illustrated by Gbadegesin and Areola's study (1987) of maize on 50 sites. The sites were located in western Nigeria, between latitudes 7^{o}50'N and 9^{o}0'N and longitudes 3^{o}20'E and 4^{o}0'E. About 78% of the total variation in the grain yield of a maize cultivar was explained by soil OM alone. Only when it has decomposed under adequate moisture and temperature regimes does OM release nutrients to plants. Soil OM also holds more than five times its weight of water, correlating more highly with available water in soil = (r = 0.84**) and water-holding capacity (r = 0.81**) than with other soil variables.

The northern part of Gbadegesin and Areola's study area (1,190 mm rainfall) is located in Group 3 of our study and has a different environment from the southern part (2,078 mm rainfall), which is in our Group 6. The two parts are adjacent and share the same soil type but have different environments.

The environmental effect on a genotype depends on both soil and weather. The former is usually persistent from year to year and can be regarded as fixed; the latter is more complex because it has persistent features represented by the general climatic zone and unpredictable features represented by time variation (e.g., year to year) (Lin and Binns 1988). An unpredictable variation of the environment from year to year in a given location is a deviation from a mean or tendency of the amounts, rates, and timing of the availability of various resources required by a crop at that location. That set of conditions may occur in any one year although not necessarily at the same location. Consequently, a spatial scatter of field trials would, as expected, capture that unpredictable variation, particularly if the trials are in the same group of ecozones.

Soils supply crops with water and nutrients; but the capacity of a soil to do this in a given location is not fixed from year to year, as was assumed by Lin and Binns (1988). Soil water-holding capacity and release of water to plants and soil nutrient status and exchange capacities depend on weather conditions, including rainfall and related leaching, erosion, flooding, atmospheric N fixation, and the rate of OM decomposition, itself greatly influenced by ambient temperature and moisture status. Weather conditions and rate of OM decomposition, in their turn, determine the rate of mineralization and the availability of nutrient to crops. Thus, neither the soil nor weather variables are fixed. They could be randomly tested across ecozones of the same group to capture the variations that may occur in different years at any one site within that group.

Some researchers still hope that many trials spread across all representative ecological zones in one single year would obviate the need for years of testing, an idea that is being tested by Shorter et al. (1991). Although the idea is reasonable, as the above discussion indicates, the breeders must tailor their crop's responses to the targeted environments (Jensen 1988). Once the region to which new varieties are to be released is known, then one site in an ecozone from the group of ecozones could be used as a trial site (Shorter et al. 1991).

Jensen (1988) suggested subdividing large geographical areas to achieve homogeneity of testing sites. His concept of homogeneity is the same as that of similarity among ecozones used here. The need to define ecozones for which cultivars are being developed and then to breed and select for local adaptation to such ecozones (not only to run multisite trials in such places) has been emphasized by Simmonds (1991). However, specific stresses (e.g., salt tolerance or disease/pest complexes) are expected to be evaluated in ecozones where such stress conditions are best expressed, preferably within the targeted group of ecozones. The response of genotypes to targeted environments will therefore not be confounded and be more easily understood, thus easing genotype selection and speeding release to farmers.

Conclusions

To develop, for example, a cassava cultivar that is adapted to a 6-month rainy season, its selection must be done in an ecozone that has a rainy period of 6 months or more. By having an established set of agricultural ecozones, several sites can be selected from those groups of ecozones that have 6 months or more of rain.

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Table 1. The 100 descriptive variables used to map Nigeria into 12 agricultural environments.

No.	Variable (scale or measurement): description (reference)
1-3	Type of geologic rock (present = 1, absent = 0): basement complex, sedimentary, or alluvium (Ayoade and Oyebande 1978)
4	Mean altitude (m) (Maps 1978)
5	Minimum distance to Nigerian coastline (km) (Maps 1978)
6	Mean annual number of rainy days (Maps 1978)
7	Annual global radiation (kg cal/cm^2) (Maps 1978)
8	Mean, annual, daylight net radiation (kg cal/cm^2) (Maps 1978)
9	Mean, annual, photosynthetically active radiation on a very clear day (cal/cm^2) (FAO 1978)
10	CV for variable 9 (FAO 1978)
11	Mean annual temperature (^{o}F) (Maps 1978)
12	Mean annual temperature range (^{o}C) (Oguntoyinbo 1978)
13	Mean time of day when most rain fell (0600 = 0 h) (Ilesanmi 1972)
14	Mean annual rainfall for 1951-1962 (mm) (Maps 1978)
15-17	Percentage of rainfall in daily showers (<10.4 mm, 10.4-25.4 mm, >25.4 mm) (Olaniran 1986)
18	Mean annual rainfall for 1951-1965 (mm) (Ilesanmi 1972)
19	General vegetation (forest = 10, mixed = 5, savanna = 0) (Hopkins 1974)
20-29	Specific vegetation type (present = 1, absent = 0): Coastal, mangrove, aquatic grassland and herbaceous swamp, swamp forest and riparian forest, submontane forest, moist lowland forest, dry forest, woodlands, wooded tropical steppe, edaphic and biotic savanna (Maps 1978)
30	Number of peak rainfall (one = 10, two = 20) (Oguntoyinbo 1982)
31	Expected week when rain ceases (Akintola 1986)
32	Expected week when rain starts (Akintola 1986)
33	Actual evapotranspiration (mm) (Oguntoyinbo 1978)
34	Mean annual number of sunshine (h) (Oguntoyinbo 1978)
35-45	Ground water (hydro-geological) classes (present = 1, absent = 0): Coastal alluvium (mangrove and freshwater swamps), river coarse alluvium, coastal sedimentary lowlands, Chad Basin, Keri-Keri sandstone, Sokoto Basin, Nupe sandstone of the Niger Basin, Anambra Basin, Cross-River Basin, Benue Basin, crystalline area (Maps 1978)

(Continued)

Table 1. (Continued.)

No.	Variable (scale or measurement): description (reference)
46-57	Mean monthly rainfall 1951-1962 (mm) (Maps 1978)
58-60	Soil nutrient fertility class: Nitrogen (ratios of 10:<0.10%, 15:0.10%-0.15%, 20:>0.15%); phosphorus (10:<10 ppm, 15:10-20 ppm, 20:>20 ppm); potassium (10:<0.15 meq, 15:0.15-0.25 meq, 20:>0.25 meq) (Enwezor et al. 1989)
61	Percentage of land under forest reserve[a], 1974 (Maps 1978)
62-75	Daylength on 14 selected days in the year (h): day 1, 15, 45, 75, 105, 135, 165, 195, 225, 255, 285, 315, 345, 365 (Jagtap 1994)
76	Mean, annual, potential evapotranspiration (mm) (Ayoade 1976)
77	Annual, total potential maximum evapotranspiration (mm) (Olaniran 1979)
78-79	Longitude and latitude (Maps 1978)
80-90	Major soil types (present = 1, absent = 0): Hydromorphic and alluvial (marine and saline, riverine and lacustrine with weakly developed soils); Regosols (brown and reddish brown soil); Ferrisols; Ferrasols; Red; red-yellow; yellow (these last three are mainly ferruginous tropical soils); Crystalline acid soils; Lithosols on ferruginous crusts; Lithosols on sandy materials (Areola 1982)
91	Albedo under major land use types (%) (Oguntoyinbo 1979)
92	Duration of rainy season (days) (Oguntoyinbo 1982)
93	1963 population density (persons/mile^2) (Maps 1978)
94-96	Mean annual rainfall during 1961-1970, 1971-1980, and 1981-1990 (mm) (Gill 1979; IITA 1993)
97	Occurrence of calm winds per year (%) (Maps 1978)
98	Mean relative humidity in January (Iloeje 1972)
99	Annual water balance (Agboola 1979)
100	1991 population density (persons/km^2) (Allen and Shinde 1981; FRN 1992)

a. Reflects current or residual effects of fertility attributes of forest cover and of the forest's potential to be a reservoir for rodents, large animals, and other pests for nearby farms.

Table 2. Number of groups identified by two clustering methods for different degrees of similarity between agricultural ecozones of each group.

Method	Degree (%)							
	95	90	85	80	75	70	65	60
Average linkage	91	36	12	4	3	2	2	1
Group average	87	32	10	5	3	2	2	1

Table 3. Twelve groups of agricultural ecozones defined at the 85% level of similarity by the average-linkage clustering of 337 ecozones on 100 variables.[a]

Code of ecozone group	Ecozones in group (no.)	Total land area (%)	Annual rainfall (1951-1990 average)[c]	Rainfall (mm) in					Calm winds in year (%)	Maximum PET[b]/year (mm)	Sunshine (h/year)
				Apr	May	June	Sept	Oct			
1	98	28.0	Very low	0	50	80	150	50	1-14	>2400	>3000
2	21	6.5	Very low	0	80	125	200	50	7	2300	2875
3	74	23.3	Low	0	125	150	230	100	6-14	2200	2750
4	14	4.6	Low	0	125	150	250	150	6-13	2150	2850
5	30	9.9	Moderate	0	150	150	280	150	10-28	2100	2500
6	41	11.8	Moderate	100	200	230	250	200	7-14	1850	2125
7	10	3.2	Moderate	100	230	250	300	250	28	1800	2125
8	5	1.6	High	100	250	250	330	250	10-33	1650	2125
9	17	4.2	High	100	250	250	250	230	10-33	1650	1750
10	9	2.9	High	100	250	300	360	250	11	1700	1875
11	5	1.3	Very high	200	275	360	435	330	17	<1700	<1500
12	13	2.7	Very high	200	330	435	435	330	33-47	<1700	<1500

a. *Two other variables, 1991 population density and the longitude of the centre of the ecozone, are not presented, being highly variable for each ecozone.*

b. *PET = potential evapotranspiration.*

c. *Very low = <900 mm; low = 900-1100; moderate = 1100-1300; high = 1300-1500; very high = >1500.*