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GENOTYPE AND ENVIRONMENT INTERPLAY IN CROP PRODUCTION

By

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Genotype and Environment Interplay in Crop Production

The Vice-Chancellor,
Deputy Vice-Chancellor (Academic)
Principal Officers of the University,
Deans and Directors,
Heads of Departments,
My Academic and Professional Colleagues,
Members of My Immediate and Extended Family,
Gentlemen of the Print and Electronic Media,
Distinguished Ladies and Gentlemen,
Great UNAABITES

1.0 INTRODUCTION

It is indeed an honour and privilege for me to present the 25th inaugural lecture of this University, which incidentally is the 4th from the College of Plant Science and Crop Production and, 2nd from the Department of Plant Breeding and Seed Technology.

Stability of the performance of crop varieties across contrasting environments is essential in cultivar development. However, there is always a problem of judgment when varietal performance is not consistent from one environment

to another. In order to overcome this problem, there is need to understand the nature and magnitude of the inconsistency for a better decision making. Hence, research focus aimed at providing solution to the wide ranging scope in cultivar development forms the basis of this inaugural lecture, titled "**Genotype and Environment Interplay in Crop Production"**

2.0 HISTORICAL BACKGROUND

Africa is the continent where millions of people are on the brink of starvation in a world of plenty. Food availability per capita in sub-Saharan Africa has declined by 3% since 1990 when compared with per capita increases of more than 30% in Asia and 20% in Latin America. International Academy Council (IAC) report of 2004 showed that almost 200 million Africans were undernourished at the dawn of the millennium compared to 133 million in 1980; it further reported that, currently, 33% of sub-Saharan Africans and 6% of North Africans were undernourished. Undernourished children in Africa now stand at 33 million, most of who are found in sub-Saharan Africa.

Projections are that, by 2050, world population will increase from the current 6 billion to about 10 billion. During the past 50 years, agricultural research and technology transfer

have helped to increase the output of world crops two and half-fold. Currently, more than a billion people can be categorized as the world's absolute poor, subsisting on less than $1 of income per day, and 800 million of these do not have secure access to food. Therefore, the challenge for agricultural researchers to meet the food demand is astounding.

From the perspective of food security, the stability of agricultural production is important. Food production is very much a function of climate, which in itself is unpredictable; the principal characteristic of climate being variability.

Agricultural production may be increased through increased efficiency in utilization of resources such as increased production per unit of land and of money, and through a better understanding and utilization of genotype-by-environment interaction (GEI).

• Genotype refers to genes that make up the plant.
• Environment is a set of non-genetic factors that affect the phenotypic value of a genotype, i.e., the sum total of all factors external to the genotype.
• Phenotype refers to the physical appearance

Cultivars must of necessity be tested in multiple years and locations before they are released. This is because yield,

which is a quantitative character is more influenced by environment than qualitative traits.

2.1 ENVIRONMENTAL VARIABLES

(1) Physical and chemical attributes of soils – Among several factors limiting Africa's agricultural productivity is declining soil fertility. Averagely, some 24 kg of soil nutrients are lost per hectare per year. It is in fact estimated that African soils are losing $4 billion worth of soil nutrients annually (Africa Fertilizer Summit, 2006; Sanchez and Swaminathan, 2005). More than 80% of farmland in sub-Saharan Africa is so badly depleted of nutrients that it has been rendered infertile. This soil fertility crisis is severely eroding Africa's ability to feed itself. Also due to the burgeoning population, the traditional shifting cultivation has broken down, leading to shorter fallow periods and such that soils are not allowed to rest and build up organic matter and nutrients. In some areas, fallows have in fact completely disappeared; as a result of such reduced soil fertility, crops yields are adversely affected.

The effects of continuous cropping and soil nutrients mining are aggravated by the low level of inorganic fertilizer used in the continent. Fertilizer use in Africa is the lowest in the world at less than 10% of the world average. In 1994/95,

sub-Saharan Africa used only 10 kg of fertilizer per hectare compared to 77 kg/ha in South Asia and 65 kg/ha in Latin America. Such low use of fertilizer may be due to high costs, which are two to six times the world average, thus, making fertilizer unaffordable. There is, therefore, the need to make fertilizer available and affordable.

In order to try to improve on productivity, farmers are indeed encroaching on even more fragile ecosystems, such as, forest and savanna in search of new land to till. As a result of the effort by farmers to use more fertile lands, we are witnessing a shifting of ecological zones with the desertification of the sahel, the sahelinization of the savanna and the savannization of the forests. We must make great efforts towards revitalizing the soil through improved fallowing and other innovative practices in order to halt the deepening food crisis in Africa. Related to the soil fertility problem is the aspect of soil degradation brought about by soil erosion. This is accompanied by other problems, such as deteriorating soil structure, reduced moisture retention capacity, and soil nutrient depletion. The depletion of nutrients – nitrogen and phosphorus, in particular, has caused crop production to stagnate or decline, thus, deepening the food crisis in many African countries. About 16% of all soils in Africa are classified as having low nutrient reserves, compared to only 4%

in Asia. Also fertilizer productivity (expressed in terms of maize yield response) in Africa is estimated at 36% lower than in Asia, and 92% lower than in developed countries. All these point to the need for greater emphasis in restoring soil fertility in sub-Saharan Africa.

(2) Climatic factors: The productivity potential of crops in Africa is quite high due to solar radiation and high temperatures. A sustained increase in mean ambient temperature beyond 1^0C will cause significant changes in forest and rangeland cover, species distribution and composition, migration pattern and biomass distribution. The African continent is particularly vulnerable to the impact of climatic change because of widespread poverty, inequitable land distribution and high dependence on rain-fed agriculture. Africa is predicted to be exposed to both frequent and severe extreme weather events, including localized drought and flooding.

Higher temperatures will result in rising sea levels and more frequent occurrence of extreme weather events, such as flooding, droughts, and violent storms, causing changes in agricultural practices. Climatic change has aggravated soil degradation in the dry areas, particularly in pastoral, agro-pastoral and arid systems. Prolonged drought has led to the

elimination of grass cover in some areas, the elimination of some vegetation, a drop in groundwater table, and an increase of evepotranspiration and wind erosion.

(3) Number and kind of biological organisms

Pests, diseases and weeds are problems in nearly all farming systems. In some areas, many pests and diseases are known to threaten the productivity of major crops. Maize has many pests including stem and ear borers, army worms, beetles, and aphids. Maize diseases include ear rot, caused by *Fusarium verticillioides,* which can also produce mycotoxins that threaten human and animal health. Combined attacks by pests and weeds can severely damage cowpea plants and cause losses as high as 90%. Banana are vulnerable to Panama disease and black sigatoka leaf spot disease. The latter may reduce the yield in banana and plantain by up to 40%. Higher losses have been reported for plants infected with banana streak virus.

Striga is a major pest in maize in sub-Saharan Africa. In Nigeria, weed-related yield losses ranging from 65 to 92% have been reported. Other crops, such as sorghum, millet, and cowpea, are also infested. Depending upon the extent of infestation, reductions in per hectare grain yield of 30 to 60% are common.

The possibilities for chemical control of pests and diseases are restricted, due to the limited availability and high cost of pesticides. Consequently, farmers have to find alternative solutions. The choice of resistant varieties is one of the most powerful tools, whenever available.

(4) Genotype and Environment Interaction

• In the study of Genotype x environment interaction (GXE), the term 'genotype' refers to individuals (e.g., families, recombinant inbred, testcrosses or hybrid, etc) that differ in their genotypes at many loci rather than those at a single locus. When a genotype is grown in several environments with two or more replications, the phenotypic value can be modeled as:

$Pjk = \mu + gi + tj + (gt)ij + eijk$

where, μ = pop mean;

g, = genotype effect

tj = environment effect;

(gt)ij = gxe interaction; and

eijk = error term within the environment.

• Many phenotypes are possible for a given genotype.

The phenotype can be expressed as P = G + GE + E. Hence, the total variance due to non genetic effect is GE + E. When a genotype is being tested, these components can affect the

repeatability of the performance depending on the magnitude.

The GXE can be described from the pattern of interaction thus:

Pattern of Interaction of GXE

- One genotype is superior
- The difference between them is constant (Non-cross over interaction)

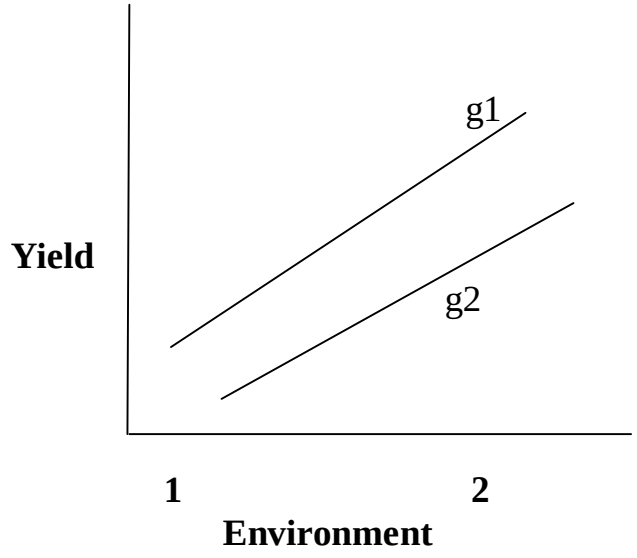

Fig.1: Pattern of interaction of GXE where one genotype is constantly superior

Pattern of Interaction GXE

- One genotype is superior to the other, but the difference is not also constant.

Non-cross over interaction

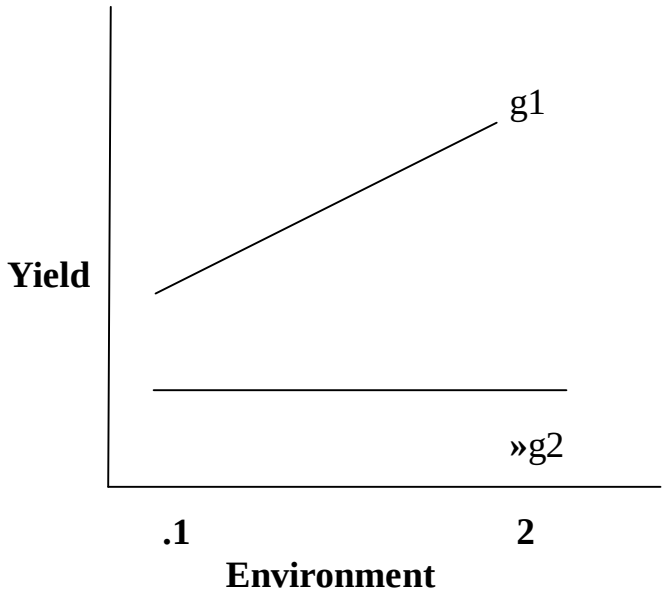

Fig. 2: Pattern of GXE interaction where the superiority of one genotype varies with environment

Pattern of Interaction GXE

- Cross over interaction - The better genotype differs between environments.

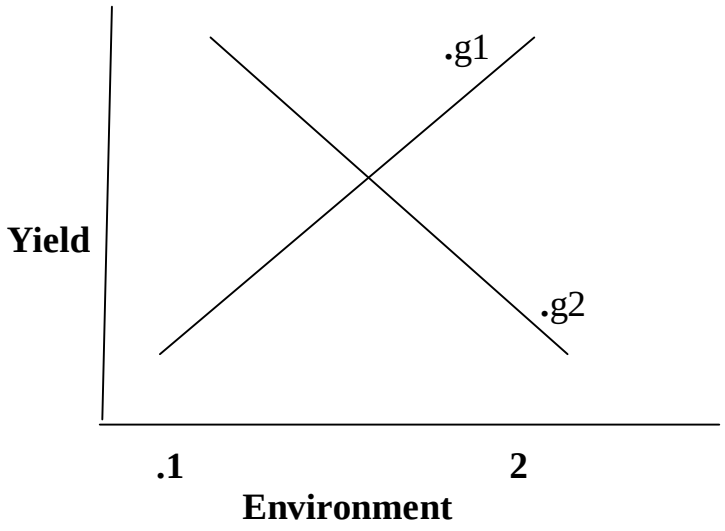

Fig. 3: Pattern of GXE interaction where there is cross-over in which better genotype differs between environment

- Cross over interaction - Difference between the genotypes changes with environment.

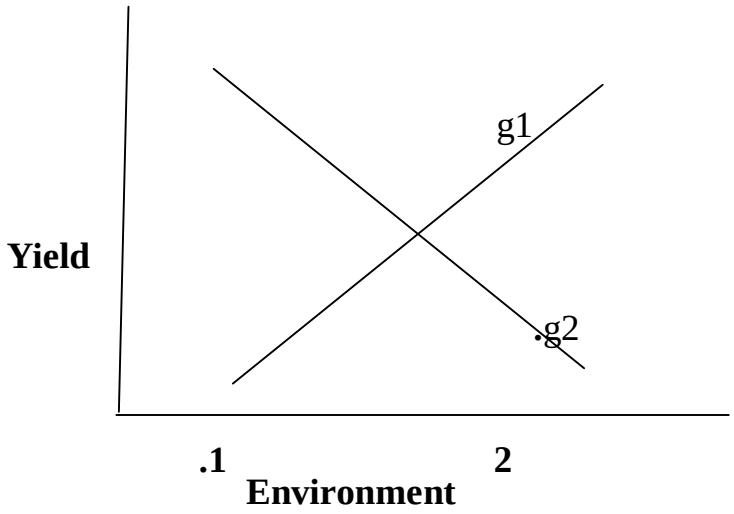

Fig. 4: Pattern of GXE interaction with cross-over but superiority varies between environment.

Genotype x environment interaction (GXE) is the norm rather than the exception for most quantitative traits in plants. It becomes of practical significance only when cross-over interactions occur. It can, therefore, be concluded that GXE comprises of non-crossover interaction and crossover interaction. The non-cross over interaction is due to heterogeneity of genotype in different environments, whereas,

crossover interaction is due to an imperfect correlation between genotype performance and environment.

(5) STABILITY ANALYSIS

• Stability has many concepts. The static concept implies that a genotype has a stable performance across environments, with no 'among-environments' variance, i .e., the genotype is unresponsive to increased levels of inputs. This concept is not desirable in production agriculture.

• The dynamic concept implies that a genotype's performance is stable, but for each environment, its performance corresponds to estimated/predicted level. This is called agronomic concept. Stability analysis aims to examine the reaction of genotype relative to other genotypes to different environments. It permits the identification of genotypes that are stable or unstable.

In meeting the demands for better adapted varieties, the breeder may breed either for clearly defined ecological conditions or for a broader range of conditions. Clearly, the latter approach requires the development of varieties possessing wide adaptability. The alternative approach of breeding varieties for specific ecological conditions may be satisfactory for horticultural crops growing in environments which

are rendered reasonably uniform through controlled application of water and nutrients, but it has serious limitations for a dryland field crop such as okra and Soybean. Even with a uniform soil environment, a considerable degree of general adaptability is important because of the marked seasonal variations in other environmental conditions.

In many crops, large and significant interactions often occur between genotypes and environments. In order to establish the genetic worth of new lines, evaluation should ideally be carried out over several locations. The effect of genotype x environment interactions can be accurately assessed and this, in turn, will enable more reliable recommendations to be made as to whether a new variety can be grown over a range of environments or only in certain specific environments. However, in practice, the breeder is often compelled to restrict the number of environments in his evaluation due to scarce resources. In such situations, the presence of large genotype x environment interactions may lead him to discard a number of promising genotypes particularly if a few high-yielding ones contribute disproportionately to the interaction (Comstock and Moll, 1963).

Apart from the evaluation of a potential variety in different environments, it must show an appreciable degree of uni-

formity for agronomic characters before it can be considered for release. It must also be distinct from other varieties which are already under cultivation.

While earlier studies on GE interactions concentrated on the assessment of genotype adaptation and zoning locations, recent developments and applications of statistical methods have frequently focused on setting adaptation strategies for breeding programmes and defining recommendation domains for cultivars with distinct objectives. As such, they may require partly different analytical approaches and provide different results with regard to the definition of sub regions, responses of a set of genotypes to obtain indications and generate predictions relative to future breeding materials, that they may be produced from the genetic base of which the tested genotypes are assumed to be a representative sample.
For public institutions, the breeding of diversified, specifically adapted germplasm can be a major element of a research policy enforcing sustainable agriculture. Safeguarding crop biodiversity by increasing the number of varieties under cultivation will have positive implications for the stability of production at the national level.

Identifying crucial test sites can be a valuable objective for

the routine evaluation of genotypes carried out by public institutions, such as those committed to the use of recommended varieties, or those responsible for the assessment of the value for cultivation and use of newly released germplasm.

Decision on the adaptation strategy, which can have a considerable and lasting effect on the organization of a plant breeding programme, should be based on the analysis of more data sets if available, and verified after a reasonable period of time on the basis of new data.

The phenomenon of genotype-environment interaction is a ubiquitous problem in plant breeding programme and has long been a challenge to plant breeders. A variety developed by a plant breeder is usually grown at different locations for many years under different conditions. Crossa (1990) pointed out that assessing any genotype without including its interaction is incomplete and, thus, limits the accuracy of yield estimates.

Static stability is analogous to the biological concept of homeostasis; a stable genotype tends to maintain yield across environments. The term ”Environmental sensitivity” has also been used in this respect, where greater sensitivity cor-

responds to lower stability. Dynamic stability implies that for a stable genotype there must be yield response in each environment that is always parallel to the mean response of the tested genotypes, i.e., zero GE interaction.

Static stability may be more useful than dynamic in a wide range of situations, especially in developing countries (Simmonds, 1991). From a farmer's point of view, location is a constant and not a variable factor, and yield consistency over time is the only relevant component of a genotype's yield stability. In reality, yield consistency in space also deserves consideration in the presence of sizeable Genotype x Location interaction, since a selected or recommended genotype should have stable yield both across years and across locations in its area of adaptation or recommendation.

The assessment of yield stability in relation to genotype responses to environments provides a simple means for considering all the relevant GE interaction effects. Assessment based on GY interaction effects within locations can be recommended whatever the adaptation strategy; breeding for high yield stability can be considered a useful target when the relevant GE interaction variation is wide. High yield stability may be associated with low mean yield (or low sta-

bility with high mean yield), which complicates genotype selection or recommendation.

Despite its potential interest, increased yield stability has tended to be a minor objective in breeding programme worldwide (Romagosa and Fox, 1993). A number of studies reviewed by Becker and Leon (1988) confirmed the early indication by Allard and Bradshaw (1964) that variety types, where the genetic structure implies high levels of heterozygosity and/or heterogeneity, are less sensitive to environmental variation and are, therefore, more stable-yielding. Unfortunately, such types may sometimes offer fewer opportunities for maximizing the yield potential. Decisions regarding yield stability depend on the size of other GE interaction variance components, which may only be estimated if the trials are repeated in time.

Emphasis is, therefore, placed on the estimation of genotypic and genotype-environmental components of variance, and location similarity is assessed on the basis of adaptation patterns for all genotypes. It is usually preferable to estimate yield stability and reliability values with reference to all GE interaction effects.

When a significant GE is present, breeders usually are inter-

ested in knowing the causes of the interaction in order to make accurate predictions of genotype performance under different environments. Understanding genotypic responses to individual factors aids in interpreting and exploiting GE. At a level other than optimal, an environmental factor represents a stress. Differences in the rate of increase in genetic response at sub-optimal levels reflect differences in efficiency and differences in the rate of decrease in genotypic response at super-optimal levels reflect differences in intolerance (Baker, 1988). Crop's respond to a number of environmental signals; nutrients, toxic elements, salinity, gases in the atmosphere, light of different wavelengths, mechanical stimuli gravity, wounding, pests, pathogens and management. The extent of an individual's adaptability to environmental conditions reflects the magnitude and sophistication of the controls over the synthesis and action of specific proteins.

Adaptability is a quantitative estimation of the range of environmental conditions to which a particular genotype can fit and, is determined by the extent and sophistication of its plastic traits. Plants that have incorporated a variety of environmental signals into their developmental pathways possess a wide range of adaptive capacities.

Biotic stresses are major constraints to crop productivity. Differences in insect and disease resistance among genotypes can be associated with stable or unstable performance across environments.

Nutritional deficiency or disorder may be related to the absence of certain genes in the crop. All these can be responsible for differential crop performance. For example, a single recessive gene locus controls iron deficiency symptoms in soybeans (Devine, 1982).

Differential survival rates of genotypes also could be responsible for GE. Genetic and environmental factors and their interactions affect the number of seeds each genotype produces and the proportion of seeds of each genotype that reaches maturity. Producing reduced number of viable seeds by a genotype may reduce its fitness, thereby, leading to differential response to environments.

It has also been reported that genotypes respond differentially to herbicides and allelochemicals. Other major stresses include atmospheric pollutants, soil stresses, temperature, drought/flooding and management operations, precipitation and altitude of trial locations.

Genetic variation exists for plant responses to many stress factors. Differential response of genotypes to these stresses could be a cause for GEI. Genotypic difference in disease resistance can be a common cause of non-crossover GEI and genes related to plant maturity and height may be causes of cross-over GEI. The detection of GEI in trials and breeders desire to handle these interactions appropriately has led to the development of procedures that are generically called "stability analysis".

(6) CONTRIBUTION TO KNOWLEDGE

I have the opportunity of working on a number of crops for the past 23 years, some quite extensively and others slightly. My studies have been essentially directed at classification of genetic variability, inter-character relationship, stability analysis and on insect resistance in autogenous crops.

(i) **Measurement and classification of genetic diversity** Okra (*Abelmoschus spp)* is an important vegetable crop in the world. It is rich in minerals and vitamins. Genetic diversity is the raw material for evolution, and without it, little genetic advancement can be achieved. My studies have been to catalogue the variation pattern in both (*Abelmoschus esculenctus L.Moench)* and *Abelmoschus caillei* (A. Chevel) Stevels using multivariate techniques. Some characteristic

features of the two species are presented in Table 1.

Genotypic and phenotypic variances of 15 characters were studied during early and late season in *A. esculenctus*. Okra genotypes showed considerable variability for most characters in both seasons. Variation was exhibited for pod per plant, number of leaves and pods per plant and the variation between seasons.

Estimates of co-efficient of variation, heritability and expected genetic advance differed from season to season with respect to each character. GCV ranged from 46.7% for number of pods per plant in the early season to 4.4% for lifespan in the late season. Heritability estimates varied from 18.1% for number of pods per plant to 81.5% for length of mature pods during the early season. Hence, the genetic advance is a function of genetic variability and heritability thus:

$$Gs = K(\sigma p)H$$

where, Gs = genetic advance;
K = selection pressure;
and H =heritability

Relatively high estimates of genetic advance were recorded for the two seasons, for plant height at flowering, edible pod

Table 1: Some Characteristic features of West African Okra and *Abelmoschus esculentus*

Character	West African Okra (Abelmoschus callai)	Abelmoschus esculentus
Pod yield/plant (g)	295	114
Final plant height (cm)	175	86.5
Stem diameter (cm)	6	2.6
Number of branches/plant	30	5.0
Size of Epicalyx segment	Large	Small
Persistence of epicalyz segment	Persistent	Less-persistent
Photoperiodism	Sensitive	Non-sensitive
Number of pods/plant	13	6.0
Length of branches (cm)	28	12.5

length, final plant height, number of seeds per pod. Since the component characters were influenced by environments, genetic advance also varied between seasons (Ariyo, 1990).

The variation pattern in okra was catalogued using multivariate ordination techniques. The Coefficient of Racial Likeness (CRL) according to Pearson (1926) and Principal co-ordinate analysis (PCO) by Gower (1960) were employed. The results obtained were complemented by Metroglyph analysis and Single Linkage Cluster analysis (SLCA) to give a pictorial scatter gram of morphological variation. The CRL showed that only eleven accessions were separated from each other on the basis of the ten characters evaluated. The SLCA showed that most accessions tended to cluster together but UI C-6-2, Pusa sawani, TAe 38, UI 86 and UI 10 were widely separated from the collections. UIC-6-2 and UI 10 which had the largest CRL values were the most distinct (Fig.4). The metroglyph of the accessions identified three groups (Fig.5); Group 1 contained – Pusa Sawani, UI 79-5 and V35 while members of group II were UI 104, UI 212, UI 86 and UIC-6-2; the remaining accessions were scattered and could not be grouped. While CRL and PCO measured the extent of variability among the accessions, metroglyph analysis and SLCA classified the variation. Ariyo (1990) therefore, concluded that either CRL

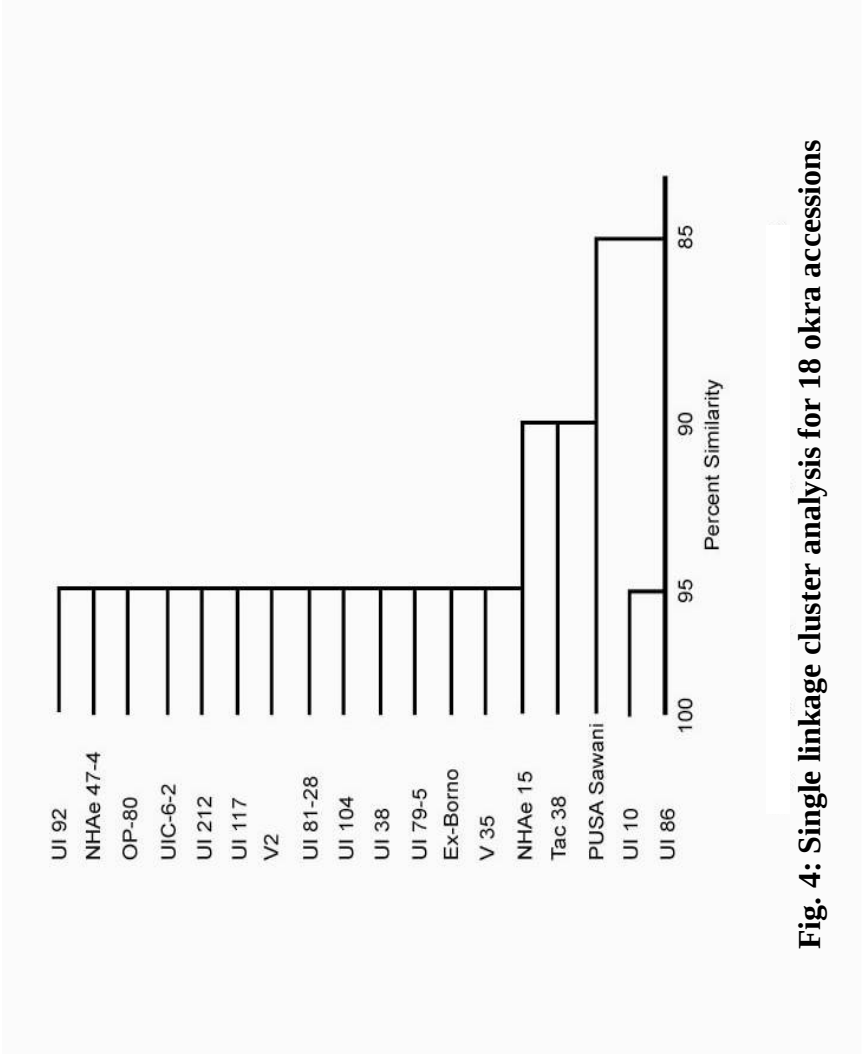

Fig. 4: Single linkage cluster analysis for 18 okra accessions

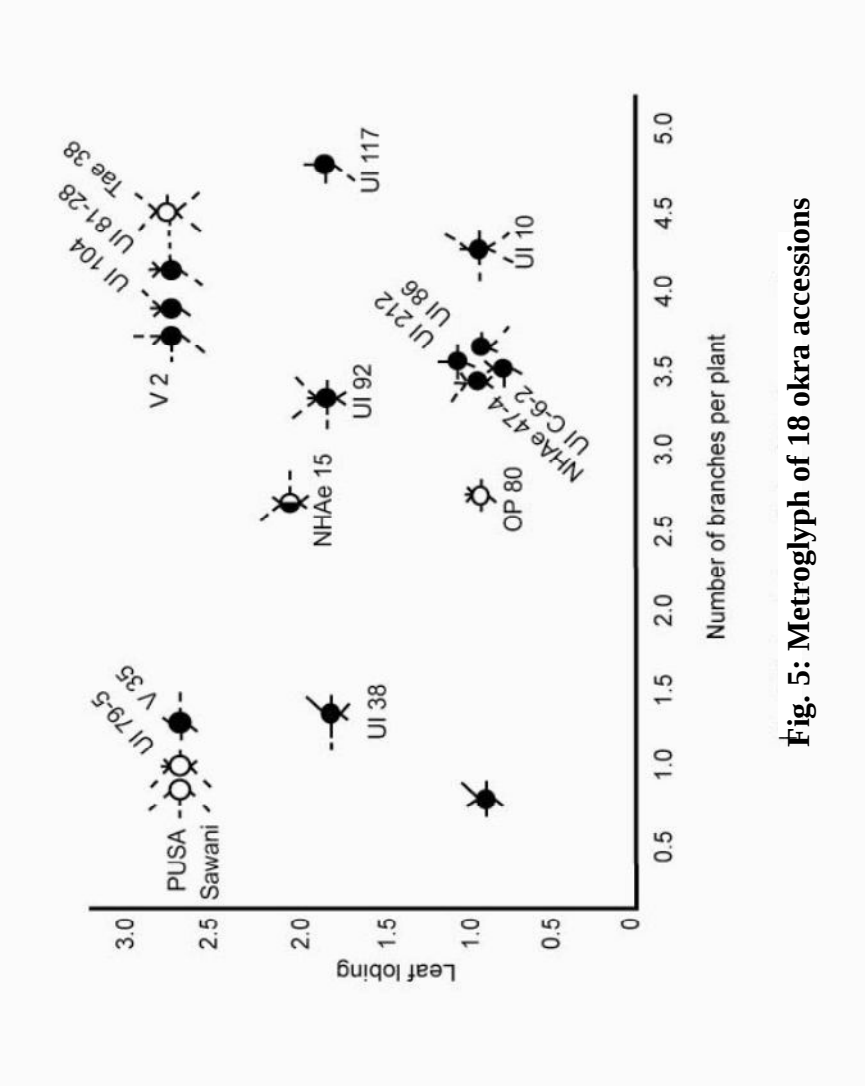

Fig. 5: Metroglyph of 18 okra accessions

or PCO could be used in determining the extent of variation but PCO's presentation was easier to appreciate.

Similarly, 30 genotypes of okra (*A. esculenctus)* comprising of 25 accessions from eco-geographical areas of Nigeria, Ghana, Turkey, Zambia, Japan and Zaire were studied for genetic diversity using Mahalanobis D^2 technique. Uncorrelated linear functions of the original values were obtained by transforming the original correlated unstandardised character means by pivotal condensation method (Rao, 1952). The differences among the varieties for the set of the characters taken together were tested accordingly (Wilks, 1932). The relative contribution of each character to D^2 value between each pair of genotypes was determined (Bhatt, 1970). The D^2 technique classified a large majority of genotypes from Nigeria into clusters 1, 2 and 3 contained one entry each from Japan and South East Nigeria, respectively. It was observed that the clustering pattern did not follow eco-geographical distribution as cluster 1 contained the most genetically divergent genotypes by including those from Nigeria, Ghana, Turkey and Zambia. Cluster 5 also contained accessions from Nigeria and Zaria. Ariyo (1987), therefore, concluded that genetic diversity had no relationship with eco-geographical divergence.

Using Factor, Principal Component and Canonical analyses, the variation pattern in West Africa *Okra (A. caillei) (A Chev.)* Stevels, was catalogued (Ariyo, 1992; 1993). The level of variability observed supported the opinion that this okra type constituted a separate species. The relatively low heritability estimates for some characters suggested the ineffectiveness of direct selection for such characters. That the heritability estimates for the characters differed among seasons suggested different responses of the characters to changing environments, thus, highlighting the influence of environments on the estimation of genetic parameters (Ariyo, 1989). Variability was also studied in rice. (Nassir and Ariyo, 2005).

(ii) Plant Character Correlations

Knowledge of inter-character relationships is very important in plant breeding for indirect selection for characters that are easily measured and for those with low heritability. Correlation studies among characters have also been of great value in the determination of the most effective breeding procedures. As the number of independent characters affecting a dependent character increases, a certain amount of inter-dependence was bound to be associated. Under such a complex situation, correlations alone become insufficient to explain relationships among characters. Path coefficient

analyses becomes relevant. It permits identification of direct and indirect causes of association and measures the relative importance of each character.

Ariyo et al. (1987) calculated genotypic, phenotypic and environmental correlation coefficients for characters in okra during two growing seasons. It was observed that the correlation values varied between seasons. In some cases, differences in both magnitude and direction of correlation coefficients were observed during the seasons. While various pod-related characters exhibited significant positive genotypic correlations with pod yield, only edible pod length and edible pod weight showed significant phenotypic correlations with pod yield during the two seasons (Tables 2 and 3).

Significant positive environmental correlation with pod yield were exhibited by edible pod length, final plant height, edible pod weight, number of pods per plant, height at flowering and number of leaves per plant, either in early or late season or both seasons (Table 4).

The direct and indirect effects of some characters on pod yield showed that edible pod weight had the largest positive direct effect in the early season with its largest indirect effect through reduction in edible pod width. In the late season, edible pod weight also had the largest direct effect on

Table 2: Genotypic Correlation Co-efficients among fifteen okra characters

Characters	Sea-sons	Height at flower-ing cm	Edible pod length (cm)	Edible pod width (cm)	Number of branches / plant	Final plant height (cm)	Number of seeds pod	Weight of 100 seeds (g)	Length of mature pod (cm)	Number of leaves/ plant	Life-span (days)	Duration of flower-ing (days)	Num-ber of pods plant	Edible pod weight (g)	Pod yield/ plant (g)
Number of days	ES	0.96**	-0.45**	-0.14	0.62***	0.63**	0.22	-0.53**	-0.69**	0.51**	0.58**	0.10	-0.43**	-0.48**	-2.13**
to flowering	LS	0.21	-0.40**	-0.30	0.27*	0.35**	0.54**	-0.38**	-0.47**	0.50**	0.56**	-0.30	0.44**	-0.44**	0.22
Height at	ES		0.11	-0.14	0.63**	1.22**	-0.26*	-0.25*	-0.99**	0.51**	1.03**	0.65	-0.21	-0.14	-0.32*
flowering (cm)	LS		-0.11	-0.69**	-0.03	0.92**	0.39**	-0.31*	0.11	0.29	0.27*	-0.35**	0.05**	-0.29**	-0.21
Edible pod	ES			-0.23	-0.34**	0.10	-0.47**	+0.36**	0.39**	-0.24	-0.03	0.24	-0.23	+0.04	0.43**
length (cm)	LS			-0.27*	-0.93**	0.11	-0.50**	+0.002	0.81**	-0.38**	0.07	0.39**	-0.29*	-0.17	0.46**
Edible pod	ES				0.16	-0.16	0.13	0.02**	-0.11	0.34**	-0.03	0.02	0.08	0.87	0.78**
width (cm)	LS				0.67**	-0.77**	-0.22	0.10	-0.27*	+0.34**	-0.15	-0.38**	0.63**	0.67**	0.80**
Number of	ES					0.74	0.29*	-0.52**	-1.02	1.06**	0.99*	0.85**	0.82**	0.15	0.77**
branches/plant	LS					-0.17	-0.47**	-0.67**	-1.15**	1.34**	0.11	-0.19	1.61**	0.42**	1.03**
Final plant	ES						-0.20	-0.45*	-0.62**	0.73**	0.94**	0.75**	-0.03	-0.02	0.08
height (cm)	LS						0.30*	-0.17	0.26*	-0.09	0.10	0.23	-0.27**	-0.37**	-0.24
Number of	ES							0.12	0.49**	0.23	-0.08	-0.20	0.32*	0.05	0.34**
seeds/pod	LS							0.41**	-0.08	0.63**	0.25*	-0.24	0.07	-0.29*	+0.50**
Weight of	ES								1.47**	-0.47**	-0.28*	-0.01	-0.34**	0.28*	0.45**
100 seeds (g)	LS								-0.41**	-0.36**	-0.12	0.17	-0.39**	0.10	0.98**
Length of mature	ES									-0.88**	-0.44**	-0.09	-0.29*	0.41**	0.58**
pod (cm)	LS									-0.37**	-0.17	0.20	-0.16	0.04	0.78**
Number of	ES										0.79**	+0.64**	0.28	0.17	0.37**
leaves/plant	LS										0.29*	1.57**	0.21	-0.99**	-0.27*
Lifespan	ES											0.86**	-0.16	-0.09	0.11
(days)	LS											0.62**	0.39**	-0.17	0.50**
Duration of	ES												0.07	0.30*	0.62**
flowering (days)	LS												0.15	0.14	0.13
Number of	ES													0.30*	0.10
pods/plant	LS													0.67**	1.23**
Edible pod	ES														1.04**
weight (g)	LS														0.40**

[1]ES = Early Season; LS = Late Season.
*, ** = Significant at 5 and 1 percent levels, respectively

Table 3: Phenotypic correlation co-efficients among fifteen okra characters

Characters	Sea-sons	Height at flow-ering cm	Edible pod length (cm)	Edible pod width (cm)	Number of branches / plant	Final plant height (cm)	Num-ber of seeds pod	Weight of 100 seeds (g)	Length of mature pod (cm)	Num-ber of leaves/ plant	Lifespan (days)	Duration of flower-ing (days)	Number of pods plant	Edible pod weight (g)	Pod yield/ plant (g)
Number of days	ES	0.82**	-0.41**	-0.15	0.37**	0.48**	0.11	-0.45**	-0.45**	0.42**	0.48**	-0.01	-0.23**	-0.36**	-0.70**
to flowering	LS	0.18	-0.37**	-0.24	0.40**	0.27*	0.46**	-0.33**	-0.44**	0.22	0.49**	-0.25*	0.05	-0.29*	0.22
Height at	ES		0.19	-0.16	0.53**	1.19**	-0.17	-0.25*	-0.88**	0.67**	0.97**	0.64**	-0.02	-0.02	0.05
flowering (cm)	LS		-0.05	-0.40**	0.02	0.85**	0.34**	-0.24	-0.08	0.10	0.14	-0.33**	0.02	-0.13	0.03
Edible pod	ES			-0.19	-0.23	0.14	-0.36**	+0.32*	0.29*	-0.19	-0.07	0.15	-0.11	0.15	0.35**
length (cm)	LS			-0.19*	-0.40**	0.14	0.08	0.03	0.68**	-0.15**	-0.05	0.22	-0.12	0.08	0.30*
Edible pod	ES				0.13	-0.12	-0.34**	0.03	-0.12	0.30*	0.02	0.07	0.10	0.95**	0.48**
width (cm)	LS				0.24	-0.58**	-0.17	0.10	-0.19	0.14	-0.38**	-0.24	0.11	0.40**	0.19
Number of	ES					0.59**	0.20	-0.34**	-0.67**	0.80**	0.61**	0.49**	0.31*	0.17	0.83**
branches/ plant	LS					-0.18	-0.26*	-0.41**	-0.55**	0.23	0.34**	-0.01	0.23	-0.16	0.22
Final plant	ES						-0.14	-0.36**	-0.63**	0.69**	0.75**	0.57**	-0.04	-0.04	0.15
height (cm)	LS						0.29*	0.11	0.26*	-0.02	-0.01	-0.24	-0.02	-0.06	-0.24
Number of	ES							0.11	0.40**	0.16	-0.01	-0.05	0.19	0.03	0.11
seeds/pod	LS							0.30*	-0.20	0.25*	0.14	-0.27*	0.01	-0.14	0.46**
Weight of	ES								0.70**	-0.43**	-0.21	0.01	-0.21	-0.17	0.25*
100 seeds (g)	LS								0.37**	-0.11	0.02	0.22	-0.11	0.21	0.30
Length of mature	ES									-0.87**	-0.48**	-0.28*	-0.43**	0.03	-0.07
pod (cm)	LS									-0.14	-0.11	0.18	-0.04	0.08	0.30*
Number of	ES										0.66**	+0.51**	0.19	0.17	0.33**
leaves/ plant	LS										-0.09	0.29*	0.17	-0.24	0.04
Lifespan	ES											0.87**	-0.03	-0.05	0.03
(days)	LS											0.71**	0.03	-0.15	0.01**
Duration of	ES												0.10	0.22	0.30*
flowering (days)	LS												-0.01	0.05	0.00
Number of	ES													-0.02	0.41**
pods/plant	LS													-0.08	0.04
Edible pod	ES														0.79**
weight (g)	LS														0.46**

[1]ES = Early Season; LS = Late Season.
*, ** = Significant at 5 and 1 percent levels, respectively.

Table 4: Environmental correlation coefficients among fifteen okra characters

Characters	Sea-sons	Heig ht at flow-ering cm	Edible pod length (cm)	Edible pod width (cm)	Number of branche s/ plant	Final plant height (cm)	Number of seeds pod	Weight of 100 seeds (g)	Length of mature pod (cm)	Num-ber of leaves/ plant	Life-span (days)	Duration of flowering (days)	Number of pods plant	Edible pod weight (g)	Pod yield/ plant (g)
Number of days	ES	0.08	-0.26**	-0.22	-0.04	-0.24	-0.15	-0.16	1.07**	-0.08	0.35**	-0.29*	0.03	-0.10	0.03
to flowering	LS	-0.06	-0.24**	-0.09	0.30*	-0.13	0.06	-0.29*	-0.19	-0.03	0.33**	-0.05	-0.38**	-0.11	-0.37**
Height at	ES		0.78**	-0.33**	0.55**	0.99**	0.16	-0.26*	0.41**	0.50**	0.79**	0.81**	0.11	0.44**	+0.17
Flowerin(cm)	LS		0.29*	0.58**	0.12	0.50**	0.07	-0.02	0.22	-0.15	-0.39**	-0.35**	0.00	0.17	0.36**
Edible pod	ES			0.02	-0.03	0.37**	-0.12	0.12	-0.46**	0.17	-0.23	-0.13	0.06	0.46**	0.31*
length (cm)	LS			-0.02	-0.02	0.24	0.23	0.10	-0.03	0.03	-0.35**	-0.22	-0.04	0.47**	0.31*
Edible pod	ES				0.11	0.14	-0.06	0.06	-0.20	-0.03	0.23	0.24	0.16	0.32*	0.05
width (cm)	LS				-0.02	-0.18	-0.06	0.10	0.07	0.02	-0.75**	0.00	-0.16	0.14	-0.05
Number of	ES					0.42**	0.09	-0.03	0.11	0.45**	0.02	0.01	-0.09	0.19	0.87**
branches/plant	LS					-0.28*	-0.15	-0.29*	-0.08	-0.12	0.19	0.13	-0.11	0.42**	0.06
Final plant	ES						0.05	0.14	-0.81**	0.40**	-0.06	-0.01	0.21	-0.11	0.37**
height (cm)	LS						0.14	0.04	0.29*	0.05	-0.30*	-0.33*	0.20	0.48**	0.47**
Number of	ES							0.08	0.18	0.08	-0.15	0.23	0.06	0.00	-0.15
seeds/pod	LS							0.04	0.36**	-0.05	-0.14	0.37**	0.02	0.06	0.70**
Weight of	ES								5.31**	-0.17	0.05	0.06	0.05	-0.41**	-0.19
100 seeds (g)	LS								0.33**	0.06	0.28*	0.32*	0.04	0.35**	0.05
Length of mature	ES									-0.86**	-0.85**	-1.39**	-0.23**	-01.61**	-2.16**
pod (cm)	LS									0.11	0.11	0.12	0.08	0.26*	0.14
Number of	ES										-0.01	0.04	0.09	0.22	0.47**
leaves/plant	LS										0.04	0.23	0.16	0.10	0.11
Lifespan	ES											0.93**	0.15	0.03	0.09
(days)	LS											0.89**	-0.18	-0.13	-0.24
Duration of	ES												0.13	0.08	-0.07
flowering (days)	LS												-0.11	-0.04	-0.07
Number of	ES													-0.34**	0.62**
pods/plant	LS													0.13	0.26*
Edible pod	ES														0.55**
weight (g)	LS														0.51**

[1]ES = Early Season; LS = Late Season.
*, ** = Significant at 5 and 1 percent levels, respectively

pod yield with the largest indirect effect through reduction in the number of days to flowering (Table 5). Since environmental correlation coefficients were low in most cases, phenotypic correlation coefficients would be good indices of genotypic correlations. In this case, edible pod length, edible width, number of branches per plant, number of seeds per pod, weight of 100 seeds, length of mature pods and edible pod weight which were genotypically correlated with pod yield during the two seasons indicated that pod yield could be improved through selection for these characters. Characters that were phenotypically correlated but not genotypically correlated will not produce repeatable estimates of inter – character associations and any selection based on the relationship is likely to be unreliable. Although there was a significant genotypic correlation between edible pod weight and number of pods per plant, not much success may be expected in selecting for a large number of pods per plant through edible pod weight since the two characters were not phenotypically correlated. However, significant genotypic and phenotypic correlation between number of days to flowering and lifespan suggested that the number of days to flowering can be used as a criterion for selecting lines with short lifespan. Early flowering lines will be best suited to areas with short growing season. Because of the close association between edible pod width and edible pod weight,

Table 5: Direct and indirect effects of some characters on pod yield in Okra

Characters			Indirect effect on pod yield through								
	Seasons	Direct effect on pod yield	number of days to flowering	edible pod length (cm)	edible pod width (cm)	Number of branches/	Final plant height (cm)	Lifespan (days)	Number of pods/ plant	Edible pod weight (g)	Genotypic correlation coefficients
Number of days	ES	5.61		-0.95	2.09	3.29	-12.34	6.05	1.62	-7.51	-2.13**
to flowering	LS	1.43		-0.38	-1.16	-0.22	0.12	-0.14	0.36	0.79	0.22
Edible pod	ES	2.11	-2.53		3.43	-1.81	-1.96	-0.31	0.87	0.87	0.43**
Length (cm)	LS	0.95	-0.57		-0.14	0.74	0.04	-0.02	-0.24	-0.31	0.46
Edible pod	ES	-14.92	-0.79	-0.49		0.85	3.14	-0.31	-0.30	13.60	0.78**
Width (cm)	LS	0.52	-0.43	-0.26		0.54	-0.25	0.04	0.51	1.21	0.80**
Number of	ES	5.31	3.48	-0.72	-2.39		-14.50	-10.33	-3.09	2.34	0.77**
branches/ plant	LS	-0.80	0.39	-0.89	0.35		-0.06	-0.03	1.31	0.76	1.03**
Final plant	ES	-19.59	3.54	0.21	2.39	3.93		9.81	0.11	-0.31	0.08
Height (cm)	LS	0.33	0.50	0.11	-0.40	0.14		-0.03	-0.22	-0.67	-0.24
Lifespan (days)	ES	10.43	3.26	-0.06	0.45	5.26	-18.42		0.60	-1.41	0.11
	LS	-0.25	0.80	0.07	-0.08	-0.09	0.03		0.32	-0.31	0.50**
Number if	ES	-3.77	-2.41	0.49	-1.19	4.35	0.59	-1.67		4.69	0.10
pods/plant	LS	0.81	0.63	-0.28	0.33	-1.29	-0.09	-0.10		1.21	1.23**
Edible pod	ES	15.64	-2.69	0.08	-12.96	0.80	0.39	0.94	-1.13		1.04**
Weight (g)	LS	1.80	-0.63	-0.16	0.35	-0.34	-0.12	0.04	-0.55		0.40**

[1]ES = Early Season; LS = Late Season.
*, ** = Significant at 5 and 1 percent levels, respectively.

and since edible pod weight cannot be virtually determined on the field, edible pod width may be a more appropriate character for selection when high yield is the main objective.

Similar studies were carried out on cowpeas (Ariyo, 1995) and Soybean (Ariyo, 1995).

(iii) Analysis of Genotypex Environment Interaction It is part of plant breeding procedures to conduct yield trials of genotypes in a number of environments. The results of such trials have proved useful by providing important information on cultivar performance, adaptation and genotypex cultivar selection recommendations and release. The phenotype of a variety is a composite of three variables: genotype, environment and genotypex environment interaction. If all the genotypes respond linearly to all the environments tested, their relative performance in other environments may be predicted with confidence. The presence of gxe interaction is a major problem in gathering a reliable estimate of heritability and it makes it difficult to predict with greater accuracy the rate of genetic progress under selection for a

given character.

Various techniques have been used to assist in the analysis of GXE variation. The regression techniques have been widely used (Yates and Cochran, 1938, Finlay and Wilkinson, 1963; Eberhart & Russal 1966; Ariyo, 1987, 1991, 1995). Although the usual analysis of variance detects gxe interaction when genotypes are evaluated in different environments, it is unable to determine the responses of individual genotypes. However, joint regression analysis is able to furnish the responses of different genotypes evaluated in different environments. The technique involves the quantifications of each environment by the means of all genotypes tested and its measure of adaptability is based on the assumption that a genotype responds linearly to environmental conditions. The sensitivity of a genotype to different environments is judged from the magnitude of its regression coefficient and the slope's deviation from linearity. Although, the use and validity of joint regression analysis have been criticized (Baker, 1969; Byth et al., 1976; Powel et al., 1986; Ariyo, 1987), it has nevertheless proved valuable in cultivar development for crops (Ebertant and Russell, 1966; Breese, 1969, Ntare and Akenova, 1985, Ariyo; 1990).

The result of the joint regression analysis for 20 genotypes

of okra for five characters is presented in Table 6. The GXE interaction was partitioned into its components, heterogeneity (non-additivity) and the deviation from regression. A significant GXE mean square value is an indication of the presence of GXE interaction. In the case of number of branches per plant all the GXE interaction was accounted for by the heterogeneity component thus indicating that a linear relationship can adequately explain the GXE interactions. Also the significant mean squares for deviation suggested that a proportion of GXE interaction was non-linear. Under such a case, joint regression technique is sufficient. However, a reasonable proportion of GXE interaction was accounted for by the deviation component of other characters. This detracts from the assumption that the GXE interaction can always be explained in a linear relationship between genotype and environment.

In search of more sensitive techniques, the stability variance as measured by ecovalence mean square (Wricke, 1962; Kang Miller, 1984) and stability variance as measured by unbiased estimator σ_i^2 Shukla (1972) have frequently been used. Only six and eight genotypes were classified as unstable for pod weight and number of branches per plant, respectively. The two techniques produced similar results as they perfectly agreed as to which genotypes were stable for

Table 6: Joint regression analysis of 20 okra genotypes across 4 environments

Source of variation	d.f.	Days to flowering	Number of branches/plant	Plant height (cm)	Pod weight (g)	Number of pods/plant	Pod yield/plant (g)
Environment	3	124.7**	3.6**	18,302.3**	64.2**	88.5**	55,521.7**
Genotype	19	60.0**	4.8**	2,193.1*	8.9**	15.6**	3,395.2**
Heterogeneity	19	16.1**	0.8**	627.3**	4.5**	20.9**	2,969.00**
Deviation	38	7.4**	0.2	224.0**	1.5	9.4**	1,567.2**
Pooled error	160	1.3	0.2	86.2	1.0	3.1	247.0

Table 7: The stability variance for each of the 20 okra genotypes as measured by the unbiased estimator (σ^2_i) of Shukla (1972)

Genotype	Days of flowering	Number of branches/ plant	Plant height (cm)	Pod weight (g)	Number of pods/ plant
UI 92	0.8	1.1[a]	229.9[a]	0.2	19.9[a]
UI 10	1.0	0.8[a]	-5.4	1.6	8.4[a]
UI 104	1.0	-0.3	140.7	4.7[a]	2.8
UI 81-28	8.1[a]	0.4	67.1	0.4	21.7[a]
NHAe 47-4	0	0.3	487.0[a]	2.0	12.2[a]
Ex-Borno	6.9[a]	0.8[a]	713.0[a]	-0.1	10.3[a]
UI 79-5	5.4[a]	0.2	111.9	3.7[a]	13.1
V35	1.6	1.1[a]	400.2[a]	1.1	2.6
UI 117	8.9[a]	1.6[a]	102.7	1.5	38.8[a]
NHAe 15	5.6[a]	0.5	857.2[a]	2.9[a]	30.7[a]
UI 86	24.5[a]	0.1	314.5[a]	1.4	14.6[a]
OP-80	4.1[a]	0.4	530.2[a]	0.1	14.6[a]
V2	8.9[a]	0.1	225.9[a]	1.2	8.1[a]
Tae 38	7.7[a]	0.8[a]	399.3[a]	0.2	46.7[a]
Pusa Sawani	11.2[a]	3.2[a]	1148.0[a]	1.7	3.7
UI C-6-2	1.4	0.7[a]	936.9[a]	3.5[a]	4.2
UI 38	4.0[a]	0.1	13.7	0.6	0.4
UI 212	19.8[a]	0.1	86.3	0.6	5.8
UI 9	6.4[a]	0	103.7	3.6[a]	111.6[a]
UI 210	15.6[a]	0	439.9[a]	17.9[a]	5.5

[a] Stability-variance (σ^2_i) significantly greater than 0.

number of pods per plant and plant height (Tables 7, 8, and 9).

The deviation mean squares gave a different stability pattern of genotypes in respect of the characters. Although there were areas of agreement among the three stability techniques, regression technique was less discriminatory. Since yield is the ultimate in crop production, the mean yield, linear regression coefficient, and three stability parameters were computed (Table 10). NHAe 15, 0p-80, and UI 210 with regression coefficients significantly greater than 1.O had above average response and produced were consistently higher yield in all the above environments. Estimates of the stability-variance parameters, σ_i^2, and W-mean squares were significant for nearly the same genotypes with the exception of UI 0, where, σi^2 was not significant. With the exception of UI 10, V_{35} and UI 38, all the remaining genotypes were considered unstable by having significant stability-variance parameters and W-mean square. However, the deviation MS technique considered Ex-Borno, UI 79-5, OP-80, Pusa Sawani, UI C-6-2, UI 38 and UI 9 as stable by having deviation MS which were not significant.

The heritability estimates of the six characters indicated that the linear response of number of branches to environment

Table 8: The stability variance for each of the 20 okra genotypes as measured by Ecovalence mean square (Wricke, 1962; Kang and Miller, 1984)

Genotype	Days of flowering	Number of branches/plant	Plant height (cm)	Pod weight (g)	Number of pods/plant
UI 92	1.2	0.9[b]	230.8[b]	0.3	19.5[b]
UI 10	-2.6	0.8[b]	7.8	1.8	8.7[b]
UI 104	1.4	0	145.8	4.6[b]	2.7
UI 81-28	8.1[b]	0.4	76.6	0.5	20.6[b]
NHAe 47-4	0.4	0.3	473.4[b]	2.0	10.3[b]
Ex-Borno	6.9[b]	0.9[b]	688.5[b]	1.6	9.7[b]
UI 79-5	0.9	0.4	119.0	3.6	12.4
V35	1.9	1.2[b]	467.8[b]	2.2	2.5
UI 117	12.6[b]	1.5[b]	110.3	1.5	36.8[b]
NHAe 15	5.7[b]	0.5	825.0[b]	2.9	29.1[b]
UI 86	23.6[b]	0.1	288.1[b]	1.4	13.8[b]
OP-80	4.3[b]	3.2[b]	515.3[b]	0.2	13.8[b]
V2	9.0[b]	0.1	221.9	1.3	7.6[b]
Tae 38	7.6[b]	0.8[b]	391.3[b]	0.3	44.3[b]
Pusa Sawani	10.7[b]	0.7[b]	1087.5[b]	1.8	3.5
UI C-6-2	1.6	0.7[b]	851.1[b]	0.7	4.0
UI 38	4.1	0.2	26.0	0.7	0.3
UI 212	19.2[b]	0.1	94.7	0.4	5.5
UI 9	6.5b	0	111.3	3.6[b]	11.0[b]
UI 210	15.2	0.1	429.7	17.6	5.2

[b] Ecovalence variance significantly greater than 0.

Table 9: Deviation mean square (S^2_{di}) for each of the 20 okra genotypes (Eberhart and Russell, 1966)

Genotype	Days of flow-ering	Number of branches/plant	Plant height (cm)	Pod weight (g)	Number of pods/plant
UI 92	2.2	0.2	124.2	0.5	27.2[c]
UI 10	2.7	0.3	9.8	0.2	0.1
UI 104	0.4	0.4	30.8	2.4	3.6
UI 81-28	8.6[c]	0.6	209.0	0.6	20.4[c]
NHAe 47-4	4.1[c]	0	397.9c	2.1	20.3[c]
Ex-Borno	1.7	0.5	58.0	2.4	0
UI 79-5	5.4[c]	0.2	25.4	3.0[c]	4.5
V35	2.4	0.3	187.0	2.9[c]	1.9
UI 117	1.5	1.1[c]	38.3	1.1	19.6[c]
NHAe 15	2.7	0.6[c]	52.2	0.8	15.5[c]
UI 86	21.1[c]	0.2	384.8c	1.8	19.6[c]
OP-80	6.0c	0.6[c]	2.5	0.2	1.0
V2	13.7[c]	0.5	74.5	1.8	8.6[c]
Tae 38	6.3[c]	0.3	305.4c	0.4	7.5
Pusa Sawani	2.5	0.3	722.1	0.6	4.6
UI C-6-2	3.2	0.7[c]	1091.4c	0.5	0.3
UI 38	4.5[c]	0.0	296.5	0.7	0.4
UI 212	17.5[c]	0.2	57.0	0.9	7.6
UI 9	14.6[c]	0.6[c]	133.1	3.3[c]	10.5[c]
UI 210	21.7[c]	0.2	106.5	4.9[c]	6.0

[c] Deviation mean square (S^2_{di}) significantly greater than 0.

Table 10: Mean pod yield, regression co-efficient, b, unbiased estimator (σ^2_i), ecovalence mean square (W-MS), and deviation mean square (S^2_{di}) for 20 okra genotypes

Genotype	Mean pod yield (g)	Regression co -efficient (b)	(σ2i)	W-MS	S^2di
UI 92	180.2	1.21	5149.2[a]	4985.0[c]	906.0[d]
UI 10	108.5	1.20	222.0	318.0	2842.2[d]
UI 104	127.9	1.36	1169.0[a]	1215.0[c]	1171.0[d]
UI 81-28	144.8	1.38	3051.0[a]	2998.0[c]	2851.0[d]
NHAe 47-4	143.7	1.21	874.0[a]	935.0c	1139.0[d]
Ex-Borno	58.6	0.32[e]	1358.0[a]	1394.0[c]	19.0
UI 79-5	83.4	0.52	930.0[a]	988.0[c]	400.0
V35	107.0	1.11	526.0	605.0	808.0[d]
UI 117	104.0	0.18[e]	5610.0[a]	5422.0[c]	1736.0[d]
NHAe 15	126.2	1.70[e]	4080.0[a]	3973.0[c]	1817.0[d]
UI 86	119.9	1.22	2747.0[a]	2710.0[c]	3655.0[d]
OP-80	104.1	1.67[e]	1532.0[a]	1559.0[c]	324.0
V2	108.9	1.39	1101.0[a]	1150.0[c]	992.0[d]
Tae 38	106.6	0.10[e]	5611.0[a]	5423.0[c]	2513.0[d]
Pusa Sawani	66.6	0.47	1060.0[a]	1112.0[c]	382.0
UI C-6-2	92.6	0.39[e]	1186.0[a]	1231.0[c]	155.0
UI 38	84.8	0.86	-6.0	102.0	61.0
UI 212	139.2	0.93	1935.0[a]	1942.0[c]	2745.0[d]
UI 9	123.3	1.31	629.0	703.0[c]	587.0
UI 210	143.5	1.60[e]	1936.0[a]	1941.0[c]	1230.0[d]

[e] Regression co-efficient, significantly greater than 1.0
[d] Stability parameters S^2_{di} significantly greater than 0

was largely under strong genotypic influence. However, the low heritability estimates for other characters showed that their responses were environmentally determined. The fact that pod yield had the least heritability estimate suggested that pod yield was not predictable. However, since the number of branches, an important component of pod yield had the highest heritability estimate, high pod yield could be bred for by selecting genotypes with higher number of branches.

This lecturer also applied these techniques in studies in Cowpeas (Ariyo et al., 2002), Soybean (Ariyo, 1995) and rice (Nassir and Ariyo, 2005).

Following the observed deficiencies of the previous methods a more flexible model was proffered (Kempthorne, 1984; Crossa *et al.*, 1989; Gauch, 1992). The model extends the classical additive main effect for genotypes and the interaction. The combination of additive component with the multiplicative interaction components leads to the model called Additive Main Effects and Multiplicative Interaction (AMMI) model. A number of workers have demonstrated the effectiveness of the model in understanding GXE interaction in yield, estimating yields more accurately, and selecting superior genotypes more reliably (Brady,

1994; Zobel *et al.*, 1988; Crossa *et al.*, 1991; Ariyo, 1998; Ayo-Vaughan, 2000; Nassir & Ariyo, 2005).

Table 11 presents the results of the evaluation of eleven genotypes of soybean grown in four environments. Only four of the genotypes yielded above average. Abuja produced the highest yield of 862.6kg/ha followed by Zaria with a yield of 760.8kg/ha. Abeokuta produced the lowest yield during the two years. Figure 6 presents the biplot of the AMMI model which accounted for 92.38% of the total sum of squares. This lecturer also went further to estimate the yields of the top five genotypes using the AMMI model (Table 12). TGx1446-2E exhibited the least interaction in all locations while TGX1448-1E showed the largest interaction with the environments. Zaria had the largest negative interaction effect while Abuja had the largest positive interaction effect. Only TGX1448-2E showed stability effect by having interaction close to zero. Both TGx1489-1D, Samsory 2, TGx 1455-2E, TGX 1649-9F and TGX 1660-18F which yielded below average were adapted to Abeokuta and no particular genotype appeared adapted to Abuja. When a genotype and environment have the same sign on the PCA axis, their interaction is positive, if different and their interaction is negative. The TGX 1648-3F, TGX 1448-1E and TGX 1660-18F with large interaction with environments

Table 11: Soybean genotypes grown in 4 environments, means and first PCA from AMMI analysis

Genotype	Abeokuta 1 (1991)	Abeokuta 2 (1992)	Zaria	Abuja	Mean	First PCA Score
1) TGX 1440-1E	747.3	652.3	924.0	1,251.3	898.8	7.73
2) M-351	456.3	530.7	505.0	796.7	572.2	2.79
3) TGX 1660-19F	676.0	659.7	881.0	680.0	710.8	-7.79
4) TGX 1648-3F	431.7	632.3	449.0	845.3	672.9	13.23
5) TGX 1489-1D	413.0	699.7	845.7	778.0	684.1	-3.66
6) Samsoy 2	460.0	717.7	752.3	694.7	661.2	-5.50
7) TGX 1448-1E	772.7	631.7	915.7	1,579.3	974.8	17.20
8) TGX 1455-2E	426.7	604.3	584.7	642.3	564.5	-3.24
9) TGX 1649-9F	374.7	427.0	635.3	456.7	473.4	-6.87
10) TGX 1660-18F	535.0	670.0	806.3	391.0	605.6	-14.53
11) TGX 1448-2E	607.0	699.7	1,069.3	1,060.3	859.1	0.65
Mean	536.4	630.2	760.8	862.6	697.5	
First PCA	-4.13	-10.29	-11.31	25.72		

Table 12: Seed yield of the top five genotypes as estimated by AMMI model

Genotype	Main Effect	Interaction	Final Yield
Abeokuta 1			
1) TGX 1440-1E	737.7	-31.92	705.78
2) TGX 1648-3F	549.7	32.17	581.87
3) TGX 1448-1E	813	-71.04	741.96
4) TGX 1660-18F	444.5	60.01	504.51
5) TGX 1448-2E	768.6	-2.68	765.92
Abeokuta 2			
1) TGX 1440-1E	830.7	-79.54	751.16
2) TGX 1648-3F	643.5	80.16	723.66
3) TGX 1448-1E	907.5	-176.99	730.51
4) TGX 1660-18F	538.3	149.51	687.81
5) TGX 1448-2E	791.8	-6.69	785.11
Zaria			
1) TGX 1440-1E	962.1	87.43	1,049.53
2) TGX 1648-3F	774.1	88.10	862.2
3) TGX 1448-1E	1,038.1	-194.53	843.57
4) TGX 1660-18F	668.9	164.19	833.09
5) TGX 1448-2E	992.4	-7.35	985.05
Abuja			
1) TGX 1440-1E	1,027.9	198.82	1,226.72
2) TGX 1648-3F	875.9	-200.36	675.54
3) TGX 1448-1E	1,139.9	442.38	1,582.28
4) TGX 1660-18F	770.7	-373.71	396.99
5) TGX 1448-2E	1,024.2	16.72	1,040.92

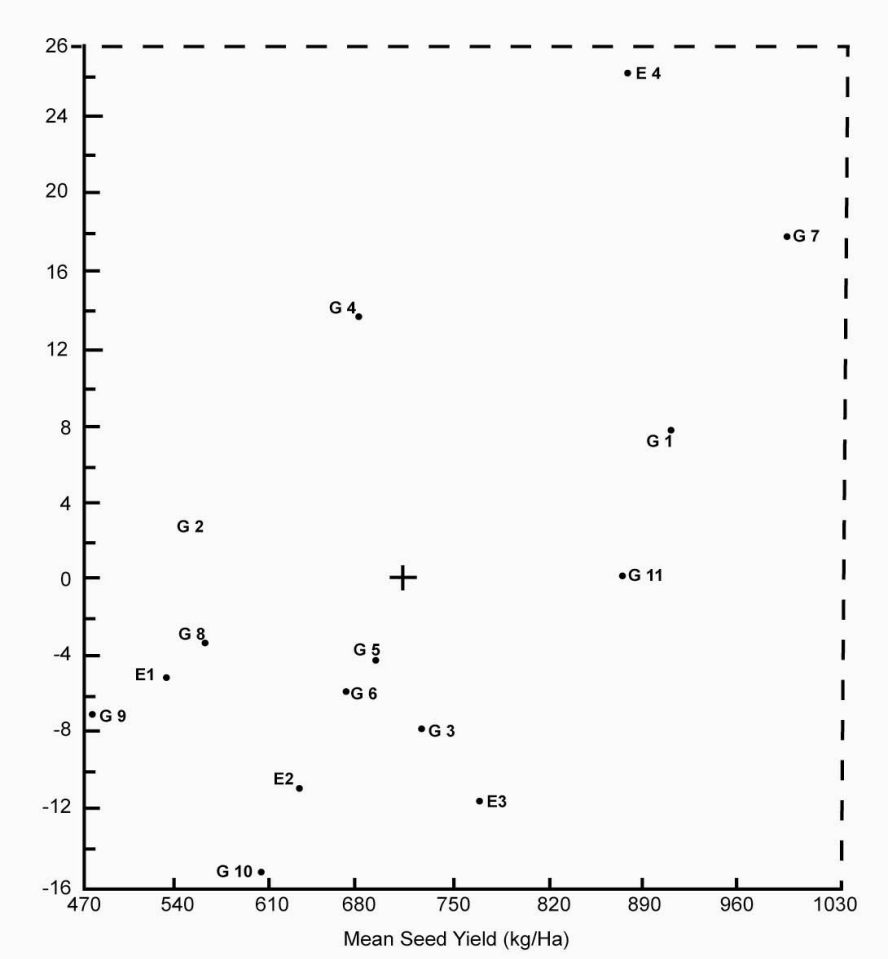

Fig.6: Biplot of the AMMI model for soybean yield trial with 11 genotypes grown in four environments.

cannot be predicted in performance. The yield estimates are adjusted estimates and are, therefore, different from treatment means. AMMI estimates are more precise, thereby, leading to increased probability of making successful selection.

Similarly, AMMI model was used in the analysis of GXE interaction in Cowpeas (Ariyo et al., 2002),and Okra (Ariyo and Ayo-Vaughan, 2000).

(iv) Genotype main effect plus genotypex environment interaction (GGE) Techniques.

It is a known fact that the observed phenotypic variation (P) consists of variations of the environment (E), genotype (G) and genotype x environment interaction (GE).

The environment, E may be further partitioned into year (Y), Location (L) and year x location interaction (Y x L) and genotypex Location x year interaction (GLY) (Comstock and Moll, 1963). For single-year multi-environment trials, no GY, LY and GLY can be estimated. Therefore, E is composed of only L and GE is composed of GL. It has been noted in all trials that E is always the pre-

dominant source of variation and G and GE are relatively small and E can account for 60-80% of the total yield variation. The large environment main effect is, however, not relevant to cultivar evaluation, but G and GE are. It is, therefore, pertinent to remove E from data and concentrate on G and GE. The concept then becomes: P – E = G + GE.

This technique has been extensively used in the analysis of multilocation trials of rice (Sanni, 2008) and Okra Adekoya (2008). My Vice-chancellor Sir, it appears the search for appropriate technique will never end.

(7) RECOMMENDATIONS

(i) Improvement of the genetic base of our crops to cope with adverse and varying environmental conditions. The cheapest way to crop production is to raise crops that are hardy and need little or no inputs with regards to herbicides, fertilizers, insecticides, fungicides, etc. For example, cassava is a staple food for about 200 million Africans. Nigeria is the largest producer of the crop. This has been possible through the development of high-yielding disease resistant, adapted and consumer acceptable varieties. Similarly, the crossing of very hardy old African rice *(Oryza glaberima)* with more frail but high yielding Asian rice *(Oryza sativa)* resulted to NERICA (New Rice for Af-

rica). The rice type combines the best features of both parents, such as resistance to drought and pests, higher yields even under little irrigation and fertilization.

(ii) Capacity building in Agricultural biotechnology

Capacity building is the ability of individual organisations or countries to meet their needs with regards to development in a sustainable way. Biotechnology can play a decisive role in agricultural production because it is capable of directly modifying plants in response to new needs. Biotechnology should be seen as means of solving problems where traditional techniques have failed. In-vitro culture of meristems and buds is now widely used for the micropropagation of many species for commercial purpose. It is also used for germplasm conservation of vegetatively propagated species and for the exchange of virus-free materials. In-vitro culture of zygotic embryo has enabled us to overcome barriers to a number of inter-specific crosses from zygotic failure. Similarly in-vitro culture of anthers permits the regeneration of a large number of haploid plants from which homozygous diploid plants can be obtained. Transformation can be accomplished through somatic hybridization or gene transfer. Several interspecific and inter-generic hybrids have been obtained through proto plast fusion. Biotech-

nology includes recombinant DNA technology which is a series of techniques for genetic engineering that allows the manipulation of DNA.

(iii) Improvement in Crop Environment

As earlier stated, the phenotype of a crop is determined by a combination of genotype, environment and genotype x environment interaction. Experience has shown that environment can account for 60-80% of variation in phenotype. As a matter of fact, the environment determines the phenotype a genotype will manifest. The crop environment consists of a complex interact-tion of interdependent variables. At the centre of this interaction is the farmer, exercising some measure of control and choice regarding the types and results of the interaction. No matter the potential of the crop, it will not show unless the environment is right. Among the environmental factors limiting crop production are declining fertility and water. In order to optimize crop production there should be improved integration of soil, water and nutrient management for sustainable production.

(iv) Collaboration and Partnership

Agricultural research and development programmes in developing countries have been poor, ineffective and are getting weaker because of lack of adequate funding.

There is therefore, need to go into collaboration and partnership with other organizations in order to benefit from capital flows, technology transfer and accessibility to advanced laboratories and capacity building. Nigeria is today the leading producer of cassava in the world due to the pan African collaboration among international, regional and national research and extension programmes leading to high-yielding, disease/pest re-sistance varieties.

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