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An Integrated Evaluation of Agricultural Research in Tropical Africa:

The Case of the Nigerian Food Crops Research System

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Abstract

This paper uses stochastic frontier production analysis to evaluate the performance of Nigeria's food crop research investment system, with emphasis on maize, rice, and cassava. Thre complementary models are used: an environmental model, a stochastic dominance model, and an aggregate production function model. While technical productivity results are positive, social rates of return on food crop research investment appear thus far to be modest. The challenge is to discover why social rates of return are inadequate and how this can be remedied through the food crop research investment program.

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Agricultural productivity is an important key to Africa's economic growth. Improving agricultural productivity is central to any successful strategy for achieving sustainable economic growth. In turn, raising agricultural productivity depends not just on competitive economic incentives, but also on the level of investment. The question is whether investment in agricultural productivity provides sufficient returns to warrant continued support. One way to address this question is to examine returns to agricultural research in comparison to traditional methods of agricultural production.

In order to test this hypothesis, an economic test of agricultural research efficiency is carried out through the calculation of marginal internal rate of return (MIRR) of food research system in Nigeria. This rate is expected to be low or negative due to a continuing decline in food productivity. If this is the case, another question among many might be raised: is such a poor rate of return due to an unadequate research output? To answer this question some varieties are physically evaluated by means of an environmental or agronomic model to assess their appropriateness as viable research output. Selected varieties were taken from annual reports of the International Institute of Tropical Agriculture (IITA). The appropriateness is determined by two main characteristics, namely high yield attainability and yield stability. Once such characteristics are shown to prevail in the research system, another question is in order, that is, are those yields high and stable enough for them to be accepted by farmers? A stochastic efficiency model is then used to address this question of farmers' acceptance.

The Economic Efficiency Model:

Specification of the aggregate production function relating output (Y) to inputs requires the inventory of basic inputs. In Nigeria, labor *(Lt)* and land (IV,) are two principal conventional resources. Fertilizer and mechanical power are omitted because they are not significant in the Nigerian agriculture, do not show marked variation over long periods of time and are not measured with consistency by current data. Unconventional resources of education and research *(Rt)* are relevant. Data on educational attainment of farmers are not available, and research expenditures constitute the only non-conventional input directly incorporated in the model. The model takes the form:

$$(1)\quad Y_t = AL^{\alpha} N^{\beta} R^{\gamma}$$

Because the impact of R on Y is not instantaneous, equation (1) is modified by using a lagged Cobb-Douglas spline as follows:

$$(2)\quad Y_t = C_0 L_t^{C_1} N_t^{C_2} R_t^{C_3} R_{t-1}^{C_{3+1}} \ldots R_{t-k}^{C_{3+k}}$$

Problems related to the estimation of equation (2) are well known. The length of the lag K for obsolescence of productivity gains is not directly given by ordinary least squares estimated of the equation, but must be based on the knowledge of the production process and statistical properties of the equation fitted for alternative lag lengths. From African experience, it appears that research investment initially has an impact on the production process approximately three years after expenditure. The impact rises, peaks and eventually falls to complete obsolescence. In the environment of developed countries, complete obsolescence is reached in approximately 13-16 years on the average (Knutson and Tweeten). In developing countries, complete obsolescence may occur later than it does in developed countries due to a slowness in technology replacement and adoption. Given the short series of data available, the lag structure was chosen to extend from year one to year 12 so that k=12.

The impact curve of food crop research can be conceptualized as being of polynomial shape, thus allowing use of the Almond distributed lag structure to estimate equation (2). The degree of such a polynomial lag structure depends on the number of turning points on the impact. For simplicity and to place minimum demands on data available, the degree is set to be two-a quadratic distribution curve.

The equation to be estimated is similar to (2) but its lagged component gives a partial regression of the form:

$$(3)\quad Y_t = \alpha + \beta_0 \hat{R}_t + \beta_2 \hat{R}_{t-2} + \ldots + \beta_k \hat{R}_{t-k} + U_t$$

or:

$$(4)\quad Y_t = \alpha + \sum_{i=0}^{k} \beta_i \hat{R}_{t-1} + U_t, \quad \text{with} \quad R_t = \log R_t$$

Since B_i is assumed to follow a quadratic distribution, equation (4) becomes:

$$(5)\quad Y_t = \alpha + \sum_{i=0}^{k} \left(a_0 + a_1 i + a_2 i^2\right)\hat{R}_{t-1} + U_t$$

After expanding the equation (5) and changing notation, the estimated equation becomes:

$$(6)\quad Y_t = f\left(L_t, N_t, Z_{ot}, Z_{1t}, Z_{2t}\right)$$

The variables *Zot* and *Zlt* stand for tra.nsformed research variables while Zgt represents the error term of the estimated equation. From (6), the marginal product of the research *(MPR)* for a given period is:

$$(7)\quad MPR = \beta_i \frac{Y}{Z}$$

or in monetary terms:

$$(8)\quad MPR_m = P\beta_i \frac{Y_i}{Z_i}$$

The research benefits are accumulated over time and the time distributed value of MPR_m is:

$$(9)\quad \sum MPR_m = \sum_{i=1}^{k} \beta_i \frac{Y_i}{Z_i}$$

Discounting the marginal benefits and setting them equal to zero gives:

$$(10)\quad P\sum_{i=1}^{k} \frac{B_i\gamma_i}{Z_i(1-r)^k} - 1 = 0$$

with result that

$$(11)\quad r = \left(MPR\right)_m^{1/k} - 1$$

Using the above information, computation of MIRR for corn, cassava and rice research in Nigeria are reported in Table 1. These results show that internal rates Of return are very low compared to international standards. This does not, however, suggest that there has been over-investment in food research in Nigeria. At the same level of research support, an increase in rate of adoption pushes these rates upward, and reveals that their still exists a room for further research investment. In order to prove the sensitivity of marginal rates of return to changes in adoption rate, the following formula was used:

$$(12)\quad Q_{it} = (Yield)x(total \;\; area \;\; of \;\; crops)$$

In fact the equation (12) was substituted in (10) for Yi. For simplification it is assumed that *MPR*, increases when the crop is cultivated on its entire allocated area due to extension effort nad increased technical expertise of farmers. Under such a scenario, MIRR is significantly improved with 15, 11 and 19 per cent rates of return respectively for maize, rice and cassava. This finding shows how the rate of adoption positively affects the marginal rate of return. But the above rates do not account for lower prices that would result from greater output, for imperfections in the price system and for the cost of education required to raise adoption rates to higher levels.

Table 1
Estimated Marginal Rates of Return for Selected Crops in Nigeria

Period	Cassava	Corn	Rice
0	neg.	neg.	neg.
1	-do-	-do-	-do
t	-do-	-do-	-do
3	-do-	-do-	-do
4	5.8	3.1	-do
s	9.1	7.0	-do
6	11.1	9.0	-do
l	11.6	10.0	-do
8	12.2	10.0	-do
9	12.1	10.0	-do
10	11.4	10.0	-do
11	10.4	9.3	-do-

R^2 for estimated production functions were .5486, .5870 and .6607 respectively for cassava, corn and rice.

The Environmental Model

The above findings from economic efficiency analysis are just a partial approach te, the problem. Rates might be low, not only because adoption rates are low, but released varieties are not physically fit for ecological environments of Nigerian agriculture. Thus to test the hypothesis that released varieties were adaptable to a wide range of environments, the model was constructed as follows:

$$(13) \qquad \hat{V}_i = \bar{X}_i - \bar{X}$$

Favorable environments would have a positive environmental index $\hat{V}_i$ since the local mean Xi of a variety i would be higher than the overall mean X of all varieties. Hahn (1978) used information in (13) in the following regression equation:

$$(14) \quad X_{ij} = a_0 + a_{1j}\hat{V}_i + U_j$$

The sign and magnitude of the regression ciij is the key to the evaluation procedure. Regression equations as many as the number of variable will produce *atj, atk . . . a, rn* coefficients to be compared pairwise. If aij > aik the varietal performace of the cultivar j is superior to that of cultivar k. In order to simplify the evaluation procedure and ti use the information available at minimum cost, instead of casing several equations of the type described in (14), the following modifies model is proposed.

$$(15) \quad X_{ij} = a_0 + a_1\hat{V}_i + \sum_{j=1}^{m-1} a_{2j} D_j D_j + \sum_{j=1}^{m-1} a_{3j}\hat{V}_i D_j + U_{ij}$$

The variable Dj is a dummy for type of variety (*Dj = 1* if variety is j and*Dj = 0* otherwise), the coefficient *al* is the environmental impact of location i on yield response of variety j while *a2j* accounts for a shift in intercept due to varietal response. The *a3j* coefficient measures the interaction between location and variety. The overall performance of a given variety is captured by the sum *a1+ a3j* for each type of variety. Using the model in (15) performance indices as measured by *ai -f- a3j* were computed for maize, rice and cassava. Faut in order te, assess the stability of those performance indices, an empirical fra.rnework casing two dimensional graphic was used. In the ordinate, the performance indices of varieties are recorded while the varieties mean yield were measured in the abscissa. The intersection point of the overall mean performance and that of the average yield represents the stability point around which varieties parameters converge. Those va.rieties whose parameters are far away the stability area (measured within one standard error) are recognized as instable. The figures 1 - 3 report the results of variety performance and stability. Four maize varieties out of five chosen for the study perform well both yield-wise and stability-wise. The four varieties are: FARZ26, FARZ27, FARZl and FARZ23. For rice only 6 clones out of 11 varieties turned to be recommendable, those are FAROX 56/30, IRB, TOs42, T0978, T03490 and IR Z2. As to the Cassava research one variety (TMS60444) was very poor while two others indicated a very high potential but unstable (TMS 30572 and TIMS 30555).

The problem of adoption of good varieties could have been facilitated if the utility function of farmers was known, but in the case of Nigerian agriculture, no study has been made to elicit those functions. In order to advise properly on choices to be made, a stochastic efficiency model was used to classify varieties according to certain preferences or risk groups.

Stochastic Efficiency Analysis

The environmental model evaluates the physical performance of varieties solely on the basis of physical factors (environment and genetic potential) but farmers do not ordinarily adopt high yielding varieties on the basis of physical response alone. Farmers' attitudes must be considered in any recommendation made. The analysis of those attitudes requires implicit or explicit recognition of farmers' utility fonctions. Explicit utility functions have been estimated by classical methods (CM) of Von Neumann-Morgenstern and modifications thereof as well as by the Ramsey method. In addition to these methods used by farm- management specialists, the condensed approach by Harper and tweeten (H-T) measures utility using psycho- sociological scales weighted to form a quality of life index in Benthamite fashion.

In both CM and H-T methods, extensive surveys and income data by grouhs of farmers are needed to elicit the shape of utility functions. Because such data are rarely available in developing countries, methods of making decisions under certainty and risk without knowledge of the utilitv functions of decision makers are employed herein. One such method is a stochastic dominance or efficiency analysis.

The stochastic efficiency analysis uses three decision rules: 1) first stochastic dominance rule (FSD); 2) second stochastic clominance rule (SSD) and 3) third stochastic dominance rule (TSD). The FSD cule assumes that the decision maker prefers more to less. The SSD rule Cakes into consideration risk averting behavior of the decision maker. Finally the TSD rule is based under the assomption that some risk taking is allowed. For all three rules a specific probability function is assumed-uniform, triangular or other distribution. In this study, none of those specific probability functions is assumed, instead a non-parainetric approach is followed by searching an empirical distribution of yields. Using Anderson notation, let

$$(16) \qquad f\left(x_i\right) = p \qquad 1 > p \geq 0; \quad i = 1.....n$$

represent a given empirical probability function of yield xi of variety f. Given the yield distribution *f (x;)* for alternative varieties, the decision maker would tend to choose the distribution which has a higher probability for a given yield level. If

$$(17) \qquad F_1(R) = \int_a^R f(x_i)dx_k < \int_a^R g(x_i)dx_j$$

the decision maker would prefer variety f to variety g according to the FSD rule. Application requires the analyst to compute probability distributions of given varieties and compare them within the admissable range determined by observed minimum and maximum yields. For simplicity a discrete empirical distribution is assumed so that

$$(18) \qquad F_1(R) = \sum_{all \quad x \leq R} f(x_i) \leq \sum_{all \quad x \leq R} g(x_i)$$

becomes the FSD criterion**.** Usually there are more than two varieties to compare in which case the rule in (17) is repeated in pairwise fashion to isolate the distribution that dominates others. In other words, if *Fl(R) <_ Gl(R) <_ . .-Q1(R),* then *Fl(R) is* said to be stochastically dominant over other remaining varieties. To be precise; the comparison needs not be completely pairwise since the transitivity property of this rule can be used to infer dominance.

To introduce the SSD rule, let *Fl(R) iii (l8)* be rewritten as

$$(19) \qquad F_1(R) = \sum_{all \quad x_j \leq R} f(x_i) \qquad i = 1....n$$

The subscript i is to denote specific observations within range (a,b). The main idea behind the SSD rule is that if Fl(xl) <_ G1(xi) within the specified range then the decision maker would take tha.t distribution which ha.s a sinaller area Linder its curve. Mathematically the rule is that:

$$(20) \qquad F_2(x_r) = \sum_{i=1}^{r} F_1(x_{i-1})\Delta x_i \qquad r = 2......n$$

be smaller than any other competing distribution. The TSD formula is defined in the following manner:

$$(21) \qquad F_3(x_r) = (1/2)x\left[F_2(x_i)F_2(x_{i-1})\right]x_i \qquad r = 2.....n$$

The tables *2* through 4 summarize the information regarding stochastic efficiency of tested varieties. Before analyzing results, some review of methodology involved in calculating the efficiency level is -useful. The frequency distribution of yield was identified for each variety. This frequency was empirically treated as equivalent to the probability function in equation (16). Once the probability function was found, formulas in *(18 -21)* were applied to derive dominance values related to each level within the range of yields of each variety.

To select those varieties that dominate others, a decision was made to have a common range of yield over which to compare varieties. For this purpose the smallest yield of all minima was taken as a lower bound while the greatest yield maxima constitued the upper bound. The plotting of dominance values against yields within the defined range gibes efficiency curves. At any yield, the dominant variety should have its efficiency curve to the right of a.ll others. Using this rule, Tables 2 through 4 were derived.

For interpretation of results, emphasis should be put on FSD and SSD efficiencies. Those two types of efficiency are the oves that can be considered relevant for the appraisal of applied agricultural research in low income countries. The TSD rule allows for the economic agent to accept soi-ne risk in his enterprises as he becomes wealthier. The mean variance tradeoff is ambiguous, however, and TSD has limited relevance to small scale farmers in Nigeria. Other studies have indicated that the TSD criterion was not empirically useful or important in the evaluation of alternative choices [Anderson et. al., *1977, p. 289]*.

Table 2
Stochastic Efficiency of Maize Varieties
Yield (lkg/ha)

	Yield (kg/ha)				
Clone	**1.857**	**2.652**	**2.688**	**2.757**	**2.949**
Local	0.00	0.00	0.00	0.00	0.00
FARZI	2.30	0.00	0.00	1.00	1.00
FARZ23	1.00	0.00	0.00	0.00	0.00
FARZ26	0.00	1.23	2.30	2.30	2.30
FARZ27	0.00	0.00	1.00	0.00	0.00

*A zero entry means efficiency according to FSD. The no-zero entries denote the efficiency levels achieved. Boxed entries are those corresponding to the mean yield of a given variety, and as such represent the level of efficiency for that varietv.

Table 3
Stochastic Efficiency of Dryland Varieties

	Yield (kg/ha)				
Clone	**1.803**	**1.883**	**1.926**	**1.975**	**2.391**
TO_S2300	0.00	0.00	0.00	0.00	0.00
TO_S2513	0.00	0.00	0.00	0.00	0.00
TO_S4020	0.00	0.00	0.00	0.00	0.00
TO_S2583	0.00	0.00	0.00	0.00	0.00
FAROX 56/30	1.23	1.23	1.23	1.23	1.23

*For interpretation of the table, refer to table XIII**.**

Table 4
Stochastic Efficiency of Irrigated Rice Varieties

	Yield (kg/ha)				
Clone	**2.782**	**3.496**	**3.781**	**3.797**	**3.947**
SML 140/10	0.00	0.00	0.00	0.00	0.00
TO_S490	1.00	1.00	0.00	1.00	1.00
TO_S78	0.00	3.00	2.30	2.30	2.30
TO_S42	2.30	2.30	2.30	2.30	2.30
IRB	0.00	0.00	1.00	0.00	0.00

*****For interpretation of this table, refer to Table XIII.

On the basis of results reported on Table 2, itwould appear that the local variety is inefficient at ail levels. One would expect to see the local variety qualify as a potential variety for risk avert farmers, but on the contrary it is the improved variety FARZ26 that is revealed to be SSD efficient, meaning that a farmer who faces uncertainties about crop yield response would be better off with FARZ26. Other improved maize varieties are as inefficient as the local one. But there are some differences between the local maize and those inefficient improved clones. While the local variety is inefficient over the entire range of recorded means, other varieties are efficient at one level or another on some points of the yield range. This is the case of FARZI, which is SSD efficient at 1.847 kg/ha, and also of FARZ23 and FARZ27 that are FSD efficient at 1.84 7 kg/ha and 2.688 kg/ha, respectively.

The significance of such a différence is important in this way: the mean yield under which boxed efficiency levels are reported are the overall means of those varieties from observations taken in difierent environments. If a specific environnent whose mean yield is 2.652 kg/ha is considered, FARZ26 will turn out to be efficient at ail levels. The saure reasonong applies to FARZI and FARZ27. Thus, even though it is known that for maize varieties, FARZ26 is SSD efficient for ail environments, it is interesting to recognize that in some specific environnents, FARZI, FARZ23 and FARZ27 can be recommended to some group of farmers whose preference functions correspond to levels of efficiency reported.

The picture for dryland rice varieties in Table 3 is very différent; ail but one varietv are iefficient over thé entire range. The efficient variety, FAROX 56/30 is dominant at ail levels of efficiency. An attempt to introduce those inefficient clones will only result in poor adoption rates since those varieties do not match with any of the fariners' preference functions. For irrigated varieties. TOs490 is FSD efficient, while T0978 and T0342 are both SSD and TSD efficient. Agaiii, the local standard SNIL 140/10 is completely dominated by ail improved clones. One of IRRI clones, namely IRS is specifically efficient for environments whose mean yields are about 3781 kg/ha.

In conclusion it can be said that food crop research in Nigeria lias produced maize and rice varieties that are stochasticallv efficient and that can be selected to meet different preference functions. Because yof thé existence of such a wide range of varieities, it is felt that thé diffusion of those varities in different environneiits in Nigerian agriculture can be easily accomplislied if other econocnic factors are adjusted.

Summary and Conclusion

This study evaluates the research investment in food crop research in Nigeria with emphasis on maize, rice and cassava. Three complementary methods of analysis were used. One method called in this study an environmental model, was used to determine whether crops varieties developed by the Nigerian research system responded favorably to their environment and to what extent such a response was reliable on the basis of stability criterion. Results relating to maize, rice and cassava indicated that 50 percent of tested varieties were both responsive and stable.

Since the choice of varieties depends on more than environmental response, a second technique, known as stochastic dominace analysis, was used to select varieties based on risk preferences functions of farmers. The technique does not require the estimation of farmers' utility functions risk performances, but only identifies varieties that will satisfy farmers with alternative rislk preferences. The assumed rislk preference patterns are associated with three stochastic rules, namely (1) first stochastic dominance, (2) second stochastic dominance, (3) third stochastic domonance.

The risk prefernce function related to the first stochastic dominance was based on the assumption that the farmer wants maximum average yield. Varieties identified as satisfying such a rule were FARZI, FARZ27 and FARZ23 for maize. For rice, TOs490 and FAROX 56/30 were found to be also FSD efficient. For the second risk preference function, the varieties satisfying such a rule were found to be FARZI and FARZ26 for maize; again, for FAROX 56/30, along with TOsiS and TOs42 are found to be SSD efficient for rice.

One of the techniques used was the aggregate production function approach to estimating social marginal internal rates of return. Results from this method indicate that actual rates of return are low. Adoption rates, levels of prices and farmers' technical efficiency influence rates of return.

In conclusion, results indicated that the Nigerian food crop research system as represented by maize, rice and cassava has produced some promising varieties with high degree of adaptation and capable of vielding high private returns to farmers. However, social rates of return on food crop research investment are modest.

It is possible that more complete development of the whole infrastructure of extension coupled with supply of inputs at low cost could raise rates of adoption of new varieties. Further evaluation is needed of the social rates of return to determine whether such efforts are warranted. Results depend on techniques and quality of data. The diversity and length of data series were quite limited; more extensive data would have improved and given more weight to the conclusions.

Figure 1
Stability Analysis of Selected Maize Varieties in Nigeria

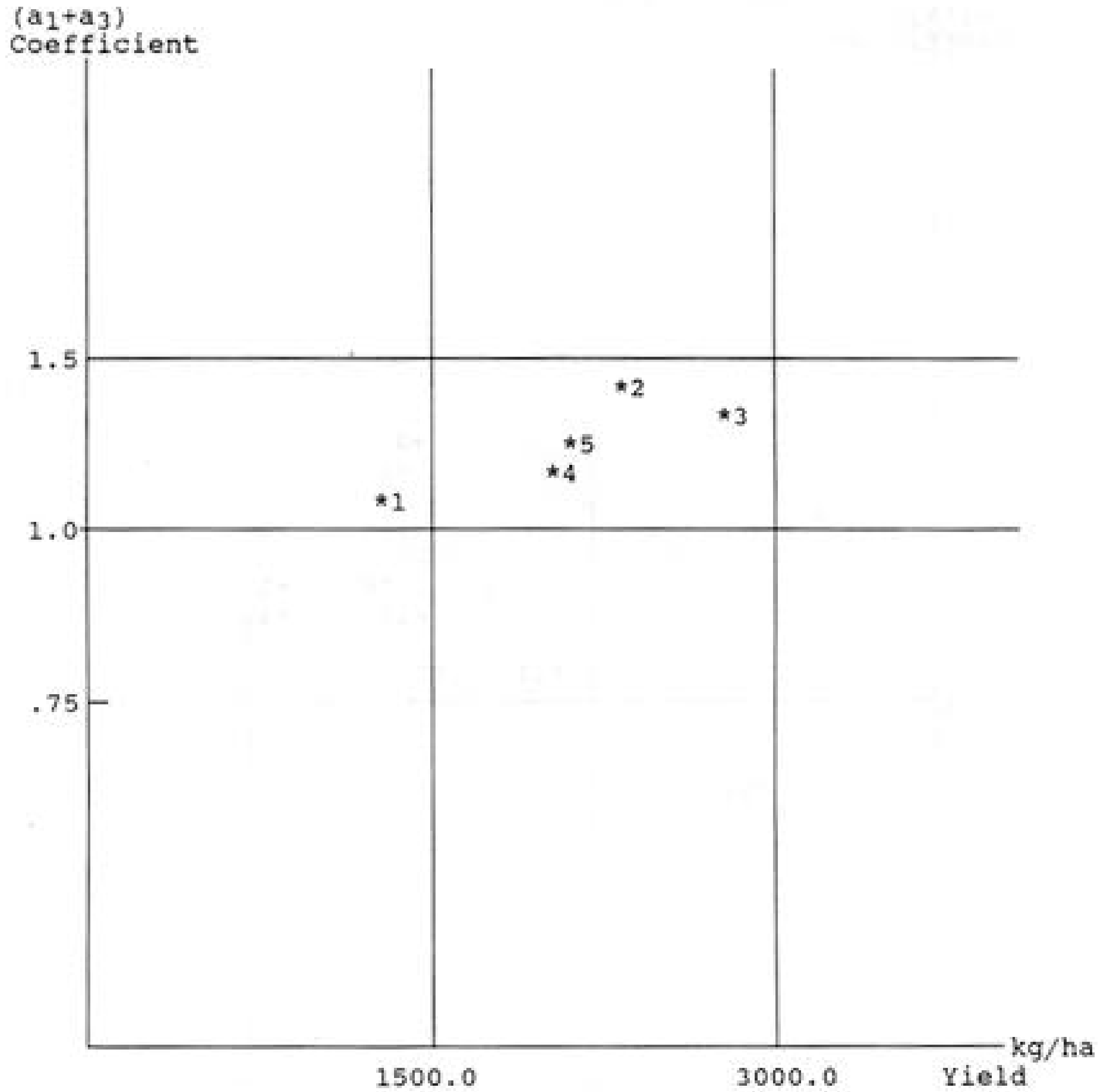

Figure 1: Stability Analysis of Selected Maize Varieties in Nigeria

Figure 2
Stability Analysis of Selected Cassava Varieties in Nigeria
(Hahn Results)

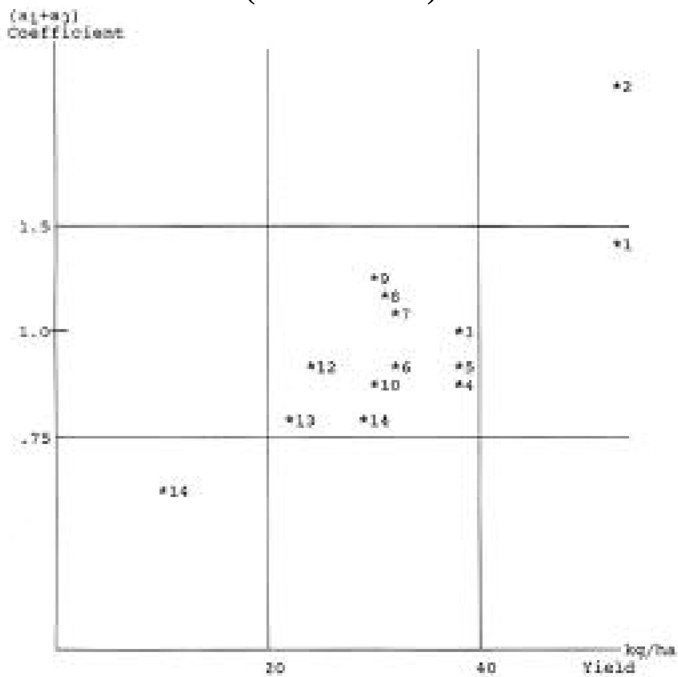

Figure 2: Stability Analysis of Selected Cassava Varieties in Nigeria (Hahn Results)

Figure 3
Alternative Distributions with Same Value at End Points

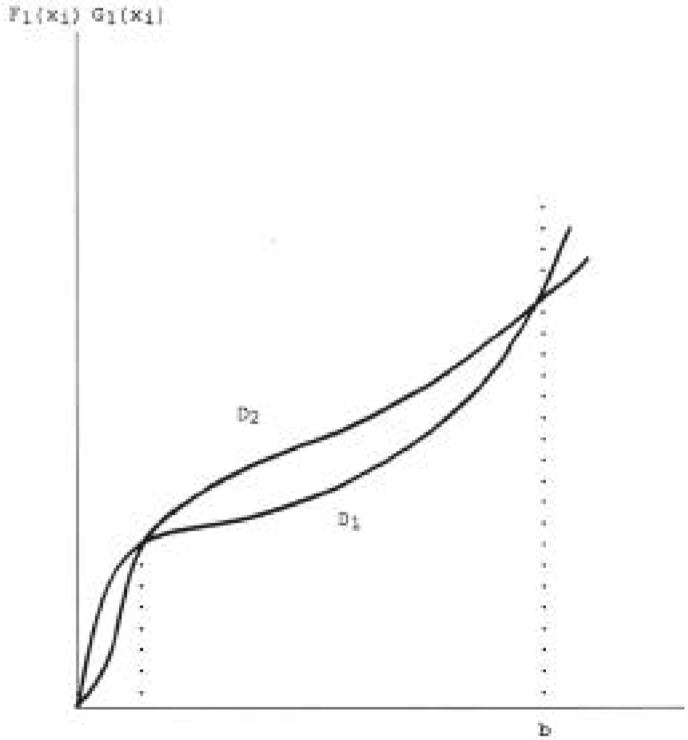

Figure 3: Alternative Distributions with Same Value at End Points

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