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THE DEMAND FOR FERTILIZER BY SENEGALESE PEANUT FARMERS

by

James F. Oehmke
Department of Agricultural Economics
Michigan State University

Ag. Econ. Staff Paper #85-80

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1. Introduction

In 1980 Senegal's subsidized fertilizer program was discontinued because of the large cost to government. A series of somewhat disconnected programs to insure fertilizer distribution has been used since 1980, resulting in inefficient distribution and only small decreases in government costs. The government run fertilizer plant consistently lost money and finally was sold in 1984. Under the retenue system farmers were forced to purchase fertilizer, but deliveries were late and quantities smaller than promised (Crawford and Kelly). The result is that the Senegalese government is withdrawing from all direct involvement in the fertilizer industry. All production and distribution will be handled by the private sector.

In order to evaluate the policy decision to privatize the fertilizer industry it is necessary to understand the derived demand for fertilizer. This is also a prerequisite for any positive description of the fertilizer market as it will look in the absence of government intervention. Unfortunately the absence of a free market means that the data necessary for the usual econometric analyses are lacking.

This paper analyzes the demand for fertilizer using expected utility analysis. Individual fertilizer use is calculated directly from the farmer's constrained expected utility maximization problem.

The model developed in this paper incorporates aspects of risk, utility theory, and individual rationality to make predictions about fertilizer use. The model can be implemented empirically using existing data. There are some rough, order of magnitude checks that can be made on the results. These are discussed in more detail below.

The methodology used to approximate expected utilities is of considerable importance in its own right. It marries two emerging techniques: the use of flexible form stochastic production functions (Antle, Antle and Goodger) and experimental information on individuals' attitudes towards risk (Dillon and Scandizzo, Binswanger). It is a natural extension of these techniques that highlights their power of economic analysis. The application to Senegal provides an important and illuminating example of this type of analysis.

2. A Model of Fertilizer Use

The farmer's preferences are represented by a utility function of his income, U(I). He maximizes his expected utility EU subject to his budget constraint. Expected utility is a function of the probability distribution of income:

$$(1) \qquad (1)\ EU(H(I)) = \int U(I)dH,$$

where H(I) is the cumulative distribution function of income.

Assume that the only income generating opportunity is farming. The farmer has one unit of land, on which he can sow millet or peanuts or both. He can also choose to apply fertilizer. His yields per unit of land are uncertain at the time of planting and fertilizer application. The probability distribution of yields per unit land for millet and peanuts are M(F) and P(F), where F is the amount of fertilizer used. The prices of millet, peanuts and fertilizer are Pm, Pp and Pf. The price of seed per unit land is Psm for millet and Psp for peanuts. The farmer takes prices as fixed.

Let A and B be the fractions of land devoted to millet and peanuts, resp. Then the distribution of net income from farming is

(2) $G(I)=A*Pm*M(Fm)+B(Pp*P(Fp)-Pf*(Fm+Fp)-Psm*A-Psp*B$
$s.t.\ A+B\leq 1.$

where Fm and Fp are the amounts of fertilizer applied to millet and to peanuts, A is the fraction of land devoted to millet, and B is the fraction of land devoted to peanuts. The first two terms in the equation for G(I) are the incomes generated from the harvests of millet and peanuts. The quantity produced is the product of the yield per unit land and the amount of land planted: $A*M(F_m)$ and $B*P(F_p)$. These quantities are sold at the price P_m and P_p, respectively. The third term is the cost of the fertilizer. The remaining two terms are the costs of seed, and equal the costs per unit land times the amount of land planted. The uncertainty about the level of net income depends directly on the distributions of yields, $M(F_m)$ and $P(F_p)$.

Purchases of seed and fertilizer are made on a cash basis. The farmer has limited funds of amount C available at planting time. His budget constraint is

(3) $A*P_{sm}+A*P_f*F_m+B*P_{sp}+B*F\leq C.$

The left hand side of the constraint represents expenses incurred by the farmer, and consists of fertilizer and seed costs. Expenditures on these out of pocket expenses are constrained to be less than the amount of available cash.

The farmer's income will equal his net income from farming plus the amount of any cash not spent on inputs. Thus, the distribution of income is:

(4) $H(I) = G(I) + C- (A*P_{sm} + A*P_f*F_m + B*P_{sp} + B*P_f*F).$

The farmer maximizes expected utility of income subject to the budget and land constraints. The choice variables are the quantities of land to put in peanuts and millet, A and B, and the quantities of fertilizer, F_m and F_p. The model assumes that land and labor costs are zero. The government of Senegal owns all the land, and farmers have a form of squatter's rights to the parcel they farm. The government charges no rent, nor is it feasible for the squatter to rent the land to someone else (or to some other use). Hence the shadow price of this land appears to be very close to zero. Similarly, the apportunity cost of labor is very small. There is almost no off-farm employement, and extended family members provide labor at what appears to be very little loss in household production. The cost of labor is essentially the disutility from lost leisure: we assume this cost is zero.

More formally, the farmer solves

$$(5) \quad \max_{(A,B,F_m,F_p)} \quad EU\,(H(I)) \text{ s.t. (2) and (3).}$$

For the purposes of this paper it is more interesting to solve this empirically than to provide an algebraic analysis.

3. A Simple Simulation

The section presents a simulation of the calculations required to determine whether a particular farmer will purchase fertilizer. The simulation is a drastically simplified version of the model. It is intended only to provide an example of how the interactions between risk aversion and uncertain yields influences the demand for fertilizer.

Only one crop is available to the farmer, and he has decided to plant that crop. His remaining choice is whether to apply fertilizer. Only two options are available: i) to apply no fertilizer, or ii) to apply the dosage recommended by agronomists. The distribution of yields is extremely simple. Without applying fertilizer the yield is 400kg/ha with probability 1/2 and 550kg/ha with probability 1/2. If fertilizer is applied the yield is 500kg/ha with probability 1/2 and 850kg/ha with probability 1/2. The price of output is 80CFA/kg. These figures correspond roughly to peanut production in the Sine-Saloum region of Senegal. By applying fertilizer the farmer increases his expected yield from 475kg/ha to 675kg/ha. But the variance also increases from 11,250kg^2/ha^2 to 61,250k^2/ha^2.

Each farmer has a utility function of form

$$(6) \quad U(I+w) = (I+w)^{1-S}/(1-S)$$

where I is current income and w is wealth.
These utility functions are characterized by their constant partial risk aversion coefficient, S. The elasticity of marginal utility for this class is equal to S; hence they are described as constant elasticity utility functions (Newberry and Stiglitz). It is assumed that an equal number of farmers have values of S equal to 8, 2, 1.2, .5, and .15.

The individual farmer will choose to apply fertilizer if the expected utility of the income generated from farming with fertilizer exceeds the expected utility of income generated from farming without fertilizer. To calculate these expected utilities first calculate the distributions of income H(I) for a given price of fertilizer.

For example, suppose that the price of fertilizer is 12,000CFA for the recommended dose. If the farmer does not apply fertilizer his income distribution will be

20,000+400*80=52,000 with probability 1/2

(7)

20,000+550*80=66,000 with probability 1/2

The farmers' income has two parts. The first is the currency holding, since none of it is spent on fertilizer. The second is the income from farming, which equals the quantity of output times the price of the output. If the farmer uses fertilizer his income distribution is

20,000-12,000+500*80=48,000 with probability 1/2

(8)

20,000-12,000+850*80=76,000 with probability 1/2.

The distribution (8) differs from (7) because the cost of the fertilizer must be subtracted from the cash holdings, and because the distribution of yields changes with the application of fertilizer.

Now assume that the farmer has a relative risk aversion coefficient of 2. Thus his utility function is -1/I. The expected utility of farming without fertilizer is

(9) $(1/2)(-1/52,000)+(1/2)(-1/66,000) = -0.0000172$

For the same farmer the expected utility of farming with fertilizer is

(10) $(1/2)(-1/48,000)+(1/2)(-1/76,000) = -0.0000170$

Since the expected utility from farming without fertilizer is less than the expected utility using fertilizer, the farmer will choose to purchase the fertilizer. Of course, at a higher price for fertilizer he may choose not to purchase fertilizer.

Repeating the above calculations for various fertilizer prices gives an indication of the maximum amount that the farmer is willing to pay for the recommended dose of fertilizer. By changing the parameter S this maximum amount can be approximated for different farmers with different utility functions. Results for the utility functions assumed above are presented in Table 1.

A risk-neutral profit maximizer would be indifferent between purchasing and not purchasing the recommended does of fertilizer at a price of 16,000 CFA for the recommended dose. Risk averse farmers will not be willing to pay this amount because of the increased risk (higher variance in yields) from fertilizer use. As the value of S increases farmers become more risk averse, and hence will be unwilling to pay as much for the fertilizer.

Table 1 indicates that as farmers become less risk averse, they are willing to pay more for the fertilizer. This is seen from the inverse relationship between rho and the "will buy at" price: as rho falls farmers are willing to buy at a higher price. This is because farmers who are less risk averse place less emphasis on the increased variance from fertilizer use relative to the increased mean yield. This can be conceptualized by noting that as rho falls, the utility function becomes less curved, and approaches a linear function of income as rho $\rightarrow$ 0. Hence farmers with small rho act almost as expected profit maximizers act and will be concerned mainly with mean yields. As a result, they are almost willing to pay the actually fair price of 16,000 CFA/150kg.

This example makes two important points. First, risk may be an important determinant of the demand for fertilizer. Second, the quantity demanded depends not only on the average increase in yield, but also on the effect of fertilizer on the entire yield distribution, especially the variance. The remainder of the paper is devoted to a more realistic estimation of the demand for fertilizer bearing in mind these two points.

4. Empirical Implementation: The Utility Function

Assume that the utility function has form $U(I) = I^{(1-S)}/(1-S)$. The relative risk aversion coefficient defined by rho = $- IU''(I)/U'(I)$ is constant and equal to S. Assuming this functional form is equivalent to assuming a constant elasticity of marginal utility. More importantly for empirical implementation, information about relative risk aversion can be elicited from farmers quickly and easily.

Binswanger has established the feasibility of farmer' interview to measure partial risk aversion. For a farmer with initial wealth receiving an income I, the coefficient of partial risk aversion is defined by $P = -V'(I)/IV'(I)$, where $V(I) = U(W+I)$. Under the assumption that the accumulated wealth of a Senegalese peasant is small relative to his current income, V(I) can be used as an approximation for U(I). This is consistent with the assumption made in the model that the peasant has about 30,000. Hence measuring P provides an estimate of rho and therefore of S.

The advantages of the constant relative risk aversion utility function stem from two facts: i) once rho is determined, so is the utility function; and ii) it is easier to elicit information about rho than about some other common measures of risk aversion that determine the utility function.

The other likely choice of utility function is the negative exponential function

$U(I) = -e^{-AI}$, which has constant absolute risk aversion $- U''(I)/U'(I)=A$. The advantage of the negative exponential function is its analytic tractability, since one can use the moment generating function of the income distribution to calculate expected utility. Moreover, interview procedures do exist for eliciting information about individuals' absolute risk aversions (King and Robison). Unfortunately, these procedures are extremely hard to apply in Senegal.

For example, King and Robison present each subject with a sequence of choices between two lotteries, where each lottery contains several (at least four) outcomes. When working with uneducated people, particularly in Senegal and other Islamic countries, it is extremely difficult to explain this type of probability structure. Preliminary investigations by Kelly suggest that most respondents cannot adequately conceptualize the necessary lotteries. Hence data elicited by this technique may have little practical application to the Senegalese problem.

A more workable approach is to assume a constant partial risk aversion function, as above, and use Binswanger's method to elicit information about the coefficients of partial risk aversion. In this method respondents are asked to choose among several lotteries, but each lottery has at most two outcomes. The lotteries with two outcomes have an equal probability of returning either outcome. Hence the probability structure of any lottery can be depicted in terms of a simple coin toss, which the farmers have little trouble understanding.

The analysis presented in this paper assumes that there are three types of farmers characterized by their coefficients of partial risk aversion. These coefficients are assumed to take the values 0, 1, and 2. These values can be easily changed, or the range expanded, when results from Kelly's study are in.

It is now possible to estimate the expected utility of various income distributions for each of the six representative individuals. The next step is to estimate the distributions that can be achieved by the individuals.

5. Empirical Implementation: The Flexible, Moment-Based Regressions

The probability distribution of income from farming is systematically related to the probability distributions of yields by equation 2. This section estimates the probability distributions of yields using the flexible, moment-based approach suggested by Antle, and Antle and Goodger.

The FMB approach assumes that each measured yield is a random draw from a set of possible yields. These sets are endowed with probability measures showing the likelihood of drawing any particular yield. The measures are systematically related to the factors of production. Measurement of this relationship is accomplished by measuring the effect of inputs on the moments of the yield distribution. The FMB approach uses a series of regressions to quantify how endogenous (e.g. fertilizer) and exogenous (e.g. rainfall) inputs affect the mean yield (first moment), variance of yields (second moment), and higher moments of the distribution. The results determine the distribution G and hence the distribution of income, H(I). The coefficients with respect to a particular input, e.g. fertilizer, show how the distribution G changes when different quantities of fertilizer are used. For example, application of fertilizers generally increases the expected yield. However, fertilizer may also increase the variance (second moment) of yields. The FMB approach quantifies both these effects. Hence it is possible to calculate how fertilizer use affects the distribution of income. This calculation is directly analogous to the derivation of equation (6) from equations (5).

The FMB approach is applied to existing Senegalese agronomic data. Table 2 presents 16 years of experiment station data on the response of peanuts to soil preparation and fertilizer. Three levels of soil preparation were tried: no preparation, light tilling, and plowing with heavy animal traction (ox or horse). For each soil preparation, 8-27-18 fertilizer was applied in amounts of 0 kg/ha, 150 kg/ha and 200 kg/ha to different parts of the test plot. Trials without fertilizer were discontinued in 1976.

Table 3 presents similar data on eight years of millet trials. The soil preparations are the same as for peanuts: no preparation, hand tilled, and animal tilled. The fertilizer application levels are 0, 150 and 450 kg/ha. The yields reported in Tables 2 and 3 are biased upward. The procedure used in measuring yields included controlling for any "negative events" such as weather damage to plants, consumption of output by animals, or destruction of plants by animals. Since negative events affect Senegalese farmers, eliminating their input on the agronomic trials imparts an upward bias to the yield estimates. The extent of this bias can be enormous. Preliminary investigations based on farmer interviews suggest that actual yields may be 1/2 or 1/3 the values shown in Tables 2 and 3. Work in progress includes examination of data collected by agronomists on field trials conducted in actual farm fields. The prior belief is that the field trials data are more indicative of the conditions faced by farmers. However, for the moment the analysis proceeds based on the agronomic experiment data.

The FMB approach consists of regressing the moments of the sample yield distributions on explanatory variables. These variables include dummy variables for soil preparation, the quantity of fertilizer per hectare, and dummy variables for the year in which the crop is grown. The latter variables are designed to capture the effects of rainfall, length of growing season, average temperature, and other variables which differ from year to year. Work in progress uses meterological data for some of these variables instead of the yearly dummies.

The statistical analysis performed in this section assumes that it is possible to estimate separately the peanut and millet production functions. If the disturbances in the two sets of equations are correlated, then some form of seemingly unrelated regression will improve the efficiency of the estimators. This procedure is not followed for two reasons. First, many of the influences causing contemporaneous of the residuals across crops, such as lack of rain, bad weather, animal damage, and some types of insect damage, will be accounted for in the year dummy variables. Second, the estimators used in this analysis are unbiased, and hence provide adequate representation of the influences of the independent variables on crop yields.

The flexible, moment-based analysis of the production functions for peanuts and millet proceeds along lines described in Antle. The particular algorithm used for this estimation is found in Oehmke. Results are presented in Tables 4 and 5.

For the first two moments of each yield distribution generalized least squares regressions are reported. Inaccuracies in the data prevented use of GLS procedures in the case of the third moment regressions. The GLS procedure requires calculation of a sixth moment regression in order to determine the appropriate third moement weights. Inaccurate data cause increasing problems for higher moments and thus the sixth moment results were unreliable (a more complete discussion is provided in Oehmke). For this reason an OLS third moment regression is used in calculating the distribution functions. Recall that the OLS regression coefficients are unbiased; the problem is that the standard errors are biased upwards. Thus it is possible that a statistically significant coefficient appears insignificant when tested by the OLS errors. The low R^2's on the third moment regression unfortunately suggest that this will not be a problem.

Table 4 presents regression results based on the peanut data. Table 4a contains GLS estimation of the first two central moments of the yield function for peanuts. The R^2 is .80 for the first moment regression, indicating a reasonably good fit; it falls off to .20 for the second moment regression.

The independent variables Soil Prep. #2 and Soil Prep. #3 are dummy variables which take the value one if the soil was hand tilled or tilled using animal traction, respectively. Their coefficients indicate the effect of these tilling procedures relative to no tillage. Each preparation has a positive effect on mean yield as expected, but neither is significant at the 5% level.

Fertilizer has a positive and highly significant coefficient in the first moment regression. The value 2.8 indicates that a fertilizer increase of 1kg/ha results in a yield increase of 2.8kg/ha, so that a farmer applying the recommended dosage of 150kg/ha would see an average increase in yields of 420kg/ha. Application of fertilizer increases the variance of yields. However, this increase is not statistically significant.

Table 6 presents results from the regressions of millet yields. The soil preparation dummies are significant in the first moment regression and have extremely large estimated coefficients. While it is expected that tillage would have a significant positive effect on yields, increases of 500 and 700kg/ha appear to be much higher than farmers can expect.

Fertilizer is significant in the first moment regression with a coefficient of 0.36, thus applying the recommended dosage of 150 kg/ha would increase mean yields by 80 kg/ha. The positive coefficient in the second regression indicates that use of fertilizer increases the variance of yields, but this coefficient is not significant.

5. Defining The Yield Distributions

The distribution of income depends on the distributions of peanut yields and millet yields through equations (4). This section describes the calculation of the yield distributions from knowledge of the moments of the distributions.

Suppose that the econometrician knows n+1 (noncentral) moments of a distribution F centered on $[0,1]$; call these moments $c_1, \ldots, c_n$. Then the expression

$$(11) \quad \sum_{j \leq nt} \binom{n}{j} (-1)^{n-j} \Delta^{n-j} c_j$$

is an approximation to $F(t)$ (here Δ is the difference operator defined by $\Delta c_j = c_{j+1} - c_j$).

Two problems arise in applying this formula directly to the Senegalese yield data. First, the distributions of yields are not centered on $[0,1]$. This can be accomodated by changing the scale of the estimated distribution functions. Certainly 0 is a relevant lower bound for yields. An upper bound T is given by any number which has a zero a priori expectation of being achieved as a yield under the current technology (for example 10,000 kg/ha). The scaling function s: $[0,T] \rightarrow [0,1]$ is defined by $s(x) = x/T$. Define the distribution function $F_s:[0,1] \rightarrow [0,1]$ by $F_s(x) = F(s^{-1}(x))$. Then F_s can be regarded as a scaled version of F. Moreover, F can be recovered from knowledge of F_s by $F(y) = F_s(s(y))$.

The second problem with applying (8) to the Senegalese data is that the approximation (11) is based on noncentral moments, while the previous section contains results on central moments for 2^d and higher degree moments.

Expanding the k^{th} central moment shows

$$(12) \quad E(x-\mu)^k = E(\sum_{j=0}^{k} \binom{k}{j} \mu^j x^{k-j})$$

where μ is the first (noncentral) moment of the distribution. Since the first moment regression provides information on μ and the k^{th} regression provides information on $E[x^k]$, for each k (12) is a single equation in the k-1 unknowns $E[x^{k-j}]$. (When j=k, $E[x^{k-j}] = 1$). In particular, when k=2, (12) is a single equation which can be solved for the unknown $E[x^2]$. This can be substituted into equation (12) when k=3 to yield a single equation in the unknown $E[x^3]$, etc. Hence the knowledge of central moments gained in the previous section is sufficient to approximate the distribution of yields.

The approximation (12) is a step function with k+1 steps (since we know $F(1)=1$). In some instances it is desirable to have a smooth approximation to F, which can be achieved by using a polynomial approximation to the step function. The approximations used in this paper are presented in Figures 1 and 2.

Each of the cumulative distribution functions in Figures 1 and 2 is a quartic function $F(x)=ax^4 + bx^3 + cx^2$. The first degree term and the constant are omitted so that $F(0) = 0$ and $F'(0)=0$. The parameters a, b, and c are estimated subject to the constraints that $F(1)=1$ and $F'(1) = 0$. Imposing zero derivatives at the end points results in the ogive shape of each of the estimated cdf's.

The estimated cumulative yield distribution functions are depicted in Figures 1 and 2. In each case the addition of 150kg/ha of fertilizer increases expected yields by shifting the graph to the right. The effect of fertilizer on the variance and higher moments of the distribution is small and does not show up to any significant degree in these graphs. The implication of the graphs that yields are almost certainly positive is due to the imposition of the boundary conditions $F(0)=0$ and $F'(0)=0$. While there may be a small positive probability of getting zero yields in reality, the graphs are consistent with the data since there are no zero yield observations in the data.

6. Applications to the Demand for Fertilizer

For simplicity assume that the farmer has the choice between applying no fertilizer and applying the recommended amount, although his choice with respect to peanuts is independent of his choice with respect to millet. Since the recommended dose is 150 kg/ha for each crop, the farmer has four possible choices, as shown in Table 6.

The distribution of income for each of these choices depends on the distribution of yields for peanuts and millet in each of these choices. To calculate these yield distributions assume that farmers use no soil preparation for peanuts since preparation has no significant influence on the mean or variance of yields. Assume farmers use preparation #2 on millet, since this has a large, positive, statistically significant effect on mean yields and no statistically significant effect on variances. The mean of the yearly dummy variable coefficient is used as a proxy for the average deviation from the base year.

Using the cdf's, the maximization problem (5) becomes

$$(13) \quad \max_{A_1 B, F_m, F_p} \int_0^{2000} \int_0^{3000} H(I(A,B))\,dP(x;F_p)\,dM(y,F_m).$$

Solving this maximization problem determines the optimal fertilizer levels F and F_p.

It is assumed that the prices of peanuts and millet are 100 CFA/kg and 170CFA/kg, respectively. In the past these prices have often been determined by the government, although the government price-setting does respond somewhat to market pressures, especially with respect to millet. An important consequence of assuming fixed output prices is that there is no price uncertainty and hence income uncertainty is determined completely by yield instability. For example, the existence of parallel markets in Senegal implies that some farmers are not selling their crop to the government and are receiving prices higher than the official price (Newman). Thus it may be appropriate to introduce price uncertainty into the model. For a thorough discussion of price uncertainty, yield uncertainty, and their affects on income the reader is directed to D. G. Johnson and to Newberry and Stiglitz. The simulation results will of course depend on the assumed values of the output prices.

The maximization problem is solved through numerical integration over possible fertilizer applications and land allocations. The utility maximizing results are presented in Table 7. These results must be interpreted with care since the hypothetical farmer is not allowed to apply fertilizer at rates less than 150kg/ha. If the crop response to fertilizer is concave the table will indicate that farmers choose not to purchase fertilizer in some cases when in reality they might simply apply fertilizer at a rate lower than 150kg/ha. This imparts a downward bias to the estimated demand for fertilizer in the higher price ranges.

The expected income maximizer is risk neutral and in the parameterization (6) of the utility function his value of S is 0. Risk neutrality implies that this type of farmer will devote all his land to the crop with the highest expected profit. Table 7 is consistent with this intuition. When the price of fertilizer is below or equal to 90CFA/kg he will plant ony peanuts and apply 150kg/ha of fertilizer. At prices of fertilizer higher than 90CFA/kg the Table indicates that the expected income maximizer will shift to growing unfertilized millet on all his land. Recalling the caveat mentioned above, his behavior in a more realistic model could be to stay with peanuts but apply less than 150kg/ha fertilizer.

A farmer having utility function U(I)=log(I) will exhibit the behavior shown in column two of Table 7 (this utility function is the limiting case of (6) as $S \rightarrow 1$). The greater risk aversion induces the farmer to diversify and plant some of his land in peanuts in all cases. This farmer will apply fertilizer to peanuts at fertilizer prices less than or equal to 140 CFA/kg. At fertilizer prices as low as 40 CFA/kg, the universal variability of peanut yield is enough to prevent this farmer from switching out of peanuts into millet.

The pattern does not change drastically for the farmer with risk aversion coefficient equal to 2. When the price of fertilizer is 160 kg/ha the farmers will not use any fertilizer. He will split his land between the two crops, presumably for purposes of risk diversification, with 20% of the land in peanuts and 80% in millet. As the price of fertilizer falls to 140 CFA/kg, the farmer choses to apply the fertilizer to peanuts. When the price falls to 90 CFA/kg, the farmer places an extra 10% of the land in peanuts. This is consistent with the expected income maximization results showing that if the price of fertilizer falls to 90 CFA/kg or lower then growing peanuts with fertilizer provides higher expected income than any other crop choice. The higher variance associated with the peanut yield distribution keep the farmer from switching entirely to peanuts. The pattern of 30% of the land in fertilized peanuts and 70% in unfertilized millet is maintained at fertilizer prices between 50CFA/kg and 90CFA/kg. When the fertilizer price falls to 40CFA/kg., the increased income from planting peanuts induces the farmer to place another 10% of the acreage in peanuts. This behavior is not exhibited in the farmer with log utility (although it would occur at lower prices), most likely because the farmer with risk coefficient S=2 places a higher value on risk reduction through crop diversification relative to planting low variance crops than does the farmer with log utility.

The overall pattern emerging from Table 7 is the following. The dominant influence on fertilizer use appears to be the farmers' risk aversion. As the degree of risk aversion inverses, farmers are more likely to diversify their holdings and plant both millet and peanuts. The effect of fertilizer on peanuts is strong enough so that it is used on the peanuts even at high prices. The response of millet to fertilizer is weak and the farmer will use fertilizer only at extremely low prices.

Much of the lack of response to fertilizer price is due to the assumption that farmers purchase either 0 or 150 kg of fertilizer. Allowing purchases of intermediate levels would result in some fertilizer use at even higher prices (assuming that the marginal product of fertilizer is declining). However, there will be prices at which the indicated purchases of 150 kg/ha of fertilizer will greatly exceed the actual purchases.

As an example of the effect of the discrete fertilizer choice imposed in this model consider the farmer with potential risk aversion coefficient S=2. It is indicated that he will purchase 150 kg/ha of fertilizer when the price exceeds the (discrete choice) actuarially fair price (between 90 and 100 CFA/kg). This implies that his marginal returns from the last unit of fertilizer exceed his cost, and so he would restrict his purchases of fertilizer to, say, 100 kg/ha. Because this choice is not allowed in the model, the farmer will purchase the 150 kg/ha at prices as high as 140 CFA/ha. Thus the discrete nature of the farmers choice must be taken into account in interpreting the simulation results.

While the simulation results are complete enough to calculate demand elasticities at various fertilizer prices, some comments on the elasticity of demand are appropriate. First, demand is inelastic at prices above 120CFA/kg, with little or no fertilizer pruchased. The discrete nature of the fertilizer choice imposed in the model implies that at prices between 90 and 120CFA/kg the result that farmers will apply 150kg/ha of fertilizer to peanuts probably has a significant upward bias. As the price falls below 120CFA/kg the demand for fertilizer becomes less inelastic, but only slowly. From 90 to 40CFA/kg the simulations indicate that there will be a substantial amount of shifting into fertilizer, and hence that the demand curve for fertilizer is relatively elastic. At prices of about 30-40CFA/kg farmers are applying a substantial amount of fertilizer and additional application will probably have only a minimal effect on yields (although this is not modeled in the regression analysis). Hence at low prices the demand for fertilizer becomes inelastic once again. The description of the demand for fertilizer emerging from this discussion is that the demand is fairly elastic at prices between 40 and 90CFA/kg and inelastic elsewhere.

7. Consistency of Results

Although previous studies have been unable to systematically analyze the demand for fertilizer, some observations about optional fertilizer purchases have been made. These observations are often summarized by the following rule of thumb: the value of output per kg. must be two to three times the cost of the fertilizer per kg. in order for farmers to voluntarily purchase fertilizer.

The results of the expected utility analysis are at variance with the rule of thumb. Expected utility maximizers have positive fertilizer demand when the value:cost ratio is above a minimum level lying between 1 and 1.5, with an increase in risk aversion increasing the minimum level. The most likely explanations for this discrepancy are 1) mismeasurement of risk preferences, 2) inaccurate modeling of fertilizer response, and 3) incomplete description of the farmers' cash flow problems.

Risk preferences are measured by the parameter S in the utility function $U(I) = I^{1-S}/(1-S)$. While the functional form of U is chosen for its simplicity, it is a reasonable specification for risk neutral to slightly risk averse farmers. That is, for S=0 this specification exactly captures the behavior of an expected income maximizer, and for small positive S the function captures the behavior of slightly risk averse farmers. This form could have problems capturing the behavior of extremely risk averse farmers ($S \geq 4$), but this group probably makes up a small fraction of the farmer and is not the cause of the discrepancy with the rule of thumb. Thus it seems that the functional form of U is not a major cause of the divergence of the results from the rule of thumb.

In the model farmers are assumed to have 30,000CFA ($60 U.S.) which they can spend on seeds and fertilizer. While many Senegalese farmers have access to this amount of funds, there may be nonfarm expenses occuring between planting and harvest that take precedent over agricultural input purchases. Certainly food is one such expense; in Senegal religious celebration such as baptisms and weddings may be another. Thus one possible problem is that 30,000CFA is too lenient of a budget constraint. The budget constraints of 25,000CFA and 20,000CFA were examined for the expected income maximizer and the farmer with partial risk aversion coefficient of 2 at prices for fertilizer of 90CFA/kg and 70CFA/kg, respectively. The expected income maximizer does not change behavior with a constraint of 25,000CFA, and limits purchase of fertilizers with a constraint of 20,000CFA only because the cash-in-hand constraint is directly binding. The risk averse farmer also changes behavior only when the cash constraint is binding. Hence the rule of thumb and the simulation results would agree if farmers were too poor to purchase both seed and fertilizer. This argument is of course less convincing when credit from institutions or family members is available. The importance of the cash constraint is an empirical question that merits further investigation.

A third possible explanation for the simulated value:cost ratios of 1 to 1.5 is that the experimental yields were twice what farmers could reasonably expect to get. If this is true then increases in agronomic trial yields due to fertilizer application are twice what farmers reasonably expect to achieve. As a crude approximation this indicates that the simulated value of the fertilizer is twice the actual value. Hence the simulated value:cost ratio should be multiplied by a factor of 2 to obtain a more realistic ratio. When this procedure is followed the (corrected) simulated value:cost ratio is between 2 and 3, corroborating the rule of thumb. Again using a crude approximation, this explanation implies that the prices in Table 7 are perhaps twice what they should be, so that a risk neutral farmer will not use fertilizer if the price is greater than 90/2 = 45 kg/ha. These empirical comments suggest that the FMB yield estimation procedure and the expected utility framework can provide realistic results. Problems arise due to the imperfect quality of the data used. If these problems can be corrected, then the framework used in this paper promises to be fruitful in examining the demand for fertilizer.

8. Implications for Policy

The results of the simulations have implications for several different policy arenas.

The regression results and yield distribution results suggest that agricultural research can be closely directed. For example, millet does not respond well to fertilizer, and money spent on increasing millet yields would perhaps be best directed at understanding how field preparation affects millet, or at breeding new varieties that are fertilizer responsive under the Senegalese agroclimatic conditions. The millet variety used in agronomic trials is not responsive to fertilizer; this suggests that little money should be put into research or extension connected with fertilizer and the current millet variety. The reverse is true for peanuts: it appears that peanuts are responsive to fertilizer with increased mean yields and little effect on variance. This fact deserves further examination, and dissemination to farmers.

A free market for fertilizer can be realized if the production and distribution of fertilizer can be accomplished at costs less than 120-140CFA/kg (60-70CFA/kg if the agronomic data yields are twice actual yields). The market will be thin if prices are 120-140CFA/kg but will grow rapidly if prices can be brought down 20-30%. A worthwhile project would be to estimate what production and distribution costs are, and how much these costs will decline as distributors become more adept at their jobs. If distributors will become more efficient, it may be in the government's interest to extend credit or otherwise subsidize the fertilizer distribution industry for a short period of time until distributors become more adept.

Local geographic changes in the proportions of millet and peanuts produced can provide indicators to location of likely retail marekts. Areas that historically produce relatively more peanuts, say for agroclimatic reasons, would tend to demand relatively greater quantities of fertilizer. Areas that historically produce relatively more millet will purchase relatively less fertilizer. One possible reason for greater millet production is the nonexistence of a good market in which to trade peanuts (cash crops) for millet (food staple). Should this explanation have merit, it can be useful to aid the developemtn of commodity markets along with fertilizer markets.

Finally, if budget constraints become a problem for farmers who wish to apply fertilizer, then establishment of local credit systems could ease the problem.

9. Conclusions

This paper has analyzed the demand for fertilizer by Senegalese peanut farmers using an expected utility framework. A constant partial risk aversion form is assumed for the utility function. It is possible to empirically measure the risk aversion parameter when this form is assumed. The farmer maximizes his utility subject to a budget constraint by choosing fertilizer and seed inputs. These choices affect the probability distribution of yields. The effects are empirically estimated using the flexible, moment-based approach. Based on these measurements, simulations show the optimal fertilizer use by farmers under varying risk aversion and price scenarios.

The results indicate that fertilizer will be used predominantly on peanuts. At any reasonable price level millet is not fertilized. Risk aversion is important in determining the optimal mix of peanuts and millet. Expected profit maximizers will plant all their land in the one crop that they think is most profitable; whether this crop is peanuts or millet depends on prices of outputs and inputs. Risk averse farmers will diversify their holdings and plant both millet and peanuts. As the degree of risk aversion increases land becomes evenly allocated between millet and peanuts. For prices of fertilizer up to 100 CFA/kg most farmers will use fertilizer on their peanuts. Hence the demand for fertilizer tends to be closely linked to the growing of peanuts.

The demand for fertilizer tends to be inelastic at high and low prices, and relatively elastic at prices of 40-90CFA/kg. These ranges are based on agronomic trial data: should these data overestimate the yield response of fertilizer by a factor of two then a crude approximation suggests that the elastic range will be 20-45CFA/kg.

Implications arising from this study include 1) research on use of fertilizer with the currently popular millet variety is probably misdirected, 2) extension work showing that fertilizer does not significantly increase the variability of peanut yields could alter farmers' perceptions and increase fertilizer demand, 3) the feasability of a fertilizer market will depend on providing and distributing fertilizer at prices in the elastic range of the demand curve, 4) credit for distributors and farmers may be important in determining the extent of the market 5) a fertilizer market is most likely to develop in areas that plant a relatively high proportion of peanuts and have access to peanut and millet markets.

The outstanding topic for further research is to conduct studies on the production and distribution of fertilizer in Senegal and to combine them with this study. The combination will provide a much richer and more complete description of the future of the Senegalese fertilizer industry.

Table 1

Purchases of Fertilizer by Risk Averse Farmers

Partial Risk Aversion (rho)	8	2	1.2	.5	.15
Will Buy At	9,000	13,000	14,000	15,000	15,000
Will Not But At	10,000	14,000	15,000	16,000	16,000

CFA/150 kg

Expected value without fertilizer = 58,000 CFA

Expected value with fertilizer = 74,000 CFA

Actuarially fair price of Fertilizer = 16,000 CFA

Assumed price of peanuts = 80 CFA/kg

TABLE 2

SENEGALESE PEANUT YIELDS

SOIL PREPARATION #1

Year	Fert = 0kg/ha	Fert = 150kg/ha	Fert = 200kg/ha
1966	2200	1925	2150
1967	1380	1656	1897
1968	1378	2001	2341
1969	1005	1205	1570
1970	1234	1267	1673
1971	1660	2463	2897
1972	1636	1929	2180
1973	1607	2316	2155
1974	1436	2069	2377
1975	1465	1888	2283
1976	1766	2814	2645
1977		745	948
1978		1588	1909
1979		1061	1330
1980		1110	1291
1981		1876	2977
1982		1644	1802

SOIL PREPARATION #2

Year	Fert = 0kg/ha	Fert = 150kg/ha	Fert = 200kg/ha
1966	1837	2075	2062
1967	1226	1532	1599
1968	1344	2040	2134
1969	978	1116	1677
1970	1279	1420	1778
1971	1656	2077	2566
1972	1494	1908	2017
1973	1741	2354	2418
1974	1894	2450	2465
1975	1862	1531	1756
1976	1662	2535	2589
1977		776	883
1978		2056	2398
1979		1328	2177
1980		1020	1147
1981		2182	2873
1982		1747	1858

TABLE 2 (CONTINUED)

SENEGALESE PEANUT YIELDS

SOIL PREPARATION #3

Year	Fert = 0kg/ha	Fert = 150kg/ha	Fert = 200kg/ha
1966	1737	2150	2062
1967	1267	1677	1552
1968	1548	2250	2204
1969	1319	1765	1893
1970	1316	1668	1673
1971	1808	2278	2294
1972	1581	2102	2140
1973	1702	2238	2241
1974	2111	2575	2780
1975	1133	1170	1540
1976	2390	2685	2447
1977		896	969
1978		2072	2497
1979		1477	1961
1980		1005	1260
1981		2309	2886
1982		1575	1863

TABLE 3

SENEGALESE MILLET YILEDS

SOIL PREPARATION #1
(NO TILLING)

Year	Fert. = 0kg/ha	Fert. = 150kg/ha	Fert. = 450kg/ha
1973	312	252	879
1974	494	1322	1258
1975	633	938	1186
1976	50	472	572
1977	379	1497	1861
1978	438	1072	1305
1979	383	1408	1680
1980	378	1283	361

SOIL PREPARATION #2
(HAND TILLING)

1973	240	270	612
1974	726	1009	1370
1975	477	1022	1336
1976	381	875	941
1977	611	1887	1647
1978	650	1147	1363
1979	566	558	1875
1980	366	1365	1505

SOIL PREPARATION #3
(ANIMAL TRACTION)

1973	167	1134	981
1974	1005	1222	1823
1975	461	1297	1180
1976	259	775	1009
1977	658	1301	1981
1978	708	1016	1200
1979	508	1261	1861
1980	672	1322	1588

TABLE 4

GLS REGRESSION ANALYSIS OF THE STOCHASTIC YIELD FUNCTION FOR PEANUTS

Independent Variable	First Moment (kg/ha)	Second Moment $(kg/ha)^2$
Constant	1211.7	13,908
	(58.4)	(11,702)
Soil Prep. #2	2.4	-10,273
	(43.2)	(11,021)
Soil Prep. #3	30.0	-20,220
	(43.2)	(10,364)
Fertilizer	2.8	19
	(0.2)	(23)
Dummy-1966	442.1	25,579
	(90.4)	(28,252)
Dummy-1967	-82.4	20,139
	(57.7)	(8309)
Dummy-1968	371.6	1972
	(54.6)	(6934)
Dummy-1969	-146.2	37,056
	(79.2)	(20,401)
Dummy-1970	-73.0	631
	(53.1)	(6322)
Dummy-1971	611.1	28,884
	(90.7)	(28,513)
Dummy-1972	335.1	-3029
	(44.3)	(3506)
Dummy-1973	523.7	6598
	(49.7)	(5508)
Dummy-1974	717.2	22,873
	(83.5)	(23,693)
Dummy-1975	56.2	128,372
	(141.2)	(77,168)
Dummy-1976	832.1	37,528
	94.8)	(31,989)
Dummy-1977	-828.2	7295
	(46.0)	(6744)
Dummy-1978	405.4	38,674
	(114.4)	(39,438)
Dummy-1979	-141.3	94,748
	(153.8)	(75,191)
Dummy-1980	-640.6	-4429
	(46.0)	(3135)
Dummy-1981	800.2	92,114
	(162.7)	(84,690)
	$R^2 = 0.80$	$R^2 = 0.20$

TABLE 5

GLS REGRESSION ANALYSIS OF THE STOCHASTIC YIELD FUNCTION FOR MILLET

Independent Variable	First Moment (kg/ha)	Second Moment $(kg/ha)^2$
Constant	491.0	53,452
	(119.7)	(157,326)
Soil Prep. #2	533.0	-3002.8
	(66.2)	(31,804)
Soil Prep #3	736.8	23,896
	(65.1)	(29,825)
Fertilizer	0.36	12.2
	(0.14)	(86.1)
Dummy	-427.5	-37,359
	(139.9)	(168,883)
Dummy	217.5	-17,919
	(130.0)	(159,819)
Dummy	-24.0	-37,645
	(128.8)	(157,092)
Dummy	-364.2	4321
	(128.8)	(157,719)
Dummy	277.8	15,192
	(143.8)	178,233)
Dummy	-22.7	-24,947
	(128.8)	(157,084)
Dummy	115.7	17,527
	(155.6)	(212,627)

TABLE 6

CHOICES OF FERTILIZER USE
PEANUTS

		Fert.	No Fert
Millet	Fert	$F_p = 150$ kg/ha $F_m = 150$ kg/ha	$F^p = 0$ $F_m = 150$ kg/ha
	No Fert	$F_p = 150$ kg/ha $F_m = 0$	$F_p = 0$ $F_m = 0$

TABLE 7

FERTILIZER USE BY SENEGALESE PEANUT FARMERS

Price of Peanuts = 100CFA/kg
Price of Millet = 120CFA/kg

Price of Fertilizer	Land in Millet	Land in Peanuts	Millet Fertilizer	Peanut Fertilizer
		S=0 (Expected Income Maximizer)		
160 CFA/kg	100%	0%	0kg/ha	0kg/ha
140 CFA/kg	100%	0%	0kg/ha	0kg/ha
120 CFA/kg	100%	0%	0kg/ha	0kg/ha
100 CFA/kg	100%	0%	0kg/ha	0kg/ha
90 CFA/kg	0%	100%	0kg/ha	150kg/ha
80 CFA/kg	0%	100%	0kg/ha	150kg/ha
70 CFA/kg	0%	100%	0kg/ha	150kg/ha
60 CFA/kg	0%	100%	0kg/ha	150kg/ha
50 CFA/kg	0%	100%	0kg/ha	150kg/ha
40 CFA/kg	0%	100%	0kg/ha	150kg/ha
		S=1 (Log Utility)		
160 CFA/kg	90%	10%	0kg/ha	0kg/ha
140 CFA/kg	90%	10%	0kg/ha	150kg/ha
120 CFA/kg	90%	10%	0kg/ha	150kg/ha
100 CFA/kg	90%	10%	0kg/ha	150kg/ha
90 CFA/kg	90%	10%	0kg/ha	150kg/ha
80 CFA/kg	90%	10%	0kg/ha	150kg/ha
70 CFA/kg	90%	10%	0kg/ha	150kg/ha
60 CFA/kg	90%	10%	0kg/ha	150kg/ha
40 CFA/kg	90%	10%	0kg/ha	150kg/ha
		S=2		
160 CFA/kg	80%	20%	0kg/ha	0kg/ha
140 CFA/kg	80%	30%	0kg/ha	150kg/ha
120 CFA/kg	80%	30%	0kg/ha	150kg/ha
100 CFA/kg	80%	30%	0kg/ha	150kg/ha
90 CFA/kg	70%	30%	0kg/ha	150kg/ha
80 CFA/kg	70%	30%	0kg/ha	150kg/ha
70 CFA/kg	70%	30%	0kg/ha	150kg/ha
60 CFA/kg	70%	30%	0kg/ha	150kg/ha
50 CFA/kg	70%	30%	0kg/ha	150kg/ha
40 CFA/kg	60%	40%	0kg/ha	150kg/ha

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FIGURE 1

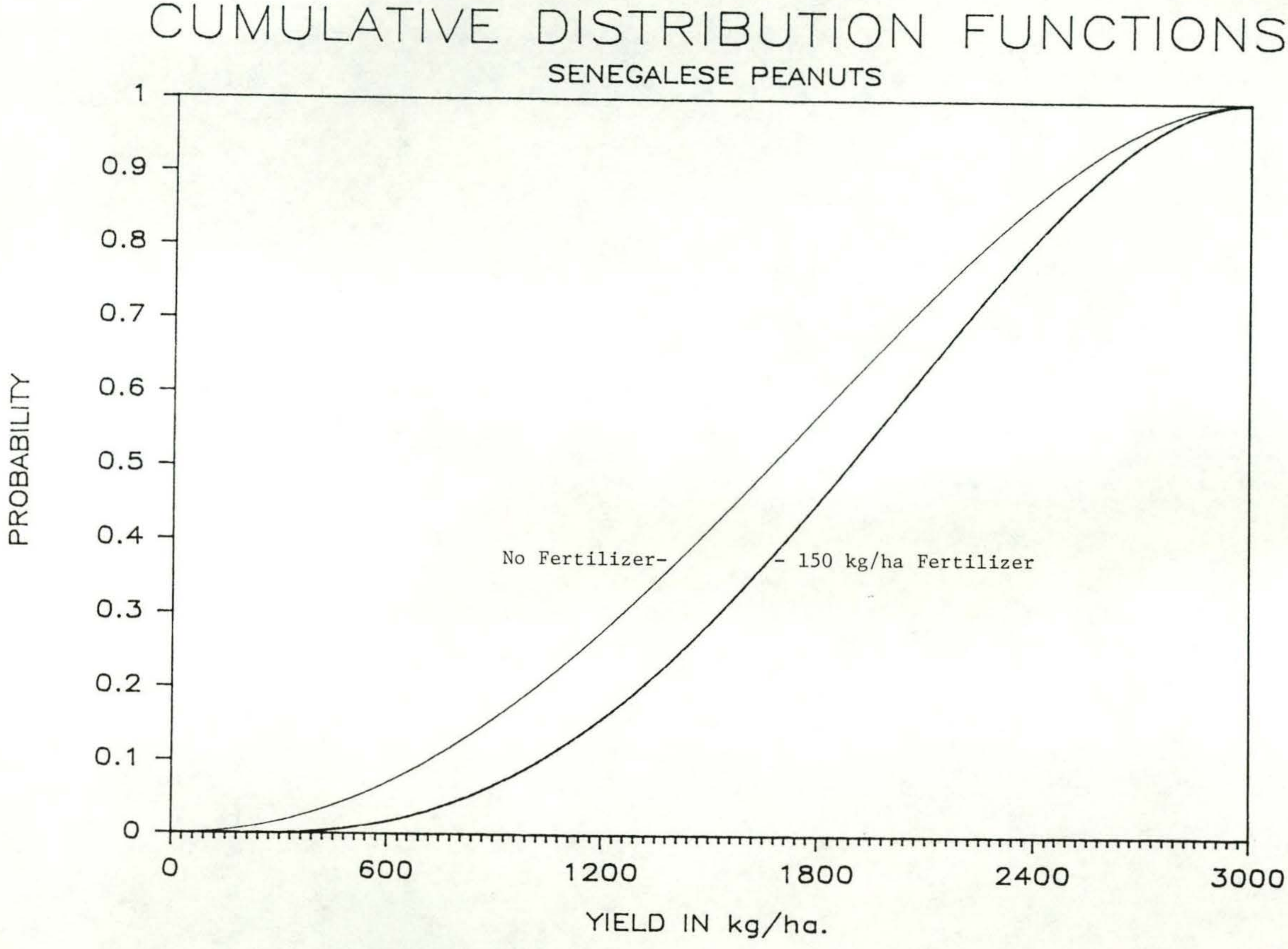
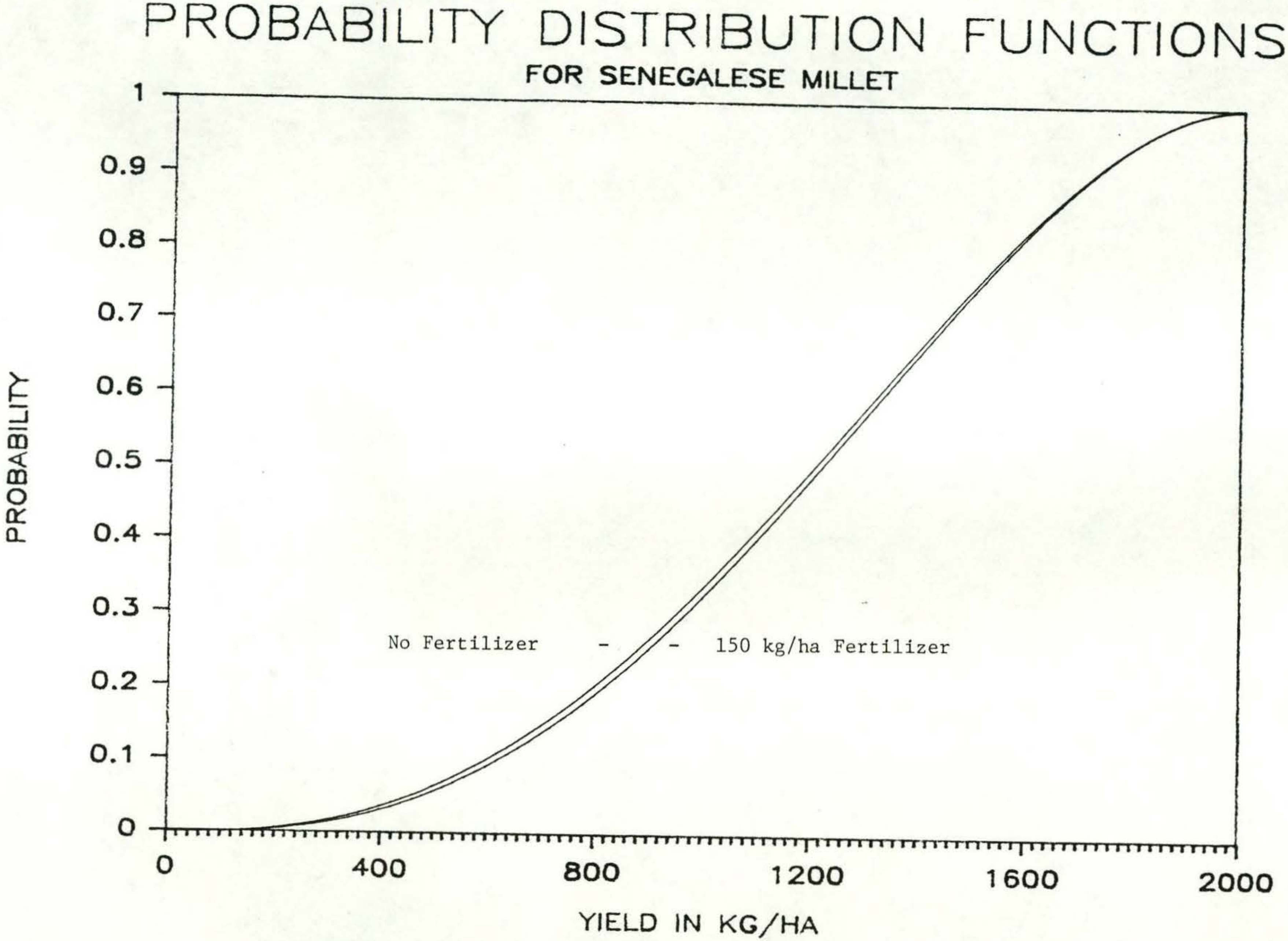

CUMULATIVE DISTRIBUTION FUNCTIONS
SENEGALESE PEANUTS
PROBABILITY
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
No Fertilizer-
- 150 kg/ha Fertilizer
0
600
1200
1800
2400
3000
YIELD IN kg/ha.

FIGURE 2


PROBABILITY DISTRIBUTION FUNCTIONS
FOR SENEGALESE MILLET
PROBABILITY
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
No Fertilizer
- - 150 kg/ha Fertilizer
0
400
800
1200
1600
2000
YIELD IN KG/HA