STOCHASTIC MAIZE PRODUCTION TECHNOLOGY AND PRODUCTION RISK ANALYSIS IN DADAR DISTRICT, EAST ETHIOPIA

B Fufa & RM Hassan[1]

Abstract

A stochastic production technology that allows risk effects of factor inputs was estimated for maize farmers in Ethiopia. The results suggested that the promoted improved maize technology exhibits constant returns to scale whereas non-adopters use decreasing returns to scale technology. The study showed that timely planting is critical for maize yield stability among both adopters and non-adopters and suggests the importance of using oxen and higher efforts to achieve that. Nevertheless, the results showed that most of the factors under the control of the farmers do not offer powerful explanation to maize yield variability compared to natural factors such as rainfall, frost, pests and diseases.

1. INTRODUCTION

The usual approach in modeling technological relationships in production is based on mean levels of inputs and output. In this formulation the firm's decision problem is solved by equating the marginal value of output to factor costs. However, it is widely recognized that agricultural products, especially crop yields, are stochastic (random) and levels of inputs used also influence higher moments (e.g. variance, etc.) of the distribution of output (de Janvry, 1972; Just & Pope, 1979; Antle, 1983). If producers are concerned about risk involved in the use of inputs, optimal choices may depend on moments of the distribution of returns other than the mean.

The stochastic nature of agricultural production is a major source of risk. Thus, variability in yield is not only explained by factors outside the control of the farmer such as input and output prices but also by controllable factors such as varying the levels of inputs (Just & Pope, 1979; Antle, 1983). It has been shown that a risk-averse farmer thus uses more (less) of a risk-reducing (increasing) factor than a risk neutral firm. It follows that risk has an important bearing in the design and transfer of new technologies as the rate of

[1] *Department of Agricultural Economics, Extension and Rural Development, University of Pretoria, South Africa.*

adoption does not only depend on their yield levels but also on their risk effects (de Janvry, 1972; Hassan & Hallam, 1990).

Production decisions are also influenced by market risks associated with the uncertainty about future prices of inputs and outputs and reliability of input supplies (Hardaker, Hurine & Anderson, 1997). Although market risks are essentially exogenous, farmers can affect yield variability and the distribution of returns by the choice of inputs in a given enterprise or a combination of enterprises. Thus production risks have a tremendous impact on agriculture in general, and the production patterns and supply behaviour of small-scale farmers in particular.

Agriculture is the dominant sector of Ethiopian Economy. It contributes about 52% of the GDP and about 85% of the population earn their livelihood from the sector. Small-Scale farmers in Ethiopia have little control over market risks but they are capable of varying the level and combination of inputs and employ different farming practices and production strategies to cope-up with production risk. Most of the green-revolution technologies, like the current extension package in Ethiopia are evaluated based on their favourable yield effects whereas their risk effects are often not considered (Hassan & Hallam, 1990). For most farmers of Ethiopia securing enough food for the family is of high value than obtaining high yield. To that extent, production risk associated with the use of a new technology and its effect on maintaining household food security is an important factor in production-decisions involving the use of a new technology. Thus, the development and promotion of improved agricultural production technologies require a thorough understanding of farmers' supply response under production risk.

The objective of this study is to analyse the impact of inputs on mean levels and variability of maize yield in Dadar district of Ethiopia. The stochastic production technology framework is discussed in the next section followed by a brief background to agricultural sector in Ethiopia and farming systems in the study area. In section four the econometric model of the stochastic production technology is specified and estimated and results are presented and discussed. The final section concludes the paper.

2. THE STOCHASTIC PRODUCTION TECHNOLOGY FRAMEWORK

There is considerable evidence in the literature that the distribution of output is a unique function of its moments (Day, 1965; Anderson, 1973; Roumasset, 1976). Thus, the behaviour of firms under stochastic production can be defined in terms of the relationship between inputs and these moments.

Several methodologies have been developed to analyse production related risks. According to the traditional econometric specifications of stochastic production function, if any input has a positive effect on the mean of output, then a positive effect on variability of output is also imposed (Just & Pope, 1979). However, the effects of any input on mean output should not be tied to the effects of inputs on variability of output a priori. Hence, adequate production function specifications should include two general functions - One that specifies the effect of inputs on the mean level of output and the other specifies the effects of inputs on higher moments of the distribution of output such as the variance. Following Just & Pope (1979), a stochastic production technology is specified as:

$$Y = f(X,\mu) + h(X,\theta)\varepsilon \qquad (1)$$

Where, Y is output level, $f(X,\mu)$ and $h(X,\theta)$ are the mean (deterministic) and the stochastic (variance) components of the production function, respectively. X represents input levels, μ *and* θ are parameters and ε is the error term.

The premise of the above model is that the variance of the production function error term may be related to explanatory variables, implying heteroscedasticity. A multi-stage Linear Least squares (MLS) in linear functions or Multistage Non-linear Least squares (MNLS) in case of Non-linear functions, procedure should therefore be applied to generate consistent and asymptotically efficient estimates of the parameters of this production.

The estimation procedure is given as follows:

a) First, a Non-linear least squares (NLS) or linear least squares (LS) estimator of β is obtained from the regression of Y *on* $f(X,\mu)$ or $\ln Y$ on $\ln f(X,\mu)$ in logarithms. Under broad range of conditions, the NLS or LS of $\hat{\beta}$ *and* $f\left(X,\hat{\beta}\right)$ are shown to be consistent. The residual, $\hat{U}$ from this regression is then calculated as:

$$\hat{U} = Y - f\left(X,\hat{\beta}\right) = \hat{h}(X,\theta)\varepsilon \text{ or } \hat{U} = \ln Y - \ln\hat{f}(X,\mu) \qquad (2)$$

b) An NLS or LS estimator of θ and $h(X,\theta)$ is obtained by regressing $\hat{U}^2$ *on* $h^2(X,\theta)$ or $\left|\hat{U}\right|$ on $\ln h(X,\theta)$ in case of logarithms to produce the consistent estimators of $\hat{\theta}$ *and* $\hat{h}(X,\theta)$.

c) A NLS or LS estimator of μ is finally obtained by weighted regression of Y^* *on* $f^*(X,\mu)$ or $\ln Y$ on $\ln f(X,\mu)$ (3)

Where, $Y^* = \dfrac{Y}{\hat{h}\left(X,\hat{\theta}\right)}$, $f^* = \dfrac{f(X,\mu)}{\hat{h}\left(X,\hat{\theta}\right)}$ or $Y^* = \dfrac{\ln f(X,\mu)}{\ln \hat{h}\left(X,\hat{\theta}\right)}$, $f^* = \dfrac{\ln f(X,\mu)}{\hat{h}\left(X,\hat{\theta}\right)}$

If the function $Y = f(X,\beta)$ is hetroscedastic, the predicted values of the residuals from the regression on the explanatory variables will enable to capture the values of the residuals related to these variables. The weighting of this function by the predicted values of the residuals from (2) will give consistent and asymptotically efficient parameter values of the function. The gain in efficiency attained by using the described MLS or MNLS procedure ensures desirable statistical properties and valid statistical tests and allows the assessment of the impact of risk effects of factor inputs as measured in step b.

3. AGRICULTURE IN ETHIOPIA AND THE STUDY AREA

Agriculture is the main driving force for economic development in Ethiopia. Recently, the population growth rate of 3% per annum exceeded the annual agricultural growth rate, which is about 2% per annum. This resulted in a huge food insecurity problem in the country. Domestic supply has failed to meet the food requirement of the population. An estimated 50 to 60% of the county's population is currently food insecure, or live below the poverty line. As a result, the country has to depend on food aid to feed a large proportion of its the population. For instance, food aid accounted for 10.7% of the total food supply during 1985 to 1996.

However, attempts to increase the contribution of agriculture to the overall economic development of the country began in 1960s with comprehensive agricultural extension package programmes. The main components of the promoted technology package consisted of mainly improved seed and fertilizer. In the 1980s, another project known as the *Peasant Agricultural Development Programme* was initiated, which continued to promote the use of the same technologies used in the previous extension package programmes under cooperatives. The Training and Visit (T&V) system of extension was then introduced along with this program. Limited success has been attained with the T&V program due to lack of sufficient on-the-shelf technologies to be disseminated and management problems associated with running the extension system.

In 1994/95, under the general framework of Agriculture Led Industrialization Development Strategy (ALIDS), the government, supported by the World Bank and Sasakawa Global 2000[2], implemented a huge agricultural extension program called "Participatory Demonstration and Extension Training System" (PADETS). The focus of the extension program is the promotion of improved agricultural technologies such as high yielding (improved) seed varieties, fertilizers and chemicals for the control of diseases, insects and weeds. In addition, improved management practices (methods) like line sowing, timely cultivation and timely weeding are also components of the agricultural extension package being promoted. To overcome cash constraint faced by most farmers in the country, credit for the purchase of the inputs is available on 25% down payment basis. The farmers are expected to pay the remaining amount at the end of harvesting season. Food crops such as maize, sorghum, wheat and teff received the greatest attention by the extension program and remarkable yield increases are reported to have been achieved at farm level. For instance, statistical figures from the Ministry of Agriculture show that with locally available seeds 5, 2.7 and 1.8 tons/ha of maize, wheat and teff, respectively were obtained.

Cereals constitute the major portion of total agricultural produce in the country. Total production, area harvested and yields of cereals showed slight increasing trend over the past seven years since the implementation of PADETS (Figure 1). Total production (metric tones) and area harvested (hectares) were low in 1998 as compared to the other years. The yield of cereals (kilograms) has almost been constant over the years indicated. However, the graph shows that total cereal production and total area harvested move together very closely. This indicates that in the past few years increases in cereal production have been due to expansion in area under cereal production rather than increase in yield.

[2] *Sasakawa Global 2000 is a non-governmental organization working on agricultural development, especially the transfer of new technologies to farmers.*

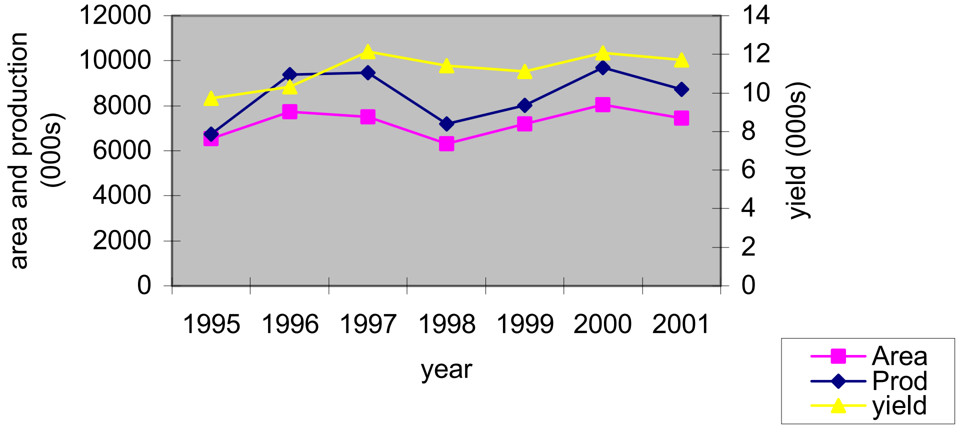

Figure 1: Graph of total production, area harvested and yield of total cereal production in Ethiopia

Maize is among the major cereals grown in the Ethiopia. Figure 2 shows that maize yields (kilograms) almost stayed stable from 1996 on wards. Total maize production (metric tones), however, varied from one year to the other. In most cases a good production year has been followed by a bad production year resulting in lower levels of maize production. Nonetheless, the slight increasing trend in total production seems to come from the increase in area devoted to maize production (hectares).

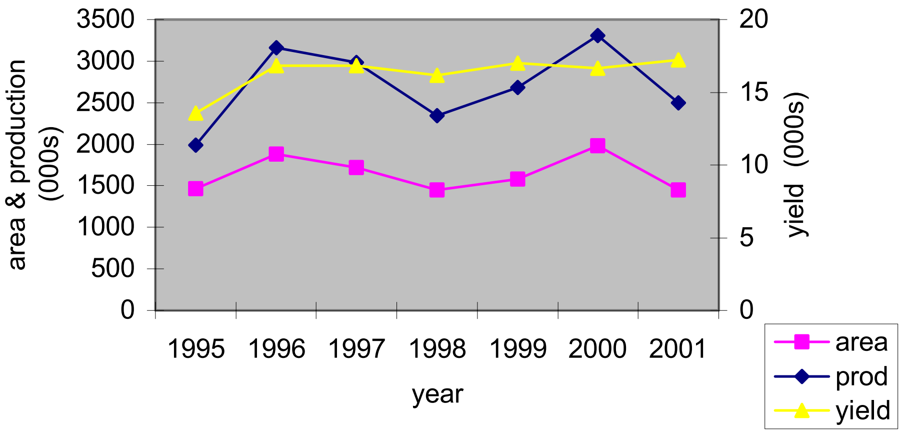

Figure 2: Total production, area harvested and yield of maize in Ethiopia

In addition, evaluations of the per hectare maize yield obtained from the extension package and the traditional methods of maize production show that significant yield increase can be obtained by using the extension package. For instance, in 1999/2000 production year the average per hectare maize yield was 57.60 quintals using the extension package whereas the non-extension package farmers obtained only 16.20 quintals per hectare. The average per hectare maize yield obtained using the extension package since the implementation of the extension package over the past six years is about 46.25 quintals per hectare. Whereas, using the traditional maize production method farmers obtained about 15.9 quintals per hectare on average. This shows the big potential to increase maize production in the country by more than threefold using the extension package.

This study is conducted in Dadar district located in the East Hararghe zone of Oromiya regional state in Ethiopia. It is one of the major maize producing districts in this zone. Being a major cereal grown in the area, maize is the staple diet and important source of income for many farmers. In addition, maize stalks are used for firewood and construction purposes. The current extension package has been practiced in the district since 1997. Fertilizer, improved varieties of maize and cultural practices like line sowing and cultivation are the major components of the extension package. Other important factors of maize production in the area include human labour, oxen labour and land. The yield risk effect of the different factors of maize production has not been studied in the country in general and in the study area in particular.

The study is based on cross sectional production data collected during the 2001/2002 agricultural production year in the district. Combinations of purposive and random sampling were used in the survey. In the first stage of the survey, farmers were broadly classified in to two groups selected on purpose. The first groups consisted of those farmers that use maize extension package and the second group included farmers that are not users of the package. Fifty farmers from each group were selected randomly in the second stage sampling. A stochastic production function that includes the impact of inputs on output variability is specified for the two groups of farmers.

4. ECONOMETRIC SPECIFICATION OF THE STOCHASTIC TECHNOLOGY MODEL

Following the stochastic technology framework presented in equations 1 to 3 earlier, maize yield equations that include the stochastic component were specified for the two groups of farmers. A log linear Cobb-Douglas production function was found to fit the data well. The empirical Cobb-Douglas production function for adopters of maize technology in the area was specified as follows:

$$\log(Yld) = \alpha_o + \alpha_1 \log(Land) + \alpha_2 \log(Fert) + \alpha_3 \log(Lcul) + \alpha_4 \log(Lox) + \alpha_5 \log(Lplt) \quad (4)$$

Where *Yld* is maize yield in quintals, *Land* is land planted to maize in qindi[3], *Fert* is total amount of fertilizer applied to maize in kilograms, *Lcul* is human labour used for maize cultivation in man days, *Lox* is oxen labour used in ploughing and planting of maize in oxen-days and *Lplt* is human labour used in maize planting in man-days. The empirical log linear Cobb-Douglas production function for non-adopters of maize technology is given by:

$$\log(Yld) = \alpha_o + \alpha_1 \log(Land) + \alpha_2 \log(Lcul) + \alpha_3 \log(seed) + \alpha_4 \log(Lplt) \quad (5)$$

All variables are as defined above and *seed* is amount of maize seed used in kilograms. All adopters use line-sowing method of planting following almost the recommended rates. Whereas non-adopters use broadcasting method of sowing and seed rates applied are highly variable. Thus, seed rates used is included in the specification of the production function for adopters only.

The maize extension package technologies require timely ploughing and land preparation. As a result most farmer which use the extension package in most cases are those that have access to oxen labour. On the other hand, hoe culture is the dominant means of ploughing in the area. Due to lack of oxen most farmers, especially non-adopters relay on human labour for planting in the area. In the specification of the production function for non-adopters human labour for planting was found to be a more relevant input than oxen labour.

Results of the specification of the mean maize yield function for adopters show that all variables had the admissible signs and except for planting labour they all were statistically significant (Table 1). The estimated elasticities suggest a constant returns to scale technology for adopters of improved maize practices (homogeneity of degree one). Land allocated to maize production and fertilizers have high elasticities with respect to yield. With 10% increase in maize area mean yield of maize increases by 3.51%. In addition, 10% increase in fertilizer increases mean maize yield by 3.5%. The results also indicate that highest yield increase is obtainable from larger maize plot size (1.4 quintals) and use of oxen (0.97quintals).

[3] *Qindi is a local measure of land size. One hectare is equivalent to eight (8) qindies.*

Table 1: LS Estimates of the Cobb-Douglas production function for adopters

Variable	Coefficient	Standard error	P-value	Marginal Product
Constant	0.141***	0.363	0.0004	
Log (Land)	0.351***	0.098	0.0009	1.405
Log (Fert)	0.350***	0.079	0.0001	0.077
Log (Lcul)	0.124**	0.059	0.0412	0.176
Log (Lox)	0.128**	0.060	0.0385	0.968
Log (Lplt)	0.009	0.017	0.5720	0.003

***Significance at 1%; **Significance at 5%; R-squared 0.87.

Results from the estimation of the second moment (based on equation 2) maize yield function show that the size of the maize plot, fertilizer and planting labour were found to be risk-increasing in maize production whereas cultivation labour and oxen reduce production risks (Table 2). However, the effects of all factors were statistically insignificant. The land holding size of the farmers in the area is dwindling gradually due to increase in population pressure. Increase in land holding in the area comes from farming marginal areas. However, the maize production technologies promoted are less responsive to less fertile lands. The yield obtained from such marginal lands is, thus naturally unstable. In addition, because of the unpredictable nature of rainfall, the use of oxen is crucial for timely ploughing and planting during the rainy season and hence its positive impact on the stability of maize yield (risk-reducing) in the area. Timely cultivation is one of the critical recommendations of agronomic practices in the package. Both improved seeds and fertilizer are highly responsive to timely cultivation. The use of more labour in maize cultivation thus is expected to contribute to more stabile yields.

The elasticities of the factors of production with respect to maize yield variance are shown in table 2. For 10% increase in maize area, the variability of maize yield increases by 1.45%. A 10% increase in amount of fertilizer applied to maize increases maize yield variability by 4.48%. But a 10% increase in the use of oxen-days decreases maize yield variance by 2.29%. A 10% increase in cultivation labour also decreases maize yield variance by 0.35%. However, variability in maize yield for adopters is not explained well by the factors of production mentioned above. Factors beyond the control of farmers such as rainfall, frost, outbreak of pests and disease seem to have stronger influences on the risk associated with maize production in the area.

Table 2: Second moment estimates of the parameters of the Cobb-Douglas production function for adopters

Variable	Coefficient	Standard error	P-Value
Constant	-0.890	0.237	0.592
Log (Land)	0.146	0.324	0.654
Log (Fert)	0.448	0.297	0.139
Log (Lcul)	-0.035	0.027	0.203
Log (Lox)	-0.229	0.149	0.132
Log (Lplt)	0.212	0.169	0.218

R-squared 0.23.

The consistent MLS estimates of adopters' mean yield function (equation 3) are given in Table 3 showing a slightly different coefficients' values the sum of which is slightly higher than one (e.g. suggesting increasing returns to scale). The elasticities show that 10% increase in area under maize production and fertilizer application would increase maize yield by 4.5% and 4% respectively.

Table 3: MLS estimates of the Cobb-Douglas production function of maize for adopters

Variable	Coefficient	Standard error	P-value
Constant	-1.5900	0.3554	0.9419
Log (Land)	0.4530**	0.0798	0.0000
Log (Fert)	0.4020**	0.0870	0.0000
Log (Lcul)	0.0334*	0.0184	0.0770
Log (Lox)	0.1493**	0.0555	0.0100
Log (Lplt)	0.0215	0.0282	0.4490

***Significant at 1%; **Significant at 5% ; R-squared 94%.

The mean yield estimation results for non-adopters suggest that larger maize plots and planting labour are the most significant determinants of yield levels (Table 4). Unlike adopters, non-adopters production technology seems to exhibit decreasing returns to scale. The elasticities of the mean maize yield show that a 10% increase in maize land increases mean maize yield by 6.51%. In addition, a 10% increase in human labour in man-days increases mean maize yield by 1.34%. Where as the marginal products show that for each additional quindi increase in maize land, mean maize yield increases 1.679 quintals and each additional increase in human labour for planting in man-days increases mean maize yield by 0.36 quintals.

Table 4: LS estimates of the parameters of the Cobb-Douglas production function for non-adopters

Variable	Coefficient	Standard error	P-Value	Marginal Product
Constant	0.015***	0.287	0.0008	
Log (Land)	0.651***	0.199	0.0022	1.679
Log (Lcul)	0.008	0.122	0.9477	0.008
Log (Seed)	0.029	0.161	0.8550	0.015
Log (Lplt)	0.134***	0.035	0.0005	0.355

***Significant at 1%; R-squared 61%.

The use of higher seeding rates and cultivation labour were found to increase the variability in maize yield while larger size plots and planting labour reduce production risks for non-adopters (Table 5). This might be due to the fact that local varieties are adapted to the agro-ecology of the area and, therefore, less affected by limited nutrient supply of the soil in marginal lands. Expansion in area planted to maize production could thus have a tendency to stabilize yield. Non-adopters tend to use broadcasting methods of sowing local varieties of maize, while adopters use line sowing, which makes use of more labour in planting. Accordingly, use of more labour for planting may be an indication of improved cultivation practices such as line sowing, which are risk reducing. Cultivation labour is found to be significant risk increasing factor of maize production for non-adopters in the area. This requires further investigation in to the practices of the farmers and the determination of optimal cultivation method for these varieties. In addition, amount of maize seed use is risk-increasing factor. This also indicates the need for further investigation in the determination of optimal amount of local seed to be used to achieve stable yield.

Table 5: Second moment estimates of the parameters of the Cobb- Douglas production function for non-adopters

Variable	Coefficient	Standard error	P-value
Constant	-0.928	0.171	0.496
Log (Land)	-0.065	0.119	0.589
Log (Seed)	0.007	0.096	0.943
Log (Lplt)	-0.015	0.021	0.475
Log (Lcul)	0.133*	0.073	0.075

*Significant at 1% ; R-squared 0.08.

The statistical significance of parameters estimates as well as the value of the coefficients of determination has significantly improved with the consistent MLS estimator procedure as shown in Table 6.

Table 6: MLS estimates of the parameters of the Cobb-Douglas production function for non-adopters

Variable	Coefficient	Standard error	P-value
Constant	0.1550***	0.4985	0.0065
Log (Land)	0.7073***	0.1826	0.0004
Log (Lcul)	0.0864	0.1689	0.6115
Log (Seed)	0.0210	0.1608	0.8965
Log (Lplt)	0.1446***	0.0373	0.0004

***Significant at 1% ; R-squared 66%.

5. CONCLUSIONS AND IMPLICATIONS

As typical to many smallholder agriculture, production decisions of small-scale maize growers in Ethiopia are influenced by production risks. Nevertheless, the risk effects of the major factors of production including components of the extension package, has not been studied in the country in general and the study area in particular.

This study revealed that timely planting through the use of oxen or more labour for cultivation improve stability of yield on plots of maize farmers participating in the improved technology package. On the other hand, cultivation of larger plots of maize and use of fertiliser were found to be risk increasing for this group of adopters. While maize technologies that give higher yield levels (e.g. fertiliser) should be given greater emphasis in technology development, researchers should also take in to account the risk effects of those factors. Due to the erratic nature of rainfall in the area, oxen labour helps timely ploughing and planting of maize. This is reflected in its risk decreasing effect in maize production. Farmers' access to oxen should therefore be considered a critical component of the maize technology package promoted in the area. Timely planting was again very important for yield stability among non-package farmers re-emphasizing the importance of improved cultivation methods.

However, the results of this study indicate that factors other than input levels are more important determinants of production risks. Forces of nature such as rainfall, frost, pests and diseases could be the major sources of maize yield variability. Research and extension has to therefore focus on the development of maize technologies that are better suited to the agro-ecology of the area.

REFERENCES

ANDERSON JR (1973). Sparse data, climatic variability and yield uncertainty in response analysis. *American Journal of Agricultural Economics* 53(1)*:* 77-82.

ANTLE JM (1983). Testing the stochastic structure of production: A flexible moment based approach. *Journal of Business and Economic Statistics* 1(3):192-201.

DAY RH (1965). Probability distribution of field crops. *Journal of Farm Economics* 47:713-741.

DE JANVRY A (1972). Optimal levels of fertilization under risk: The potential for corn and wheat fertilization under alternative price policies in Argentina. *American Journal of Agricultural Economics* 54:1-10.

JUST RE & POPE R (1979). Production function estimation and related risk considerations. *American Journal of Agricultural Economics* 61:276-284.

HARDAKER JB, HURINE BM & ANDERSON JR (1977). *Coping with risk in agriculture*. CAB International, London.

HASSAN MR & HALLAM A (1990). Stochastic technology in a programming framework: A generalized mean-variance farm model. *Journal of Agricultural Economics* 41:196-206.

ROUMASSET JA (1976). *Rice and risk: Decision making among low income farmers*. North Holland, Amsterdam.