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ESTIMATING THE RISK OF ALTERNATE TECHNIQUES: NITROGENOUS FERTILIZATION OF RICE IN THE PHILIPPINES*

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The problem investigated is how to estimate expected profits and the risk of using nitrogenous fertilizer for purposes of making fertilizer recommendations and explaining farmer decisions. Three inappropriate methods are discussed and a new method is developed which combines experimentally determined production functions with cross-section data on crop damages. For the Philippine situation analyzed, it appears that using the amount of nitrogen fertilizer which maximizes expected profits does not substantially increase the risk above low nitrogen levels. This finding casts doubt on the hypothesis that farmers' reluctance to use modern techniques is due to their aversion to risk.

1 INTRODUCTION

The original motivation for this research was to estimate the extent that risk explains the factor-input decisions of rice farmers in selected areas of the Philippines. In order to measure the role of risk in decision-making, one needs an estimate of the probability distribution of yields for each production technique under consideration. The purpose of this paper is to develop and illustrate a methodology which was found to be useful for estimating frequency distributions of yields corresponding to different levels of nitrogenous fertilizer. It is anticipated that the method could be generalized for application to techniques which differ by two or more variables.

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While the method was developed as a positive tool of analysis, it seems to have considerable potential for normative research. Recommendations given to extension agents and farmers on amounts of various inputs to use are typically generated from experiments at a central research station. The problem with using experimental data as the basis of recommended farming practices is that soil, irrigation and environmental conditions are likely to be different, typically worse, on the farm than at the experiment station. Furthermore, experiments such as nitrogen-response trials are conducted with extensive control measures (e.g. frequent application of insecticides) which are not profitable at the farm level.

The normative question facing the agricultural economist then is how to adjust the experimental results to fit the less-controlled conditions found in farmers' fields. The method developed here provides a basis for taking environmental variables into account. The experimental production function is combined with information about damaging factors at specified farm locations to give a stochastic production function. The latter can be used in turn as the basis of algorithms which compute optimal input levels for different preferences toward risk.

The paper begins with a discussion of methods of measuring risk that have been used by other researchers or which seemed promising on *a priori* grounds. Three such approaches are rejected as being unsuitable for the problem at hand. The fourth method, which combines experiment-station data with information about crop damages gathered at the farm level, is developed in detail and is found to be useful for estimating risk and expected profit, both as functions of nitrogen per hectare. These functions are used in turn to show that the presumed conflict between profitability and risk, which has been hypothesized by several authors to explain farmers' reluctance to accept "modern techniques", appears not to exist, at least not for rice production in the Philippines.

A major objective of this study is to report on experiments involving different methods for dealing with problems concerning the measurement and effects of risk. The cost of these experiments is some loss in consistency in methods of assessing crop damages, fitting frequency functions, comparing the riskiness of alternate techniques, and other areas in which no procedural consensus exists. It is hoped that the costs will be offset by benefits to some readers who may find a few of the methods useful for exploring other problems.

2 THE MEANING OF RISK AND SOME PROBLEMS WITH ITS MEASUREMENT

In high theory, risk is what increases when a frequency distribution is changed by a "mean-preserving spread" [18] (i.e. "a change in the distribution of a random variable which keeps its mean constant and represents the movement of probability density from the centre to the tails of the distribution" [7]). In special cases this definition of risk is equivalent to variance. In common usage, in insurance parlance, and in a small part of the economics literature, risk is the probability of loss,

e.g. the chance of bankruptcy. In all cases risk relates to the frequency distribution of a random variable. For many agricultural applications the primary source of variation is the stochastic nature of crop yields. It seems appropriate then to begin our discussion of risk measurement with an analysis of some alternative methods of estimating frequency functions of crop yields.

2.1 TWO UNPRODUCTIVE METHODS OF ESTIMATING RISK

One common method for estimating risk¹ is to fit a frequency distribution to a cross-section of yields and to assume that it is a good proxy for the frequency of yields facing an individual farmer using a specific technique. This method is inadequate because it fails to control for the effects that different input levels and locational characteristics have on the frequency distribution. In effect what is done is to use variations in technique and locational characteristics as the basis for estimating variance due to environmental factors such as weather and damage by pests and disease.

In order to control for variation due to factor inputs and locational characteristics, yield per hectare was regressed on nitrogen per hectare, other chemical inputs per hectare, and dummy variables representing differences in irrigation and locations [19]. Estimation of risk was then based on the distribution of residuals from the regression, the assumption being that the residuals were primarily due to left-out environmental variables. This method was found unsatisfactory due to the substantial measurement error inherent in asking farmers about the size of their farm and the exact amounts of inputs and output and due to the importance of hard-to-measure variables such as family labor, quality of management, and soil type.

2.2 THE EXPERIMENTAL METHOD

The "experimental method" of measuring risk was developed, primarily for another purpose, by Richard Day [4]. The method involves fitting frequency distributions to time series data from agricultural experiment stations. This was done for data based on nitrogen response experiments with rice variety *IR-8*. The experiments were conducted at the Maligaya Experiment Station, Nueva Ecija and at the International Rice Research Institute (IRRI), Laguna, both in the Philippines, during the years 1966-71. The results are shown in figures 1 and 2.² Note that there

¹ This method has been used, for example, by Wharton [22, p. 44] and by U.S.A.I.D. consultants to the Philippines on crop insurance [19, p. 84].

² The histograms represent actual data. The smooth frequency functions were fit to the histograms using the method of moments with Pearson Type I frequency distribution to calculate the estimated mode. The area under the frequency curves was made to conform to the area under the histograms and the shapes of the curves were made as consistent as possible with the estimated values of the standardized third and fourth moments. In estimating the highest and lowest points for each frequency distribution, theoretical considerations were taken into account in addition to the highest and lowest sample values. In drawing a given frequency distribution curve, information obtained in related experiments (different nitrogen levels, same location and season) were also taken into account. This, of course, cannot be done in the purely mechanical method of moments.

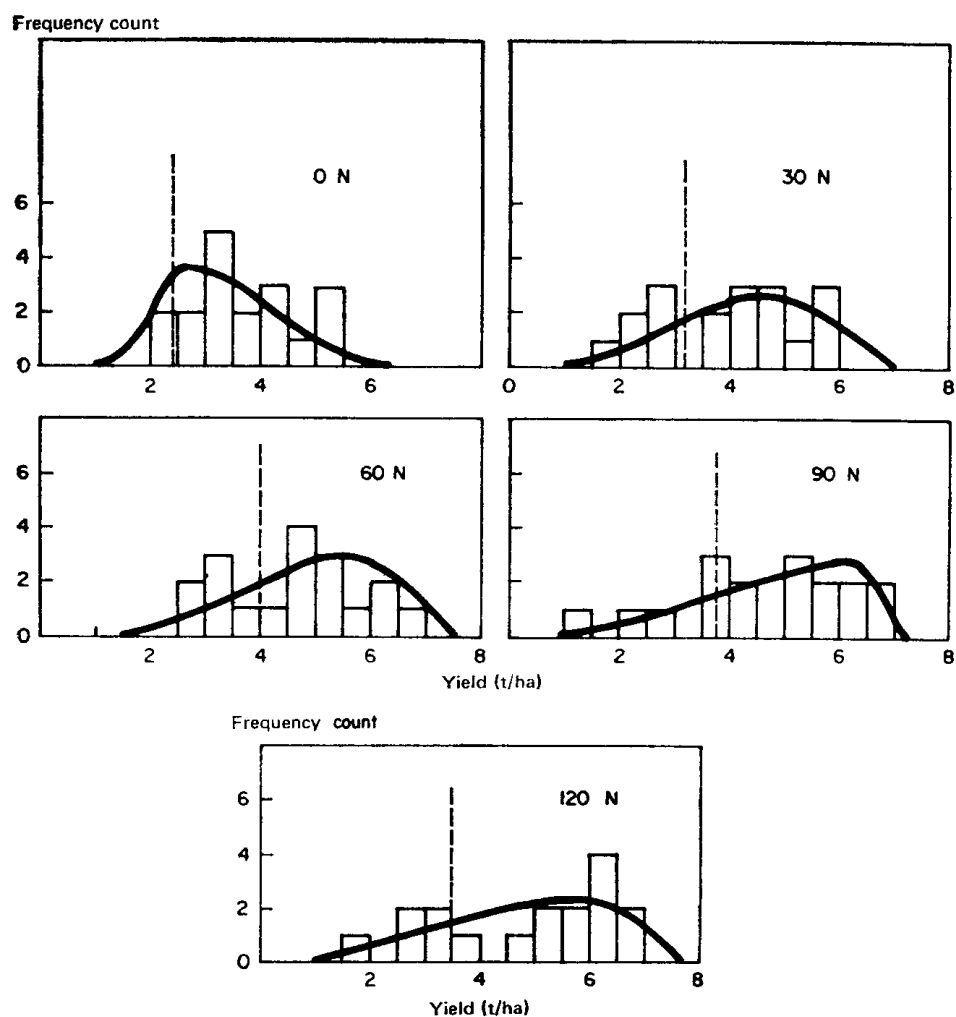


FIGURE 1: *Histograms and estimated frequency curves for IR8 produced at Maligaya Experiment Station with selected nitrogen levels (wet season).* [Data obtained from Agronomy Department, International Rice Research Institute, Los Baños, Philippines.]

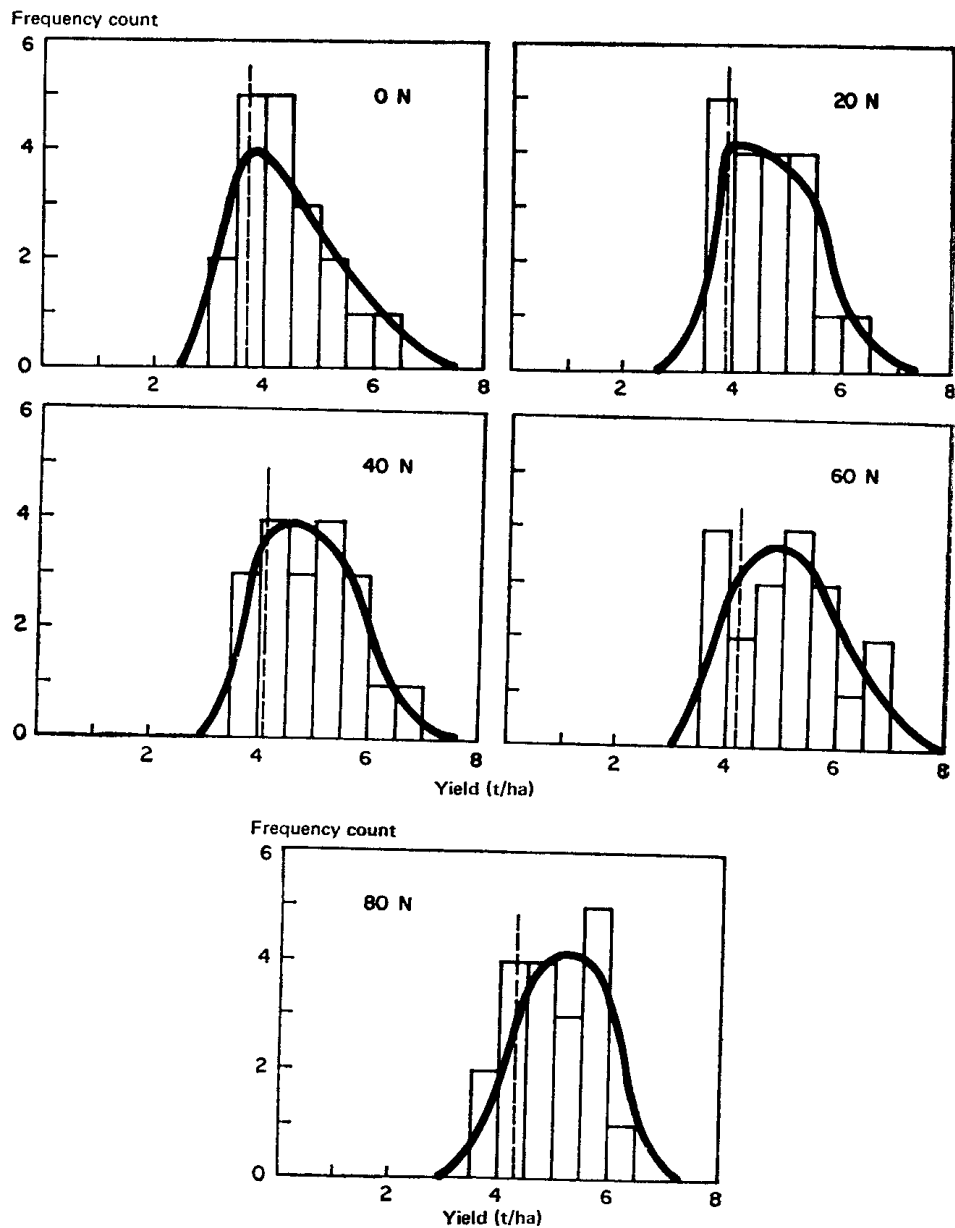


FIGURE 2: Histograms and estimated frequency curves for IR8 produced at IRRI with selected nitrogen levels (wet season). [Same source of data as figure 1.]

is one frequency distribution for each nitrogen level. This facilitates investigation of the relationship between nitrogen level and risk.

These graphs are useful for drawing preliminary conclusions about the effect that risk is likely to have on farmers' decisions. Dillon and Anderson [8] have summarized the "conventional wisdom" regarding the inhibiting effect that risk is expected to have on use of fertilizer and other "modern" inputs:

This wisdom runs somewhat as follows (overlooking the inconsistency of implying both profit and utility maximization): (1) traditional agriculture is efficient in a profit-maximizing sense; (2) development necessitates new techniques and inputs; (3) new techniques and inputs are viewed by farmers as risky; (4) farmers are risk averse; (5) risk is therefore an important impediment to development. [8, p. 31].

We can use the frequency curves in figures 1 and 2 to show that concern with risk will not necessarily inhibit the use of fertilizer; in fact, in some instances a farmer's special concern to avoid low income levels may result in an optimal nitrogen input that is even higher than the risk neutral optimum. To show this possibility, assume that a farmer's preferences are adequately represented by the "Safety-Fixed" rule introduced by Kataoka [11], applied by Turnovsky [21], named by Day, *et al.* [5] and related to lexicographic preferences and other models of risk aversion by Roumasset [19, chapter 2]. The Safety-Fixed rule is to maximize:

$$F_{\pi}^{-1}(\bar{\alpha})$$

where F_{π}^{-1} is the inverse of the cumulative frequency distribution of the variable π , and $\bar{\alpha}$ is the critical probability level. Assuming $\bar{\alpha} = .10$,³ table 1 provides the necessary information for finding the optimal nitrogen N for the frequency distributions estimated from both sets of data. Since $F_Y^{-1}(.10)$ is in terms of kg/ha of output, this had to be converted to profit (₱/ha). This was done based on the prices and costs⁴ given on the bottom of table 1; the results appear in column three.

³ $\bar{\alpha}$ is akin to the confidence level in statistical inference and depends on the consequences of loss. Due to the elaborate social institutions in the Philippines which spread risk such as the extended family and paternalistic landlord, it seems appropriate that $\bar{\alpha}$ be relatively large.

⁴ Estimates made by the staff of the Department of Agricultural Economics, International Rice Research Institute, Laguna, Philippines. The unit of currency in the Philippines is the peso (₱). One peso is roughly equivalent to US 15 cents.

TABLE 1

Risk of Fertilization based on Nitrogen Response Experiment

N	$F_Y^{-1}(.10)$	$F_{\pi(N)}^{-1}(.10)$	Expected value of $\pi(N)$
	(kg/ha)	(₱/ha)	(₱/ha)
Maligaya, Wet Season			
0	2 430	837	1 488
30	3 200	1 215	1 700
60	3 980	1 599	1 982
90	3 750	1 428	1 871
120	3 500	1 245	1 937
IRRI, Wet Season			
0	3 730	1 052	1 385
20	3 980	1 159	1 497
40	4 120	1 206	1 629
60	4 240	1 242	1 688
80	4 360	1 278	1 593

Source: Figures 1 and 2 and the following assumptions:

 $Y \equiv$ Yield of rough rice in kg/ha $\pi(N) \equiv P_Y Y - C - P_N N$ $P_Y =$ ₱.55 (per kg of rough rice) $N \equiv$ Nitrogen (in kg/ha) $P_N =$ ₱1.50 (per kg N) $C \equiv$ Fixed cost \equiv ₱500 at Maligaya wet season \equiv ₱1 000 at IRRI wet season

The risk neutral optima (*see* column 4) occur at 60 kg for both sets of data. The "Safety-Fixed" optima (*see* column 3) occur at 60 kg N for the Maligaya conditions and at 80 kg N for the IRRI data. The conclusion is that, using experimental data and the "Safety-Fixed" model of risk, we generate the prediction that concern for security will not tend to restrain farmers from using fertilizer; in fact, this type of risk-aversion may induce some farmers to use more fertilizer than the amount which maximizes expected profit.

The main problem with the experimental method is that the sources of variation in controlled experiments are quite different than on farmers' fields. Thus we cannot use the results just reported to explain actual farmer behaviour or as the basis of recommending optimal nitrogen use

for typical farm conditions. The evidence does suffice, however, to reject the *prima facie* conclusion that risk should and does inhibit the use of chemical inputs.

3 COMBINING EXPERIMENTAL PRODUCTION FUNCTIONS WITH FARM DATA ON CROP DAMAGES

The limitation of cross-section for estimating risk is that there is no satisfactory method of separating variability due to environmental changes from interfarm variations and measurement error. The problem with experimental data is that extensive control measures are used deliberately to reduce variation; thus the estimates of variability have limited generality for the farm level. The ideal would seem to be a combination of the two approaches. One method of synthesis is developed in this section.

The steps in the estimation procedure followed below are as follows. First estimate the no-damage production functions using experimental data (highly controlled conditions) after culling from the data those results which were obtained under conditions of substantial crop damage.

Next list the crop damages by type and stratify the recorded per cent damages according to the major damage types. Within each damage type stratify further according to severity, and calculate the mean per cent damage for each substratum. Now use the stratification scheme and the mean percentages to construct a matrix of possible states-of-the-world which includes the per cent damage and probability of occurrence for each state. If reliable and independent data is available on the probability of occurrence of any of the variables which define the state, e.g., data on solar radiation, that information can be exploited by making Bayesian adjustments of the prior probabilities. After making the adjustments, the probabilities form the basis of the frequency distributions over the random variable, per cent damage. The probabilities themselves can be used directly (the empirical distribution) or used to fit a smooth frequency function, e.g. by the method of moments.

Finally, if per cent damage is assumed to be independent of the production technique, as in the present study, the stochastic production function may be defined as the product of the no damage production function and unity minus the per cent damage. It is possible to modify the state-of-the-world matrix to allow for interdependencies of the damages and production inputs, but the data requirements for reliable estimates are severe. This entire procedure is explained in more detail in the subsections that follow.

3.1 THE NO-DAMAGE PRODUCTION FUNCTIONS

Barker *et al.* [3] have estimated annual production functions for the wet and dry seasons based on nitrogen response experiments on rice variety IR-8. The experiments were conducted at IRRI during the years

1966–71. For each production function, the solar radiation⁵ and the causes of any substantial damage were also recorded. To facilitate estimation of the no-damage production function, those functions corresponding to seasons with substantial recorded damage were dropped-out.

The production functions reported by Barker *et al.* were of the form:

$$\hat{Y} = a + bN - cN^2$$

where \hat{Y} is estimated yield per hectare and N is nitrogen applied per hectare. Solar radiation (SR) was not included as a regressor because preliminary attempts to do so did not yield theoretically meaningful results. In order to take at least a rough account of the effect of solar radiation, the remaining production functions were pooled by the level of solar radiation. Four levels of solar radiation were distinguished. Level *A* represents 22 000 gm-cal/cm²; *B*, 19 000–21 999 gm-cal/cm²; *C*, 16 000–18,999 gm-cal/cm²; and *D*, below 16 000 gm-cal/cm². The pooled regressions by solar radiation class⁶ are:

$$Y_A = 3\,000 + 47.4N - .138N^2; \quad \frac{dY_A}{dN} = 47.4 - .276N; \quad \frac{dY_A}{dN}(50) = 33.6$$

$$Y_B = 2\,500 + 43N - .179N^2; \quad \frac{dY_B}{dN} = 43 - .358N; \quad \frac{dY_B}{dN}(50) = 25.1$$

$$Y_C = 2\,000 + 21.6N - .138N^2; \quad \frac{dY_C}{dN} = 21.6 - .276N; \quad \frac{dY_C}{dN}(50) = 7.8$$

$$Y_D = 1\,750 + 21.6N - .179N^2; \quad \frac{dY_D}{dN} = 21.6 - .358N; \quad \frac{dY_D}{dN}(50) = 3.7$$

where the intercepts have been adjusted to be more appropriate for Biñan conditions and for the relatively low average values of insecticides and other inputs compared to IRRI conditions.⁷ The marginal product of nitrogen is also given and evaluated at the intermediate value of 50 kgN/ha to illustrate the relationship of the production functions to the level of solar radiation. Note the substantial decline in the marginal product of nitrogen as the amount of solar radiation gets lower.⁸

⁵ Following Montaña and Barker [16, 17], the measure of solar radiation used was gram-calories per square centimeter (gm-cal/cm²) during the last 45 days before harvest.

⁶ \hat{Y}_A was pooled from the dry season functions for 1966, 1968, 1969 and 1970; \hat{Y}_B from wet 1968 and dry 1971; \hat{Y}_C from wet 1966 and 1967. \hat{Y}_D was formulated by taking the lowest coefficients of N and N^2 from the other regressions. This gave a marginal product of nitrogen function consistent with that obtained from a Cobb-Douglas production function fit on nitrogen and solar radiation for all the data, pooled across all years and SR levels (see appendix A for details).

⁷ The dependence of the constant term on solar radiation may be seen in the Cobb-Douglas function of yield on nitrogen and solar radiation, which is presented in the appendix. This information was combined with the requirement that the expected production function (section 3.4) pass near the point of sample means (\bar{N}, \bar{Y}) . Changing the constant terms will not effect either the estimates of optimal nitrogen inputs or the risk graphs (figure 6 and 8).

⁸ This is consistent with the findings of Montaña [15] and Montaña and Barker [16, 17].

3.2 INCORPORATING FARM-LEVEL INFORMATION ON DAMAGES: THE BIÑAN SURVEY

A direct and efficient way to gather information about the amount of crop damage corresponding to various causes is to ask farmers. This method is especially appealing if one's research objective is to explain actual behaviour which is based on subjective probabilities. For the two farm areas studied, two methods of eliciting farmer's assessments of the extent of damage due to various causes were employed. The sample of farmers used for the first study was a subsample of a group of farmers in Laguna province previously surveyed by IRRI,⁹ namely the sample farmers in the municipality of Biñan. The farmers were asked to estimate the amount of damage to their rice crop from various causes for the three previous wet seasons.¹⁰ The answers were converted to percentages of expected yield lost due to the various causes. These per cent damage figures are reported in table 2 for each of the thirty-three farmers interviewed, in order of severity. The third source of damage is a residual category, sometimes representing more than one cause. The sources of damage are given in parentheses.¹¹

The next step is to use this sample information about damages as the basis of estimating a joint frequency distribution of damages. Since working with a large number of damage variables becomes too cumbersome, the causes of damages were reclassified according to the five categories given in table 3. The fifth category, "others", was ignored due to its low frequency of occurrence and small per cent damages when it did occur.

This leaves four damage variables which could take on values from 0-100 per cent. Instead of trying to estimate a continuous joint frequency distribution on the basis of sample observations, the damage variables were redefined in terms of discrete intervals. It will be seen that this facilitates both the estimation of the frequency functions and presentation of the results.¹² In order to define the discrete values which the damage variables were allowed to take on, reported damages were classified

⁹ The I.R.R.I. survey (*see e.g.* Barker and Cordova [2]) was based on a random sample of roughly 100 farms in the municipalities of Calamba, Cabugao, and Biñan. Biñan was chosen because the average yield per hectare was low relative to the other municipalities, and it was thought that this would provide a richer base for a study on risk.

¹⁰ They were also asked about the two previous dry seasons, but this data is not reported in what follows due to the small number of farmers who planted in the dry season.

¹¹ Tungro is a virus disease transmitted from one rice plant to another by the green leafhopper. A stemborer is an insect that lives in the stem or the leaf sheath and feeds on the rice plant.

¹² To the author's knowledge no method has been developed for estimating a continuous joint frequency distribution of general form based on the kind of sample data presented above. While the stratification used here has the disadvantage of losing the full detail of the sample information, it has the advantage of offsetting some of the measurement error, in addition to simplifying the estimation of frequency distributions.

TABLE 2
Per cent Damage for Farms in Biñan, Laguna, 1969-71, Wet Season

Farmer Number	1971			1970			1969		
	Primary Damage	Secondary Damage	Other Damage	Primary Damage	Secondary Damage	Other Damage	Primary Damage	Secondary Damage	Other Damage
1..	9.2 (H)	5.1 (W)	13.0 (S, R)	2.5 (W)	1.3 (S)	0	0	0	0
2	60.0 (H)	28.0 (S)	0	20.0 (T)	0	0	33.0 (O)	0	0
3	78.0 (H)	0	0	0	0	0	17.0 (O)	0	0
4	66.0 (H)	11.0 (RT)	0	37.0 (T)	0	0	14.0 (S)	8.5 (RT)	0
5	71.0 (H)	17.0 (S)	7.1 (RT, BD)	17.0 (T)	0	0	7.9 (T)	2.0 (RT)	0
6	12.0 (H)	4.0 (S)	4.0 (RT, BD)	16.0 (T)	2.8 (RT)	1.6 (BD)	34.0 (T)	5.7 (RT)	0
7	56.0 (H)	3.4 (RT)	0	14.0 (T)	9.0 (RT)	0	14.0 (RT)	7.0 (S)	0
8	98.0 (H)	0	0	32.0 (T)	6.8 (S)	0	32.0 (R)	0	0
9	66.0 (H)	21.0 (S)	8.8 (RT)	12.0 (T)	8.8 (S)	0	0	0	0
10	27.0 (H)	1.9 (S)	1.0 (RT)	1.7 (RT)	4.4 (BD)	0	3.4 (S)	9.9 (RT)	4.4 (BD)
11	66.0 (H)	0	0	33.0 (T)	2.5 (BD)	0	33.0 (W)	4.0 (RT)	2.5 (BD)
12	37.0 (H)	0	0	12.5 (T)	3.2 (S)	0	7.7 (RT)	0	0
13	76.0 (H)	0	0	41.0 (T)	0	0	10.0 (O)	0	0
14	56.0 (H)	18.0 (S)	0	8.5 (T)	5.7 (S)	0	0	0	0
15	56.0 (H)	0	0	16.0 (T)	0	0	5.6 (O)	0	0
16	84.0 (H)	0	0	14.0 (S)	5.5 (H)	0	5.5 (S)	0	0
17	39.0 (H)	10.0 (S)	0	18.0 (S)	4.4 (W)	0	0	0	0
18	77.0 (H)	0	0	20.0 (T)	7.7 (RT)	2.7 (S)	0	0	0
19	88.0 (H)	5.5 (RT)	0	11.0 (T)	7.0 (RT)	4.0 (S)	35.0 (T)	7.0 (RT)	0
20	69.0 (H)	8.5 (W)	0	20.0 (W)	0	0	18.0 (S)	0	0
21	0	0	0	15.0 (W)	7.5 (RT)	0	20.0 (RT)	13.0 (S)	0
22	13.0 (H)	9.0 (S)	2.6 (RT)	33.0 (T)	22.0 (S)	2.7 (RT)	46.0 (O)	3.8 (RT)	0
23	55.0 (H)	0	0	3.8 (RT)	0	0	40.0 (T)	0	0
24	53.0 (H)	0	0	8.3 (W)	0	0	2.9 (S)	1.5 (RT)	0
25	91.0 (H)	0	0	10.0 (T)	10.0 (S)	0	20.0 (O)	0	0
26	72.0 (H)	3.1 (RT)	0	35.0 (T)	2.5 (H)	0	0	0	0
27	81.0 (H)	0	0	18.0 (T)	7.0 (RT)	0	3.8 (RT)	3.8 (S)	0
28	33.0 (H)	0	0	16.0 (T)	0	5.2 (S)	2.6 (RT)	0	0
29	69.0 (H)	0	0	12.0 (T)	3.0 (RT)	0	0	0	0
30	67.0 (H)	0	0	11.0 (W)	5.5 (S)	0	2.6 (RT)	0	0
31	80.0 (H)	0	0	52.0 (T)	0	0	0	0	0
32	70.0 (H)	15.0 (H)	0	36.0 (O)	11.0 (S)	7.3 (T, RT)	12.0 (O)	0	0
33	61.0 (H)	0	0	4.0 (S)	0	0	11.0 (S)	0	0

Notation: T—Typhoon; R—Rain; W—Wind; RT—Rats; BD—Birds; S—Stem-borers; H—Tungro; O—Other.

TABLE 3

Frequency of Damage by Cause, Biñan, Laguna, 1969-71, Wet Season

Damage Cause	Frequency
Weather Damage (Typhoon, Rain and Wind) ..	35
"Hopper" Damage (Especially Tungro) ..	33
Other Insects (Stemborer)	29
Other Pests (Rats and Birds)	28
Others	8

TABLE 4

Possible Values for the Four Damage Variables, Wet Season, Biñan

Damage Variables (range of damage)	Mean per cent Damage
<i>T</i> : Weather Damage (Typhoon, Rain and Wind)—	
<i>N</i> (0 per cent)	0 $\equiv T_N$
<i>L</i> (1 - 20 per cent)	12.1 $\equiv T_L$
<i>H</i> (21 - 100 per cent)	36.7 $\equiv T_H$
<i>H</i> : "Hopper" Damage (Especially Tungro)—	
<i>N</i> (0 per cent)	0 $\equiv H_N$
<i>L</i> (1 - 50 per cent)	6.6 $\equiv H_L$
<i>H</i> (51 - 100 per cent)	70.9 $\equiv H_H$
<i>S</i> : Other Insects (Stemborer)—	
<i>N</i> (0 per cent)	0 $\equiv S_N$
<i>L</i> (1 - 8 per cent)	3.7 $\equiv S_L$
<i>H</i> (9 - 100 per cent)	9.3 $\equiv S_H$
<i>R</i> : Other Pests (Rats and Birds)—	
<i>N</i> (0 per cent)	0 $\equiv R_N$
<i>L</i> (.5 - 4 per cent)	2.4 $\equiv R_L$
<i>H</i> (5 - 100 per cent)	7.6 $\equiv R_H$

according to per cent loss. This was done by ranking the per cent damages separately for each of the four classes and partitioning them into three groups. The mean of each group was then calculated and the results are reported in table 4.

Table 4 now becomes the basis of defining the discrete values that the damage variables are allowed to take on. Define damage variable d_a as the mean per cent damage corresponding to the j th partition for the i th damage variable, $d = T, H, S$, or R and $a = N, L$, or H . Now define damage state-of-the-world i as the vector $[T_i, H_i, S_i, R_i]$. Since each

of the four damage variables can take on three values each, there are $3^4 = 81$ damage states; that is, $i = 1$ to 81. Thirty-three of these states were actually observed in the Biñan samples. These are listed in the second column of table 5.

It was assumed that the per cent damages interact in a multiplicative fashion; that is, the per cent remaining, U_i , corresponding to damage state (T_i, H_i, S_i, R_i) , is defined as $U_i = (1 - T_i)(1 - H_i)(1 - S_i)(1 - R_i)$. The values of U_i were calculated for each damage state and appear in column three.¹³

For each vector of damages reported by a farmer for a given season, the solar radiation level was also calculated based on recorded planting data and on solar radiation recorded at nearby IRRI.¹⁴ A state-of-the-world is now defined by the four damage variables and the solar radiation level, SR .

It was also assumed that the per cent remaining, U_i , was independent of the level of nitrogen.¹⁵ This assumption allows us to define a production function corresponding to each state-of-the-world; that is, the production function for state ij $(T_i, H_i, S_i, R_i, SR_j)$ is defined as:

$$(1 - T_i)(1 - H_i)(1 - S_i)(1 - R_i)[Y_j(N)] \equiv U_i Y_j(N)$$

where $Y_j(N)$ is the "no-damage production function" for the j th solar radiation level.

The data from the Biñan survey was used to calculate p_{ij} 's where p_{ij} stands for the sample frequency of the i th damage state and the j th solar radiation level. These values are also reported in table 5.

The sample frequency of the j th solar radiation level is

$$p_j = \sum_i p_{ij}.$$

Since more reliable estimates of the probabilities of the four solar radiation levels were available from IRRI [5], Bayesian adjustments of the prior probabilities (the p_{ij} 's) were made as follows.¹⁶ For each farmer in each of the wet seasons from 1969-71, the probabilities that solar radiation would be at level A , B , C , or D were found according to the

¹³ The results of this study are not sensitive to this method of estimating the U_i 's. In fact the empirical distribution, based on table 5 and the prior probabilities (p_i 's), is almost identical to the empirical distribution of actual damages observed.

¹⁴ For details see Roumasset [19, pp. 112 and 115].

¹⁵ This assumption is likely to be misleading if there is evidence to suggest that the conditional expectation of U given N depends on N . For the present study this possibility was rejected at the .01 confidence level [19, p. 116]. One way to relax this assumption is by including levels of nitrogen in the state-of-the-world matrix. However in order to get reliable estimates of the per cent damages and the probabilities on such a fine grid, one would have to conduct extensive (and long term) experiments on farmers' fields.

¹⁶ For an exposition on the calculation of posterior probabilities and Bayesian decision-making, see e.g., Halter and Dean [10].

TABLE 5
Damage Matrix, Biñan, Wet Season

Damage State Index (i)	Damage State				per cent Remaining (U_i)	Solar radiation level (j)							
						22 000 and Above		19 000-21 999		16 000-18 999		Below 16 000	
	Typhoon	Tungro	Stemborer	Rats		P_{iA}	P'_{iA}	P_{iB}	P'_{iB}	P_{iC}	P'_{iC}	P_{iD}	P'_{iD}
1 ..	N	N	N	N	1.00	..	..	.023	.028	.023	.037	.012	.008
2 ..	N	N	N	L	.98	..	..	.012	.014	.045	.073	..	..
4 ..	N	N	L	N	.96	..	..	..	..	.023	.037	..	..
5 ..	N	N	L	L	.94	..	..	.023	.028	.012	.020	..	..
6 ..	N	N	L	H	.87	..	..	.012	.014	..	..	..	..
7 ..	N	N	H	N	.92	..	..	.012	.014	..	..	.012	.008
9 ..	N	N	H	H	.84	..	..	.012	.014	.012	0.20	..	..
10 ..	N	L	N	N	.83	..	..	..	..	..	..	.023	.014
13 ..	N	L	L	N	.77	..	..	..	..	..	..	.012	.008
14 ..	N	L	L	L	.78	..	..	..	..	.012	.020	.012	.008
16 ..	N	L	H	N	.77	..	..	..	..	..	..	.023	.014
17 ..	N	L	H	L	.75	..	..	..	..	.012	.020	..	..
19 ..	N	H	N	N	.29	..	.007	..	..	.012	.020	.160	.103
20 ..	N	H	N	L	.28	..	..	..	..	..	..	.034	.022
23 ..	N	H	L	L	.27	..	..	..	..	..	..	.012	.008
25 ..	N	H	H	N	.27	..	..	..	..	..	..	.023	.014
26 ..	N	H	H	L	.26	..	..	..	..	..	..	.012	.008
27 ..	N	H	H	H	.24	..	..	..	..	..	..	.012	.008
28 ..	L	N	N	N	.88	..	..	..	..	.034	.056	.023	.014
29 ..	L	N	N	L	.86	..	..	.012	.014	.012	.020	.012	.008
30 ..	L	N	N	H	.80	..	..	..	..	.012	.020	.023	.014
31 ..	L	N	L	N	.85	..	..	..	..	.023	.037	.023	.014
32 ..	L	N	L	L	.83	..	..	..	..	.012	.020	.012	.008
33 ..	L	N	L	H	.77	..	..	..	..	..	..	.012	.008
34 ..	L	N	H	N	.81	..	..	..	..	..	..	.012	.008
43 ..	L	L	H	N	.68	..	..	..	..	..	..	.012	.008
46 ..	L	H	N	N	.26	..	..	..	..	..	..	.012	.008
55 ..	H	N	N	N	.63	..	.003	.023	.028	..	..	.055	.035
56 ..	H	N	N	L	.62	..	..	..	..	.012	.020	.012	.008
57 ..	H	N	N	H	.57	..	..	.002	.014	.012	.020	..	..
58 ..	H	N	L	N	.61	..	..	..	..	..	..	.012	.008
62 ..	H	N	H	N	.57	..	..	..	..	..	..	.012	.008
64 ..	H	L	N	N	.62	..	..	..	..	..	..	.012	.008
$\sum_i P'_{ij} \equiv P'_j$	..	..	..	..	..	..	.010	..	.168	..	.440	..	.380

farmer's harvest date in the particular season on the basis of the relevant tables in [15]. This gives ninety-one separate estimates of probability distributions corresponding to different harvest dates. For each solar radiation level the average of the probabilities was then calculated.¹⁷ The results were:

$$p_A = .01, p_B = .17, p_C = .44, p_D = .38$$

$p_{ij} \equiv p_{ij}(p_j)/\sum_i p_{ij}$ is then the posterior probability for the i th damage state and the j th solar radiation level.¹⁸

¹⁷ There are not ninety-nine observations since some of the thirty-three sample farmers were not included in the IRRI survey for the entire three-season period.

¹⁸ Since there were no sample observations for solar radiation level A, the posterior probability, $p_A = .01$, was distributed between the two most frequent damage states.

3.3 THE EXPECTED PRODUCTION FUNCTION

Now we have a stochastic production function,

$$U_i Y_j(N)$$

and an estimate of its probability of occurrence, p'_{ij} , for the i th damage state and the j th solar radiation level. The "expected production function" is now defined as

$$Y_e(N) \equiv (\sum_j \sum_i p'_{ij}) U_i Y_j(N).$$

For the data discussed above,

$$Y_e(N) = 1\,470 + 18.77N - .115N^2$$

This function meets the following crude tests of being a reasonable approximation of the situation in Biñan. Maximum expected production according to the function is obtained by applying 81 kgN/ha which conforms to the experience at IRRI regarding maximum yields under wet season conditions. The marginal product of nitrogen is low compared to that under experimental conditions, reflecting the "averaging-in" of the unfavourable states. If the function is evaluated at the mean fertilizer level in Biñan, the corresponding yield is close to the mean yield in Biñan.

3.4 RISK AS A FUNCTION OF NITROGEN LEVEL

The first steps toward estimating the risk of applying nitrogen was to fit frequency functions to the sample observations of the U_i 's for each level of solar radiation. This was done using the method of moments. Following Day [8], the distributions were assumed to conform to the Pearson type one function of limited range. The conventional method of moments was supplemented by additional constraints to incorporate *a priori* information about the population of possible U_i 's. First, the lower and upper limits of the density functions were not allowed to be less than zero per cent or greater than 100 per cent respectively. Second, the estimated density functions were not allowed to have singular points other than either zero or 100 per cent. The results for the Biñan data are shown as figures 3-5. Experimentation with alternative methods of fitting frequency functions, particularly the use of the empirical distribution or of the "compromise" method of fit illustrated in section 2.2, suggests that the results reported below are insensitive to the method of fit¹⁹.

In general, the riskiness of a given technique cannot be defined independently of individual preferences [19]. However, de Janvry [6] has defined the risk of applying fertilizer as the probability that the internal rate-of-return to fertilization is less than or equal to zero. This definition is useful for the purpose at hand and is adopted for the discussion that

¹⁹ For example, the frequency curves used in [19] were fit by hand. There was little effect on either the estimated optimum nitrogen requirements or the risk functions.

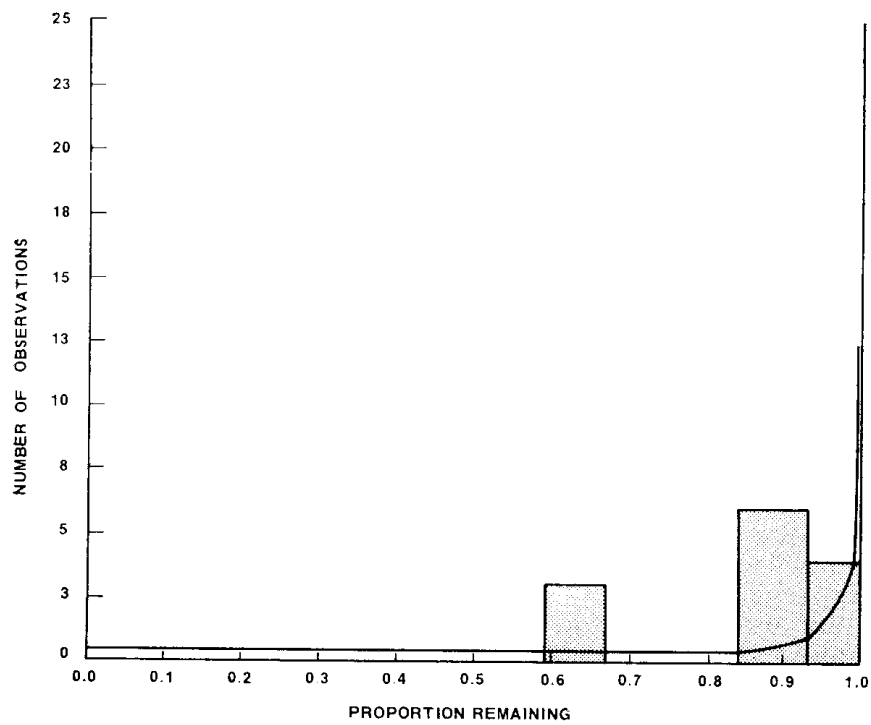


FIGURE 3: *Histogram and Density Functions for Damage (per cent) in Biñan, 1969-71 Wet Seasons, for Solar Radiation Level B*

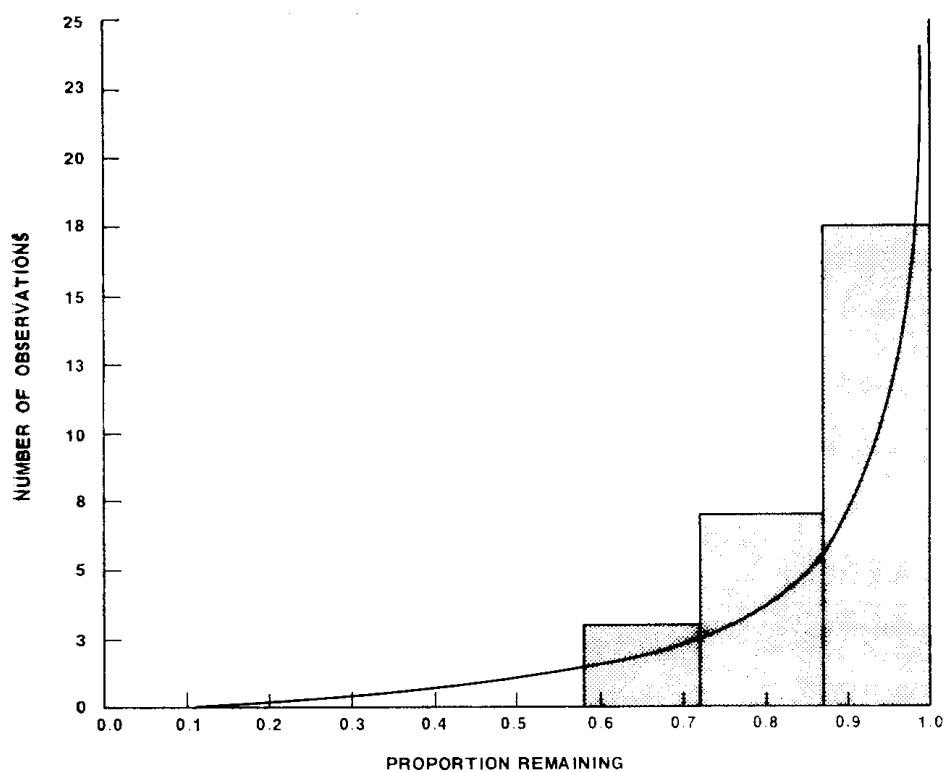


FIGURE 4: *Histogram and Density Functions for Damage (per cent) in Biñan, 1969-71 Wet Seasons, for Solar Radiation Level C*

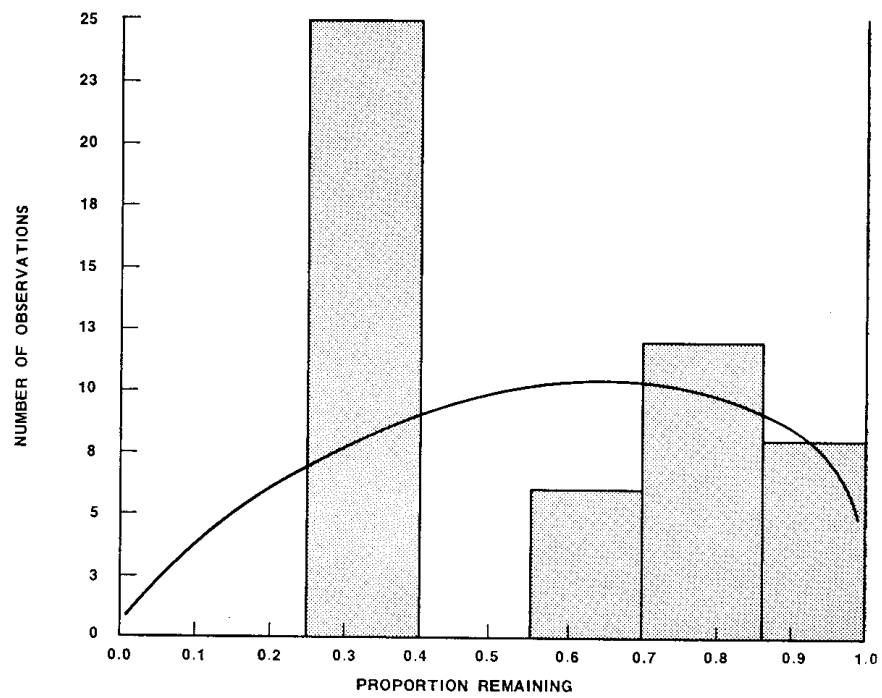


FIGURE 5: *Histogram and Density Functions for Damage (per cent) in Biñan, 1969-71 Wet Seasons, for Solar Radiation Level D*

follows. First define U_c^j as the "critical per cent remaining" for which the return to fertilizer is zero, i.e.,

$$U_c^j P_R [f_j(N) - f_j(0)] - P_N N = 0$$

$$U_c^j = \frac{P_N N}{P_R} [f_j(N) - f_j(0)]^{-1}$$

$j = A \text{ to } D$

where the price of rice (per kilo), P_R , and the price of nitrogen (per kilo), P_N , are based on actual prices received and paid by Biñan farmers, and where f_j is the no-damage production function for the j th level of solar radiation.²⁰ For each $U_c^j(N)$ find the corresponding value of the cumulative distribution of damages, $F[U_c^j(N)]$ where $F(U_i)$ is the estimated density function of U_i for the j th solar radiation level. The risk of a negative return is just the probability that the per cent remaining is less than the critical level, i.e.

$$R(N) = 1 - \sum_{j=A}^D F[U_c^j(N)]$$

This function is graphed in figure 6 and is distinguished by the label, Biñan 1. Note that risk does rise slightly with N but even at 70 kgN/ha only attains the level .079.

This graph is valid for the majority of Biñan farmers, whose landlords would advance the cost of fertilizer at a zero interest rate. A few farmers, however, were faced with a borrowing constraint from the landlord (sometimes the constraint was that nothing could be borrowed), and the best alternate source of loanable funds was the moneylender, at average rates of close to 100 per cent per season.²¹ Since the effect of interest on funds borrowed to purchase fertilizer is to increase the effective price of fertilizer, the critical per cent now becomes:

$$U_c^j = \frac{P_N(1 + 1.00)N}{P_R} [f_j(N) - f_j(0)]^{-1}$$

Risk with interest rate equal to 100 per cent (equivalent to doubling the price of nitrogen or halving the price of rice) is also graphed in figure 6 (Biñan 2). Also indicated in figure 6 are the optimal nitrogen levels, N^* , for both interest rates under the assumption of risk neutrality. These were calculated simply by maximizing expected profits, based on Y_e as derived above, and on the average Biñan prices for fertilizer and rice. While the optimum nitrogen level dropped only 18 kg. N when the interest rate assumption was changed from zero to 100 per cent, the risk increased substantially. For example, the risk of a negative rate of return to fertilization at 50 kg N is .14 for the 100-per cent-interest-rate case while it is less than .05 for the case where money can be borrowed from the landlord at a zero interest rate.

²⁰ For the 1969, 1970, 1971 wet seasons, nitrogen, purchased in the form of urea, cost ₱1.30/kg and price received for rice averaged ₱.50/kg, both adjusted to 1971 price levels.

²¹ The most common types of loans required one cavan of rice for every ₱12.00 borrowed, at a time when the price of rice was about ₱24.00 per cavan.

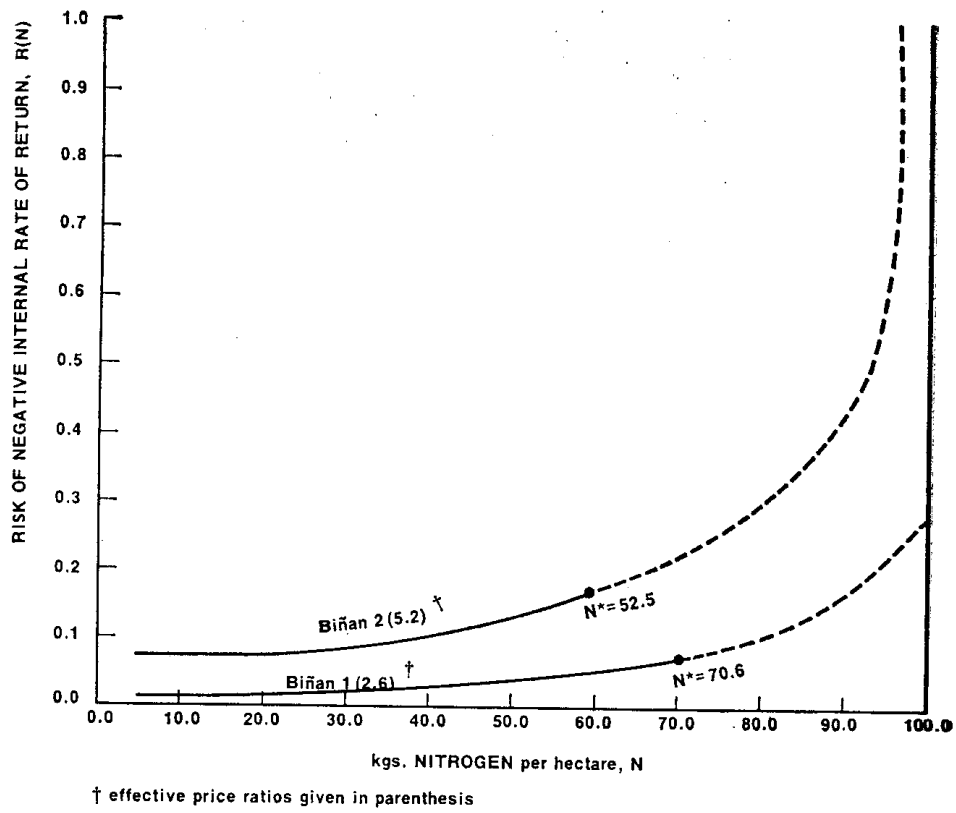


FIGURE 6: *Risk of Fertilization, Biñan*

It is not the purpose of this report to estimate the effects of risk on decision-making. Nonetheless the relationship of risk to nitrogen input shown here casts doubt on the hypothesis that risk inhibits the use of artificial fertilizer. Risk increases only very slowly with N , in the range $N \leq N^*$, and, for the majority of farmers, would seem to be quite tolerable given the minor consequences of loss (losing part of a ₱100/ha investment in fertilizer) and the substantial assets and institutional cushions against loss for Biñan tenant farmers [19, ch. 6].

3.5 RISK IN BICOL AND AN ALTERNATIVE APPROACH

Of the major rice growing regions of the Philippines, the Bicol region was outstanding both for its high adoption of high yielding varieties and low use of fertilizer compared to other regions.²² This situation appeared anomalous since the new high yielding rice varieties were bred primarily for their high response to nitrogen fertilizer. For this reason the Bicol region was chosen as a second study area to see if risk could explain the low rates of fertilization.

The barrios most intensively studied were Marayag and Hindi in the province of Albay.²³ While the rice land in both barrios is irrigated, the pay-off to fertilization is low in Hindi due to the light sandy soil and the terraced landscape wherein the irrigation water runs from one paddy to the next (carrying some of the soil nutrients along with it). Of the three barrios studied, Hindi had by far the lowest estimated returns to fertilization and the highest risk. Not surprisingly no fertilizer was applied by any of the Hindi sample farmers during the survey. Marayag is typical among the rice growing villages located in the rich valley carved out by the Bicol River. The land is relatively flat, not terraced, and the soil type is clay loam. The mean amount of nitrogen per hectare in Marayag is 30 kg/ha still only slightly more than half of the 58.5 kg N/ha reported average for Biñan.

One of the problems with the method used in assessing risk in Biñan is that it is fairly painstaking to obtain even a small number of observations and that it is not feasible to get estimates for crop damage in more than three previous seasons. The technique used in the Bicol survey was an attempt to identify a consensus among a group of leading farmers on the major sources of damage, the extent of damage associated with these sources, and their likelihood.²⁴ These inquiries were made in a separate interview, completed after the survey of rice production techniques, wherein individual farmers were asked about the use of

²² Integrated agricultural survey, Bureau of Agricultural Economics, Department of Agriculture and Natural Resources, Philippines, 1970. See also [19, p. 14].

²³ The pseudonyms "Rawis" and "Francia" were used respectively for "Marayag" and "Hindi" in [19].

²⁴ This method seems especially appropriate for groups of Filipino farmers since they are famous among social anthropologists for their ability to formulate a group consensus. In fact, there is a Tagalog word, *pakikisama*, which refers to the practice of yielding to the will of the majority so as to make the group decision unanimous [13, p. 9].

inputs, yields, sharing system, cost of credit and other factors that were likely to influence their decisions. Individuals were chosen from among the farmers interviewed, primarily on the basis of their understanding of problems that effect rice yields.

Before turning to the estimation of damages, the derivation of the no-damage production functions needs to be explained. Instead of using production functions for each solar radiation level, a weighted average of the four "no-damage production functions" used above was found for each barrio. The weights were calculated by:

- (1) finding the average number of rainy days for the 45-day period preceding the average harvest date for the same farmers in the barrio;
- (2) finding the closest harvest data in Laguna with the same number of rainy days preceding; and
- (3) finding the probability distribution of solar radiation for that harvest date [15].

The intercepts of the functions were determined by farmer consensus (e.g., "How many cavans can you get per hectare without using fertilizer, if damage is minimal?"). In addition, N in the Hindi equation was replaced by efficiency units of nitrogen, $N^* = .8N$, to roughly account for the loss of fertilizer due to leaching and paddy-to-paddy irrigation in Hindi. The resulting functions were:

$$\text{Marayag: } Y^M = 1\,760 + 26.5N - .151N^2$$

$$\text{Hindi: } Y^H = 1\,540 + 20.2N - .128N^2$$

The farmer groups interviewed were able to list the major causes of damage of their rice crop and to come to rough agreement regarding the number of seasons out of five that the damage from that cause would be minimal, light, or heavy and roughly how many cavans of rice per hectare would be lost if damage was heavy or light. When answers were given in terms of ranges (e.g., "1 to 2 years", or "fifteen to twenty cavans"), the midpoint of the range was recorded. The major problems, as in Biñan, were typhoon, tungro, and stemborer, but were somewhat more serious, especially the threat of typhoon. Classification of the causes of damage was altered slightly, with "others" representing weather, disease, and pest problems not specifically mentioned. The expected per cent damages for Marayag and Hindi turned out to be similar and were pooled. The results are shown in table 6.

Assuming independence of the causes of damage, the probabilities of the possible states are given in table 7 along with the percentages remaining after damage. The latter were used to estimate the density function of per cent damages by the modified method of moments described above. The results are illustrated in figure 7.²⁵

²⁵ The independence assumption is surely incorrect but is of little importance for the level of accuracy obtainable by this rough method of reporting crop damages. As a check, the probabilities were adjusted assuming a high correlation of the different types of insect damage. The effect on the results reported here and in [19] was negligible.

TABLE 6

Expected Damages for Two Barrios in Bicol, Marayag and Hindi, for Major Causes of Damage at Different Levels

Damage Type				Level	Per cent Damage	Probability
Typhoon (<i>T</i>)	..	..	..	None	0	25
				Light	30	60
				Heavy	80	15
Tungro and Damage (<i>H</i>)	Other	..	Hopper ..	None	0	50
				Light	20	25
				Heavy	80	25
Stemborer (<i>S</i>)	..	..	..	None	0	45
				Light	20	40
				Heavy	40	15
Others (<i>O</i>)	..	..	..	None	0	40
				Some	30	60

TABLE 7

Wet Season Damage Matrix, Marayag and Hindi

Damage State	Typhoon	Hoppers	Stem-borers	Others	p_i	U_i
1	<i>N</i>	<i>N</i>	<i>N</i>	<i>N</i>	.0025	1.0
2	<i>N</i>	<i>N</i>	<i>N</i>	<i>S</i>	.0338	.7
3	<i>N</i>	<i>N</i>	<i>L</i>	<i>N</i>	.0300	.8
4	<i>N</i>	<i>N</i>	<i>L</i>	<i>S</i>	.0200	.56
5	<i>N</i>	<i>N</i>	<i>H</i>	<i>N</i>	.0075	.6
6	<i>N</i>	<i>N</i>	<i>H</i>	<i>S</i>	.0113	.42
7	<i>N</i>	<i>L</i>	<i>N</i>	<i>N</i>	.0113	.8
8	<i>N</i>	<i>L</i>	<i>N</i>	<i>S</i>	.0169	.56
9	<i>N</i>	<i>L</i>	<i>L</i>	<i>N</i>	.0100	.64
10	<i>N</i>	<i>L</i>	<i>L</i>	<i>S</i>	.0150	.448
11	<i>N</i>	<i>L</i>	<i>H</i>	<i>N</i>	.0038	.48
12	<i>N</i>	<i>L</i>	<i>H</i>	<i>S</i>	.0056	.336
13	<i>N</i>	<i>H</i>	<i>N</i>	<i>N</i>	.0113	.2
14	<i>N</i>	<i>H</i>	<i>N</i>	<i>S</i>	.0169	.14
15	<i>N</i>	<i>H</i>	<i>L</i>	<i>N</i>	.0100	.16
16	<i>N</i>	<i>H</i>	<i>L</i>	<i>S</i>	.0150	.112
17	<i>N</i>	<i>H</i>	<i>H</i>	<i>N</i>	.0038	.12
18	<i>N</i>	<i>H</i>	<i>H</i>	<i>S</i>	.0056	.84
19	<i>L</i>	<i>N</i>	<i>N</i>	<i>N</i>	.0540	.7

Table 7—continued

Damage State	Typhoon	Hoppers	Stem-borers	Others	p_i	U_i
20	<i>L</i>	<i>N</i>	<i>N</i>	<i>S</i>	·0810	·49
21	<i>L</i>	<i>N</i>	<i>L</i>	<i>N</i>	·0480	·56
22	<i>L</i>	<i>N</i>	<i>L</i>	<i>S</i>	·0720	·392
23	<i>L</i>	<i>N</i>	<i>H</i>	<i>N</i>	·0180	·42
24	<i>L</i>	<i>N</i>	<i>H</i>	<i>S</i>	·0271	·252
25	<i>L</i>	<i>L</i>	<i>N</i>	<i>N</i>	·0271	·56
26	<i>L</i>	<i>L</i>	<i>N</i>	<i>S</i>	·0406	·392
27	<i>L</i>	<i>L</i>	<i>L</i>	<i>N</i>	·0240	·448
28	<i>L</i>	<i>L</i>	<i>L</i>	<i>S</i>	·0360	·3136
29	<i>L</i>	<i>L</i>	<i>H</i>	<i>N</i>	·0090	·336
30	<i>L</i>	<i>L</i>	<i>H</i>	<i>S</i>	·0135	·2352
31	<i>L</i>	<i>H</i>	<i>N</i>	<i>N</i>	·0271	·14
32	<i>L</i>	<i>H</i>	<i>N</i>	<i>S</i>	·0405	·98
33	<i>L</i>	<i>H</i>	<i>L</i>	<i>N</i>	·0240	·112
34	<i>L</i>	<i>H</i>	<i>L</i>	<i>S</i>	·0360	·0784
35	<i>L</i>	<i>H</i>	<i>H</i>	<i>N</i>	·0090	·84
36	<i>L</i>	<i>H</i>	<i>H</i>	<i>S</i>	·0135	·588
37	<i>H</i>	<i>N</i>	<i>N</i>	<i>N</i>	·0135	·2
38	<i>H</i>	<i>N</i>	<i>N</i>	<i>S</i>	·0202	·14
39	<i>H</i>	<i>N</i>	<i>L</i>	<i>N</i>	·0120	·16
40	<i>H</i>	<i>N</i>	<i>L</i>	<i>S</i>	·0180	·112
41	<i>H</i>	<i>N</i>	<i>H</i>	<i>N</i>	·0045	·12
42	<i>H</i>	<i>N</i>	<i>H</i>	<i>S</i>	·0068	·084
43	<i>H</i>	<i>L</i>	<i>N</i>	<i>N</i>	·0068	·16
44	<i>H</i>	<i>L</i>	<i>N</i>	<i>S</i>	·0101	·112
45	<i>H</i>	<i>L</i>	<i>L</i>	<i>N</i>	·0060	·128
46	<i>H</i>	<i>L</i>	<i>L</i>	<i>S</i>	·0090	·0896
47	<i>H</i>	<i>L</i>	<i>H</i>	<i>N</i>	·0023	·096
48	<i>H</i>	<i>L</i>	<i>H</i>	<i>S</i>	·0034	·0672
49	<i>H</i>	<i>H</i>	<i>N</i>	<i>N</i>	·0068	·04
50	<i>H</i>	<i>H</i>	<i>N</i>	<i>S</i>	·0107	·028
51	<i>H</i>	<i>H</i>	<i>L</i>	<i>N</i>	·0060	·032
52	<i>H</i>	<i>H</i>	<i>L</i>	<i>S</i>	·0090	·0224
53	<i>H</i>	<i>H</i>	<i>H</i>	<i>N</i>	·0023	·024
54	<i>H</i>	<i>H</i>	<i>H</i>	<i>S</i>	·0034	·168

The risk of a negative rate of return can now be defined as:

$$R(N) = 1 - F[U_c(N)]$$

where $F(U_i)$ is the cumulative frequency function of percent damages and

$$U_c(N) = \frac{P_N^* \cdot N}{P^*} [(f(N) - f(0))^{-1}]$$

where $f(N)$ is the no-damage production function for the relevant barrio.

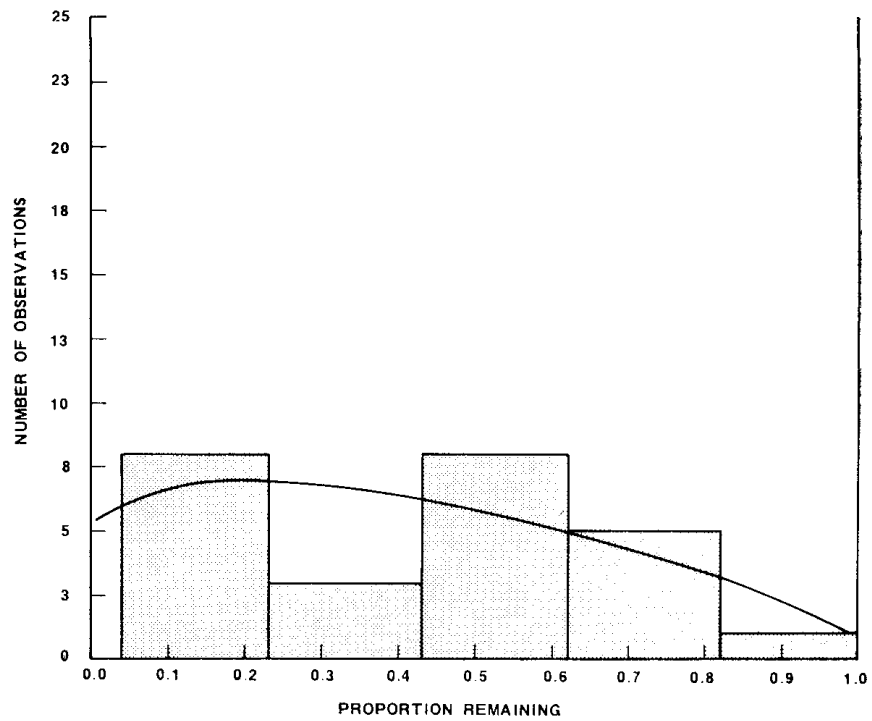


FIGURE 7: *Histograms and Density Functions for Damage (per cent) in Marayag and Hindi*

Risk of fertilization in Marayag and Hindi is graphed in figure 8 for the effective price ratios listed in table 8.²⁶ As in the Biñan case, risk increases slightly with increases in N and dramatically with shifts to less favourable regimes.

4 RISK NEUTRAL SOLUTIONS AND CONCLUSIONS

The primary purpose of this paper has been to explore methods for estimating the probability distributions of yields facing farm operators at different levels of nitrogenous fertilizer. Now that the estimates have been made, however, it may be useful to seek implications for agricultural policy.

To begin, we can calculate the amounts of nitrogen, N^* , which maximize expected utilities under the assumption of risk neutrality. The sample farmers were grouped according to location and the effective price ratios between nitrogen and rice. N^* is derived by equating the marginal product of nitrogen, based on the expected production function defined above to the effective price ratio. The results are displayed in table 8.

TABLE 8

Effective Price Ratios (P_N/P^e) for Representative Tenancy-Credit Regimes and Risk Neutral Solutions

Regime	S_0	S_I	i	P	P_N	$\frac{S_I(1+i)P_N}{S_0P} \equiv \frac{P_N^e}{P^e}$	N^*
			per cent				
Biñan 1 ..	$\frac{1}{2}$	$\frac{1}{2}$	0	P .50	P 1.30	2.60	70.6
Biñan 2 ..	$\frac{1}{2}$	$\frac{1}{2}$	100	.50	1.30	5.20	52.5
Marayag 1 ..	$\frac{2}{3}$	$\frac{2}{3}$	12	.50	1.50	3.36	60.2
Marayag 2 ..	$\frac{2}{3}$	$\frac{2}{3}$	50	.50	1.50	4.50	50.8
Marayag 3 ..	$\frac{2}{3}$	$\frac{2}{3}$	100	.50	1.50	6.00	38.5
Marayag 4 ..	$\frac{2}{3}$	1	100	.50	1.50	8.96	14.7
Hindi 1 ..	$\frac{3}{5}$	$\frac{3}{5}$	10	.44	1.54	3.85	41.9
Hindi 2 ..	$\frac{3}{5}$	$\frac{3}{5}$	50	.44	1.54	5.25	28.4
Hindi 3 ..	$\frac{3}{5}$	$\frac{3}{5}$	100	.44	1.54	7.00	11.6
Hindi 4 ..	$\frac{3}{5}$	$\frac{3}{5}$	200	.44	1.54	10.50	0

Notes:

S_0 \equiv Share of output received by tenant.

S_I \equiv Share of fertilizer input paid by tenant.

i \equiv Interest rate to tenant for fertilizer loans.

P \equiv Farm gate price per kilogram (kg).

P_N \equiv Price of fertilizer per kg N .

$S_I(1+i)P_N$ \equiv Effective price of nitrogen $\equiv P_N^e$

S_0P \equiv Effective price of rice $\equiv P^e$

N^* \equiv kg N per hectare which maximizes expected profit to the decision-maker.

²⁶ Other combinations had effective price ranges within the range shown in the 7th column of table 8. Risk and optimum N 's for these combinations were estimated by interpolation.

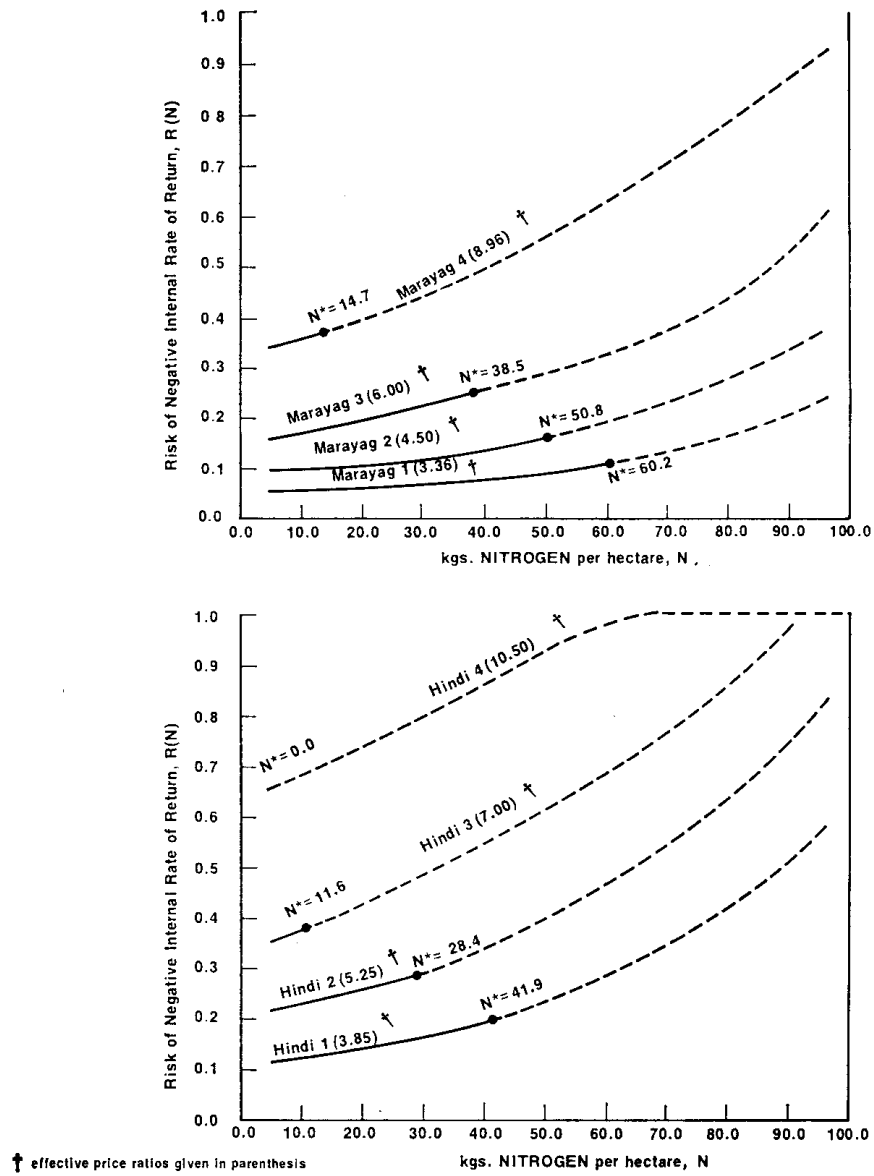


FIGURE 8: Risk of Fertilization in Marayag and Hindi

The risk-neutral optimal inputs, N^* , which can be assumed to be the efficient input levels based on the argument by Arrow and Lind [1], range from 70 kg/ha to zero; and this for farmers who all have irrigation! This suggests that blanket recommendations based on fertilizer response trials in a few sites are likely to cause serious misallocation of fertilizer (that is if they are followed by farmers). It is important that recommendations be adjusted not only to the physical conditions of a particular location but to a farmer's economic environment as well.

The wide diversity in efficient inputs for different environments may hold the key for understanding the widely reported spotty adoption of the new technology associated with *HYV*'s. It is quite possible that farmers have not switched in greater numbers to "modern" or recommended techniques precisely because those techniques are not efficient for their individual conditions. This hypothesis is explored in detail in [19] and [20].

4.1 IS THERE A CONFLICT BETWEEN RISK AND PROFIT?

The common observation that observed use of modern inputs by farmers in developing countries is less than the estimated optimum has led several observers to suggest that the residuals can be explained by risk and risk aversion. An integral part of this hypothesis is that modern techniques, while more profitable on average, are also more risky. It has been demonstrated above that when risk is measured as the probability of negative internal rates of return, risk does not increase substantially with the amount of nitrogen fertilizer applied, for $N \leq N^*$. What causes sizeable increases in risk are precisely those factors which decrease expected profit, namely unfavourable sharing arrangements, high costs of borrowing, quality of land and irrigation system, and the likelihood of unfavourable environmental conditions.

Further work reported in [19] and [20] shows that multiple goal models involving concerns for both expected profits and security perform no better, and usually worse, than the risk-neutral model. In these models risk is defined as the probability that profits will fall below some critical minimum, or "disaster level," d . Without repeating here the methodology for calculating this kind of risk, it is useful for the present discussion to note that the risk of disaster as a function of nitrogen is usually *U*-shaped.

To illustrate this phenomenon, risk of disaster is graphed as a function of nitrogen in figure 9. Note that for farmers with a high critical minimum profit per hectare, d , i.e. those who are typically thought to be the most risk averse, the level of nitrogen which minimizes risk is not zero but a substantial quantity, sometimes more than the level which maximizes expected profits. For those farmers with low disaster levels, e.g. those with substantial liquid assets or low consumption requirements, the level of risk which minimizes risk is likely to be zero, but the risk of using N^* is also low and not likely to be an inhibiting factor.

A related point is that we don't need to call on risk in order to explain differences in average fertilizer rates for different barrios. Expected

profitability seems to explain most of the variation in fertilization rates both between barrios and within barrios.²⁷ Risk is highly correlated with profitability and cannot account for much of the unexplained residual. Presumably differences in actual fertilization rates which are not explained by expected profit are due to lack of information available to and processed by the farmer and to measurement and methodological errors of the part of this researcher.

4.2 GENERALITY OF THE RESULTS

The results reported above were based on data gathered on a small number of Philippine farms and on one experiment station. Furthermore the production problem considered, the quantity of nitrogenous fertilizer which should be used, was quite narrow. To what extent can the methods and the results be generalized to other areas and other problems?

The methods introduced here have a wide range of potential uses. It is extremely important for agricultural planning, extension work, and descriptive research which use production functions as part of the analysis that the functions be adjusted to the average environmental conditions in particular locations. In the absence of a massive set of experiments at hundreds of locations and spanning several seasons, the method of collecting data on crop damages for individual locations and combining it with experimental data from a central location may be an efficient way to organize research.

One cannot conclude with certainty that the results concerning risk of nitrogenous fertilizer can be applied to other countries or even to other areas of the Philippines. But at a minimum, one learns from the exercises performed here that there is no *a priori* reason to believe that increasing production expenses, up to the risk neutral optimum, also increases risk. In fact it seems reasonable to conjecture that the risk of using another input, insecticide, decreases as one moves from say zero to some critical minimum level of input and beyond. Applying insecticide is one way of reducing the probabilities of some of the unfavourable states. In that sense it is a kind of insurance; thus we might even expect risk averse individuals to invest more in insecticide than risk neutral types.

Finally note that the tools developed here are suitable for either normative or positive research. That is we can use the estimates of crop damage to help us generate fertilizer recommendations, or we can use the crop damage experiences of farmers as a basis for estimating their subjective probabilities and thus for describing their behaviour.²⁸

²⁷ This conclusion is demonstrated more formally in Roumasset [19, ch. 6].

²⁸ Indeed, there is no compelling reason to believe that subjective probabilities diverge from objective probabilities in any systematic way, Fellner's [9] "slanting down" of subjective probabilities notwithstanding.

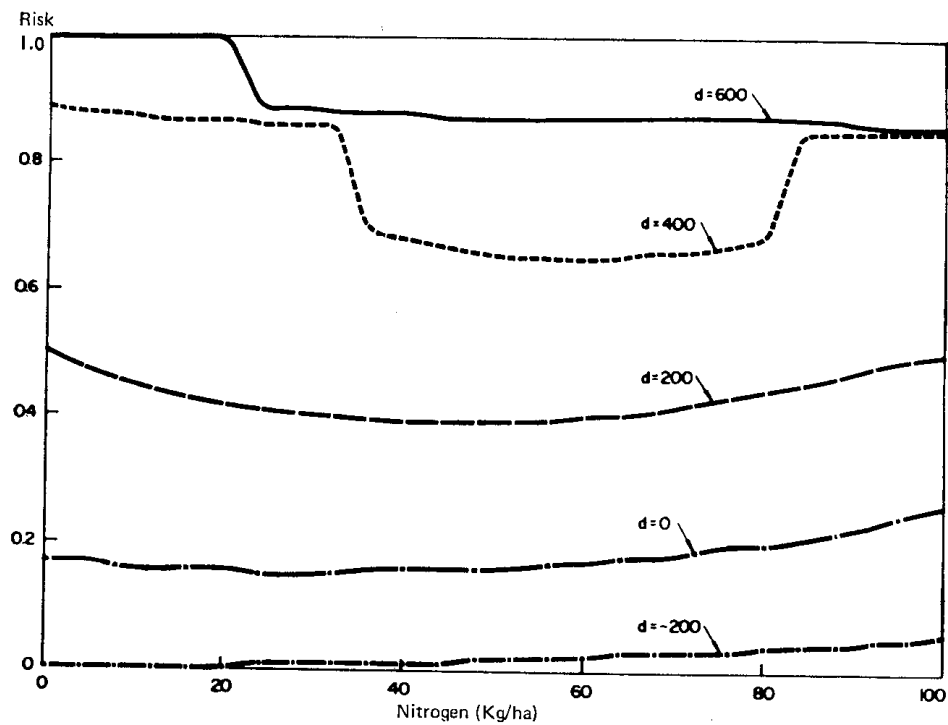


FIGURE 9: Risk of nitrogen fertilizer at different disaster levels, Biñan, Regime 2

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APPENDIX A: ESTIMATING THE NO-DAMAGE PRODUCTION FUNCTIONS FOR BIÑAN

After eliminating those years in which substantial damage was recorded at the experimental site, the annual production functions remaining from those listed in [3] are given below.

Year	OLS Regression	R^2	Solar radiation level
IRRI, IR8, Wet Season			
1966	$\hat{Y} = 5\,128 + 24.4N - .228N^2$	.63	C
1967	$\hat{Y} = 3\,654 + 18.9N - .049N^2$	.99	C
1968	$\hat{Y} = 3\,981 + 31.2N - .117N^2$	.99	B
IRRI, IR8, Dry Season			
1966	$\hat{Y} = 5\,046 + 64.1N - .236N^2$	.98	A
1968	$\hat{Y} = 3\,657 + 37.7N - .024N^2$	.97	A
1969	$\hat{Y} = 5\,140 + 39.0N - .130N^2$	.96	A
1970	$\hat{Y} = 4\,574 + 48.9N - .162N^2$	.99	A
1971	$\hat{Y} = 5\,615 + 55.8N - .241N^2$	.99	B

The regressions were pooled according to solar radiation, instead of season, on the grounds that the wet-dry (season) distinction is a proxy for environmental variables that are more accurately reflected by solar radiation. Unfortunately the technique of eliminating all years for which substantial damage was recorded left no regressions for solar radiation level D. Two sources of information were combined in an *ad hoc* technique to estimate the production function for solar radiation level D. One was the regression results for levels A-C. The other was an estimated Cobb-Douglas production function obtained from the IRRI data for the 1966-71 wet and dry seasons combined. (Since the purpose of the regression was to estimate the effect of solar radiation on the marginal product of nitrogen, all seasons were included.) The result was:

$$\lg \hat{Y} = 2.72 + .077 \lg(N + 1) + .702 \lg(\text{SR}); R^2 = .67$$

(6.01) (7.68)

(t-values in parenthesis).

It turned out that taking the lowest coefficient of N and N^2 from the regressions for solar radiation levels A-C gave a marginal product of nitrogen that was consistent with the Cobb-Douglas result. Note that while it would be difficult to prove that the coefficients estimated in this rough fashion are unbiased, they are probably more precise than the regression coefficients for levels A-C. Despite the high R^2 statistics of the latter equations, the precision of estimation is lowered by the presence of multicollinearity between the independent variables.

The pooled regressions and the estimated function for level D are graphed in figure 1A along with the weighted average of the functions, Y_{WA} , the weights given by the probabilities of the four solar radiation levels reported in the text.

The expected production function for Biñan, labeled Y_e in section 3.3, can also be expressed as $\bar{U}Y_{WA}$ where \bar{U} is the average percent damage. This function is graphed in figure 2A with the label, $Y_{\tilde{\text{Biñan}}}$. The analogous functions for Marayag and Hindi are also shown, along with the (Biñan) weighted average function from figure 1A.

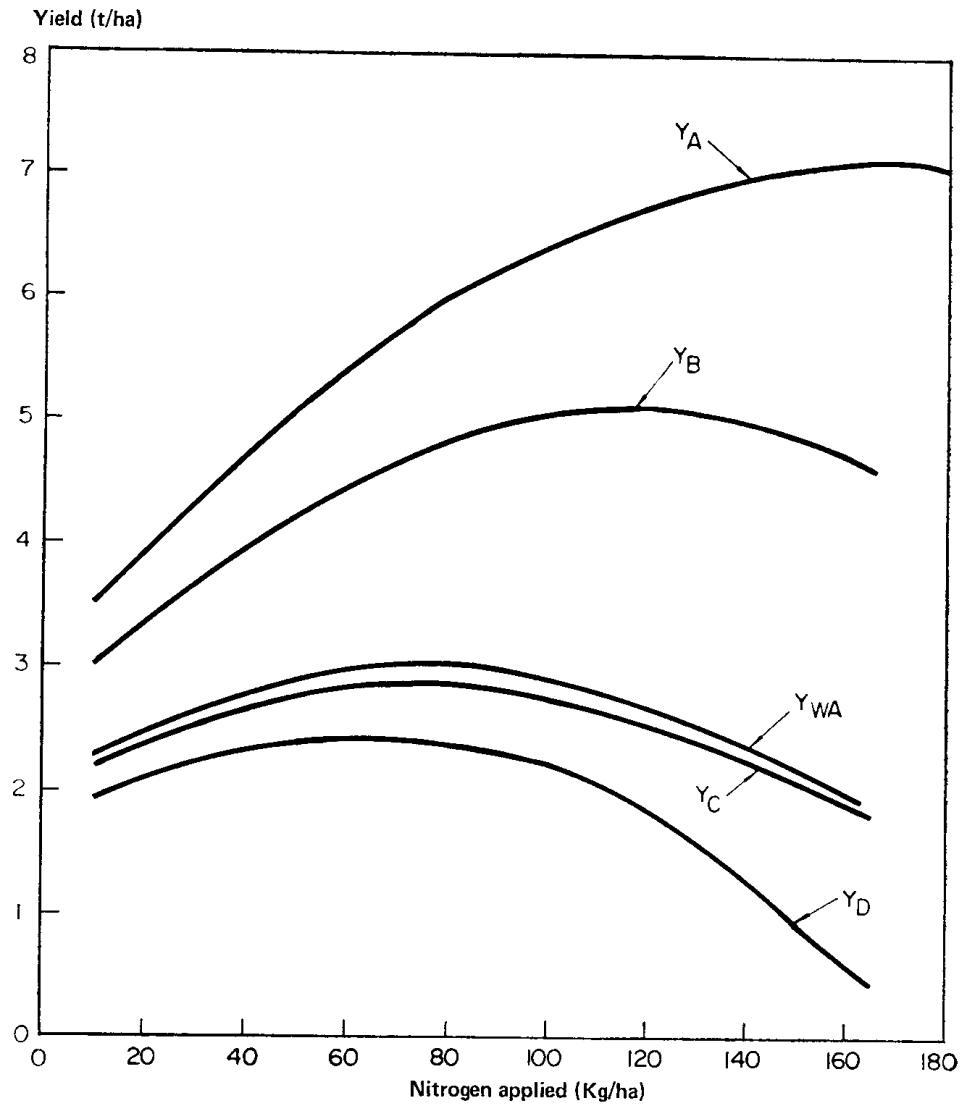


FIGURE 1A: Undamaged nitrogen response functions at four solar radiation units and the average functions for planting dates recorded in Biñan, 1971 wet season

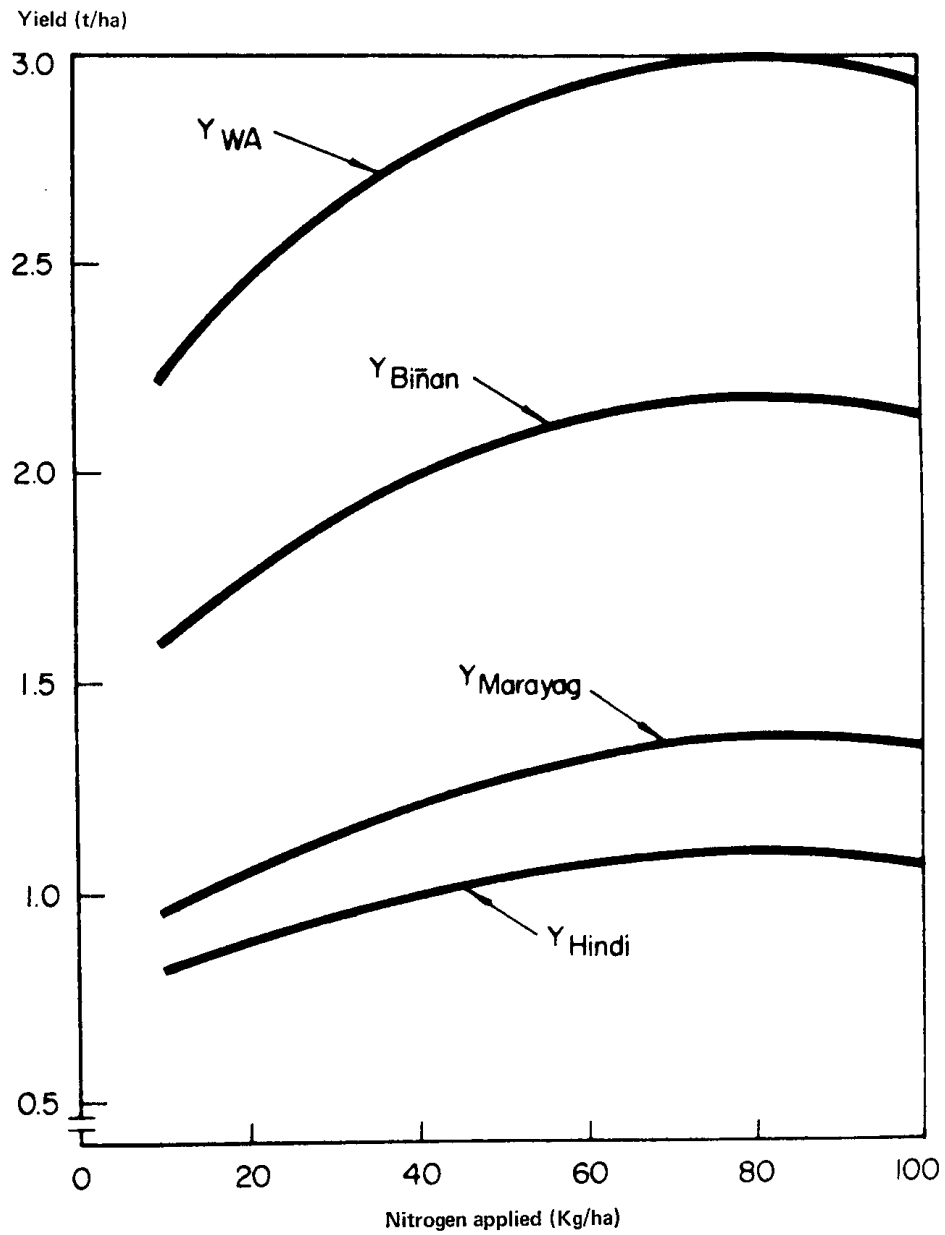


FIGURE 2A: *Wet season nitrogen response expected functions for barrios in Laguna and Albay*

APPENDIX B

In deference to Jock Anderson's stimulating article,¹ it seems appropriate to investigate the stochastic efficiency of alternative levels of nitrogenous fertilizer.

The cumulative frequency distributions of profits for two selected farmer groups are shown in figures 3A and 4A. While these were originally developed to plot risk of disaster for alternate disaster levels [19, 20], they can also be used to check for first degree stochastic dominance (FSD).

The graphs show that for both groups, neither N^* or 0 kg nitrogen is stochastic dominant² (i.e. both are stochastic efficient). Furthermore this indeterminacy is not resolved by resorting to second or third degree stochastic dominance (SSD or TSD). This is due to the fact that moving to higher order definitions of stochastic dominance serves to move the intersection point on the diagrams further to the right. Since the intersection point is somewhat far to the left using FSD, moving to SSD or TSD is not sufficient to make one or the other technique dominate.

¹ Jock Anderson, "Risk Efficiency in the Interpretation of Agricultural Production Research," *Review of Marketing and Agricultural Economics*, vol. 42, No. 3 September, 1974.

² Although N^* can be said to be *approximately* stochastic dominant (at the .1 level) for Biñan, Regime 1.

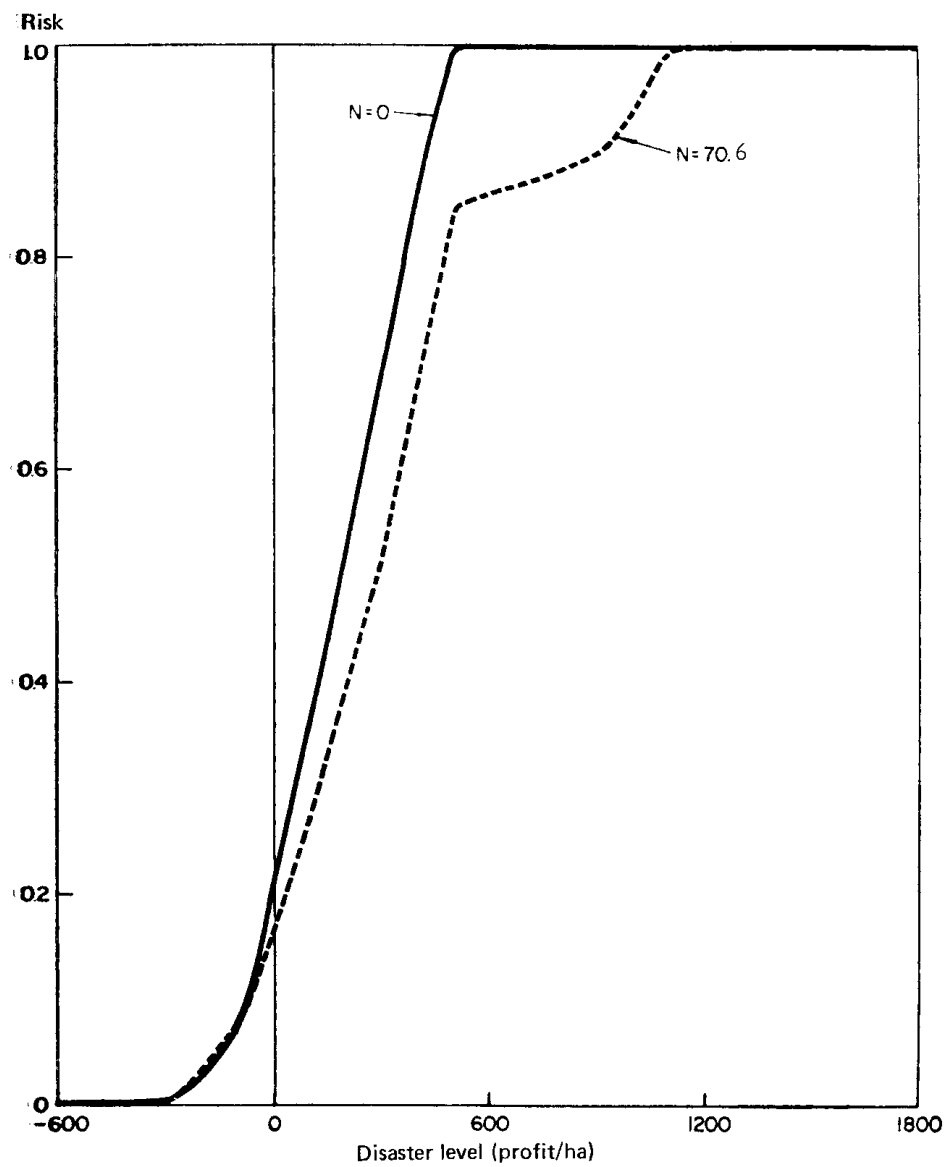


FIGURE 3A: *Risk of disaster (Stochastic Dominance) for two levels of nitrogenous fertilizer ($N = 0$ and $N = N^*$), Biñan, Regime 1*

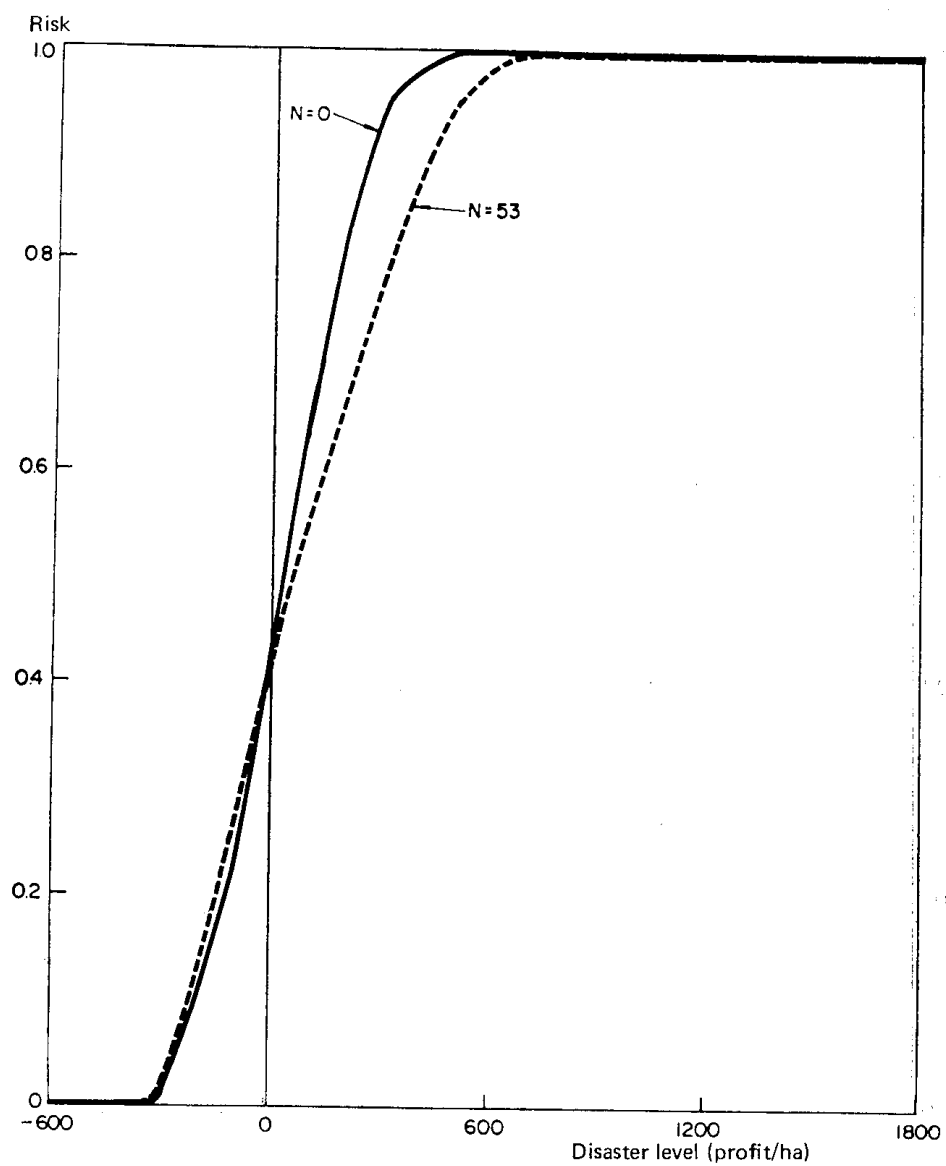


FIGURE 4A: *Risk of disaster (Stochastic Dominance) for two levels of nitrogenous fertilizer ($N = 0$ and $N = N^*$), Marayag, Regime 2*