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# INCORPORATING RISK IN PEST MANAGEMENT DECISIONS: SOME METHODOLOGICAL COMMENTS

By: Elmar Rodrigues da Cruz

Researcher at EMBRAPA's Planning Department
Ed. Venâncio 2000 - s/921
70333 - Brasilia-DF - BRAZIL

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## ABSTRACT

The paper presents an analysis of the limitations of traditional methods to make recommendations in the reported literature. It suggests that for the area of pest management account should be taken of the risks of wrong decisions that might be involved, from the point of view of individual farmers. References are quoted to illustrate that the Bayesian approach can be a viable method to incorporate risks in the recommendations to farmers. The limitations of production functions in the area of pest management are shown, and the paper concludes that risk should be included in recommendations to farmers.

## I. Introduction

The neoclassical economic theory has been severely criticized for its failure to take into account risk and uncertainty in decision making. Just (1975), Leland (1972) Sandmo (1971), Yaniv (1979), Baron e Forsythe (1979), Holthausen (1979); Lim (1980); Akiba (1980); Das (1980); Helpman and Razin (1980); Eckhoudt e Hansen (1980), Perrakis (1980); Holthausen (1981); Lippman e McCall (1981); Harris e Raviv (1981); Riddell (1981); Graham (1981); Hey (1981), Hendershott (1981); Yitzhaki (1982); Pindyck (1982), provide a few examples of extensions of the neoclassical theory to incorporate risk in topics such as i) theory of the firm with uncertain supply, demand and prices, ii) consumer theory under uncertainty, iii) uncertainty in input markets, international trade, monetary policy, market stabilization, investment appraisal, managerial decisions, and so on.

In agriculture, an extensive list of authors have also extended the conventional theory, so as to incorporate risk and uncertainty, at the level of the firm, at market level, and for policy analysis. Anderson, Dillon and Hardaker (1977) offer an excellent review of the models that deal with the topic of decision making under risk in agriculture. These models are very numerous and diversified. They can include aspects of production functions, individual comparisons, whole-farm planning, long term planning (investment appraisal), decisions with preferences unknown, decisions tailored to an individual decison maker, and so on. Interested readers in this broad spectrum of models are referred to Anderson et al. (op. cit.), Dillon (1977) and Da Cruz (1980) for a review. In this paper, attention will be given only to aspects of direct interest to pest management, as a short run unconstrained decision, from the point of view of individual farmers. At this level, justification will be given to the use of models based on decision theory, as a guide to better decisions, without any intention of undertaking a review in the area. Other aspects of risk in pest management, such as the social effects, externalities, long run strategies, and whole-farm planning with multiple constraints, were omitted due to limitations of space. In any case, apart from the academic aspect, there are grounds to believe that decision theory can be an interesting topic for experts in pest management.

Sections 2 and 4 deal with the more popular approach of incorporating risk with preferences unknown (without knowledge of utility functions), and section 3 explains why it is difficult to handle models with known preferences. The concluding remarks explain why generalized computer packages are not very popular in pest management.

## 2. Classical Statistical Significance Levels: What are the risks for pest management, and the Bayesian alternative.

This topic is not new in the literature. The argument below will follow in broad lines the ideas of Dillon and Officer (1971), with the intent of reinforcing their case.

In general, experimental results generate recommendations to farmers mostly based on tests of statistical significance. In particular, the "magic" numbers of 5% and 1% significance levels seem to be the most used in the reported literature. The problem that remains to be solved is that treatment A can be statistically better than treatment B, at the 5% level of significance without the risk of the losses of the wrong decision being assessed. If there are millions of dollars at stake for expensive crops in large farms, then evaluation of the wrong decision may involve criteria beyond the naive type I and type II errors mentioned in standard textbooks of statistics. The 5% significance level for example, may be too low for some decisions and too high for others. The example below, taken from Dillon and Officer (op. cit., p. 37) should illustrate this point:

Suppose an extension officer is faced with the problems of whether or not to recommend the spraying of barley crops in his region in the coming season with a new pesticide. Historical information available suggests that yields can be adequately represented by a normal distribution. In the previous season a trial was conducted in nine areas of the region, and the mean yield after spraying $\bar{X}s$, was 3000 kg/ha* with a standard deviation of 300 kg/ha. The mean barley yield

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* The original measures were expressed in cwt per acre. Numbers were multiplied by 100.

without spraying on control areas was 2600 kg/ha, with the same standard deviation, and corresponds with the average yields of the region. Spraying costs are \$ 75 per ha., and the net profit from each kg of barley produced is \$ 0.25. To cover its cost, spraying must therefore increase the mean yield per ha by at least 300 kilos, so that the mean break-even yield, $\mu_b$ is 2900 kg/ha. The optimal decisions are to spray if $\mu_s > \mu_b$ (if the population mean yield after spraying is greater than the mean break-even yield) and not to spray if $\mu_s \leqslant \mu_b$. However because the extension officer does not know the true population value $\mu_s$, but only has an estimate $\bar{X}_s$ of it, the problem has to be analysed in probabilistic terms. Two methods will be compared: the classical analysis and the Bayesian approach reported in decision theory textbooks, hence the term "Bayesian decision theory" (Wonnacott and Wonnacott, 1972).

In the classical analysis, a critical level of significance is chosen, say 5%. Using standard normal tables to simplify the analysis, $P(\bar{X}_s \quad 3000/\mu_s = 2900)$ implies a standard normal variable = 0.33, with the probabilit of 0.371. Thus $\bar{X}_s = 3000$ becomes higher from the break-even yield $\mu_b = 2900$ only at the 37.1 per cent level. They are statistically not different at the 5% level. The conclusion is not to spray. Another way to arrive at the same conclusion is to find the critical level c of trial yield, beyond which it will pay to spray. For significance at the 5% level, $P(\bar{X}_s > c/\mu_s = \mu_b) = 0.05$ implies standard normal variable = 1.645 so that c = 3394. This means that only after 3394 kg/ha is that the trial yield will become statistically higher from the break-even yield. Given that $\bar{X}_s$ is only 3000 kg/ha, then the classical analysis suggests that for no differences in means, it is not worth spraying.

In the Bayesian approach, subjective probabilities are allowed, so that account can be taken of relevant information beyond that contained in the experiment. The method considers the overal context of the decision problem, not just the experimental results alone. Furthermore the analysis allows for the opportunity cost of making a wrong decision. In this case if the extension officer makes the type I error (in the terminology of classical statistics) of recommending unprofitable spraying, farmers would suffer an opportunity cost of \$ $(\mu_b - \mu_s)$x (0.25) per hectare. Should he make the type II error of not recommending a truly profitable spraying, the opportunity cost would be \$ $(\mu_s - \mu_b)$ (0.25) per hectare. For a farmer with say 500 hectares of grains, and with more realistic prices, then the opportunity cost for a wrong decision can be quite high.

The basic formula behind the Bayesian approach, is the Bayes' Theorem, which can be in simple terms stated as follows (Raiffa, 1968; Wonnacott and Wonnacott, 1972):

$\theta_i$ = States of nature (eg. rain = $\theta_1$, shunshine = $\theta_2$ or $\theta_1$ = infestation of insects, $\theta_2$ = no infestation)

$p(\theta_i)$ = prior probabilities of $\theta_i$ (normally given by subjective judgement, or by historical data).

$X_i$ = sample information about the states $\theta_i$. This information can be given by field trials, for example, or other forms of empirical evidence.

$p(X_i)$ = probabilities of states, computed from sample information

$p(X_i/\theta_i)$ = conditional probability that state $\theta_i$ will occur, given only the empirical evidence of the sample information.

$p(\theta_i/X_i)$ = posterior probability that state $\theta_i$ will occur, after incorporating the empirical evidence $X_i$.

From standard statistical textbooks we have:

$$p(\theta_i, X_i) = p(\theta_i)\ p(X_i/\theta_i)$$

and

$$p(X_i, \theta_i) = p(X_i)\ p(\theta_i/X_i)$$

Upon algebraic rearrangement, Bayes theorem follows:

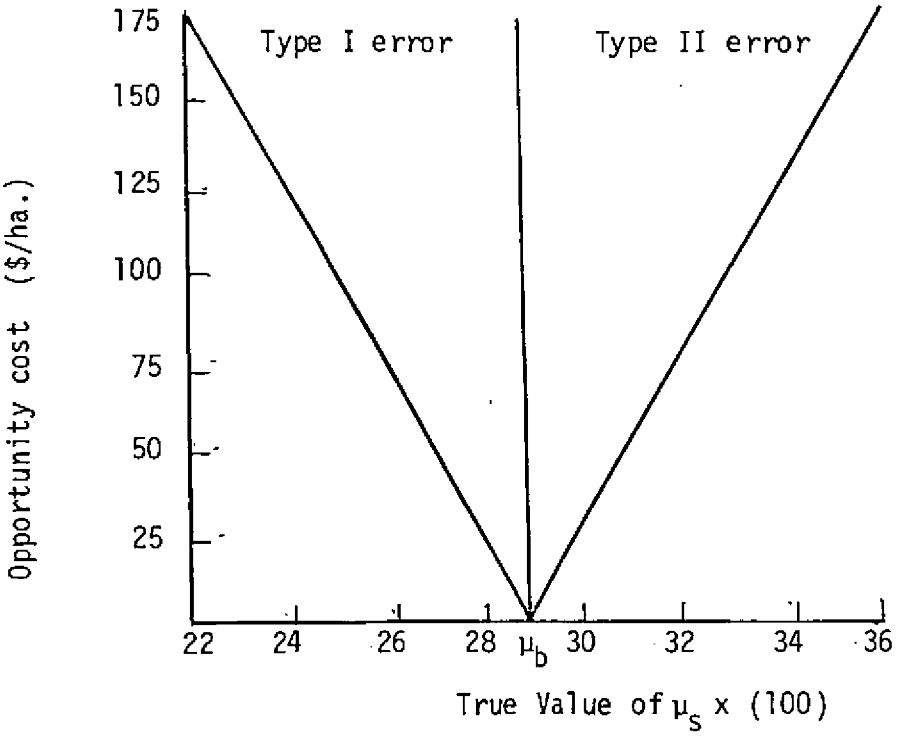
$$p(\theta/X) = \frac{p(\theta,X)}{p(X)} = \frac{p(\theta)p(X/\theta)}{p(X)}$$

without subscripts to simplify the presentation.

To obtain recommendations the Bayesian approach makes use of loss functions, which reflect the opportunity costs of wrong decisions.

Coming back to the illustrative example, because the marginal opportunity costs per hectare are identical, for both types of error, as $\mu_s$ varies about $\mu_b$, the loss functions are linear and symmetric as shown in figure I*:

FIGURE I. LOSS CURVES SHOWING OPPORTUNITY COST OF TYPE I AND TYPE II ERRORS IN HERBICIDE DECISION PROBLEM



In terms of information beyond the experiment, suppose that in addition to last season's trial in his own region, the extension officer also has information from other districts. While these results are not directly comparable with his own region, he considers he knows these other regions sufficiently well to be able to modify this information so that it becomes pertinent to his own area. Also, he knows seasonal conditions at the time of spraying are important in determining the effectiveness of spraying. All this is additional (prior) information which is obviously relevant to his problem. Consequently he wants to incorporate it along with the local trial results into the analysis of his decision problem.

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* Also very popular in the literature are quadratic loss functions. See Wonnacott and Wonnacott (1972) for an example.

Using Bayes' theorem mentioned above, he does this by way of a subjective prior probability distribution for yields which in then adjusted on the basis of the local trial results to give the posterior or revised probability distribution to be used in appraising his alternative decisions.

Based on his assessment of current seasonal conditions and his knowledge of yields with the pesticide in other regions, suppose the extension officer expects the mean yield after spraying this year to be around 3200 kg/ha with a fifty-fifty chance that it will lie between 2800 and 3600 kg/ha. Using this information standard normal tables can be used to derive the parameters of the normal prior distribuition. These are a mean of 3200 and a standard deviation of 597. Break-even yield is assumed to remain unchanged at 2900 kg/ha.

With normal prior and sampling distributions, the parameters of the posterior normal distribution are calculated as follows (Dillon & Officer, p.42).

(a) The posterior mean $M_3$ is a weighted average of the prior mean $M_1$ and the sample mean $M_2$, the respective weights being the reciprocals $V_1^{-1}$ and $V_2^{-1}$ of the variances of the two distributions. Thus $M_3 = (M_1V_1^{-1} + M_2V_2^{-1})/(V_1^{-1} + V_2^{-1})$.

(b) The reciprocal of the posterior variance $V_3$ is the sum of the reciprocals of the variances of the prior and sampling distributions. Thus $V_3{-1} = V_1^{-1} + V_2^{-1}$.

Applying these formulae, the parameters of the posterior normal distribution are a mean of 3040 and a standard deviation of 268 kg/ha. These parameters allow for the local trial results and the extension officer's subjective assessment of both current seasonal conditions and the yield results from other districts.

With a normal posterior distribution and linear loss functions for alternative actions (as shown in Figure 1), the optimal decision depends on the size of the posterior mean relative to the break-even mean. If the posterior mean is the larger, the optimal act is to recommend spraying, and vice versa. The extension officer should therefore recommend spraying since the posterior mean of 3040 is greater than the break-even yield of 2900 kg/ha. The expected profit per ha from spraying is $ 685, i.e. (0.25) (3040)-75. If spraying is not undertaken the expected profit per ha. is $ 650, i.e. (0.25) (2600).

Thus, it can be seen that the inclusion of a loss function into the analysis, which takes into account the opportunity costs of wrong decisions, can change the recommendations stemming from the classical approach.

Additional references on the Bayesian approach can be found in Lindley (1965); Pratt et al (1965); Raiffa (1968) and Schlaifer (1959). Because these are decision theory textbooks, the Bayesian analysis is also known as the decision theoretical approach. Real world applications, in the area of pest management, for example, can be found in:

a) WEBSTER (1977). He discusses the treatment of risk in farm management decisions, and reports an analysis on the spraying decision against Septoria in wheat. Probabilities of a response to spraying were obtained from a plant pathologist for a range of alternative field conditions. These probabilities were used in the context of the Bayesian model.

b) COOK and WEBSTER (1977). They put the same set of data into the context of a break-even budget for the individual farmer.

c) MENZ and WEBSTER (1981). They look at the costs and benefits of valuing the advisory scheme, from the point of view of economics of information. Improved spraying decisions against septoria could generate annually around 106 thousand pounds for farmers in the county of Kent (England), with a benefit/cost ratio of 8 to 1.

d) CARLSON (1970), in a study of californian peach growers, found that better pesticide application decisions are made if the Bayesian decision theory is used, as opposed to the conventional optimization.

e) CARLSON and MAIN (1976) offer an excellent review of the methods of economic analysis to the problem of crop disease loss.

f) MUMFORD (78) and MUMFORD (81) offer an example of decision making in the control of sugar beet pests in England.

g) FEDER (1979) shows additional theoretical results in the area, and quotes many other studies of decision making in pest management.

## 3. Input decisions under risk with known preferences

In the preceding section all the analysis omitted the preferences (encoded in utility functions) of the decision maker. Consider now a model which incorporates preferences in the way usually reported in the literature, i.e., in terms of utility functions (Dillon, 1977). Let us take the simplest case, which means a single input and a single crop, as described in Da Cruz (1980). The decision maker is assumed to maximize expected utility. The advantage of this approach is that the monetary terms of a loss function (eg. the one depicted in fig. 1) can be converted in utility terms. Monetary losses are different from utility losses if the utility functions are non-linear. The disadvantages will be seen below.

Consider a utility function $U(\pi)$ where $\pi$ is net income. Using a Taylor series expansion of $U(\pi)$ about the means $E(\pi)$ and noting that $U(\pi)=E\{(\pi)\}$ under the expected utility theorem, we can approximate $U(\pi)$ in terms of its first two moments (DILLON, 1977, p. 26).

(1) $$U(\pi) = U\{E(\pi)\} + (1/2)\{U_2E(\pi)\}V(\pi)$$

Where $V(\pi)$ is the variance of net income, and $U_2$ is the second derivative of $U(\pi)$ with respect to $\pi$. Hence we make the usual assumption that $U(\pi)$ has a finite second derivative $U_2$ for the relevant range of $\pi$ and $U_1$ is positive and continuous everywhere. The decision variables of the problem are the input levels $X_i$ and, noting that.

(2) $$E(\Pi) = E(P_y)E(Y) - \sum_{i=1}^{K} X_iP_i - F$$

(3) $$\text{and } V(\Pi) = E\{(P_y)\}^2V(Y)+\{E(Y)\}^2V(P_y)+V(P_y)V(Y)$$

Where:

$E(Y) = f(X_1,X_2...X_k)$

$P_i$ = Input Prices assumed to be known at the time of the decision. $i = 1...k$

$E(P_y)$ = Expected product price

$X_i$ = Inputs $i = 1...k$

F = Fixed costs

V(Y). = Variance of Y

$V(P_y)$ = Variance of $P_y$,

maximisation of (1) with respect to $X_i$ can proceed (DILLON, 1977, p. 113 et seq.). Taking the total differential of (1) and rearranging, we have

$$(4) \qquad -\{\partial U/\partial V(\Pi)\}/\{\partial U/\partial E(\Pi)\} = \{\partial E(\Pi)/\partial X_i\}/\{\partial V(\Pi)/\partial X_i\}$$

The right hand side of (4) has been referred to as the Rate of Substitution in Utility (RSU) of $E(\Pi)$ for $V(\Pi)$ (DILLON, 1977, p. 113). Under risk aversion RSU is positive, thus and increase in variance of profit must be compensated by an increase in $E(\Pi)$ in order to ensure same utility level, as implied by the total differential of $U(\Pi)$ in (2). Risk neutrality implies RSU=0, i.e. increases in $V(\Pi)$ with $E(\Pi)$ constant do not affect the level of utility. If RSU is negative then the decision maker is a risk preferrer and more $V(\Pi)$ is compensated by less $E(\Pi)$ to keep his utility constant.

Substituting (2) and (3) into (1) and rearranging, we see that the classical result MVP = MFC (Marginal Value Product = Marginal Factor Cost) can be expressed under risk as

$$(5) \qquad P_i = E(P_y)MEP_i - RSU\{((E(P_y))^2 + V(P_y))MIR_i + 2V(P_y)E(Y)MEP_i\}$$

Where:

$MEP_i = \{\partial E(Y)/\partial X_i\}$ = MARGINAL EXPECTED PRODUCT OF INPUT $X_i$

$MIR_i = \{\partial V(Y)/\partial X_i\}$ = MARGINAL INCREMENT TO RISK OF INPUT $X_i$

If RSU = 0 then (5) becomes the classical riskless result* since the whole of the second term of the right hand side vanishes.

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* This classical result is found in any introductory economics textbook. In simple terms it means that a decision maker should increase (or decrease) the level of particular input until the point where the marginal revenue equals marginal cost.

The interpretation of (5) is strainghforward. ANDERSON et al. (1977) and HAZELL & SCANDIZZO (1974) suggest that risk averse farmers require $E(P_y)MEP_i$ to be greater than $P_i$ as a compensation for taking risk.

HOWEVER DILLON (1977, p. 116) and POPE & JUST (1977) recognise the fact that some risk averse farmers may use certain inputs (e. g. insecticides and pesticides) beyond the optimal economic point in order to reduce production risk. Assuming that RSU is positive for risk averse farmers (see equation (5)), then $MIR_i$ is negative if more input levels decrease variance of yields. This implies $E(P_y)MEP_i < P_i$, hence the value of the marginal expected product will be less than the input price, because of the overutilization of a particular input. An elegant (and more complex) mathematical presentation of an alternative approach that permits risk aversion in both over or underutilization of inputs is given in POPE and JUST.

For the purposes of this paper, it is enough to notice that solution of equation (5) for a particular input can be quite complicated, even for simple utility functions. It requires the estimation of a response function to provide MEP; a yield risk function to provide MIR; and the decision-maker's rate of substitution in utility (RSU), plus of course, input and output prices.

A simple functional form of utility functions is the negative exponential (Freund, 1966; Wiens, 1976; Buccola and French, 1978). It takes the form:

$$(6) \qquad U_E(\Pi) = K - \Theta \exp(-\lambda\Pi) \qquad \lambda, K\ \Theta > 0$$

Once this function is estimated, the monetary values of a loss function are substituted for $\Pi$, and then transformed in a utility loss function.

The negative exponential RSU (ERSU) stemming from (6) is a constant, because assuming a normal distribution of Y (Income), then the expected value of the negative exponential utility function can be computed directly by appealing to its primitive form, without recourse to Taylor series expansion (LOISTL (1976); (BUCCOLA & FRENCH (1978)).

(7) $$E(U(Y) = \int_{\infty}^{\infty} \ell^{-py^2+qy}\, dy$$

Where:

$P = .5\ \sigma y^2$

$q = \frac{1}{\sigma y^2}\ (y - \lambda\sigma_y^{\ 2})$

Upon integration we obtain:

(8) $$E(U(Y)) = \ell^{q^{2/4p}} \quad \frac{\pi}{p}.$$

Where $\pi$ = 3.1416...

Inserting p and q and rearranging we have:

(9) $$E(U(Y)) = K - \Theta\ell^{\,-\lambda\mu + .5\lambda^2\sigma_y^{\ 2}}$$

Where $\mu = E(Y)$

To derive the ERSU we set E(U(Y)) at the level U* and rearranging K:

(10) $$U^* - K = -\Theta\ell^{\,-\lambda\mu + .5\ ^2\sigma_y^{\ 2}}$$

Because K is the asymptote of (6), if $U^* > 0$

Then $K > U^*$. So multiplying (10) by (-1):

(11) $$K - U^* = \Theta\ell^{\,-\lambda\mu + .5\lambda^2\sigma_y^{\ 2}}$$

Taking logs of (11):

(12) $\log (K-U^*) = \log \Theta - \lambda\mu + .5\lambda^2\sigma_y^2$

Upon rearrangement:

(13) $\mu = \frac{1}{\lambda} (.5\lambda^2\sigma_y^2 + \log \Theta - \log (K-U^*))$

We now find ERSU directly by differentiating (13) with respect to $\sigma_y^2$. After dividing all terms of right hand side by $\lambda$:

(14) $\frac{\partial\mu}{\partial\sigma_y^2} = .5\lambda = \frac{1}{2}\lambda$ = ERSU, which is a constant.

Even though this exponential rate of substitution in utility is extremely simple (to enter in the solution of equation 5), the estimation of $\lambda$ requires a lenghthy questioning procedure for each individual farmer (Da Cruz, 1979), in order to quantify their utility functions. Measurement problems can also happen in the remaining terms of equation five. These comments illustrate the point why so many authors are discouraged to quantify farmers preferences, and are inclined to work with preferences unknown, as it is the case of Moscardi and Janvry(1977). For the same reason, we take again the lead of section 2, and present section 4 below, with unknown preferences in the decision analysis.

## 4. Incorporating risk of losses in production functions

There is a controversy in the literature about how far allocative efficiency prevails in agriculture. In very simple terms, it can be said if farmers use input levels so as to maximize profits, by equating marginal value products and marginal factor costs, then they are considered to be efficient. Hence allocative efficiency implies that a farmer should use for example the optimum amount of pesticides, in order to maximize profits. When cross-sectional samples of farmers are available, then allocative efficiency can be measured from production functions. From the point of view of pest management it can be interesting to find out whether farmers are being efficient or not. Two approaches will be discussed here, following the argument of Dillon and Anderson (1971):

- The typical approach
- The decision theory approach

The typical approach is to estimate a Cobb- Douglas production function from a cross-sectional sample of farmers in a given region. In this production function the main determinants of agricultural output are included, such as:

$X_1$ - Land
$X_2$ - Buildings
$X_3$ - Machinery
$X_4$ - Seeds
$X_5$ - Fertilizer
$X_6$ - Pesticides
$X_7$ - Field labor
$X_8$ - Management, and so on.

After estimation of the function, for each input corresponds an estimate of the regression coefficient. Multiplying the estimate of the coefficient of each input by the ratio of average value of the output over the average value of the input, a measure of the marginal value product (MVP) of each input is obtained. Since the Cobb-Douglas function is based on the logarithms of the variables,these coefficients b are the production elasticities of each input. The typical approach takes estimated MVP's and MFC's (Marginal Factor Costs) of the mean farm, and makes some statistical tests of equality between MVP and MFC. Notice that geometric means are used, since the variables are expressed in logs. A typical test is to take the ratio MVP/MFC for a given input and check if it is significantly different from 1.0 (unity) at a predetermined critical level.

This approach was used by Chennareddy (1967), Heady and Dillon (1961) Hopper (1965) and Sahota (1968) and others, mostly for India and Bangladesh. Dillon & Anderson(op. cit., p. 26) argue that such sampling theory tests are the basis of rejecting or accepting the hypothesis of efficiency. As an example, they quote Chennareddy as accepting the hypothesis of efficiency because no significant differences from unity were found in the ratios of most of the inputs included in the production function. Chennareddy found that only two ratios (out of twelve) were significantly different from one, at the 10 percent level. Such statements based on the mechanical use of traditional significance levels, by giving the same attention to cheap inputs (such as seeds), as well as to expensive ones (eg. machinery) have little economic content. Dillon & Anderson argue that significant tests based on arbitrary probability levels provide no basis for the assessment of efficiency. What is required is the evaluation of efficiency involving the expected opportunity loss of the average input allocation relative to the most profitable allocation, that is feasible with total expenditure unchanged.

The decision theory approach combines such opportunity loss function, with the statistical production function.

Consider the regression-based Cobb-Douglas type production function estimated from a cross-sectional sample:

$$Y = b_0 \Pi X_i^{bi} \tag{15}$$

which relates agricultural income Y to the inputs $X_1$, $X_2$ ... $X_n$, each $b_i$ being the best linear unbiased estimate of the population elasticity $\beta_i$. Costs of the inputs are introduced through the profit function:

$$\pi = Y - \Sigma c_i X_i \tag{16}$$

where $c_i$ is the unit price of $X_i$.

Opportunity loss L incurred by nonoptimal operation of the average firm is defined as

$$L = \tilde{\pi} - \bar{\pi} \tag{17}$$

where $\tilde{\pi}$ and $\bar{\pi}$ denote respectively the profit computed at the optimal and geometric mean input levels (denoted by $\tilde{X}_i$ and $\bar{X}_i$ respectively). Since optimal operation is constrained to employing only the geometric mean total of resource outlay (i.e. $\Sigma c_i \tilde{X}_i = \Sigma c_i \bar{X}_i$), this opportunity loss can be expressed as

$$L = b_0(\Pi\tilde{X}_i^{bi} - \Pi\bar{X}_i^{bi}). \quad (18)$$

The loss L will be zero if $\bar{X}_i$ equals $\tilde{X}_i$ for all i, and positive otherwise.

The measure by which Dillon and Anderson propose judging efficiency of resource use is the expectation of the opportunity loss L when account is taken of the fact that the production coefficients $b_i$ are probabilistic estimates based on data from a cross-sectional sample reflecting nonhomogeneity due to variations in resource endowments, weather effects, and managerial services and attitudes. Thus the question they pose is: What is the expected opportunity loss suffered by a geometric mean producer relative to the expected profit he would achieve if he were to operate at the constrained optimal input levels implied by the $b_i$, given that these $b_i$ are only sample estimates and have some associated probability distribution?

Dillon and Anderson suggest a Monte Carlo procedure to estimate this expected opportunity loss, (EL), taking into account the random nature of the coefficients $b_i$'s.

An index by which the degree of nonattainment of profit maximization by the average firm may be subjectively assessed is given by the ratio of expected loss to expected optimal profit, i.e., $EL/E\bar{\pi}$ ($=EL / \{EL + E\bar{\pi}\}$). The greater the divergence of this ratio above or below zero, the greater the degree of inefficiency implied by operation at geometric mean input levels. Multiplying the absolute value of the ratio by 100 gives the percentage of the potentially achievable profit foregone through failure to allocate resources optimally in terms of profit maximization. Using this index, Dillon and Anderson found that many farmers supposed to be profit maximizers, under the typical approach, were operating well below the economic optimum when the expected opportunity loss is considered. Thus they reversed the findings for India, based on the typical approach. Risk aversion is then suggested as a possible reason for this discrepancy. Farmers should then be considered as utility maximizers rather than profit maximizers. This point reinforces the importance of risk in decision making. Furthermore, it stresses the need to extend the conventional economic analysis, so that risk can be explicitly incorporated in the results.

Notice however that this section was aimed only as a possible answer to the question: are farmers efficient or not? This question is relevant for policy purposes. If farmers are efficient, then only a shift in the production function can raise productivity of a region. Thus more resources shoud be spent on agricultural research. If farmers are inefficient then a rearrangement of existing resources can raise productivity. Hence more money should be spent in the extension services. Noronha (1981), using the decision theory approach recommended by Dillon and Anderson, found that farmers in selected areas of Brazil are efficient in the allocation of their resources.

Turning now to specific recommendations to farmers in the area of pest management (as opposed to the government policy level), the production function approach may not be the most appropriate. A production function can indicate the optimal level (MVP = MFC) of a given input (eg. fungicides) only for situations identical to that of the underlying data included in the function. The approach does not usually handle conditional statements, so typical in pest management. Hence, questions like "should I spray if the disease starts to build-up three weeks later than usual?" or "what if the amount of sunshine this year is much greater than usual?", are very difficult to be handled in the context of production functions. Results can be very misleading if a variety of situations is included in the production function. In this case, the optimum level, when MVP=MFC will be a "typical" level. It may be too much for some situations and too little for others. Thus, as a decision rule in the area of pesticides, the production function approach is far from convenient. Also from the social point of view, the resistance build-up of pests can make private recommendations widely different from those socially desirable. Although this is not a weakness of the results of production functions alone, the Bayesian approach reported in section 2, can more readily revise expectations as new information becomes available.

## 5. Concluding remarks

It was seen that pesticide recommendations without taking risk into account, can be the opposite from those based on risk models. Furthermore, it was seen that treatment of risk must be kept as simple as possible (eg. with preferences unknown) because of the complexity of risk modelling, at least from the point-of-view of non-specialists in risk analysis. On the other hand, pesticide recommendations are usually based on two dimensions: the amount and the timing. Even in the case of biological (natural) control of insects, these two elements may be present. Many questions of the type "what if?" may be relevant for the analysis of the decision. These peculiarities of pest management may be and indication of why so many economic studies reported in the literature rely on specific computer programs, specially written for the analysis. Rather than using generalized packages, the analysts prefer instead to utilize specific models for each particular application. Even though many of these models are based on the broad guidelines of Bayesian analysis, the peculiarities of each decision stimulate the use of specific questions. In order to illustrate this point, in the case of Septoria reported by Webster for the southeast England, if the weather service forecasts the so called "King period", that is, an infection period for Septoria, due to amounts of rain on successive days between flag leaf emergence and flowering (op. cit. p. 247), and if the variety is susceptible to disease, and if the topography is favourable to disease, then there is a case for spraying. In the case of Carlson (1970), the subject was peach losses in California due to brown-rot. Here there is no King period involved, the disease control actions are several, and furthermore the marginal probability distributions of loss forecasts were many, due to data availability. A generalized computer package to take into account all those peculiarities would have to be somewhat large, and even so there would still exist the danger of its failure to meet some specific element of a given region. Nevertheless, for very simple applications, EMBRAPA's Methods and Planning Department (DDM) has a computer package called PACTA*. Details of it can be found in Da Cruz and Silva (1983).

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* The advantage of this package is that it can be run on micro-computers under alternative probabilistic situations. Treatments are pairwise compared, in order to establish which one dominates the others under risk. Probability distributions can be based on experimental data or on the expert's judgements, and they can be revised using Bayes' theorem. These distributions need not necessarily be normal or symmetric, and the same can be said about the distributions of prices and costs.

A major limitation of this paper is that it discussed methods only from the point of view of individual decision makers. More discussion is required among scientists, in order to evaluate externalities and social effects in general from pest management programs. In particular, more emphasis should be given to topics such as equity, pollution, insurance schemes, labor training in safety measures, and so on.

Despite of the limitations, it is hoped that the main massage of this paper can be properly understood, namely, that conventional economic models can be inadequate for pest management analysis.

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