Rob King

RISK ANALYSIS FOR AGRICULTURAL PRODUCTION FIRMS: CONCEPTS, INFORMATION REQUIREMENTS AND POLICY ISSUES

Proceedings of a Seminar Sponsored by
Southern Regional Project S-180
"An Economic Analysis of Risk Management
Strategies for Agricultural Production Firms"
New Orleans, Louisiana
March 25-28, 1984

Department of Agricultural Economics
Agricultural Experiment Station
College of Agriculture
University of Illinois at Urbana-Champaign

July, 1984

AE-4574

RISK REDUCING INPUTS RELATED TO AGRICULTURAL PESTS

Gerald A. Carlson

In many cases the variability in crop yields in individual fields is related to sporadic pest damage. Also, occasionally, pest attack may affect large areas so that aggregate production and commodity prices are affected. When agricultural economists exhort their colleagues to examine the sources of agricultural risk they often have the damage from diseases, insects, nematodes, weeds and other pests in mind. Inputs which reduce pest damage such as pesticides, specialized labor or pest resistant crop varieties are generally believed to reduce yield and, perhaps, price risk, and they are often referred to as "risk reducing inputs" as opposed to other inputs which either increase risk or have no effect on variability in farm income at all.

It is less clear why agricultural economists want to know if pest control inputs reduce risk, or what the risk related evidence is for inputs like pesticides and use of pest scouts. Many pest control biologists, if not the majority, would describe any pest control system using more pesticides as less stable than one that used less. Pest density forecast systems have not been widely adopted, though relatively inaccurate scouting has. Upon closer examination there appear to be many sources of production variability associated with variable pest densities over time, pest dispersion across space, damage per pest and variability in pest control efficacy. I'll try to examine some aspects of these issues by posing three questions: (1) Why worry whether pest control inputs are risk reducing? (2) What models and methods are particular to pest control risks? and (3) What is the evidence on the risks reduced by pesticides and other pest control inputs?

Why Worry Whether Inputs are Risk Reducing?

Much of the interest in characterizing inputs seems to stem from the desire to not impose unreasonable restrictions when estimating production functions, especially models with the commonly used multiplicative error terms. As Just and Pope (1978) demonstrate, when one uses the multiplicative error specification, this restricts all inputs to be risk increasing. Pope and Kramer define marginally risk reducing inputs as those which will be used at lower levels by risk neutral than by risk averse individuals or firms. It seems that this problem can be avoided by using models with additive error structures as proposed by Just and Pope (1979) or by recasting the problem so the risk component enters as a variable in the model and thus reduces to the more conventional errors in variables problem (Rossi).

Gerald A. Carlson is Professor, Department of Economics and Business, North Carolina State University, Raleigh, North Carolina.

The perspective of many agricultural economists is that with risk averse decision makers there will be use of certain inputs at levels beyond that optimal for risk neutral individuals if the marginal effect of input use on yield variability is negative. Begin with the profit (Π) function:

$$\tilde{\Pi} = P_y \tilde{Y}(X_1, X_2, X_3, \tilde{N}) - \underline{C}\ \underline{X} \ . \tag{1}$$

P_Y is product price, X_1 is the pesticide input, X_2 is pest control information, X_3 is all other purchased inputs, $\tilde{N}$ is the random pest input, $\tilde{Y}$ is the random output reflecting yield and quality, and $\underline{C}\ \underline{X}$ is the cost of production from inputs X_1, X_2 and X_3, given unit prices C_1, C_2 and C_3. Assuming no price risk and a utility function related to only the first two moments in the profit function, gives the following utility maximizing condition for pesticides (Anderson, et al.):

$$P_y \cdot \frac{\delta E(Y)}{\delta X_1} = C_1 + B\ P_y^2 \cdot \frac{\delta V_y}{\delta X_1} \tag{2}$$

In this case, E(Y) is average yield, V_y is variance in yield and B is the risk aversion coefficient which is >0 for a risk averse person. The last term is an extra component of factor cost which will be negative if an input such as pesticides reduces yield variability ($\delta V_y/\delta X_1 < 0$). The critical term ($\delta V_y/\delta X_1$) can either be positive or negative; I'll refer to it as the risk nature of input X_1.

Figure 1 shows a family of dose-response curves for a pesticide used on a crop-pest situation which would exhibit marginal variance reductions in yield.

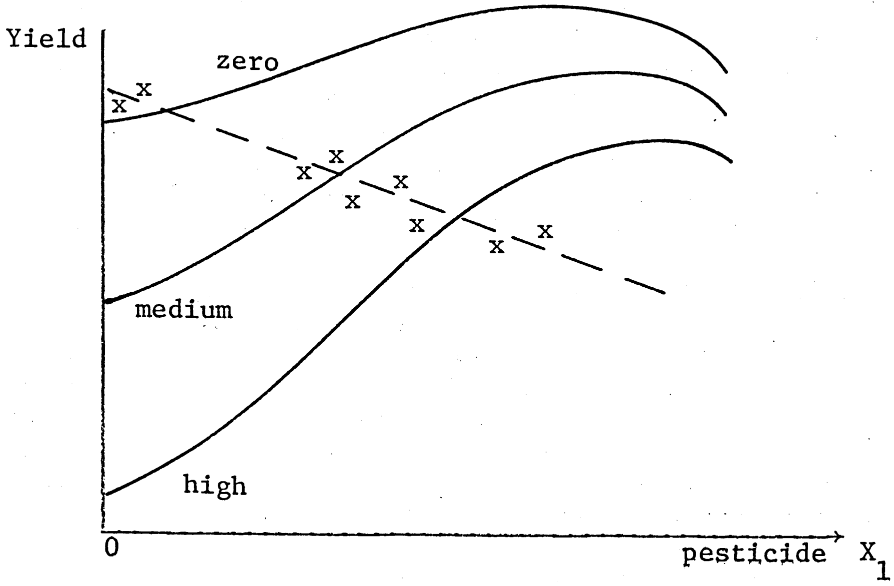

Figure 1. Dose-response functions with variable pest infestation.

What this description of the agricultural technology shows is that with the restriction of treating whole fields rather than individual pests, there is likely to be a much larger marginal product of a given pesticide input with high rather than medium or zero levels of pest attack (N). If pesticide use decisions are made prior to knowing the true pest state, then responses like those in Figure 1 are plausible. The possibility of a negative marginal product of pesticides at higher dosages reflects the fact that many pesticides have phytotoxic effects; that is, they can damage crop growth or tarnish fruit. In addition, some pesticides enhance plant growth and will increase yields in the absence of the pest (shown for the zero pest case).

A serious problem introduced when pest level is variable is that biased estimates of marginal products are possible. The biases can be either positive or negative, depending on the data points observed; it is quite possible to estimate negative marginal products of pesticides such as that implied by the dashed line in Figure 1. This is merely another version of an identification problem, with the dashed line showing the pesticide demand response to higher expected pest attacks, rather than describing part of the pest control function. To avoid this problem a simultaneous equation model explaining pest levels and output can be utilized (Pingali and Carlson).

A second reason to be concerned with the risk nature of inputs is that risk-reducing inputs will be used at levels in excess of the risk neutral optimal levels. This is a special concern when private and social costs of the input diverge. For pesticides for example, if there are important costs external to the farm that increase as pesticide use increases, then the risk reducing nature of this type of input is associated with higher external costs. The larger is the $\delta V_y/\delta X_1$ term for pesticides in equation (2) the higher the external costs. In other cases, external costs may be reduced by higher pesticide use. This would include the case where pest spread from farm to farm is reduced by pesticides. Also, for other inputs such as chemical fertilizers for which $\delta V_y/\delta X_i$ is positive, the external costs associated with these inputs will be reduced by their risk-increasing nature. Perhaps, understanding how use levels and external costs of agricultural inputs are affected by their risk nature can help in evaluation of public regulation of these inputs.

Finally, public financial support for development of improvements in agricultural inputs ought to be partially guided by the risk nature of the inputs or changes in the inputs. When a new discovery in, say a crop variety, shows promise and at the same time is risk reducing compared to existing varieties, this could be considered in decisions on development and release of the variety. Without getting ahead of the story it appears as if there is some evidence that many of the new cereal varieties are more risky than conventional varieties (Roe and Nygaard).

Overall, the justification for examining the risk nature of inputs can come from arguments related to external cost, public funding, or better understanding of the problems in estimating econometric models with risk altering inputs. Before turning to the evidence for pest control inputs, let us briefly examine the various ways in which risk can enter production decisions regarding pests.

How Might Risk Enter Pest Control Decisions?

In early models involving risk related to pest control, the major source of risk was variable pest density (Carlson (1970), Hillebrandt). The level of pest density was not known at the time when pest control input choices had to be made by farmers. The possibility of uncertain pesticide efficacy was also considered by Carlson (1970). Feder provides a model in which pest density, control efficacy and damage per pest are all random variables. He finds that marginal increases in one source of risk holding the others constant is associated with higher levels of pesticide use. Feder expresses increases in risk as an increased spread in damage per pest with the mean held constant. His profit (Π) model with a single pesticide input (X) can be written as:

$$\Pi = (P_oY_o - C_o) - \tilde{d}\tilde{N}[1 - \tilde{k}(X)] - C X \qquad (3)$$

where $(P_oY_o - C_o)$ is the return that would occur if no pest were present, $\tilde{d}$ is damage per pest, $\tilde{N}$ is pest density and $\tilde{k}$ is the control function provided by pesticide input (X) (where ~ refers to a random variable). The total reduction in crop value from surviving pests is $\tilde{d}\tilde{N}$ $[1 - \tilde{k}(X)]$, and cost of a pest control action is C X.

Feder only assumes that the utility function is concave in profit. There are two optimal input choices which can be defined. The first is the conventional optimal input level X* such that $E[U'(\tilde{d}\tilde{N}\tilde{k}' = C)]$. The other optimal condition is known as the "economic threshold," which is that pest level (N*) which satisfies $E[U(\tilde{d}\tilde{N}^*\tilde{k}'(o) = C)]$. This latter condition is important, because frequently there are rather standard pesticide dosages (X*) and the farmer's question is to find what infestation level (N*) justifies taking a control action in terms of expected utility of crop saved compared with the utility of the dollars expended. Lower threshold levels mean larger proportions of acreages are treated, and as would be expected, thresholds are reduced for lower pesticide costs (C), higher damages per pest (d) and higher effectiveness levels (k).

Randomness in each of the three elements $(\tilde{d},\tilde{N},\tilde{k})$ is possible, and as Feder shows, increased variability in each is associated with higher optimal input level (X*) and lower action threshold populations (N*). Uncertainty with respect to each of these variables has both a biological and a management component. Biologically, damage per pest is random because there is genetic variability in pest individuals, weather factors, pest voracity, and because crop susceptibility changes rapidly through the season. Pest density is random because of the uneven distribution over time and space, but principally because of the difficulties in detecting and identifying pests prior to the time an action is taken. The control function $(\tilde{k})$ is random primarily because of weather (chemical and physical properties of chemicals being sensitive to environmental conditions) and timing and placement of applications.

There are further complexities which are frequently needed to make the above model more descriptive of a farmer's situation. As mentioned above, pesticides will frequently directly affect plant growth and product quality in addition to their effects on the monitored pests. A direct pesticide effect can be added by making the base yield and price functions of pesticide use level $[P_o(X)\ Y_o(X)]$. As might be expected, direct crop damage due to the pesticide is an increased cost and this will raise the pest threshold (N*) and decrease optimal pesticide dosage (X*). Usually, the direct effects of pesticides on plants are highly variable (being sensitive to weather conditions) with the variability decreasing the higher the dosages. For a phytotoxic effect this could lead to slightly higher optimal dose levels, and for a growth stimulating effect it would certainly promote higher use levels compared to the case with certain, direct plant effects.

Most crop-pest situations involve more than one pest specie to be controlled by the same control action. This could be accommodated in the above model by considering each of the random variables as vectors $(\underline{\tilde{d}}\ \underline{\tilde{N}}\ \underline{\tilde{k}})$ for the major pest species present. Complication arises when the crop damage is not a simple additive function of the damage by each specie such as when an insect type causes root damage that allows soil pathogens to be more destructive. Also, many of the pesticides will have widely different toxicities to the various pest species. As a result, a premium is on management ability that permits the identification of species and use of appropriate pesticides and pesticide mixtures. About 25-30 percent of all corn herbicides and cotton insecticides are applied as farmer prepared "tank mixtures" while other combinations are formulated by pesticide companies to help accommodate such multiple-pest infestations.

A third adjustment to the Feder model that will be needed in some cases is to note that base yield is a random variable $(\tilde{Y}_o)$ which may not be distributed independent of the pest density $(\tilde{N})$ or damage per pest $(\tilde{d})$. The same dry weather that brings about a large pest population may also decrease base yields. Although it may not be critical to separate direct yield effects of drought from drought-induced pest damage, such interactions may be important when considering crop selection and pesticide use. Crop prices $(\tilde{P}_y)$ and pest damage $(\underline{\tilde{d}\tilde{N}})$ may also be correlated over time. When an entire crop region is affected by a severe pest, we would expect both price and pest damage to be high. This occurred in 1979 and 1980 with the blue mold fungus on tobacco.

Each of the above components can be added to the Feder model to give a profit model:

$$\Pi = (\tilde{P}_o(X)\ \tilde{Y}_o(X) - C_o) - \underline{\tilde{d}}\ \underline{\tilde{N}}\ [1 - \underline{\tilde{k}}(X)] - CX \qquad (4)$$

where product price $[\tilde{P}_o(X)]$ is determined by a market error term (ε), and the random effect of pesticide use on product quality $[\tilde{P}(X)]$; yield variability $[\tilde{Y}_o(X)]$ is composed of random yield factors (u) and the direct effect of pesticides on crop yield $[\tilde{Y}(X)]$.

A final modification of this pest control model can be made by adding the possibility of crop and variety selection as a means to control pests (Carlson, 1979a). Since many alternative crops are resistant to certain pest species, it often pays to rotate crops and varieties. This is particularly important for less mobile insects, pathogens, nematodes and weeds. Lazuras and Swanson have examined rotations and insecticide control of the corn rootworm and Taylor and Burt have developed a model to find optimal rotations through time for weed control in wheat. There are many combinations of rotations of various durations both with and without pesticides to consider. The Lazuras-Swanson model considers four combinations: the alternative crop (soybeans), the major crop (corn) with insecticide, the major crop following rotation without insecticide, and the major crop with no insecticide. The rotation elaboration can be incorporated into the risk model above by modeling farmer's crop acreage (A) choices for each crop-pesticide combination, and include yield and price variability in the absence of the pest for each of the crops, and add variability in rotation efficacy:

$$\Pi_A = A_1 \, [\tilde{P}_S \tilde{Y}_S - C_S] + A_2[\tilde{P}_o(X) \; \tilde{Y}_o(X) - C_o - \underline{\tilde{d}}\underline{\tilde{N}} \, (1 - \underline{\tilde{k}}(X)) - C \, X]$$
$$+ A_3[\tilde{P}_o \tilde{Y}_o - C_o - \underline{\tilde{d}} \; \underline{\tilde{N}}] + A_4[\tilde{P}_o \tilde{Y}_o - \underline{\tilde{d}} \, \underline{\tilde{N}}_R], \qquad (5)$$

where the subscript s is for the substitute or non-host crop for the pest, and A_1, A_2, A_3 and A_4, represent acreages in the substitute crop, the major crop with pesticide, the major crop without pesticide, and the major crop following rotation with the substitute crop, respectively. The number of pests present following rotation ($\underline{\tilde{N}}_R$) is the same as defined above except now it has an additional error component due to the efficacy of the rotation in reducing pest density. Little seems to be known about the variability of this term except that it definitely falls as a farmer utilizes the substitute crop for more years. As for pesticides, the marginal effect of rotation (measured in time not acres) is that the more uncertain the efficacy of rotation in reducing pest density the longer the non-host crop should be used.

The pesticide input itself is frequently difficult to measure and specify for econometric or optimization formulations. Consider it a vector ($\underline{X}$) and substitute it into equation (5). One dimension of ($\underline{X}$) which is closely linked to variability in the control function $[\tilde{k}(X)]$ is the timing of pesticide applications. Percent pest control may be closer related to time of application than dosage. Therefore, it is not sufficient to add pounds of chemicals, or numbers of applications or dollar expenditures to measure pesticide input. An example of this is for post-emergent control of weeds in such major crops as cotton and soybeans. Marra and Carlson found that including a random variable for days-not-fit-for-herbicide-application decreased economic thresholds (N*) by 25-40 percent relative to ignoring this risk. Farmers with smaller machinery complements face a higher chance of losing field days and incurring higher weed damage to yields. They will have a higher economic threshold ($\underline{N}^*$) because they can treat only the fields with higher weed populations in equating $\tilde{d} \; \tilde{N}^* \; k'(o)$ with herbicide costs (C X).

If one substitutes the profit equation (5) for equation (1) and substitutes this into (2) the marginal effects of increasing pesticides (X_1) on overall profit variability could be obtained but it would be complex. Some attempts have been made to find the marginal effects of increasing risk or increasing risk aversion in certain empirical studies, but most econometric studies have only done so indirectly (Pingali and Carlson, Burrows).

What is the Evidence on the Riskiness of Pest Control Inputs

Most economic studies which attempt to find optimal input use (X^*) or pest thresholds (N^*) do not include the risk components mentioned above. Others have been primarily directed toward evaluation of particular inputs such as IPM (Hall, Burrows, Grube). IPM inputs in the context of the above model are monitoring or prediction systems to estimate the probability distribution of $\tilde{N}$ prior to taking an action so that the control function $\tilde{k}(X)$ is less random and the level, mix or timing of X is made conditional on a forecast of N. (Cost of monitoring is C_2X_2 included in C_o.)

Table 1 shows a tabulation of sources of risk, utility formulation and direction of marginal risk effects in eight pest control studies. The Feder model as described above has no empirical verification, but is most complete from the utility perspective since it also examines the effects of considering various Pratt-Arrow risk averseness assumptions.

Three of the studies provide empirical evidence that pesticides reduce profit variability. Only the Lazuras and Swanson study shows the opposite effect that when a low risk and low cost rotation alternative crop is available, that higher pesticide use (in terms of proportion of fields treated) is associated with higher profit variability. Though they tend to emphasize the marginal contributions of increases in risk aversion on pesticide use, the effects of pesticide use on overall farm profitability is given. Their study is particularly interesting because rotation actions affect profit variability via both pest damage variability as well as overall enterprise variability. From examination of their tables it is shown that a 77 percent increase in the use of the non-host crop will reduce pest damage variance by 79 percent, but only reduced net return variance by 7 percent. It seems that most of the reduction in profit variability is coming from more certain pest control than by selecting a more diversified crop portfolio.

The Musser et al. study only explicitly accounts for one source of variability (pest density), and it is difficult to determine where the observed changes in mean, variances and skewness arise. Perhaps the most interesting empirical aspect of this study is the high degree of skewness in the profit probability distributions for various pest control systems.

The Cochran et al. study uses a Monte Carlo analysis to simulate apple pest control of coddling moth, scab and mites. Various thresholds, pesticide treatments and monitoring systems are simulated. I was surprised at the similarity in mean and variance of returns for a wide range of thresholds.

The other input often examined in these studies is the accuracy of the monitoring system. Variability in net returns is reduced with improvement in pest monitoring accuracy when higher IPM or pest monitoring inputs are used in four of six studies which examined it. In the Cochran et al. study there is often little change in profit variability from the case with 100 percent monitoring accuracy compared with inaccurate monitoring. The Musser et al. study finds an increase in variability of profits in moving from no monitoring to some, but a decline in variance in going to a system which monitors well enough to modify pesticide type as well as frequency of use. The Moffit et al. study is unique in that it considers co-existence of an area-wide and an individual farmer pest monitoring system. They find that improvements in the accuracy of the public, area-wide forecast will discourage the use of private monitoring provided the costs of improving the area-wide program are not included in the comparison. They also find a narrow range of accuracy improvement for the area forecast for which pesticide use increases.

Most of the risk studies examined here use an explicit mean-variance utility formulation, though several have used stochastic dominance or disaster avoidance formulations. The latter utility specifications are better suited to non-symmetrical probability distributions. Both Musser et al. and Carlson (1979b) found different optimal monitoring input levels with stochastic dominance than with the EV specification. Lazuras and Swanson find a highly skewed infestation distribution over fields, but they transform it to a symmetrical one prior to performing the EV analysis. The important lesson seems to be that contrary to the utility formulation in equation (2) that when dealing with sporadic pest infestations more than the first two moments of the profit distribution must be considered. For econometric analysis the moment methods of Antle (1983b) could be applied. For simulation or optimization models entire probability distributions should be used, or even simple triangular distribution approximations when profitability data are sparse (Anderson).

Overall, the evidence is fairly clear that pesticides reduce profit variability except where some other input such as rotation is even more efficient in reducing profit variability and use of the pesticide is linked to crop rotation choices. The monitoring inputs seem to reduce profit variability, although there are cases where use of a monitoring system may increase variability over some range of monitoring input.

What Risk Questions Should Pest Control Studies Address in the Future?

Fifteen years ago I was struggling with these same issues while preparing a paper on risk in pest control. What will I and others be doing fifteen years from now? I don't think we will have made great strides in assessing risk aversion coefficients of farmers, nor have much better models of how variability enters utility functions. I don't believe we will have access to great banks of pesticide and other pest control input data. Likewise, I don't think crop protection biologists are going to cooperate to collect much better pest frequency data, though this will certainly improve. Two areas I believe that can push us ahead are (1) more carefully modeling of the dynamic aspects of pest control risks, and (2) closer analysis of the allocative errors due to farmers assessing pest control risks different than "true" risks.

Antle (1983a) has shown that information on random events are valuable to farmers whether the farmer is risk-averse or not, given a dynamic setting. Estimating conditional input demand equations for pest control inputs appears to be a needed addition to existing empirical work. Along this line Perez has estimated demand curves for pesticides from a dynamic model of a perennial crop, apples. He found, for example, that farmers were protecting young trees more than for their current value of crop saved. This implies that recommendations for pest control need to be recast in some cases to be for specific crop status categories.

Biases in farmers' information on the pest control technology ($\tilde{k}(X)$), pest densities ($\tilde{N}$), or damage per pest ($\tilde{d}$) may be a major source of allocative error in pest input use. With new pest species, new biotypes, new pesticides and infrequently occurring weather events, it is easy for many farmers and pest control consultants to not know "true" pest losses or gains from inputs used. Pingali and Carlson developed a three-input, two-pest model of an apple orchard. They find that farmers' subjective estimates of pest densities are biased and magnitudes of these errors help explain individual farmer pesticide use and tree pruning levels. Further, they find certain human capital variables associated with ability to perceive and correctly monitor the pest environment which could be modified to reduce input misallocations. Roe and Nygaard have applied a similar model to fertilization choices under risk.

Farmers often seem to be applying high rates of pesticides. Assuming that unusually high levels of pesticide use are associated only with risk averseness and the risk reducing nature of pesticides as indicated in equation (2) blinds researchers to other explanations for this phenomenon. With a little ingenuity maybe we won't hear this same sort of talk fifteen years from now.

Table 1. Sources of Risk, Utility Formulation and Evidence on Marginal Risk Effects of Pest Control Inputs

	Measured Sources of Risk[a]	Utility Formulation(s)[b]	Crop(s)	$\delta V_{\Pi}/\delta X_i$ Marginal Risk Effects Found	
				Pesticides	Other
Carlson (1970)	$\tilde{N}$, $\tilde{K}$	EV, DA	peaches	–	monitoring (-)
Carlson (1979b)	$\tilde{N}$	EV, SD	cotton		monitoring (-)
Cochran et al. (1982)	$\underline{\tilde{N}}$ $\tilde{Y}$	EV, SD	apples	-	monitoring (?)
Feder (1979)	$\tilde{N}$ $\tilde{d}$ $\tilde{k}$	M-P-S	none	–	
Hall (1977)	$\tilde{N}$	EV	citrus, cotton		monitoring (-)
Lazarus & Swanson (1983)	$\tilde{N}$ $\tilde{d}$ $\tilde{P}_y$ $\tilde{Y}$ $\tilde{P}_s\tilde{Y}_s$	EV	corn, soybeans	+	rotation (-)
Moffit et al. (1982)	$\tilde{N}_1$ $\tilde{N}_2$	EV, SD	soybeans		monitoring (-)
Musser (1981)	$\underline{\tilde{N}}$	EV, SD	vegetables	-	monitoring (?)

[a] $\tilde{N}$ = pest density ($\underline{N}$ refers to multiple pest species, N_1 is scout observation, N_2 is area forecast), $\tilde{d}$ = damage per pest (N), $\tilde{k}$ = percent pest reduction, $\tilde{P}_y$ = crop price, $\tilde{Y}_s$ = yield of substitute crop, $\tilde{Y}$ = yield, $\tilde{P}_s$ = substitute crop price.

[b] EV = expected profit-variance of profit, SD = stochastic dominance analysis, M-P-S = mean-preserving-spread, DA = disaster avoidance.

References

Anderson, J. R., J. L. Dillon and B. Hardaker. Agricultural Decision Analysis. Ames, Iowa: Iowa State University Press, 1977.

Anderson, J. R. "Sparse Data, Climatic Variability, and Yield Uncertainty in Response Analysis," Am. J. of Agri. Ec., 56(1974):77-83.

Antle, John M. "Incorporating Risk into Production Analysis." Am. J. of Agri. Econ. 65 (1983a):1099-1106.

Antle, John M. "Testing the Stochastic Structure of Production: A Flexible Moment-Based Approach," J. of Bus. & Ec. Stat. 3(1983b):192-201.

Burrows, Thomas M. "Pesticide Demand and Integrated Pest Management: A Limited Dependent Variable Analysis." Am. J. of Agri. Econ. 65(1983):806-810.

Carlson, Gerald A. "A Decision Theoretic Approach to Crop Disease Prediction and Control." Am. J. of Agri. Econ. 52(1970):216-223.

Carlson, Gerald A. "Pest Control Risks in Agriculture," Chapter 11 in Risk and Developing Agriculture, J. Roummasat, J. M. Boussard and I. Singh (ed.) New York: Agricultural Development Council, 1979a.

Carlson, Gerald A. "The Role of Pesticides in Stabilizing Agricultural Production", Chapter 11, in Pesticides: Contemporary Roles in Agriculture, Health and the Environment, J. Sheets and D. Pimental (eds.), Humana Press, Clifton, NJ, 1979b.

Cochran, Mark, et al. "Evaluation of Strategy Performance and Risk Efficiency of IPM Programs in Apple Production", Agricultural Economics Staff Paper No. 82-27, Michigan State University, East Lansing, Michigan, 1982.

Feder, Gershon, "Pesticides, Information and Pest Management under Uncertainty," AJAE, 61 (1979):97-103.

Grube, Arthur, "Economic Analysis of Field Scouting and Insecticide Use in Cotton Production," Ph.D. Thesis, North Carolina State University, Raleigh, North Carolina, 1979.

Hall, D. C., "The Profitability of Integrated Pest Management: Case Studies for Cotton and Citrus in the San Joaquin Valley, Bulletin of the Ent. Soc. of Am. 23 (1977):267-274.

Just, Richard, and Rulon Pope, "Stochastic Specification of Production Functions and Economic Implications," J. of Econometrics, 7(1978):67-86.

Just, Richard and R. Pope, "Production Function Estimation and Related Risk Considerations." Am. J. Agri. Econ. 61 (1979):277-284.

Lazarus, W. and E. R. Swanson. "Insecticide Use and Crop Rotation Under Risk: Rootworm Control in Corn." Am. J. of Agri. Econ. 65 (1983):738-747.

Marra, Michele and G. A. Carlson. "An Economic Threshold Model for Weeds in Soybeans," Weed Science. 31(1983):604-609.

Moffitt, L. J. et al., "Farm Efficiency and Insect Infestation Forecasts: The Case of Soybeans in Illinois," ERS Staff Report No. AGES821013, NRED, ERS, U.S. Dept. of Agric., Washington, DC, 1982.

Musser, Wesley N. et al. "An Economic Examination of an Integrated Pest Management Production System with a Contrast Between E-V and Stochastic Dominance Analysis." S. J. of Agri. Econ. 13(1981):119-124.

Perez, Luis, "Farmers Use of Pesticides on North Carolina Apple Orchards: The Role of Information, Biological Capital and Risk Aversion, Ph.D. Thesis, North Carolina State University, Raleigh, North Carolina, 1981.

Pingali, Prabhu and G. A. Carlson. "Human Capital, Adjustments in Subjective Probabilities and the Demand for Pest Controls." Working Paper, Department of Economics and Business, North Carolina State University, Raleigh, NC, 1984.

Pope, R. and R. Kramer, "Production Uncertainty and Factor Demands for the Competitive Firm," Sou. Ec. J. 46(1979):489-501.

Roe, Terry, and David Nygaard, "Wheat, Allocative Error and Risk: Northern Tunisia", Economic Development Center Bulletin V, Department of Agricultural and Applied Economics, St. Paul, Min. 1980.

Rossi, Peter, "Stochastic Specification of Cost and Production Relationships", Working Paper, J. L. Kellogg Graduate School of Management, Northwestern University, Evanston, IL. 1983.

Taylor, C. R. and O. R. Burt, "Optimal Management Strategies for Wild Oats in Spring Wheat," Am. J. of Agri. Econ. (forthcoming).