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# AN ECONOMIC EXAMINATION OF AN INTEGRATED PEST MANAGEMENT PRODUCTION SYSTEM WITH A CONTRAST BETWEEN E-V AND STOCHASTIC DOMINANCE ANALYSIS

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## INTRODUCTION

Agricultural economists have long recognized pest populations as common property resources, and, as such, pest control through chemical pesticide application involves a tradeoff between increased crop yields and reduced environmental quality (Carlson; Regev et al.). Integrated pest management (IPM) attempts to minimize this tradeoff by substituting pest information and management skills for chemical pesticides. In part, IPM involves monitoring pest populations in order to utilize beneficial biological interactions. Weather patterns, stage of crop growth, and natural biological enemies of pests are among the factors included in IPM. In addition, entomologists have extended the integrated control concept to include selective rather than nonselective pesticide application that is applied only when pest populations exceed the "economic threshold" level (Hall and Norgaard). In an earlier economic analysis of IPM, Hall concluded that the major advantages of IPM are: (1) a substantial reduction in overall pesticide use, (2) no significant reduction in profits, (3) no significant loss of yields, (4) an overall reduction in pest management costs, and (5) a reduction in risk for the producers.

This article presents an economic analysis of a continuing integrated pest management experiment at the University of Georgia. Epperson and Allison presented some economic results on these experiments in an earlier paper. However, this article explicitly considers more general risk and returns implications of the experiments for producers. Risk is analyzed in both a stochastic dominance framework and an expected value and variance framework, and the results are contrasted. In addition, the potential environmental consequences of the various pest management strategies are considered.

## CONCEPTUAL FRAMEWORK

Non-point source pollution control generally has been considered to involve a tradeoff in social objectives. While such control obviously reduces environmental damages, it can also reduce net farm income. The current state of economic methodology in reference to non-point source pollution is to estimate tradeoffs between environmental loadings and net farm income (Taylor and Frohberg; Seitz et al.). Current federal nonpoint source pollution policy recognizes this tradeoff in authorizing subsidies for Best Management Practices (BMPs).[1] As the components of IPM are considered BMPs for reducing pesticide pollution, economic analysis of IPM should consider tradeoffs between net farm income and environmental loadings. However, analysis of IPM requires consideration of risk, which is usually not included in standard analysis of BMPs. Since pesticides are inputs used to manage risk as well as the expected value of agricultural income (Carlson; Just and Pope), consideration of the impact of IPM in an expected utility framework is advisable. In the current policy context, risk-averse producers may not require a subsidy to adopt IPM, even if adoption reduces expected net income if risk is also reduced; alternatively, a subsidy may be necessary, even if expected net income is not reduced if IPM increases risk.

The conventional method of empirical analysis in an expected utility framework is to consider the tradeoff between expected value and variance of net returns, commonly identified as E-V analysis. Originated by Markowitz for security analysis, E-V analysis has been extensively used by agricultural economists for various applications (Scott and Baker: Hazell; Buccola and French: Mapp et al.), including IPM (Hall). Hall analyzed IPM in an E-V framework in using variance of net income with IPM and conventional practices as a measure of risk. While convenient computationally, E-V analysis does have some well-known limitations. A Taylor series expansion of expected utility of net income, E[U(R)], demonstrates these weaknesses:

$$(1) \quad E[U(R)] = U[E(R)] + U''[E(R)]\, V(R)/2! + U'''[E(R)]\, M_3(R)/3! + \cdots$$

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[1] BMPs are considered agricultural practices that will contribute to pollution goals, considering current technology and economic conditions. Some BMPs may not reduce net farm income as compared to current practices; however, federal policies recognize that subsidies may be necessary for farmers to adopt BMPs (Bailey and Waddell; Hurt and Reinschmiedt).

where $U[E(R)]$ is the utility function evaluated at $E(R)$, $U''[E(R)]$ and $U'''[E(R)]$ are the second and third derivatives of $U[E(R)]$, $V(R)$ is the variance of the net income, and $M_3(R)$ is the skewness of net income (Anderson, Dillon, and Hardaker).

If the third and higher terms of (1) are zero, E-V analysis is appropriate. Sufficient conditions for this proposition are either that the decision maker has a quadratic utility function or that net income is normally distributed (Pratt; Robison and Barry). Of these two conditions, the normality assumption generally seems much less restrictive, but this requirement may be questionable for situations in which limited historical experience exists. In situations for which the third term in (1) is not zero, economic theory suggests the impact of $M_3$ on $E[U(\Pi)]$. The absolute risk coefficient is defined as $-U''(R)/U'(R)$ and is generally considered to be declining with R in order to rationalize risky assets as not being inferior goods (Pratt). A necessary condition for this relationship is that $U'''(R)>0$ (Arditti). Referring to equation (1), $M_3>0$ will increase $E[U(R)]$. A distribution with positive or right skewness will have a higher probability of higher incomes and a lower probability of low incomes than one that has no skew or negative skew. Aside from expected utility then, this assumption has intuitive appeal.

Stochastic dominance is an alternative methodology in an expected utility framework that does not require these restrictive assumptions (Hadar and Russell; Anderson, Dillon and Hardaker). This methodology is not as efficient computationally and does not necessarily lead to as small an efficient set as E-V analysis. In an analysis of experimental data on nitrogen and phosphorus fertilizations, Anderson found 20 of 36 fertilization rates first-degree stochastic dominant, while eight rates were E-V efficient. Advanced methods can further reduce the efficient set and have been applied to a farm planning problem (King and Robison) and agricultural policy analysis (Kramer and Pope). Because of limited alternatives, the elementary concepts of first- and second-degree stochastic dominance are adequate for this paper.

Stochastic dominance is based on relationships between the cumulative probability distribution functions of alternative plans. Since the decision criteria are not very intuitive, a graphical explanation is illustrated from distributions of three alternatives, A, B, and C, in Figure 1. An alternative is first-degree stochastic dominant over a second alternative, if the cumulative probability distribution of the first, F, is less than or equal to that of the second, G, for all relevant alternatives. Formally, F dominates G if the following relationship holds for all values of net returns, R, in an interval [a, b]:

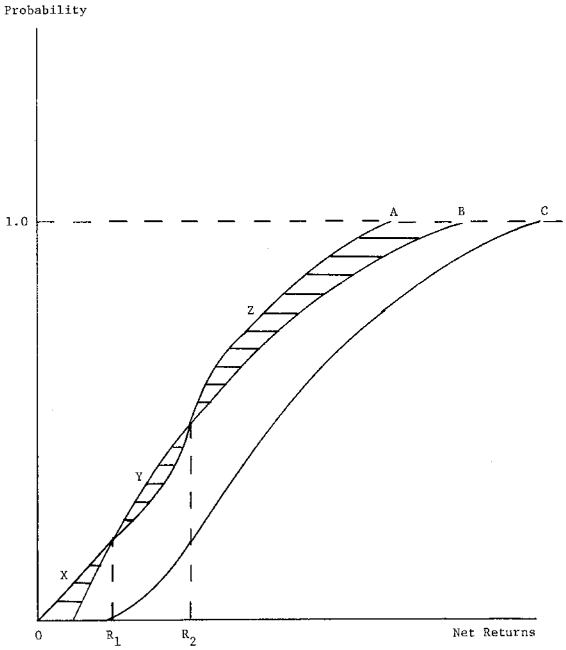

**FIGURE 1.** Illustration of First and Second Degree Stochastic Dominance

$$(2)\quad \int_a^R f(R)dR \leq \int_a^R g(R)dR$$

where f(R) and g(R) are probability density functions for the two alternatives. Graphically, the cumulative distribution function of the first is to the right of the distribution function for the second for all levels of net income. In Figure 1, C meets this criteria in comparison with A and B.

Second-degree stochastic dominance can sometimes be utilized to rank alternatives not comparable with first-degree stochastic dominance. For example, A and B in Figure 1 cannot be ranked with first-degree stochastic dominance: the cumulative probability distribution function for B is less than A for all net incomes, except in the interval between $R_1$ and $R_2$. Second-degree stochastic dominance occurs when the area, for which one distribution function is above the second, is cumulatively less for all values of net returns. Formally, F is second-degree stochastically dominant over G if the following holds for all values of R in the relevant interval:

$$(3)\quad \int_a^R F(R)dR \leq \int_a^R G(R)dR$$

In Figure 1, X is the area in which A is above B between 0 and $R_1$, Y is the area in which B is above A from $R_1$ to $R_2$, and Z is the area in which A is above B for values greater than $R_2$. Since the area of X is greater than Y, the total cumulative area in which A is above B is greater for all levels of net returns, and B is, therefore, second-degree stochastic dominant over A. It can be noted that first-degree stochastic dominance implies second-degree stochastic dominance. This relationship is also illustrated in Figure 1: C is second-degree stochastic dominant over A and B. For empirical applications, all combinations of alternatives are first considered with the criteria of first-degree stochastic dominance and the dominated alternatives eliminated. Then, the remaining alternatives are compared with second-degree stochastic dominance to determine the second-degree stochastically dominant set.[2]

The theoretical assumptions underlying these stochastic dominance criteria are quite general. If an individual's utility function is monotonically increasing, or more is preferred to less, first-degree stochastic dominance will identify preferred alternatives. If an individual has a concave downward utility function, or is risk averse, second-degee stochastic dominance will identify preferred alternatives. Since these assumptions are very general, the stochastically dominant set may be quite large. In recognition of that possibility, this paper uses both an E-V and a stochastic dominance framework and compares the results.

## DATA AND ANALYSIS

The pest management experiments examined in this study were conducted under center-pivot irrigation on Tifton sandy loam soil at the Coastal Plains Experiment Station in Tifton, Georgia. Controlled factors in the experiments were soil moisture, soil fertility, soil pH, tillage method, and seed varieties. Most nutrients and pesticides were applied through the center-pivot irrigation system. The cropping system that was analyzed encompassed: turnip greens for processing, planted on February 20; field corn, planted on April 15; and southern peas for processing, planted on September 1. All pest management levels involved six replications in a randomized block design that have been repeated for five years, 1975–79 (Epperson and Allison).

The experiments involved four different pest control strategies represented as different management levels. Management Level I was a standardized experimental control. The soil was sterilized prior to cultivation each year, and plots were hand weeded before weeds were one inch high. Therefore, herbicides and nematicides were unnecessary. Insecticides were applied with the aim of complete control. In addition, a preventive foliage fungicide was applied. Management Level II, which is similar to conventional or non-IPM practices, included a broad soil fumigant, hand weeding if necessary, a nematicide, and a foliage fungicide. Herbicides and insecticides were applied routinely to achieve complete pest control. A nematicide, foliage fungicide, and several herbicides were included in Management Level III in a manner similar to that of Management Level II. However, insecticides were applied on the basis of scouting reports. Because Management Level IV did not seek to achieve complete pest control, only one herbicide was used to reduce overall weed-crop competition. A soil fumigant, hand weeding, and a nematicide were not used, although a foliage fungicide was applied for prevention. Insecticides were applied on the basis of scouting reports; however, the insecticides used were less toxic than those on other levels (Epperson and Allison).

Using 1979 prices, multiple enterprise budgets were calculated for all replications in each year. Averages of some of the most interesting economic variables are included in Table 1 for the four treatments. These averages are consistent with the concept of IPM. The higher level of pest control in Level I, as reflected in the high value of total chemical costs, did result in the highest yields and gross returns. In contrast, Level IV had lower yields and gross revenues, but costs were sufficiently reduced with the use of IPM so that net income was higher. The data for Levels II and III represent intermediate steps in the level of pest control.[3]

It can be noted that the chemical expenditures do not necessarily represent the environmental effects of pesticide use. Hurt and Reinschmiedt have noted that knowledge about the relationship between agricultural management and non-point source pollution is very limited, especially con-

**TABLE 1.** Multiple Crop Returns and Pest Control Input Costs in 1979 Dollars by Pest Control Intensity, Averages for 1975–1979

| Returns and Costs | Pest Control Intensity | | | |
|---|---|---|---|---|
| | Level I | Level II | Level III | Level IV |
| | - - - - - - - - - - dollars/acre - - - - - - - - | | | |
| Gross Returns | 1,014.18 | 864.37 | 773.35 | 778.81 |
| Net Returns | -352.92 | -192.29 | 136.43 | 269.51 |
| Fumigants | 700.00 | 350.00 | 0.00 | 0.00 |
| Herbicides | 0.00 | 28.11 | 23.36 | 16.65 |
| Insecticides | 22.84 | 27.91 | 23.94 | 13.13 |
| Nematicides | 0.00 | 59.36 | 101.86 | 0.00 |
| Total Chemicals | 722.84 | 465.38 | 149.16 | 29.78 |

Source: Epperson and Allison

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[2] First- and second-degree stochastic dominance can also be applied to discrete probability distributions. The particular equations for the discrete situations are available in Hadar and Russell and Anderson, Dillon, and Hardaker and are not reproduced in this paper.

[3] Epperson and Allison provide more detailed information on both yields and budgetary calculations.

cerning pesticides. In earlier research, White et al., reacted to this lack of knowledge by using quantities of pesticides as a measure of potential pesticide damages. This paper adopts that concept and uses total pesticide expenditures as an index of potential environmental problems.

A final note on the methodology concerns trends in the data. Since 1979 prices were used in all the budgets and the treatments were relatively constant, any trends in the data reflect technological change. Because IPM is a new management concept, it is reasonable to expect that the scientists gained more experience as time progressed, so that higher levels of output and/or lower levels of pesticide application existed in later years. Epperson and Allison stated that such learning had occurred over the five years. Since variability due to technological trends could not be considered risk, the net income data were detrended with regression analysis before the risk analysis was implemented.[4]

Sample moments calculated from the detrended data are presented in Table 2. The detrended data have considerably higher sample means than those for the raw data in Table 1. The change for Level II is especially noteworthy, changing from a negative to a positive value. The learning process obviously has made Levels II, III, and IV more viable in reference to expected net returns. However, Level I is still not a viable alternative, which is not unexpected considering that it was largely an experimental control. For the remaining three treatments, Level II has the lowest variance, Level III the highest variance, and Level IV an intermediate value. In an E-V context, Level III is inefficient as compared to IV, having both a lower mean and a higher variance. However, Level II cannot be eliminated under this criterion, because both its mean and variance are lower. These E-V-efficient treatments do have considerably different environmental consequences—Level IV has a lower use of all pesticides, and especially fumigants (Table 1). Before this tradeoff is emphasized, the skewness estimates suggest that this E-V analysis is only tentative; all the estimates in Table 2 are large, and Level III has a positive skewness, while II and IV have negative values.

The sample cumulative distributions of the detrended data from the alternative treatments in Figure 2 allow a stochastic dominance analysis of the data. All other levels are first-degree stochastic dominant over Level I, which is not surprising considering the negative mean. In addition, Level IV is first-degree stochastic dominant over II and III, and Level III has second-degree stochastic dominance over Level II: Area A is much larger than Area B, where B is the only area in which III is higher than II. The skewness values in Table 2 are in part consistent with these results. Despite the E-V results, Level IV has a higher skewness than Level II. In a pairwise E-V context, Levels II and III would both be efficient; however, Level III has a positive skewness, while Level II is negatively skewed. It can be noted that a favorable skewness is not suffi-

**TABLE 2.** Sample Moments of Time Corrected Net Income IPM Data

| IPM Level | Mean[a] | Variance[b] | Skewness[c] |
|---|---|---|---|
| | \$ | $\$^2$ | $\$^3$ |
| Level I | -191.85 | 7,374.81 | $1.87 \times 10^{11}$ |
| Level II | 124.09 | 18,754.19 | $-4.29 \times 10^{11}$ |
| Level III | 236.00 | 33,526.92 | $29.04 \times 10^{11}$ |
| Level IV | 376.58 | 29,142.39 | $-8.49 \times 10^{11}$ |

[a] Sample mean $= \frac{1}{n} \sum_{i=1}^{n} (Y_i + bT_i)$

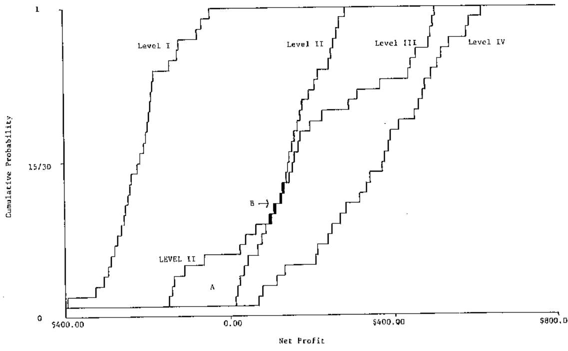
where n = number of observations= 30, $Y_i$ = observation i of net income, b = regression coefficient for time for the treatment, and T = 5 for the first year, 4 for second year . . . and 0 for the last year of the experiment.

[b] Sample variance $= \frac{1}{n-k-1} \sum_{i=1}^{n} (e_i)^2$

where $e_i$ = residual i from the linear time trend regression, and k = number of coefficients in the regression = 2

[c] Sample skewness $= \frac{1}{n-k-1} \sum_{i=1}^{n} (e_i)^3$

**FIGURE 2.** Cumulative Probability Functions for Net Profits of Four Multiple-Crop IPM Systems



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[4] Conventional polynomial regression procedures were used to detrend the data. In general, the higher-level polynomials had superior fits, using standard statistical criteria. However, examination of the scatter plots indicated that the quadratic and cubic equations probably would remove stochastic variations rather than technological trends. Therefore, it was judged that the linear time trend equations were the most adequate for detrending. Based on the linear regressions, the largest trend effects were observed in Level II, with 69 percent of the increase in net profit over time attributable to learning, while only 15 percent of the increase in net profit could be attributed to learning for Level IV.

cient for stochastic dominance to conflict with E-V analysis—the desirable positive skewness of Level III was not sufficient to overcome its unfavorable mean and variance in reference to IV.

## CONCLUSIONS

The two different forms of risk analysis in this paper gave contrasting results. In an E-V framework, Level II, which is the most conventional pesticide treatment method, and Level IV, which has the highest level of IPM, are both efficient. More risk-averse producers could be hypothesized to likely use Level II, while less risk-averse producers would be hypothesized to adopt Level IV. However, Level IV was found to be first-degree stochastic dominant over Level II. Stochastic dominance would imply that all producers, regardless of their risk preferences, would prefer Level IV. As stochastic dominance has more general assumptions than E-V analysis, Level IV would be expected to be preferred by all producers. Of course, this conclusion must be tempered by the usual caveats concerning farm applicability of experimental results. In addition, the aggregate effects of adoption of this IPM treatment may be undesirable for farmers as a whole (Taylor).

If the analysis in this paper is duplicated at the farm and aggregate level, Level IV is a classic BMP for this irrigated, multiple cropping system. Assuming that greater pesticide expenditures lead to greater environmental hazard, Level IV has less potential environmental effect than the more conventional Levels II and III. Therefore, the tradeoff between environmental quality and economic well-being of the farmer does not exist. Farmers can presumably increase their expected net profits and be in a more desirable risk situation, while decreasing potential environmental loadings from pesticides by adopting Level IV. The desirable characteristics of Level IV, in contrast to more conventional pest management practices, suggest that the experimental treatments be expended to even lower levels of pesticide use. For example, thresholds for pesticide applications could be raised from those of Level IV. Another example would be discontinuance of some of the pesticide applications in Level IV for particular pests. The analysis in this paper suggests that such treatments may be preferred by producers and have less environmental impacts, even if such treatments had lower net returns or less desirable risk characteristics than Management Level IV. Furthermore, these treatments may still qualify as BMP's, if the amount of subsidy for adoption was small compared to the reduction in potential environmental hazards.

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