A Simulative Approach to Evaluating Risk Efficiency Among Various Pest Management Compliance Levels

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ABSTRACT

A multispecies physiological, mechanistic soybean plant growth model was used to compare net returns from different levels of producer compliance to IPM extension recommendations. While the majority of producers that comply with IPM extension recommendations follow a delayed spraying regime, preliminary results indicate that strict and timely adherence to extension guidelines provides for first degree stochastic dominance over the prevalent delayed spraying strategy, and a no control approach.

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Agricultural production is fraught with risk. Producers' vulnerability to random natural events has led to implementation of production strategies to limit risk exposure to acceptable levels. Application of chemical pesticides has unfortunately been a risk reducing strategy with negative environmental implications. Integrated pest management (IPM) methods attempt to minimize pesticide inputs by substituting information and management skills, while realizing no significant reduction in profits or economic yield.

It has recently been suggested that an important shortcoming in IPM research methodology has been the attempt to provide useful pest management guidelines without considering the total cropping system (Miranowski). A more useful and appropriate area of investigation would be the economics of integrated crop and pest management, which would consider optimal pest, fertility, water, soil management, and other input decisions. Attempts at implementing this comprehensive decisional approach are hindered by the lack of sufficient biological data documenting inter-system linkages in the production process. In addition, research budget limitations and the nature of agricultural production allow only a limited number of input variations to be tested and evaluated annually. A more effective system modeling approach would compress the production season to allow any combination of subsystem management strategies to be implemented, evaluated according to established criteria (usually yield or net returns), recalibrated, and then reapplied, allowing the iteration to continue until an efficient set of strategies is determined.

The recent development of bioeconomic simulation models, which allow production systems evaluation through seasonal iteration, is a major step toward the implementation of an integrated crop and pest management research methodology. These models allow production system components to be independently scrutinized and evaluated, and then combined in determining an optimal overall management strategy. Specific components may include plant growth processes, soil management, irrigation, fertilization, as well as the pest-predator subsystem.

The pest damage component of a production system may be the most difficult to model for a number of reasons. The stochastic nature of pest and predator influx rate and calender date; the complex nature of pest interaction and its effect on crop yield; the sheer numbers of competing organisms in the field, allow damage effects to be only an approximation. For these reasons previous IPM work has relied upon single species crop damage models (Hueth and Regev; Carlson; Hall and Norgaard). However, it has been argued that the lack of a sufficiently detailed pest damage model relative to other system components may virtually negate the validity of yield results and do little to enhance the information state available to producers confronting risky control alternatives (Reichelderfer). The recent development of a multi-pest, crop growth model addresses this problem by strengthening pest damage modeling capabilities to more accurately reproduce actual field conditions (Wilkerson, et. al.). Sophisticated managerial tools of this type are necessary for the implementation of a comprehensive systems approach to pest control. They allow evaluation of pest control strategies to be conducted and extension recommendations given, with greater confidence in expected outcomes.

IPM Program Evaluation

IPM program evaluations have traditionally compared yields and costs of program participants with those of non-participants (Hatcher, et. al.). Research quantifying the risk associated with a particular management strategy has not included the degree of producer participation which ultimately defines the success or failure of local or regional IPM programs. Given extension IPM recommendations, are there differences in expected yield and net income for those producers who follow guidelines faithfully throughout the production season, and those that only practice sporadic compliance? Will delayed compliance result in beneficial outcomes in years when strict adherence may prove to be short sighted?

Given the stochastic nature of weather, insect migration and population dynamics, the levels of risk associated with various pest control alternatives is an important factor in strategy evaluation. The bioeconomic simulation model provides a method of alternative strategy evaluation under stochastic conditions.

Our aim in this paper is to examine the effects of variational compliance with IPM extension recommendations. Cumulative probability distributions for net returns, generated by nine years of weather data (temperature, rainfall, radiation, and pan evaporation), are sampled in a stochastic dominance framework in order to select a risk efficient set of production strategies. Modeling compliance in this manner allows a comprehensive approach to IPM program evaluation and can serve as a reference point in risk assessment for both the producer and extension.

Model and Procedure

This study utilizes the Florida Soybean Integrated Crop Management (SICM) model (Wilkerson, et. al.). This model is a multi-species bioeconomic simulation model. It includes a soybean crop growth model, a soil water component, insect growth and damage models, and an economic component as it's principal elements. The insects included are the velvetbean caterpillar, Anticarsia gemmatalis (Hubner), (VBC), the corn earworm Heliothis zea (Boddie), (CEW), and the southern green stinkbug Nezara viridula, (L), (SGSB). These species represent the principal sources of diminished yield in southern Georgia soybeans due to insect damage by defoliation, stem and leaf destruction, and pod and seed damage, respectively. The insect population dynamics and damage relationships, as well as the other model components are sufficiently documented to preclude a description here (Wilkerson, et. al.). Producer delayed compliance with extension recommendations is modeled according to data compiled from survey's of southern Georgia soybean producers (Hatcher, et. al.). The data indicate that producers sampled adhered to extension recommendations 69 percent of the times an economic threshold was reached. When a spraying threshold was adhered to, those producers sampled applied a treatment within the recommended three day window of economic advantage 41 percent of the time. In the remaining instances a spray was applied after this window had passed, up to seven days post threshold which generally implies vulnerability to economic yield loss. We designate this strategy as differential control.

The model was initialized according to Extension Service recommendations (Suber and Todd). These recommendations call for a foliar treatment of Ambush (permethrin, .03 gal. of active ingredient per acre) on the day following a pest scouting report indicating defoliation in the plant stand during the vegetative through mid-pod fill stages of soybean growth, has reached twenty percent. Methyl parathion (2 pints of active ingredient per acre) is applied during the later growth stages to combat damage from pod and seed feeding insects, and is indicated by counts of SGSB and CEW which reach thresholds levels. This information was compiled as a FORTRAN subroutine which was called by the main program daily during the production season, and implemented when the seedling stand became vulnerable to pest damage.

In addition, two other pest management scenarios were modeled to evaluate degree of compliance on net returns. A one hundred percent adoption strategy allowed a treatment to be undertaken on the day after a defoilation and/or insect count threshold was reached, which we designate as 100 percent extension compliance. Finally, a strategy was included in which no pest control measures were taken, regardless of pest infestation and defoliation levels.

The SICM model was recalibrated to reproduce Georgia Coastal plain soil type conditions, and was driven by nine years of weather data (1975-1983) from the Coastal Plains Experiment Station at Tifton. The model was run once for each year for each of the deterministic scenarios (100 percent compliance; no control). Thirty replications for each weather year for the stochastic case were run incorporating a random number generator (Cheney and Kincaid) to initially model compliance and then timeliness of threshold adherence. The soybean cultivar was Bragg in each model run. For each run, the following parameters were initialized:

a) May 20th planting date,

b) Irrigate to avoid most water stress,

c) 36 inch row spacing,

d) VBC and CEW infestation intensity and calendar date according to historical data from the Tifton entomological experiment station,

e) SGSB counts at 3.5 per three row foot.

Use of Stochastic Dominance

The application of stochastic dominance to evaluate and rank alternative production strategies has been well established in the literature. King and Robison applied the method to a farm planning problem; Danock, et. al., applied the procedure to the problem of machinery selection under conditions of weather variability; Musser, et. al., used stochastic dominance and E-V analysis to compare net returns of four multiple crop IPM systems. The distributions ranked in our analysis corresponded to the three pest mangement strategies described earlier. The stochastic dominance approach appears appropriate since it exploits all the information contained within the data. Rather than simply revealing the economic feasibility of a particular pest management strategy, the stochastic dominance method provides for producer risk to be directly considered in the form of expected variability of net returns.

Results

Sample moments calculated from the simulation results for the three management scenarios are presented in Table 1. The benefits derived from strict adherence to IPM extenstion recommendations are evident by a higher value for expected net returns over the nine year period, and the lowest variance among the strategies analyzed. As expected, the no control option proved to be inappropriate for those producers whose principal objective is profit maximization. Ignoring an extension threshold recommendation completely in a production region characterized

Table 1. Expected Per Acre Net Returns and Variance of Three Pest Management Strategies, 1975-1983.

Strategy	Net Returns	Net Returns Lowest	Net Returns Highest	Variance
100% Extension Compliance	$132.52	101.27	169.59	670.24
Differential Control	$ 65.85	16.22	108.69	987.83
No Control	$(57.69)	(159.14)	59.33	4,528.17

by weather conditions generally favorable to insect propogation, provided for the riskiest alternative in terms of expected profits and variance of returns. Positive profits were realized in two of the nine weather years, corresponding to light, early VBC influxes, and minimal pressure from CEW and SGSB. This particular combination of infestation allows the leaf canopy to regenerate new growth after insect pressure has diminished, and allows predators in the field to provide an effective constraint on pest population growth. However, this scenario occurred only twenty percent of the time. A farmer involved in soybean production in the southeast depending on light insect infestations, and the natural abilities of the soybean plant to regenerate vegetative growth, as well as predator control of pests, can expect to experience significant losses in his soybean enterprise in seven of nine production seasons.

Practicing a delayed spray regime proved inferior to prompt compliance for both ranking criteria. Delaying a spray for up to seven days post-threshold decreased expected net returns and increased variance of returns by approximately fifty percent compared with the strict compliance strategy. The nature of the delayed spraying strategy was not available from the data but may be explained by one or more of the following reasons:

a) the inability to contract for a prompt foliar spray;

b) inadequate machinery complements to provide a timely response to an extension threshold;

c) the desire to allow predator populations to remain in the field for as long as economically feasible to derive the greatest benefits from biological control;

d) the belief that a non-chemical control strategy would provide protection from significant pest damage. The delayed spray may indicate that the alternative strategy failed and a chemical control was required to protect the producer from significant yield loss.

These results are reiterated in Figure 1. First degree stochastic dominance (FSD), requires that one cumulative probability distribution (CPD) lie everywhere to the right of another being compared. Notice that the 100 percent compliance strategy provides a regime that is FSD over both the differential control (DC) and no control strategies, and is the only regime deemed economically efficient under risk. The timely application of foliar insecticides provides both cost and efficiency effectiveness not provided by a delayed spraying regime, regardless of the legitimacy of the delay. Also note that the DC strategy is FSD over the no control option. This result reflects the generally accepted assumption that extension compliance, though delayed, is a superior strategy in terms of risk reduction than the no control approach. However, it also makes clear the fact that a delayed spray due to producer discretion, or the technical inability to comply with a threshold call, generally results in net returns that are inferior to a strict compliance approach.

The efficient management set according to stochastic dominance criteria, consists of the 100% compliance regime. Extension threshold recommendations should be strictly adhered to, and provisions for strict compliance made explicit in pre-production planning.

Conclusions

The specific application of the SICM simulation model in this study indicates the profitability and risk associated with differing levels of producer compliance with IPM extension recommendations. A delayed spraying strategy, commonplace among those producers who were attentive to extension advice, proved to be FSD over a no control strategy.

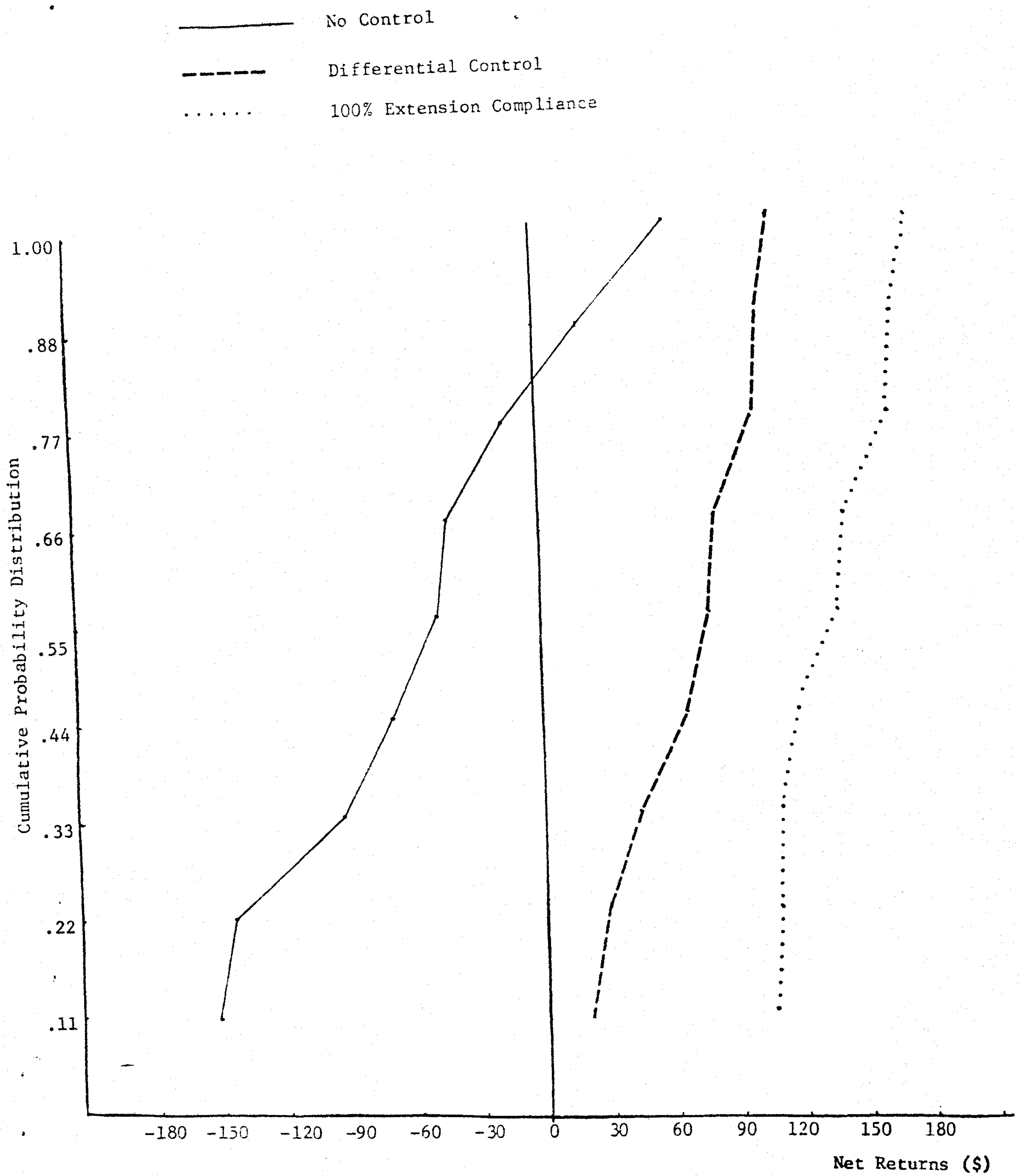

Figure 1. Cumulative Probability Distribution for Net Returns of Three Pest Management Strategies.

However, the DC regime was inferior to a prompt spray when defoliation and/or insect counts signaled a control was required. Delaying a pesticide application for up to seven days following an extension recommendation to treat, decreased expected net returns and increased the variance of returns for the nine years of weather data analyzed. Producers' reliance on the natural ability of the plant stand to resist pest attack and to generate new growth, predator's ability to maintain pest populations below economically damaging levels, and the combined effects of other non-chemical control alternatives, as well as possible technical inefficiencies provided for inferior results compared with timely compliance. Producers who adopt a DC approach to pest management may expect to realize net returns from their soybean production enterprise to be inferior to a strict compliance strategy in all years regardless of pest influx date and intensity. These results argue for strict adherence to IPM extension guidelines for chemical pesticide applications to ultimately protect yield and net returns when other types of control measures are overwhelmed.

The virtuosity of bioeconomic simulation models such as SICM lie in their ability to model production system and management variation to provide producers with information on probable outcomes of specific production strategy decisions. A more in depth analysis of IPM compliance would specifically address the questions of flexibility in strategy adherence; variation in threshold defoliation and insect counts to test the robustness of current extension recommendations; or determining whether a calendar spray schedule is as effective as percent defoliation and insect count criteria. Such information would be very useful for producers and those involved in extension research in lowering the vulnerability of the production system to economic loss from pest damage.

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