An Evaluation of Integrated Pest Management with Heterogeneous Participation

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Principal component analysis is employed to develop indices that distinguish between participants and nonparticipants in Integrated Pest Management (IPM) programs. Results of incorporating these indices into yield, net return, and production cost functions for cotton producers indicate that both yield and costs increase as the degree of producer participation in IPM increases. Although these results are inconsistent with previous research, they are consistent with the theoretical relationship between IPM and conventional input usage.

Application of chemical pesticides is one of the management practices which have contributed to increased crop yields during the last three decades. However, widespread use of these pesticides has resulted in significant increases in insect resistance as well as ecological, public health, and worker safety concerns. Thus, pest control through the application of pesticides evolved into integrated pest management (IPM) programs. The general objective of IPM programs is to optimally manage pest populations such that producers' net returns are maintained or enhanced with minimal environmental degradation. Considerable public expenditures have been made on these programs. As a result, evaluation of IPM programs is helpful in determining their effectiveness compared to traditional pest control methods. Carlson [1981]; Hall; Masud *et al.*; Reichelderfer and Bender; and Teague and Shulstad have considered the impact IPM has on production practices, returns, and risk to agricultural firms. Social costs of IPM compared to conventional practices have been evaluated by Boutwell and Watson and Reichelderfer and Bender.

These previous IPM evaluations have several limitations. As suggested by Miranowski, a comprehensive evaluation requires complete enterprise budgets. With this knowledge of cultural practices, variations in yields, costs, and returns due to different input combinations resulting from IPM participation may be investigated. Complete enterprise budgeting will then account for other sources of variation, such as different machinery complements, that could result in erroneous evaluations. Another problem with evaluating IPM program is distinguishing producers who participate in IPM from nonparticipants. The traditional method of evaluating IPM programs is to compare yields and costs for program participants with those of nonparticipants. However, as IPM programs continue to expand, identifying homogeneous participants and nonparti-

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cipants becomes increasingly difficult. As pointed out by Boutwell and Smith, participants or cooperators are no longer characterized by the use or nonuse of IPM. Instead, participants are characterized by how much of the available IPM practices and information are incorporated into their production practices. Thus, as IPM programs increasingly influence producers, a heterogeneous continuum of participation in IPM has to be evaluated.

A creditable evaluation of IPM programs requires an improved theoretical understanding of the relationship between IPM and conventional input usage. IPM has been defined as an attempt to decrease pesticide use while maintaining current levels of production [Hall]. Under this concept, IPM programs attempt to modify the production input mix, resulting in a reduction of pesticide inputs in the production process. However, IPM provides information on the optimal input mix and, as addressed by Headley and others, could be considered a technical change. Under this view, standard theory would suggest that the economic efficient level of pesticides as well as other inputs could increase. The possibility that technology may increase pesticide expenditures for individual firms has not generally been recognized nor has empirical evidence illustrated this possibility. One exception is Carlson [1980], who cites a Ph.D. dissertation by Grude that found evidence of both complementary and substitute relationships between IPM and pesticide use. Thus, a broader theoretical view of IPM may provide alternative hypotheses concerning the environmental contribution of IPM programs.

The objective of this paper is to evaluate the Georgia Cooperative Extension Service IPM program for cotton with special attention to the limitations in previous studies. IPM is related to the concept of technical change which provides a theoretical basis for investigating relationships among inputs such as pesticides and IPM. Complete firm enterprise production data were available for this study. In addition, principal components were utilized to construct IPM participation indices to accommodate heterogeneous participation. These indices are incorporated into a regression model as independent variables along with variables that account for possible differences in land, capital, and labor inputs.

IPM as a Technical Change

The idea of IPM as a technological change parameter is not new. Headley and Taylor demonstrated the possible paradox of IPM technology not decreasing pesticide use. Their discussions relate to the possible market effects of an IPM technology. Specifically, Taylor illustrates that an increase in technology may expand industry's use of pesticides if acreage increases as a result of the technology adoption. Thus, at an industry level, IPM may lead to increased pesticide usage. However, as demonstrated below, IPM may still lead to an increase in pesticide usage when acreage is held constant.

In a partial equilibrium framework, a perfectly competitive producer selects a (1 by z) vector of IPM input levels, Z, such as field scouts, along with a (1 by x) vector of conventional input levels, X, which includes pest control inputs such as pesticides. Producers, given an acquisition cost vector, w, associated with X and an output price, p, are assumed to maximize expected profit, π. This maximization is constrained by a production technology set satisfying the usual neoclassical properties of regularity, monotonicity, and strict convexity (Varian). Assuming fixed levels of IPM technology, optimal input demand functions derived from profit maximization are:

$$X_i^* = X_i(p, w, Z), \; i = 1, \ldots, x. \qquad (1)$$

The effect of an IPM technology change can be investigated by varying one of the

IPM inputs, Z_k. The result is a Hicks' neutral technological change if the marginal rate of substitution between X_i and X_j remains unchanged. Weaver [1978, 1983] relates Hicks' definition of technological change in the following mathematical form for multiple inputs:

Definition: Technological change is Hicks'

$$X_i \begin{Bmatrix} \text{saving} \\ \text{neutral} \\ \text{using} \end{Bmatrix} \text{relative to } X_j \text{ if}$$

$$B_{ij} = (\partial \ln X_i^*/\partial \ln Z_k) - (\partial \ln X_j^*/\partial \ln Z_k) \lesseqgtr 0;$$

where B_{ij} is a measure of bias in allocative impact of a change in Z_k. This definition is based on the difference between input elasticities arising from an IPM technological change, and thus, measures the response of pest control as well as other inputs to a change in IPM technology.

These elasticities measure the total effect of a change in an IPM technology which can be decomposed into two effects, an output and substitution effect. Specifically, taking the partial of (1) with respect to Z_k given,

$$X_i(p, w, Z) = X_i(y(p, w, Z), w, Z),$$

where y(p, w, Z) is the supply function, yields,

$$\partial X_i(p, w, Z)/\partial Z_k = [\partial X_i(y, w, Z)/\partial y][\partial y(p, w, Z)/\partial Z_k] + \partial X_i(y, w, Z)/\partial Z_k. \quad (2)$$

The first and second terms on the right-hand side of (2) measure the output and substitution effect, respectively. If an increase in Z_k reduces the level of input X_i given a constant level of output, the substitution effect is negative. The stronger the negative substitution effect on X_i, the higher the likelihood that X_i is Hicks' saving relative to X_j. However, an increase in Z_k may increase output resulting in a positive output effect. This may result in the output effect completely offsetting the substitution effect, resulting in an increased level of X_i for a given change in IPM technology. Input X_i may still be Hicks' saving relative to X_j due to the IPM technology having a proportionally larger effect on X_j than X_i. Considering X_i as a pesticide input, even if it is Hicks' saving relative to other inputs, IPM may still increase the level of pesticides employed. Thus, IPM in the context of changing the production process may not lead to a decrease in pesticide expenditures.[1]

Incorporating IPM parameters as technological shifters in yield, net return, and cost equations, along with conventional inputs, provides a method for evaluating IPM programs. The theoretical results developed in this section suggest that an IPM technical change should increase yields and net returns; however, its effect on production inputs is indeterminate. IPM may be positively or negatively associated with production inputs such as pesticides, depending on the magnitude of the substitution effect relative to the output effect. A measure of producers' participation in IPM is required for empirical estimation of these effects. Data employed for indices of IPM participation are discussed in the next section followed by the development of indices for estimating the total effect of IPM participation on costs and returns.

Data

Determination of reliable pest density estimates and pesticide applications requires detailed data collected at weekly intervals. This type of data collection is resource intensive, and thus, does not lend itself to a large random sampling procedure. A trade off then exists between a random sample where policy implications for the whole industry can be determined,

[1] The aggregate affect on supply of increased output by all producers as investigated by Taylor and Taylor and Lacewell should also be considered. Increase in aggregate supply resulting from a change in IPM technology may result in a decline in product price, and thus, offset any increase in inputs due to an output effect.

and weekly data where individual firm effects can be analyzed in detail. This study attempts to examine the micro-level implications of IPM programs which require a detailed weekly data collection procedure for reliable estimates. However, obtaining a significant number of growers willing to cooperate in such a comprehensive analysis is difficult. In a study by Teague and Shulstad, detailed data were collected for only six "IPM producers" and four "non IPM producers." Carlson [1981], in a two-year study on IPM evaluation used only 17 producers. A stratified random sample of 75 producers over a five-year period employed by Hall, consisted of aggregate end-of-year estimates which are not suitable for examining micro-level implications of IPM programs.

Thirty Georgia growers, with a total of 115 fields, were willing to have their operations monitored on a weekly basis during the 1981 production season under the aegis of the Cooperative Extension Service. Detailed pesticide use records were collected to determine type of chemicals applied, amount of active ingredients used, and method and date of applications for each field. Field scouts also collected data on insect populations in conjunction with the pesticide records. Complete enterprise budgets for each field were also developed to account for sources of variation other than the level of participation in IPM.

For each field, initial field histories which describe early-season production inputs and input costs, as well as the machinery operations performed up to planting, were completed. Subsequently, all chemical and irrigation applications were monitored on a weekly basis. Detailed machinery and equipment use records were also maintained to account for cultural practices throughout the season. In calculating ownership costs for machinery and equipment, actual farm costs were used in an effort to more closely approximate the cost of production. Items such as purchase price, present value, depreciation method, and average rate of interest paid on borrowed money were obtained on a mail-in basis and by telephone to calculate actual costs of machinery, irrigation, and other production inputs. Personal contacts were also made to complete the collection of season-end data which provided harvest and marketing information. As the data were continuously updated throughout the season, partial budgets were constructed for each grower and then completed after harvest. The 115 enterprise budgets were then pooled by grower for evaluation of the IPM programs.

Principal Component Indices of Participation

Ruesink has suggested that economists should, in cooperation with entomologists and agronomists, develop lists of criteria for "good" pest management. These lists can then be employed for evaluating IPM programs. Boutwell and Smith developed a list composed of five major pest management characteristics. The probable collinearity among the characteristics measuring pest management indicates that developing an index of participation is warranted. Thus, Boutwell and Smith subjectively weighted the characteristics for their relative importance in gauging the degree of IPM participation. The characteristics were then summed to provide an index. The individual insect management characteristics were obtained by a questionnaire administered through personal contact or telephone survey. A disadvantage of Boutwell and Smith's approach is that the influence a particular characteristic has on the index is arbitrary. The particular weights reflect the relative importance of characteristics to the researcher rather than their importance in explaining variations in participation. For example, a researcher may weigh heavily a characteristic important to insect control. However, the characteristic could be

TABLE 1. Characteristics of IPM Participation and Factor Loadings.[a]

Description	Factor 1	Factor 2
1. Proportion of proper to total pesticide applications.	0.510	−0.076
2. Proportion of economic thresholds treated to total number of thresholds.	−0.124	0.688
3. Pesticide applications after thresholds minus applications before thresholds relative to total number of applications.	0.512	0.033
4. Proportion of applications not identical across fields to total pesticide applications.	−0.089	0.617

[a] For a discussion of how the characteristics were developed, refer to Linder *et al.* Economic thresholds were based on Georgia Extension Service criteria for controlling bollworms, bollworm eggs, boll weevils, and tarnished plant bugs affecting cotton before the open boll stage (Lambert and Herzog).

generally practiced by all producers and not be as strong a determinant of IPM participation as an alternative characteristic. Principal component analysis solves this problem of assigning *a priori* weights to create indices by statistically transforming a set of k characteristics for n producers into factors or indices which are pairwise uncorrelated and explain the most variation within the characteristics.

The IPM program in Georgia can serve as an application of this analysis. Georgia's primary IPM program is the use of field scouts to monitor insect pressure. Thus, IPM indices were constructed from a set of characteristics specifically associated with insecticide use. Each grower employed only a cotton scout sponsored by the Extension Service. Over the course of the growing season, scouts monitored insect pressure consisting primarily of the number of bollworms (and bollworm eggs), boll weevils, tarnished plant bugs, and beneficial insects per 100 plant terminals. All cotton scouts were trained in the use of standardized scouting techniques. This provides consistent insect counts across fields allowing for a more reliable comparison of insect records for each field [Adams and Lambert]. As these characteristics were computed for each grower, all decisions made in determining thresholds for the aforementioned insects were based on cotton IPM recommendations prepared by the Georgia Cooperative Extension Service. Extension chemical pesticide recommendations were also used as guidelines in determining whether appropriate chemicals were applied [Lambert and Herzog, 1981].

Pesticide use for each grower was monitored as to type of chemical applied, amount of active ingredient used, method by which the chemical was applied, and date of application. IPM characteristics were then derived from the data based on insect records and pesticide spray records which were combined and listed in chronological order. These characteristics of IPM utilization were established by Extension IPM entomologists after consultation with agronomists and economists, and the characteristics dealt primarily with timing of chemical applications in relation to insect thresholds (Table 1). The characteristics were designed to be as objective as possible in order to develop a standard method for evaluating IPM programs.

The first and third characteristics measure the proportion of proper chemical sprays applied to the total number of sprays, where the total number of sprays is equal to the sum of the sprays before and after a threshold had been reached. The interval between the time a threshold was reached and the time a pesticide application was applied is considered by the first characteristic. Specifically, a proper insecticide application is administered within 48 hours after an economic threshold is reached and the selection of materials is consistent with insect pest(s) reported and with Extension Service control recommendations. The third characteristic is designed to capture the chemical sprays made before an insect threshold is reached. Beneficial predators can contribute to pest control, and spraying before thresholds may increase the chances of destroying these beneficials. Therefore, this characteristic is considered an appropriate measure of IPM utilization.

The second characteristic measures the number of times thresholds were reached and an application was made relative to the total number of thresholds. This characteristic measures the number of economic thresholds not accompanied by a pesticide application. Finally, the fourth characteristic was designed to capture variations in treatments across fields. Presumably, an IPM participant would not only tend to vary timing of applications but also material and rate of applications. Entomologists felt that these four characteristics generally provide a reasonable list of criteria for "good" pest management. The characteristics consider beneficial predators, economic thresholds, timing of pesticide applications, pesticide materials and application rates, and considerations of field specific treatments.

The technique by Belsley *et al.* [pp. 100–104], which tests for the presence of multicollinearity, indicates moderate to strong dependencies among the four characteristics. Thus, principal component analysis was applied to the characteristics to develop indices for IPM participation. Only factors having an eigenvalue of one or greater are considered in the analysis. An eigenvalue is the total amount of variance within a set explained by a given factor. Characteristics are standardized in factor analysis so the factors retained explain at least the amount of variance within a single IPM characteristic. This analysis reduced the four characteristics to two factors (indices), which accounted for 75 percent of the total variation in the characteristics. Table 1 presents the factor loadings for the indices. Factor loadings indicate the influence each characteristic exerts on the two indices. This provides a method to determine the role a particular characteristic plays in the indices. From Table 1, the major characteristics influencing the first index are the first and third characteristics. The second and fourth characteristics dominate the second index.[2]

IPM Regressions

Costs and returns were computed on a per acre basis for each field, and for further analysis the field data were pooled across producers. An adjusted price received, 56 cents per pound of lint cotton, used to calculate net returns was computed as the simple average of the price received among all growers. This adjusted price was employed to remove the market variability in price due to time and space from the profit data. Total variable costs, pesticide costs, and net returns were calculated in the budget. Total variable costs comprise pesticides, fertilizer, lime, seed, machinery, irrigation, and labor expenditures. Pesticide expenditure is the sum of insecticides, herbicides, fungicides, and nematicides expenditures. Approximately 79 percent of all pesticide expenditures by Georgia cotton producers in 1981 were for insecticides. Net returns were calculated by subtracting total variable costs from adjusted gross receipts. Adjusted gross receipts is yield multiplied by the adjusted price, where yield is measured in terms of pounds of cotton lint.

Models of yield, net returns, and production costs were estimated in order to evaluate economic consequences of IPM participation. The IPM indices developed

[2] Similar to other restricted least squares analysis, principal components will not determine the exact quantitative role a particular characteristic plays on a dependent variable to be explained unless the restrictions imposed are true.

above were employed as IPM technical change variables in the models along with detailed enterprise budgeting data for the 30 cotton producers in eight Georgia counties. Ordinary least squares was applied separately for yield, net returns, total pesticide costs, and total variable costs, as dependent variables, based on 30 producer observations.[3] Dummy variables were also incorporated into the regressions to account for natural resource differences among the counties such as climate and soil type.

The results in Table 2 for the yield, net return, total pesticide cost, and total variable cost equations show varying degrees of fits with R^2 equaled to 0.74, 0.55, 0.74 and 0.90, respectively. The F values are significant at the 0.01 level for the yield and cost equations. However, for the net return equation, the F value is significant only at the 0.25 level. The signs of the coefficients in every case are consistent with *a priori* expectations for the yield equation. Pesticides and fertilizer, lime, and seed variables are significant inputs in production with a positive contribution to yield. A significant wrong sign appears in the machinery, irrigation, and labor variable in the net return equation. This indicates that growers may tend to be over capitalized. The depressed market conditions for cotton in 1981 and other field crops may partially explain the negative coefficient associated with this variable. Pesticides and fertilizer, lime, and seed variables are significant at the 0.01 significance level in the total pesticide cost equation. This is consistent with the definition of total variable cost as operating and labor costs of production.

The coefficients associated with the IPM indices are of particular interest. The first IPM factor is significant in the yield equation whereas the second factor is not. This result indicates that the application of pesticides in accordance with existing thresholds does significanty increase yield. Neither of the coefficients associated with the IPM indices in the net return equation are significantly different from zero at the 0.10 level. Coefficients associated with the IPM indices in the pesticide cost equation are also not significant at the 0.10 level, which indicates that IPM has no influence on pesticide expenditures. This result is inconsistent with previous research. For example, Hall found that IPM reduced pesticide expenditures in citrus and cotton production in California and Miranowski found a substitution relationship between IPM and pesticides. An exception is noted in a Ph.D. dissertation by Grude which found both a complementary and substitution relationship [Carlson, 1980]. The coefficient associated with the first factor in the variable cost equation was significant at the 0.10 level of probability. Thus, IPM utilization may contribute to the variable costs involved in cotton production. Referring to Table 1, this factor is loaded heavily on the two characteristics concerning thresholds and the timing of chemical applications. This result differs from the results of Teague and Shulstad where IPM utilization was found to significantly lower the variable costs of production. Since IPM had no significant effect on total pesticide expenditures, the significance of the IPM variable in the total variable cost equation is the result of higher nonpesticide expenditures incurred by producers actively following IPM.

Significant differences in the county yield and net return dummy variables can be partially explained by variations in insect pressures. In 1981, Morgan, Dooly,

[3] Generalized power or translog functions were not estimated given insufficient degrees of freedom. Alternative model structures, for example logarithmic, were estimated and interested readers may refer to Linder *et al.*, for summary statistics on these models. However, linear relationships generally provided superior summary statistics which indicates that the production technology may be exhibiting a linear spline type of surface.

TABLE 2. Regression Results.[a]

Independent Variable	Equation			
	Yield	Net Return	Total Pesticide Cost	Total Variable Cost
Intercept	81.07	50.90	23.87	2.54
	(164.81)	(102.01)	(25.86)	(37.18)
Input Expenditures				
Pesticides	4.16**	1.02		1.32***
	(1.47)	(0.91)		(0.33)
Fertilizer, Lime and Seed	2.66*	0.35	−0.20	1.19***
	(1.45)	(0.90)	(0.23)	(0.33)
Machinery, Irrigation and Labor	0.02	−0.98*	0.15	0.17
	(0.78)	(0.48)	(0.12)	(0.18)
IPM Indexes				
Factor 1	66.41*	21.38	−0.98	14.69*
	(36.07)	(22.33)	(5.79)	(8.14)
Factor 2	3.82	7.51	4.77	−2.56
	(36.47)	(22.57)	(5.75)	(8.23)
County Dummy Variables				
Morgan	−243.84*	−127.97	13.00	−17.08
	(125.10)	(77.22)	(19.84)	(28.02)
Dooly	−312.23**	−179.73**	27.45	−0.79
	(124.77)	(77.22)	(18.96)	(28.15)
Turner	−253.55*	−161.42*	7.95	24.42
	(131.95)	(81.67)	(21.11)	(29.77)
Calhoun	−224.39	−132.42	47.41**	−5.29
	(144.36)	(89.35)	(20.31)	(32.57)
Terrell	−443.23**	−325.54**	104.32***	85.18*
	(209.26)	(129.52)	(22.91)	(47.21)
Candler	−137.30	−69.32	−2.35	−12.24
	(111.34)	(68.91)	(17.97)	(25.12)
Echols	142.22	−10.04	46.65*	87.64**
	(167.09)	(103.42)	(24.48)	(37.69)
R^2	0.74	0.55	0.74	0.90
F	4.13	1.76	4.58	13.50

[a] Standard errors of estimates appear in the parentheses with the following significance levels: * 0.10 significance level; ** 0.05 significance level; *** 0.01 significance level.

Turner, Calhoun, and Terrell Counties experienced sigificantly higher insect pressures compared with the east Georgia counties, Candler and Emanuel. However, any shift in the yield intercept for Calhoun County was mitigated by higher total pesticide expenditures. Total variable cost intercepts associated with Terrell and Echols Counties are significantly higher. These higher costs are in part explained by higher pesticide costs in the case of Terrell County and the sample containing inexperienced growers in Echols County. In Echols, 1981 was the first year that the sampled growers produced cotton.

Although these results do **not** generally conform with previous research, they are consistent with the economic theory of IPM presented earlier in this paper. Recall IPM technology exerts two effects; output and substitution on input usage. In Hall's research, IPM technology resulted in a relatively large substitution effect which was not offset by the output effect, and thus, pesticide expenditures were reduced. Similar results occurred with total variable costs in research by Teague and Shulstad. However, in this study the output effect just offset the substitution effect for pesticides given a change in IPM technology; therefore, pesticide expenditures tended to remain constant. Other inputs in the production process increased, possibly as a result of a larger output effect relative to the substitution effect, resulting in a corresponding increase in total variable cost. These results indicate that participation in IPM may not reduce pesticide expenditures. However, participation does lead to an improvement in the timing of pesticide applications, and thus, higher yields.

Conclusions

In summary, the recognition that participants and nonparticipants in IPM are a continuum rather than a dichotomy is necessary for program evaluation given the current state of program development. Collecting IPM characteristics of producers is one method in distinguishing degrees of participation. However, a problem exists in systematically reducing these characteristics down to a manageable size for evaluation. It is suggested in this paper that principal component analysis may be employed to alleviate this problem. Applying this analysis to IPM characteristics resulted in the development of IPM participation indices. Results of incorporating these indices into yield and total variable cost functions indicated that yield and total variable cost increase as the degree of producer participation in IPM increases, whereas pesticide expenditures and net returns remained constant. These results are consistent with the economic theory of IPM and indicate that an IPM program may not always decrease the level of pesticides for individual producers.

The predominant limitation of this study is the availability of data from only one production period. Perhaps more conclusive evidence of the benefits received by producers from IPM technology could be obtained with several years of information. In this way, the strengths and weaknesses of the IPM characteristics and methodology chosen for this study would become more apparent. By observing several years of data, the variations in production practices and production results would be reduced. Furthermore, having only a single season of production information on which to base an evaluation of improved IPM technology is not sufficiently comprehensive. Only with multiyear data can the interseasonal benefits of IPM practices be analyzed effectively.

Although firm conclusions cannot be drawn from the results of this study, implications do exist and can be taken into account for policy purposes. The results of this research show that IPM programs have made an impact on cotton production in Georgia. As mentioned by Carlson [1981], there is a tendency to underestimate the benefits resulting from IPM since information is free to all individuals, including nonprogram producers. By distinguishing between the various levels of IPM use and then documenting the benefits of IPM, justifying the existence of on-going programs can be more easily accomplished. In Georgia, the evidence for IPM suggests that the present Extension programs are beneficial.

Given that the private goal of cotton producers is to maximize profits and the social goal is to minimize the use of pesticides, the concept of IPM is consistent with respect to both of these goals. Implications of the results of this study indicate that IPM has the capacity to increase yields while at least maintaining the same level of pesticide expenditures as a non IPM approach. Therefore, continuing IPM programs and educating Georgia farmers with regard to new IPM technology, as offered by the Extension Service, may be beneficial for agriculture as well as society.

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