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RESEARCH NOTES

PESTICIDE USE DECISIONS IN AGRICULTURE—A NOTE

In terms of productivity, pesticides come next only to fertilizers and irrigation; in some situation it becomes the most critical input deciding the difference between actual and normal yields. These are also very expensive. However, unlike the use of fertilizers, economists have not devoted enough attention to the efficient use of this input and only a handful of empirical studies have been done. There are two reasons behind this lack of attention. To start with, data on response to pesticide use are meagre and more importantly, the pest-crop-environment relationships are extremely complex and difficult to model. The consequence has been that recommendations regarding pest control in general and pesticide use in particular, are usually devoid of economic content.

A series of two papers by Hillebrandt[1] initiated the involvement of economists in this area. In the first, she outlined the derivation of a pesticide dosage response based on two relationships—the pest damage and the pest-kill function. In the subsequent paper, Hillebrandt explicitly recognized the stochastic nature of the dosage response curve and suggested a game theoretic optimization procedure based on Shackle's degree of potential surprise. Relatively more sophisticated and complex models have been suggested[2] by economists and bio-statisticians but empirical verification of such models has not been forthcoming. Constrained by inadequacy of data, economists have been working with simpler models using either standard marginal productivity analysis in a certain[3] or stochastic framework with the help of decision or game theory.[4]

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[1] P. M. Hillebrandt, "The Economic Theory of the Use of Pesticides: Part I", *Journal of Agricultural Economics*, Vol. XIII, No. 4, December 1959, pp. 464-473, and "The Economic Theory of the Use of Pesticides: Part II—Uncertainty", *Journal of Agricultural Economics*, Vol. XIV, No. 1, June 1960, pp. 52-61.

[2] N. G. Becker, "Control of Pest Population", *Biometrics*, Vol. 26, 1970; S. Chatterjee, "A Mathematical Model for Pest Control", *Biometrics*, Vol. 29, December 1973; D. L. Jacquette, "Mathematical Models for the Control of Growing Biological Populations: A Survey", *Operations Research*, Vol. 20, 1971; S. H. Mann, "Mathematical Models for Control of Pest Populations", *Biometrics*, Vol. 27, 1971; and C. A. Shoemaker, "Optimization of Agricultural Pest Management: I. Biological and Mathematical Background", *Mathematical Bioscience*, Vol. 16, 1973, "Optimization of Agricultural Pest Management: II. Formulation of a Control Model", *Mathematical Bioscience*, Vol. 17, 1973, and "Optimization of Agricultural Pest Management: III. Results and Extension of a Model", *Mathematical Bioscience*, Vol. 18, 1973.

[3] R. D. Ghodake, A. S. Sirohi and Dayanatha Jha, "Economics of the Use of Pesticides in Cotton Crop", *Indian Journal of Agricultural Economics*, Vol. XXVIII, No. 4, October-December 1973, pp. 92-99; and D. P. Patil: An Economic Analysis of Pesticide Use in Cotton Production, M.Sc. (Agri.) Dissertation, Indian Agricultural Research Institute, New Delhi, 1973. Refer also R. D. Ghodake: Economics of Pest Control in Rice, Ph.D. Dissertation, Indian Agricultural Research Institute, New Delhi, 1976.

[4] G. A. Carlson, "A Decision Theoretic Approach to Crop Disease Prediction and Control", *American Journal of Agricultural Economics*, Vol. 52, No. 2, May 1970, pp. 216-223; Y. P. Mahalle: A Decision Theoretic Analysis of Cotton Pest Control, Ph.D. Dissertation, Indian Agricultural Research Institute, New Delhi, 1975; and K. E. F. Watt, "The Use of Mathematics and Computers to Determine Optimal Strategy and Tactics for a Given Insect Control Problem", *Canadian Entomologist*, Vol. 96, 1964, pp. 202-220.

In this note an effort has been made to demonstrate the application of integrated analysis on pesticide use decisions under certain and uncertain situations of pest-crop-environment. In view of the great importance of rice crop in India's agricultural economy and its high degree of susceptibility to pests, it was decided to analyse the decision problem of pesticide use in controlling stem-borer infestation in this crop.

The data used for this purpose were taken from insecticidal trials on rice crop conducted by the All-India Co-ordinated Rice Improvement Project at Coimbatore (Tamil Nadu), Maruteru (Andhra Pradesh) and Cuttack (Orissa) research stations in the *rabi* season of 1972. A randomised block design with three replications was adopted to evaluate the effectiveness of Carbofuran, Chlorofenvinphos, Paddigard, Dursban and SD 6538 as granular insecticides. Replicationwise data on quantities of pesticides (active ingredient in kg./ha.) applied, percentage dead hearts (caused by stem-borer attack) 60 days after transplanting in treated and untreated plots, and paddy grain yield (kg./ha.) were collected.

MODEL AND VARIABLES

Yield-pesticide relationships were estimated with the help of multiple regression analysis. Most of the earlier studies did not consider the level of pest infestation explicitly and pertained to a unique level of infestation. This severely restricted the usefulness of the derived yield-pesticide relationships. In this study the natural level of stem-borer infestation and its interaction with the pesticide input were explicitly considered. Equations were estimated for each pesticide by pooling observations for various research stations with the help of dummy variables. The quadratic equation was specified as under:

$$Y = a + b_1x_1 + b_2x_1^2 + b_3x_2 + b_4x_1x_2 + c_iD_i$$

where Y = the yield of paddy grain in kg. per hectare,

x_1 = the quantity of pesticide (active ingredient) applied per hectare in kg.,

x_2 = level of stem-borer infestation, measured as percentage of plants affected by dead hearts, and

D_i = intercept dummies for research stations.

Optimum quantities of various pesticides at different levels of infestation were worked out by equating the marginal value product with the cost of pesticide use. These levels of infestation were: low (0.5 per cent dead hearts), light (3 per cent dead hearts), moderate (7.5 per cent dead hearts), heavy (15.0 per cent dead hearts) and severe (more than 25 per cent dead hearts). These optimum quantities were adjusted to the nearest 'lethal' dose.

In order to analyse pesticide use strategy under uncertainty, the 'excess-benefit' criterion of game theory was used. This model was preferred because it blends the properties of 'regret' and 'Wald's' models. Under

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A few other studies on the subject are the following: H. Talpaz and I. Borosh, "Strategy for Pesticide Use: Frequency and Applications", *American Journal of Agricultural Economics*, Vol. 56, No. 4, November 1974; D. C. Hall and R. B. Norgaard, "On the Timing and Application of Pesticides", *American Journal of Agricultural Economics*, Vol. 55, No. 2, May 1973, pp. 198-201; and J. C. Headley, "Defining the Economic Threshold", paper presented at the National Academy of Sciences: Symposium on Pest Control Strategies for the Future, Washington D.C., 1971.

the most unfavourable circumstances, this model may be inferior to Wald's criterion; under extremely favourable conditions, it may be inferior to the regret principle; but under the greater number of intermediate cases, it is superior to both. The excess-benefit principle saves the decision-maker from the worst consequences for a given state of nature. The assumptions underlying this criterion are realistic in the context of an average Indian farmer who is neither a pure profit maximizer nor a pure risk averter. The model is solved as below:

PAY-OFF MATRIX

Growers' action	States of nature: Per cent level of pest infestation		
	t_1	t_2	t_j
S_1	R_{11}	R_{12}	R_{1j}
S_2	R_{22}	R_{22}	R_{2j}
•			
•			
S_i	R_{i1}	R_{i2}	R_{ij}
Probability of states of nature	P_1	P_2	P_j

For a given state of nature, t_j, the strategy which gives the lowest pay-off (say S_i^*) is chosen. If t_j prevails, the worst decision would be to play this strategy. Any other strategy would yield a higher pay-off under t_j. After deducting the lowest pay-off for t_j from the alternative strategy's pay-off, one gets the 'benefit' corresponding to the latter act. The matrix thus obtained becomes the player's benefit matrix. The maximin principle is then applied to this matrix and the strategy offering the maximum of the minimum benefits is chosen.

In this empirical work, the adjusted optimum quantities (derived in the first phase) were taken as pesticide application actions or strategies available to the decision-maker. Gross and net returns were calculated for each such action under five levels of stem-borer infestation and the latter were the pay-off matrix elements (R).

RESULTS AND DISCUSSION

The estimated quadratic equations for each pesticide have been presented in Appendix Table 1. Most of the regression coefficients were highly significant; all had appropriate signs. The regressions explained a significant magnitude of total variation in dependent variable. Optimum quantities of pesticides at various levels of infestation were worked out with the help of these equations. The results (Table I) indicated that the optimum quantity increased with increase in the level of infestation. This is in conformity with the fact that higher levels of pest infestation could only be controlled by more intensive use of pesticide. This finding supports the hypothesis proposed by Hillebrandt[5] regarding requirements of higher dose of pesticide to control

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[5] *Journal of Agricultural Economics*, December 1959, *op. cit.*

TABLE I—ESTIMATED AND DISCRETE* OPTIMUM QUANTITIES OF PESTICIDES FOR VARYING LEVELS OF PEST INFESTATION

Pesticide	Level	Optimum quantities of pesticide in kg./ha. (a.i.)†				
		Low infestation (0·5%)	Light infestation (3·0%)	Moderate infestation (7·5%)	Heavy infestation (15·0%)	Severe infestation (> 25·0%)
Carbofuran	Estimated	2·56	2·76	3·14	3·77	4·61
	Discrete	3·00	3·00	3·00	4·00	5·00
Chlorofenvinphos	Estimated	3·42	3·62	3·98	4·57	5·37
	Discrete	3·00	3·00	4·50	4·50	6·00
Paddigard	Estimated	3·93	4·53	5·64	7·47	9·91
	Discrete	4·50	4·50	6·00	7·00	7·00
Dursban	Estimated	1·17	1·26	1·43	1·70	2·07
	Discrete	1·00	1·50	1·50	1·50	2·00
SD 6538	Estimated	1·23	1·25	1·28	1·33	1·40
	Discrete	1·00	1·00	1·50	1·50	1·50

* Discrete levels are the quantities used in the experiments. This adjustment is necessary to achieve operationally lethal potencies in pesticide application.
† a.i. = active ingredients.

higher levels of infestation. A positive coefficient for the interaction term further indicated that yield response to pesticide quantity or the impact of pesticide input was higher for high levels of infestation. Again this was in conformity with Hillebrandt's contention regarding existence of a different dosage response curve for each level of infestation.

This result has been empirically established for the first time in this study. Earlier works by Ghodake *et al.*[6] and Patil[7] did not yield consistent results in this regard. Mahalle's work[8] showed desirable properties in terms of pesticide-infestation interaction but he did not empirically estimate this interaction with the help of a single equation model.

1. *Optimum Quantities of Pesticides*

The optimum quantities of the same pesticide did not vary from one station to another. This followed from model specification (data from different stations were pooled and only intercept dummies were used) and was justified on the ground that the same variety was grown at all the stations and the optimum quantities were worked out for the same pre-determined levels of infestation.

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[6] *Indian Journal of Agricultural Economics*, October-December 1973, *op. cit.*
[7] *op. cit.*
[8] *op. cit.*

These optimum quantities were obtained under the assumption that pesticide was a perfectly divisible input. Entomologists argue that pesticide application should always be in terms of discrete levels, each level comprising a biologically determined lethal dose of pesticide. In order to accommodate this biological constraint, the optimum values were adjusted to the nearest lethal dose used in the insecticide trials and these figures have also been given in Table I. It can be observed that, generally, the difference between these two levels was small.

It was observed from the table that the discrete optimum quantity of Carbofuran was the same (3.0 kg.) for three lower levels of infestation, *viz*., low, light and moderate while it was 4.0 and 5.0 kg. for heavy and severe infestation levels respectively. This gives an idea regarding the sensitivity of optimum pesticide quantity to changes in the level of infestation. A similar phenomenon was observed in the case of all other pesticides but a common infestation range was not definable wherein any given optimum quantity of pesticides remains unchanged.

2. *Performance of Various Pesticide Application Actions under Different Levels of Infestation*

The knowledge of optimum quantities at varying levels of infestation helps to decide, given a particular pesticide, what quantity should be applied. This decision depends upon the level of infestation. But, when several pesticides are available, then selection of a particular pesticide and its rate of application becomes a decision problem. This can be solved by calculating net return values for various pesticide application actions under different levels of infestation. The pesticide application actions included were the discrete optimum levels of various pesticides.

On the basis of this information, the decision-maker can easily select the action (pesticide as well as rate of application) most appropriate for the level of infestation actually obtaining.

This relationship has been graphically shown in Figure 1 for three stations included in the study. Only few pesticide application actions which occupied positions on the net return frontier or close to it, have been included in the graphs because other actions were distinctly inferior and there was no point in considering them. In general, Figure 1 showed increasing net returns with an increase in the level of infestation. This follows from the biological phenomenon that the (environmental) factors which are responsible for high pest infestation are also responsible for high yield potential.[9] Under such favourable factor-configuration, application of pesticide eliminates the damage caused by high pest population and, consequently, the residual effect on yield and net return is substantial. Thus, high yield and high net returns from pesticide use occur when the naturally high level of pest infestation is controlled by pesticide application. The situation is reverse at lower level of infestation. At Cuttack, the net return curve for Dursban applied at the rate

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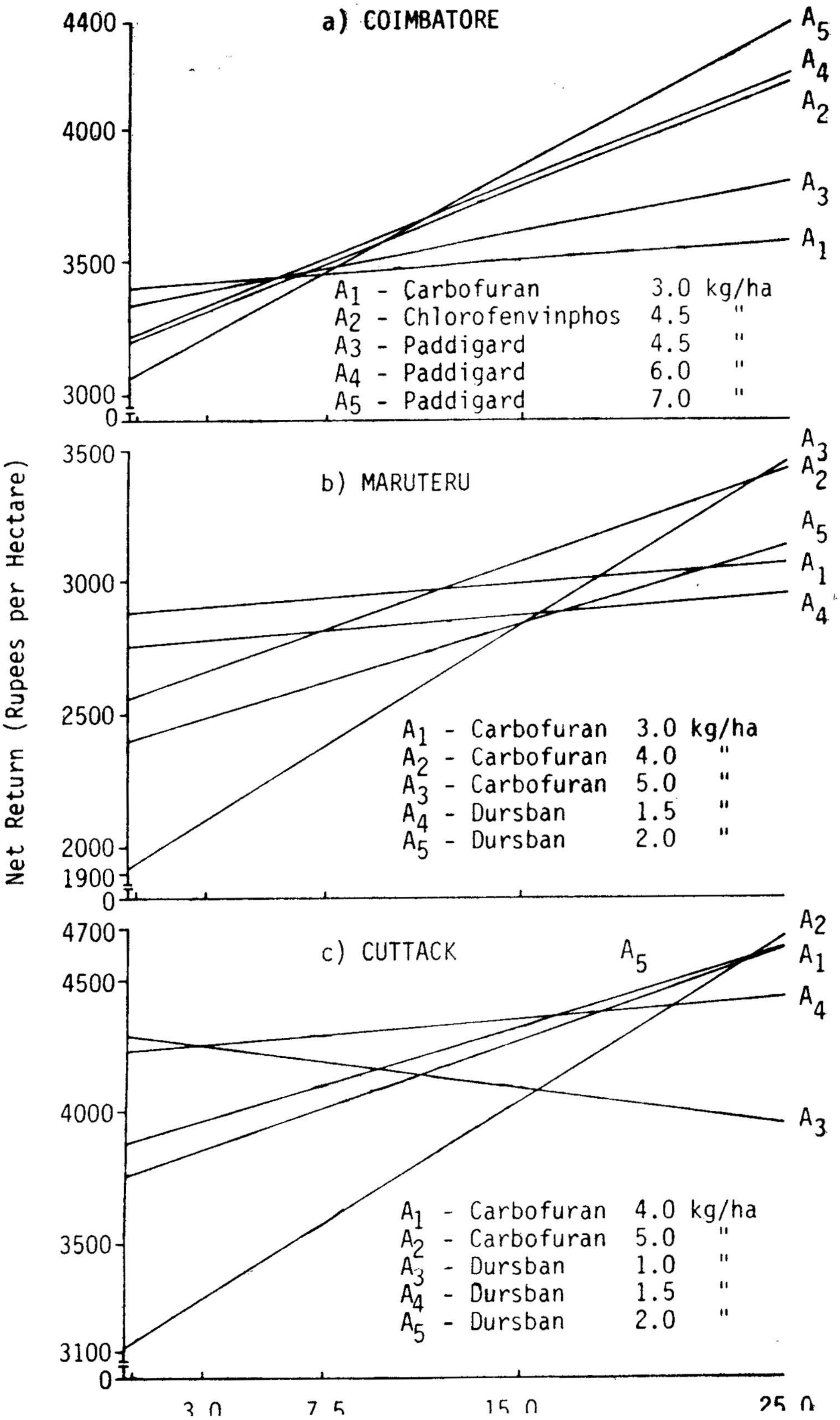
[9] S. Pradhan, "In Tropics Protection Research More Needed than Production Research", *Indian Journal of Entomology*, Vol. 33, No. 3, 1971, pp. 233-259.


Net Return (Rupees per Hectare)
a) COIMBATORE
4400
4000
3500
3000
0
A5
A4
A2
A3
A1
A1 - Carbofuran 3.0 kg/ha
A2 - Chlorofenvinphos 4.5 "
A3 - Paddigard 4.5 "
A4 - Paddigard 6.0 "
A5 - Paddigard 7.0 "
b) MARUTERU
3500
3000
2500
2000
1900
0
A3
A2
A5
A1
A4
A1 - Carbofuran 3.0 kg/ha
A2 - Carbofuran 4.0 "
A3 - Carbofuran 5.0 "
A4 - Dursban 1.5 "
A5 - Dursban 2.0 "
c) CUTTACK
4700
4500
4000
3500
3100
0
A5
A2
A1
A4
A3
A1 - Carbofuran 4.0 kg/ha
A2 - Carbofuran 5.0 "
A3 - Dursban 1.0 "
A4 - Dursban 1.5 "
A5 - Dursban 2.0 "
3.0
7.5
15.0
25.0

of 1.0 kg./ha. behaved in an exceptional manner. This may be because of the insufficiency of this quantity to control higher levels of infestation.

The figure also revealed that the overall performances shown by various pesticide application actions were different at different stations. Paddigard showed superiority at Coimbatore; Carbofuran showed better performance at Maruteru; and at Cuttack, Dursban performed well.

3. *Optimum Pesticide Use Strategy under Uncertainty*

The evaluation presented in the preceding section was based on deterministic analysis in which the selection of pesticide application was dependent upon a known level of infestation. But in reality the basic problem is lack of knowledge regarding the likely level of infestation. The results based on this analysis will not be of much help for decisions under uncertainty. This required further analysis of the performance of various pesticide application actions under uncertainty of infestation.

The excess-benefit criterion of games theory was used for this purpose. The alternative actions available to the decision-maker were the discrete optimum quantitites of different pesticides obtained from earlier analysis (Table I). States of nature were defined in terms of levels of stem-borer infestation as low, light, moderate, heavy and severe. In all, fourteen strategies—the four pesticides (Carbofuran, Chlorofenvinphos, Paddigard, and Dursban) with three application rates each and the last pesticide (SD 6538) with only two application rates—, were considered. Because of lack of information regarding probability distribution of infestation level, equal probabilities

TABLE II—AVERAGE PERFORMANCE OF VARIOUS PESTICIDE APPLICATION ACTIONS AT DIFFERENT RESEARCH STATIONS

Pesticide	Rate a.i.* kg./ha.	Coimbatore	Maruteru	Cuttack
Carbofuran	3·0	466 (6)	1179 (1)	798 (5)
	4·0	438 (7)	940 (3)	987 (2)
	5·0	0(14)	334 (8)	500 (7)
Chlorofenvinphos	3·0	545 (5)	362 (6)	135(11)
	4·5	588 (2)	337 (7)	241 (9)
	6·0	347 (8)	0 (12)	0 (14)
Paddigard	4·5	570 (3)	249 (9)	0 (13)
	6·0	605 (1)	189(10)	137 (10)
	7·0	556 (4)	50 (11)	88 (12)
Dursban	1·0	0 (13)	750 (5)	480 (8)
	1·5	266 (9)	1055(2)	964 (3)
	2·0	162(10)	766 (4)	1049 (1)
SD 6538	1·0	17 (12)	0 (14)	765 (6)
	1·5	59 (11)	0 (13)	844 (4)

* a.i.=active ingredients. Main figures are row minimum values of benefit matrix. Bracketed numbers are ranks.

were assigned to all the five levels of infestation.[10] The elements of the pay-off matrix were net returns obtained from a particular pesticide use strategy under these pre-determined levels of infestation. The game matrix for each station was worked out (not reported here). Subsequently, the benefit matrix was computed for all the stations as per procedure discussed earlier. The row minimum values of each pesticide use strategy along with their ranks at all the stations have been given in Table II. The results of this analysis have been discussed stationwise as below:

Coimbatore: Table II showed supremacy of Paddigard (6.0) in terms of average net returns at Coimbatore. It was followed by Chlorofenvinphos (4.5) and then Paddigard (4.5). Hence, Paddigard applied at the rate of 6.0 kg./ha. was the optimum pesticide use strategy at Coimbatore.

The decision-maker would have to forego an average benefit of Rs. 18 per hectare in selecting Chlorofenvinphos (4.5) instead of Paddigard (6.0). But the average benefit foregone may be Rs. 36, exactly double the amount of Chlorofenvinphos, if he selected Paddigard (4.5) instead of Paddigard (6.0). This indicated that if the best pesticide use strategy was not available for some reason, the decision-maker could select alternative strategies in the sequence indicated by the ranks. In the case of this station, the differences in benefits between the best and the next two actions were not large. For example, if the decision-maker chose Chlorofenvinphos (4.5) or Paddigard (4.5), there would be a marginal reduction in benefit by only 3 and 6 per cent respectively. Thus, these alternatives could be considered at par for all practical purposes.

Maruteru: At Maruteru, Carbofuran (3.0) stood first and Dursban (1.5) ranked second in average performance. The third position was taken by Carbofuran (4.0) Thus Carbofuran applied at the rate of 3.0 kg./ha. was found to be the optimum pesticide use strategy at Maruteru. By using this strategy the average long run profit would be maximized under uncertainty of infestation.

The choice of the second best alternative, Dursban (1.5) implied a loss in average benefit of Rs. 123. Thus, the optimal strategy was distinctly superior and the second best strategy implied a fairly large sacrifice in benefit. In percentage terms this loss amounts to about 11.

Cuttack: At this station, Dursban (2.0) topped the list of available pesticide application actions. Carbofuran (4.0) was the next best choice followed by Dursban (1.5). The difference in benefit between the first and the second best alternatives (Carbofuran 4.0) was Rs. 63 per hectare or only about 6 per cent. Thus for this station also, Dursban (2.0) and Carbofuran (4.0) could be considered to be equivalent for all practical purposes.

The above results indicated that different pesticides were found to be optimal at different locations. At Coimbatore, Maruteru and Cuttack,

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[10] Current recommendations regarding pesticide use are single-valued and usually ignore the actual levels of pest infestation. These form part of the 'package of practice'. The present exercise explicitly recognizes the fact that the level of pest infestation is a random phenomenon and this has an effect on pesticide use decisions. Because of lack of data, we had to assume that all the states of nature were equally probable.

the optimum strategies were Paddigard (6.0) Carbofuran (3.0) and Dursban (2.0) respectively. At Coimbatore and Cuttack, the superiority of the optimal strategy over the next best alternative was not as pronounced as at Maruteru. It implied that at these two stations, one could even choose the second best alternative without significant adverse effect on benefits.

Limitations

The results presented in this study have to be carefully interpreted in view of the following limitations which arise from the nature of available data and the assumptions made. Firstly, it would have been desirable to include all possible alternative strategies (varieties, agronomic practices, chemicals, etc.) used to combat the pests, in achieving optimum pest control strategy. But in this study only few pesticide application actions were considered. This was because information on most of the alternative pest control methods was not available from any source.

Secondly, assigning equal probabilities to various levels of infestation limited the scope of this study. The availability of actual probability distributions of infestation for each station would have made the results of this study more realisitc. For this purpose, the data on infestation levels of different pests for a sufficiently large number of years must be available. But this information was available only for a few years. This precluded the possibility of including actual probabilities of infestation in the game model used.

CONCLUSIONS

The success achieved in the estimation of logically consistent pesticide responses corresponding to different levels of infestation with the help of a single equation was the noteworthy result of this study. The method used showed that the performance of a particular pesticide use strategy under various levels of natural infestation was found to be quite effective. The results indicated that if the expected infestation levels were known, farmers would be maximizing their net returns by choosing an appropriate pesticide and also the level of its use. Rarely did the same chemical or pesticide level prove to be optimal under all infestation situations. When pesticide use was examined in the context of uncertainty, unique pesticide levels were naturally indicated as optimal strategies. The study symbolized an attempt to integrate economics with entomological research. In the process, some data gaps were identified; unless these data deficiencies were overcome it would be difficult to design economically sound pest management strategies.

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APPENDIX TABLE 1

QUADRATIC EQUATIONS FOR YIELD-PESTICIDE RELATIONSHIP: RABI 1972

(*Base: Coimbatore*)

Name of pesticide	Intercept	Regression coefficients						Coefficient of multiple determination
		Pesticide quantity X_1	X_1^2	X_1X_2	Natural level of infestation X_2	Intercept dummies for Maruteru	Intercept dummies for Cuttack	R^2
Carbofuran	3045·05*** (288·70)	1049·84*** (223·27)	—200·69*** (49·90)	33·74*** (9·92)	—93·83** (37·31)	—662·11 (465·63)	—836·92*** (298·16)	0·70
Chlorofenvinphos ..	3189·57*** (320·22)	661·57*** (164·79)	—78·51*** (24·61)	12·54* (7·34)	—8·98 (42·31)	1574·06** (535·76)	—282·28 (342·25)	0·55
Paddigard	3666·38*** (309·11)	397·61** (159·07)	—35·62 (23·75)	17·37** (7·06)	—56·31 (40·85)	—1779·41*** (517·17)	—433·60 (330·37)	0·67
Dursban	3123·44*** (281·67)	1819·99*** (506·93)	—735·45*** (227·48)	54·49*** (16·46)	—74·01** (35·97)	—561·99 (643·58)	1291·56*** (282·46)	0·70
SD 6538	2858·54*** (258·40)	1781·79*** (465·05)	—677·59*** (208·69)	9·16 (15·09)	—11·74 (32·99)	—1690·54*** (590·41)	1458·31*** (259·72)	0·82

Number of observations = 81. Figures in parentheses are standard errors.

*** Significant at 1 per cent level.
** Significant at 5 per cent level.
* Significant at 10 per cent level.