Vol XL
No. 2

APRIL-
JUNE
1985

ISSN 0019-5014

INDIAN JOURNAL OF AGRICULTURAL ECONOMICS

INDIAN SOCIETY OF
AGRICULTURAL ECONOMICS,
BOMBAY

THE TREATMENT OF PESTICIDES IN THE PRODUCTION FUNCTION FRAMEWORK: A SKEPTICAL NOTE

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The increasing use of pesticides in world agriculture makes it pertinent to study the factors which determine its use by the cultivators. Such a study is particularly interesting because of the complex processes governing the use of pesticides. The uniqueness of pesticides stems from the fact that unlike other inputs, agricultural pesticides are used in order to protect the potential yield from damage by pests. This yield-saving character of pesticides implies that the pesticides use behaviour of cultivators may be governed by processes that are different from those underlying the use of yield-increasing inputs like fertilizers, irrigation, etc.

I

OBJECTIVE

Several studies analysing the pesticides use behaviour of cultivators have adopted the production function framework. Headley[1] fitted a production function to cross-section farm data pertaining to the U.S.A. and estimated the marginal value productivity of pesticides for the year 1963. Campbell[2] following a similar approach, estimated the production function for 57 farms growing apples in Okanagan valley in British Columbia in 1970. The production function framework has been used by some Indian authors for analysing experimental data pertaining to pesticides. For instance, Ghodake, Sirohi and Jha[3] fitted a production function to experimental data regarding application of pesticides to cotton crop during the years 1966, 1967 and 1968 at the regional research station of the Indian Agricultural Research Institute located at Sirsa in Haryana. Mahalle and Jha[4] similarly determined optimum dosages of pesticides to be used on cotton, based on a production function fitted to experimental data generated at the Nanded, Akola, Amraoti and

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The paper is based on the author's doctoral dissertation entitled "Factors Affecting Pesticides Use: A Study with Special Reference to Cotton", submitted to the University of Bombay in 1983. The author wishes to express her deep sense of gratitude to Dr. S. H. Deshpande, Professor of Agricultural Economics, Department of Economics, University of Bombay, under whose guidance the above work was completed. She also acknowledges her thanks to Dr. P. P. Wanage for his useful comments on an earlier version of the paper.

1. J. C. Headley, "Estimating the Productivity of Agricultural Pesticides", *American Journal of Agricultural Economics*, Vol. 50, No. 1, February 1968, pp. 13-23.
2. H. E. Campbell, "Estimating the Marginal Productivity of Agricultural Pesticides: The Case of Tree Fruit Farms in the Okanagan Valley", *Canadian Journal of Agricultural Economics*, Vol. 24, No. 2, July 1976, pp. 23-30.
3. R. D. Ghodake, A. S. Sirohi and D. Jha, " Economics of the Use of Pesticides on Cotton Crop ", *Indian Journal of Agricultural Economics*, Vol. XXVIII, No. 4, October-December 1973, pp. 92-99.
4. Y. P. Mahalle and Dayanatha Jha, " Economics of Pesticides Use in Cotton Production," *Indian Journal of Agricultural Economics*, Vol. XXXII, No. 1, January-March 1977, pp. 120-136.

Achalpur research stations for three years from 1969-70 to 1971-72. The objective of the present paper is to examine the relevance of the production function framework employed in the above studies for the analysis of pesticides use behaviour of cultivators. The production function framework involves a notion of optimality of levels of use of all inputs, including pesticides. It will be our endeavour to examine the appropriateness of the notion of optimal levels of pesticides use derived within the production function framework for the analysis of pesticides use behaviour of cultivators in the real world. The present paper critically examines the relevance of the 'optimal' pesticides use levels derived from the production function framework to actual pesticides use behaviour of cultivators by fitting a production function through factor analysis regression to a sample of 274 cultivators in Coimbatore district of Tamil Nadu in the year 1976-77. The paper examines the relevance of the production function framework and the policy conclusions derived therefrom for the analysis of pesticides use behaviour of cultivators in the real world in the light of the conclusions derived from the empirical analysis.

In the following section, we discuss the concept of 'optimum' pesticides use derived in the production function framework. In section III the empirical analysis of the sample data is discussed. Section IV deals with the implications of the empirical analysis and summarises the main findings of the study.

II

THE PRODUCTION FUNCTION FRAMEWORK AND 'OPTIMUM' PESTICIDES USE LEVELS

The production function framework is often used to determine 'optimal' quantities of inputs that the cultivators use in the production process. Such an exercise is based on the assumption that the cultivators are motivated by the goal of profit maximization. It is also assumed that the marginal products of inputs are declining with an increase in input use and that they are non-negative. The inputs are also assumed to be completely divisible and that they are perfect subsitutes of each other. The 'optimal' quantities of inputs are then determined at the point where for each pair of inputs the ratio of marginal products equals their price ratio such that

$$\frac{\partial X_1}{\partial X_2} = \frac{P X_2}{P X_1} \qquad \ldots.(1)$$

where X_1 and X_2 are two inputs with marginal products $\frac{\partial Y}{\partial X_1}$ and $\frac{\partial Y}{\partial X_2}$ and Px_1 and Px_2 are the unit prices of inputs X_1 and X_2 respectively.

The above equation implies that given the technical conditions of production, input levels will be highly sensitive to change in relative prices.

The cultivators are assumed to choose 'optimal' quantities of inputs since they have complete information regarding the technical relations between inputs and output, weather conditions as well as the prices of output and inputs that are given exogenously. These 'optimal' input use decisions of cultivators are expected to be realised due to the existence of perfect financial capital markets which do not restrict the availability of funds to the cultivators.

In such a framework, the pesticides use behaviour of cultivators is explained entirely by the marginal productivity of and relative prices of pesticides. The use of the production function framework implies that it is possible to define a unique optimal level of pesticides use and that the actual pesticides use behaviour of cultivators conforms completely with the optimal pesticides use levels.

In the real world, the violation of the assumptions underlying the production function framework renders this approach to the explanation of input use behaviour of cultivators empty of empirical content. This issue has been fairly well discussed in recent economic literature by Rudra[5] and Bharadwaj.[6] The problem assumes special significance in the case of pesticides input whose behaviour with respect to output is markedly different from that of other inputs used in the production process. The unique 'yield-saving' nature of pesticides is in contrast to the 'yield-increasing' nature of other inputs. This casts serious doubts on the validity of the assumption of substitutability among the inputs and also implies a remarkably different behaviour of cultivators with respect to pesticides use when faced with uncertainty regarding yield.

In the present paper we confine our comments to the above two aspects which compel us to question the appropriateness of applying the production function framework to the explanation of pesticides use behaviour of cultivators.

The assumption of continuous substitutability among inputs is tenable only if the behaviour of various inputs used in the production process is similar with respect to output. However, while the use of inputs like irrigation, manures and chemical fertilizers leads to increased agricultural output, the use of pesticides leads to the protection of potential yield from damage by pests. The yield-increasing inputs used in the agricultural production process can be substituted for each other within limits in response to changing relative price situation. However, in view of the unique impact of the use of pesticides on output, the substitutability of pesticides with respect to other inputs may be very restricted. In fact, not only is the substitutability between pesticides and other agricultural inputs limited but it has been observed that there is a high degree of complementarity between pesticides and other yield-increasing inputs used in the production process. It has been noted in the case of the high-yielding varieties (HYVs) of crops which are grown under conditions of assured irrigation and high doses of fertilizers that they are highly susceptible to pests, thereby necessitating a liberal use of pesticides. Moreover, the use of pesticides becomes more profitable as the level of output

5. Ashok Rudra: Indian Agricultural Economics: Myths and Realities, Allied Publishers Pvt. Ltd., New Delhi, 1982.

6. Krishna Bharadwaj, "'Technical Relations' in Agriculture", in C. H. Shah (Ed.): Agricultural Development of India—Policy and Problems, Orient Longman, Bombay, 1979, pp. 265-290.

goes on rising as the potential output has to be protected from damage by pests. The higher the level of use of yield-increasing inputs, the higher is the potential yield and hence the higher is the required amount of pesticides to protect the crop from damage due to pest. Thus, pesticides use is highly complementary to the use of yield-increasing inputs like fertilizers, manures and irrigation. It is this limited substitutability of pesticides and its high complementarity with other inputs used in the production process that make the condition described by equation (1) untenable. The 'optimum' for the pesticides input cannot be defined with reference to the ratio between marginal products and unit prices of pesticides and other inputs used in the production process.

The presence of uncertainty in the real world further erodes the usefulness of the concept of 'optimum' pesticides use derived from the production function framework. The use of the production function framework for the determination of the 'optimum' pesticides use levels assumes that the cultivators possess complete information regarding the factors that affect yield, *viz.*, weather, the timing and intensity of pest attack, the pest damage function as well as effectiveness of pesticides. In reality, the knowledge that the cultivators possess regarding the above factors is far from complete. Given the degree of risk aversion of cultivators, the production function framework could still be used as an approximation of the true production relations if all inputs are substitutes of each other and yield uncertainty affected the use of all inputs in a similar way. As noted above, pesticides cannot be substituted by other inputs completely. In fact, there exists a high degree of complementarity between the use of pesticides and the use of other inputs. Furthermore, as will be explained below, the effect of yield uncertainty on pesticides use is likely to be radically different from its effect on the use of other inputs like fertilizers and irrigation.

Yield uncertainty could be due to incomplete information regarding weather, timing and intensity of pest attack, pest damage function or effectiveness of pesticides. When faced with yield uncertainty, risk-averse cultivators would reduce their levels of use of yield-increasing inputs like fertilizers and manures.[7] As pesticides use is complementary to the use of such yield-increasing inputs, the level of use of pesticides tends to be reduced.

However, there is another and more important aspect which leads to a rise in the level of pesticides use under conditions of yield uncertainty. Yield uncertainty raises the variance of the yield expected by the cultivators. As the cultivators are risk-averse, they try to maximize 'secured' profits[8] by choosing strategies which lead to a minimum variance of expected yield. Pesticides possess the unique characteristic of reducing damage due to pests and thereby reduce the variance of potential yield. Hence, when faced

7. See R. N. Batra, "Resource Allocation in a General Equilibrium Model of Production under Uncertainty", *Journal of Economic Theory*, Vol. 8, No. 1, 1974, pp. 50-63.

8. The concept of 'secured' profits is used in the sense that when faced with yield uncertainty, the risk-averse cultivators go in for 'maximin' solutions. The 'maximin' criterion implies that the cultivators would seek to maximize the minimum level of profits associated with various levels of pest attack through the use of pesticides.

with yield uncertainty, the risk-averse cultivators tend to increase their pesticides use levels. As Feder[9] argues, "a major motivation for pesticides applications is the provision of some "insurance" against damage; that is the existence of uncertainty in the pest-pesticide system is by itself a factor leading to a higher and more frequent use of chemicals."

Thus, when faced with yield uncertainty, risk-averse cultivators tend to use higher than 'optimal' levels of pesticides and lower than 'optimal' levels of all other inputs. Hence, the marginal value product (MVP) of pesticides is likely to be lower than the price per unit of pesticides while the MVPs of other inputs are likely to be higher than their respective unit prices. This implies that the equation (1) specifying the equilibrium relative levels of use of inputs under conditions of certainty does not hold. Moreover, the effect of uncertainty on input use is not similar. Hence, the production function framework cannot be used even as an approximation of the true production relations.

III

EMPIRICAL ANALYSIS

In order to test the appropriateness of the production function framework based on restrictive assumptions for the analysis of pesticides use behaviour of cultivators in the real world, we fit an empirical production function to farm data pertaining to one district in India. The Cobb-Douglas form of production function was chosen for the analysis as it was this form of the production function that was used most frequently in the earlier studies.

The general form of the Cobb-Douglas production function may be specified as follows:

$$Y = \beta_0 X_1^{\beta_1} X_2^{\beta_2} \ldots\ldots\ldots\ldots X_n^{\beta_n} \qquad \ldots(2)$$

where Y is the quantity of input, $X_1 \ldots\ldots\ldots X_n$ the quantities of inputs $1 \ldots\ldots\ldots\ldots n$ and $\beta_1 \ldots\ldots\ldots\ldots \beta_n$ the output elasticities of inputs.

The Cobb-Douglas production function is empirically estimated by transforming it into logarithms as follows:

$$\text{Log } Y = \log \beta_0 + \beta_1 \log X_1 + \beta_2 \log X_2 + \ldots\ldots + \beta_n \log X_n \qquad \ldots(3)$$

The data for empirical analysis pertain to 274 cultivators growing long staple cotton, *viz.*, Varalakshmi and MCU-5 in 38 villages of Coimbatore district of Tamil Nadu, India, in the year 1976-77. The Coimbatore district is a major long and extra long staple cotton growing district in India, and is one of the seven districts in the country where the Intensive Cotton District Programme (ICDP) is being implemented by the Government of India since

9. G. Feder, "Pesticides, Information, and Pest Management under Uncertainty", *American Journal of Agricultural Economics*, Vol. 61, No. 1, February 1979, p. 99.

1971-72. The data used in the present study were collected by the Directorate of Cotton Development, Ministry of Agriculture and Irrigation, Government of India, as part of a survey conducted to assess the progress of ICDP in the district.

The data pertaining to the 274 cultivators were grouped into twelve categories on the basis of the variety of cotton grown by them and the size of operational holding. This was done in order to avoid the problem of heteroscedastic residuals in the analysis. Firstly, the cultivators were classified according to the variety of cotton grown by them. Secondly, within each variety the cultivators were classified as small, medium and large according to the size of their net cultivated area. All those cultivators whose operational holdings were less than two hectares of land were classified as small farmers; those whose holdings were between two and four hectares of land were called medium farmers and those cultivators holding more than four hectares were termed large farmers.

In order to judge the appropriateness of this classification, the 't' statistic was used to test the significance of the differences in mean per hectare expenditure on pesticides and per hectare value of output amongst the various categories. The differences in the mean per hectare expenditure on pesticides were significant across size-groups of cultivators necessitating the retention of the size-groupwise classification of cultivators. The differences in the mean value of output were significant across the two varieties of cotton grown. As pesticides use was to be analysed in a production function framework, it was necessary to retain the varietywise classification also. Thus, the cultivators were grouped into twelve categories, *viz.*, small, medium, large and all cultivators of Varalakshmi; small, medium, large and all cultivators of MCU-5; and small, medium, large and all cultivators when varietal distinctions were ignored.

The mean levels of expenditure on pesticides, and all other inputs and the mean value of output are reported in Table I. The average per hectare expenditure on pesticides in cotton cultivation in the Coimbatore district was Rs. 2,100 and it constituted, on an average, 36 per cent of the total paid-out costs of cultivators in the year 1976-77.

Though the expenditure on pesticides was substantial in each of the twelve categories of cultivators, it was proportionately higher among the large farmers as compared to small and medium farmers. An interesting fact that emerged was that when inputs were arranged in order of their percentage shares in total expenditure on inputs, pesticides, fertilizers and hired labour ranked first, second and third respectively in each of the twelve categories of cultivators. Thus the relative importance attached to the use of these inputs appeared to be the same in all the categories.

In order to estimate the marginal productivity of pesticides, a Cobb-Douglas production function was fitted to each of the twelve categories of cultivators using the Ordinary Least Squares (OLS) method. The specification of the production function was as follows:

TABLE I—AVERAGE EXPENDITURE ON PESTICIDES AND VALUE OF OUTPUT PER HECTARE OF COTTON

Size class of cultivators	Area under cultivation (hectares)	Area under cotton (hectares)	Per hectare expenditure on pesticides (Rs.)	Per hectare expenditure on all inputs* (Rs.)	Yield of *kapas* per hectare (kg.)	Value of output per hectare (Rs.)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variety: Varalakshmi						
Small (n=58)	1·26	0·93 (73·25)†	1,800·94 (31·70)‡	5,680·23 (100·00)	2 238·51	12,611·55
Medium (n=49)	2·90	1·38 (47·48)	2,025·25 (34·76)	5,826·71 (100·00)	2,158·72	12,233·99
Large (n=38)	6·01	2·44 (40·68)	2,208·97 (37·45)	5,898·15 (100·00)	2,596·12	14,852·42
All (n=145)	3·06	1·47 (48·23)	2,048·09 (35·20)	5,821·07 (100·00)	2,368·64	13,515·84
Variety: MCU-5						
Small (n=56)	1·35	0·89 (65·97)	1,743·33 (33·14)	5,260·08 (100·00)	1,894·16	10,059·65
Medium (n=46)	2·85	1·55 (54·30)	2,030·02 (36·18)	5,610·87 (100·00)	2,058·32	10,507·30
Large (n=27)	6·82	3·00 (44·00)	2,581·82 (39·93)	6,465·79 (100·00)	1,907·93	10,058·47
All (n=129)	3·03	1·57 (51·71)	2,180·30 (37·38)	5,832·93 (100·00)	1,957·46	10,216·76
Varalakshmi and MCU-5						
Small (n=114)	1·30	0·91 (69·54)	1,773·13 (32·37)	5,477·41 (100·00)	2,072·25	11,379·88
Medium (n=95)	2·87	1·46 (50·75)	2,027·70 (35·47)	5,715·91 (100·00)	2,107·18	11,425·08
Large (n=65)	6·34	2·67 (42·16)	2,382·69 (38·66)	6,162·62 (100·00)	2,275·48	12,618·82
All (n=274)	3·04	1·52 (49·86)	2,112·75 (36·26)	5,826·83 (100·00)	2,168·84	11,912·75

Notes:—' n ' indicates number of observations.
* Includes expenditure on seeds, irrigation, hired labour, fertilizers, pesticides and other costs.
† Figures in parentheses in column (3) indicate percentages to total area under cultivation
‡ Figures in parentheses in column (4) indicate percentages of per hectare expenditure on all inputs.

$$\text{Log } V = \log \beta_0 + \beta_1 \log L + \beta_2 \log P + \beta_3 \log N + \beta_4 \log F + \beta_5 \log M + \beta_6 \log I$$

where V = value of output,

L = area under cotton cultivation,
P = expenditure on pesticides,
N = expenditure on hired labour,
F = expenditure on fertilizers,
M = expenditure on manures,
I = expenditure on irrigation.

The details regarding measurement of variables are given in the Appendix. The results of OLS estimation of the production function are presented in Table II. The estimates of marginal value products of inputs derived from the production function along with their standard errors are presented in Table III.

The independent variables in our analysis were highly correlated with each other and this led to the problem of multicollinearity in the regression. The extent of correlation amongst the explanatory variables can be ascertained from the correlation matrix pertaining to all the 274 cultivators which is presented in Table IV. It can be observed that the expenditure on pesticides is highly correlated with the expenditure on fertilizers, hired labour and irrigation.

The problem of high intercorrelations among the explanatory variables, which led to the breakdown of the OLS estimation, was overcome by using the Principal Components method of factor analysis regression to estimate the production function for the sample cultivators. A similar procedure was adopted by Campbell[10] and to some extent by Headley.[11]

Using the Principal Components method, intercorrelated explanatory variables were re-defined with the help of factor loadings derived from the correlation matrix into a set of new variables called Principal Components. In order to ensure orthogonality of the principal components, the factor loadings were rotated using the Varimax method suggested by Kaiser.[12] Thus, six principal components corresponding to the six explanatory variables were constructed. Normally, the number of principal components included in the regression is less than the number of independent variables. We used a step-wise backwards regression method and eliminated all those principal components which were not significant at 5 per cent level. The principal components regression was then undertaken, the results of which are presented in Table V. The marginal value products derived from the principal components regression are presented in Table VI.

10. *op. cit.*
11. *op. cit.*
12. H. F. Kaiser, "The Varimax Criterion for Analytic Rotation in Factor Analysis", *Psychometrika*, Vol. 23, No. 3, September 1958, pp. 187-200.

TABLE II—ESTIMATED PRODUCTION FUNCTION

$$\text{Log } Y = \log \beta_0 + \beta_1 \log L + \beta_2 \log P + \beta_3 \log N + \beta_4 \log F + \beta_5 \log M + \beta_6 \log I$$

Size class of cultivators (1)	β_0 (2)	β_1 (3)	β_2 (4)	β_3 (5)	β_4 (6)	β_5 (7)	β_6 (8)	$\bar{R}^2$ (9)	F (10)
Variety: Varalakshmi									
Small	9·1815**	0·8411**	0·3066*	—0·2570	—0·0453	—0·0744	0·0955	0·7136	25·4990**
(n=60)	(5·2617)	(3·0338)	(2·1517)	(—1·2513)	(—0·2630)	(—1·0048)	(1·4890)		
Medium	11·5964**	1·4498**	0·4861**	—0·5470*	—0·1736	—0·1796*	0·0645	0·8019	32·7012**
(n=48)	(6·8381)	(5·4481)	(3·5803)	(—2·0564)	(—1·1205)	(—2·0552)	(0·8979)		
Large	9·4827**	0·9315**	0·0764	—0·1689	0·1180	—0·0222	0·0260	0·9326	88·1577**
(n=39)	(5·9259)	(4·0176)	(0·5729)	(—0·7633)	(0·7797)	(—0·5391)	(0·2630)		
All	10·0171**	10·9278**	0·3371**	—0·3998**	—0·0289	—0·0625	0·0682	0·8634	154·8326**
(n=147)	(10·2837)	(7·3620)	(4.2786)	(—2·9900)	(—0·3102)	(—1·7983)	(1·5811)		
Variety: MCU-5									
Small	3·5742*	0·2466	0·1856	0·5410**	0·0199	0·0455	—0·0228	0·8215	43·1808**
(n=56)	(2·6498)	(1·1509)	(1·2274)	(3·2559)	(0·1343)	(1·1506)	(—0·3552)		
Medium	5·2384**	0·4376*	0·2010*	0·3291**	0·0301	0·0460*	—0·0633	0·9303	98·8181**
(n=45)	(4·8922)	(2·6868)	(2·4775)	(3·0575)	(0·2831)	(2·2279)	(—1·3796)		
Large	5·1542**	0·3974	0·1944	0·2896	0·1536	0·0448	—0·1370	0·8983	37·8004**
(n=26)	(3·1077)	(1·5703)	(1·0445)	(1·3206)	(1·0167)	(1·0246)	(—1.6161)		
All	4·5882**	0·3709**	0·1748*	0·4100**	0·0560	0·0499**	0·0617	0·9165	231·3896**
(n=127)	(6·1311)	(3·1767)	(2·5177)	(4·5964)	(0·7735)	(2.7786)	(—1·8412)		
Varalakshmi and MCU-5									
Small	4·8172**	0·2724	0·2325*	0·1825	0·1924	0·0182	0·0025	0·7157	49·2485**
(n=116)	(4·0646)	(1·4428)	(2·0172)	(1·2592)	(1·5553)	(0·4721)	(0·0490)		
Medium	8·2724**	0·8832**	0·2904**	—0·0513	—0·0718	—0·0157	—0·0350	0·7910	59·0459**
(n=93)	(7·1298)	(5·1108)	(3·0394)	(—0·3595)	(—0·6379)	(—0·4729)	(—0·7247)		
Large	6·6865**	0·5034*	—0·0079	0·2636	0·2612*	—0·0026	—0·1341	0·8866	84·4309**
(n=65)	(4·8454)	(2·5221)	(—0·0626)	(1·4847)	(2·2292)	(—0·0716)	(—1·9398)		
All	6·2696**	0·5458**	0·2255**	0·1153	0·1176	0·0060	—0·0498	0·8486	256·0365**
(n=274)	(8·9359)	(5·1084)	(3·7211)	(1·2994)	(1·7562)	(0·2980)	(—1·6081)		

Notes:— 'n' indicates number of observations.
Figures in parentheses indicate t-statistic of regression coefficients.
* Indicates significance of coefficient at 5 per cent level.
** Indicates significane of ceefficient at 1 per cent level.

TABLE III—MARGINAL VALUE PRODUCTS OF INPUTS ESTIMATED FROM PRODUCTION FUNCTION

Size class of cultivators (1)	MVP of area under cotton (per hectare) (2)	MVP of pesticides (per rupee) (3)	MVP of hired labour (per rupee) (4)	MVP of fertilizers (per rupee) (5)	MVP of manures (per rupee) (6)	MVP of irrigation (per rupee) (7)
Variety: Varalakshmi						
Small	10265·5661	2·1606	—2·2209	—0·7177	—1·8640	4·1301
(n=60)	(3383·7618)	(1·0041)	(1·7749)	(2·7291)	(1·8551)	(8·8810)
Medium	17327·9480	2·9419	—4·3706	—2·5581	—4·3499	2·7628
(n=48)	(3180·52[illegible]0)	(0·8217)	(2·1254)	(2·2830)	(2·1165)	(3·0770)
Large	15658·5994	0·5713	—1·9038	2·1767	0·8546	1·5091
(n=39)	(3897·4808)	(0·9973)	(18·0338)	(2·7916)	(50·1285)	(6·0479)
All	14049·3126	2·2399	—3·5256	—0·4543	—1·6932	3·1419
(n=147)	(1908·3653)	(0·5235)	(1·1790)	(1·4633)	(0·9415)	(1·9862)
Variety: MCU-5						
Small	2350·2194	1·0295	3·6244	0·2787	0·8982	—0·6810
(n=56)	(2042·1043)	(0·8376)	(0·1663)	(2·0744)	(0·7806)	(1·9174)
Medium	4610·4888	1·0701	2·3887	0·4271	1·1331	1·8826
(n=45)	(1715·9233)	(0·4319)	(2·4705)	(1·5090)	(0·5086)	(1·3645)
Large	4006·0826	0·8409	1·9697	1·8266	1·1462	—3·6788
(n=26)	(2551·2142)	(0·8051)	1·4916)	(1·7966)	(1·1187)	(2·2763)
All	3698·4544	0·9064	2·8302	0·7605	1·1227	—1·7972
(n=127)	(1164·2514)	(0·3600)	(0·6158)	(0·9833)	(1·2777)	(1·0230)
Varalakshmi and MCU-5						
Small	1489·3572	1·1021	4·9832	2·1687	0·3067	0·0143
(n=116)	(3264·3887)	(0·5464)	(3·9573)	(1·3944)	(0·6496)	(0·2912)
Medium	9909·8868	1·6484	—0·3903	—1·0361	—0·3825	—1·2543
(n=93)	(1939·0209)	(0·5423)	(1·0857)	(1·6242)	(8·0887)	(17·3088)
Large	6523·1645	—0·0447	2·2961	3·8234	—0·0812	—5·5801
(n=65)	(2586·3512)	(0·7140)	(1·5465)	(1·7151)	(1·1389)	(2·8767)
All	6228·7561	1·3339	0·9063	1·7244	0·1498	—1·8522
(n=274)	(3855·8241)	(0·3585)	(0·6975)	(0·9819)	(0·5027)	(1·1519)

Notes:— 'n' indicates number of observations.
Figures in parentheses indicate standard errors of estimated marginal products.

TABLE IV—ZERO ORDER CORRELATION COEFFICIENTS BETWEEN VALUE OF OUTPUT AND EXPENDITURE ON INPUTS

Size class and variables (1)	Y (2)	L (3)	P (4)	N (5)	F (6)	M (7)	I (8)	0 (9)
All cultivators								
Y	1·0000	0·9132	0·8816	0·8776	0·8821	0·5498	0·6748	—0·0606
L		1·0000	0·9101	0·9490	0·9324	0·5852	0·7461	—0·0044
P			1·0000	0·8930	0·9090	0·5581	0·7094	—0·0874
N				1·0000	0·8838	0·5824	0·8244	0·0626
F					1·0000	0·6031	0·7116	—0·0436
M						1·0000	0·5413	—0·0355
I							1·0000	—0·0350
0								1·0000

TABLE V—ESTIMATED PRODUCTION FUNCTION: PRINCIPAL COMPONENTS REGRESSION

Estimated equation $\text{Log } Y = \log \beta_0 + \beta_1 \log L + \beta_2 \log P + \beta_3 \log N + \beta_4 \log F + \beta_5 \log M + \beta_6 \log I$

Size class of cultivators (1)	β_0 (2)	β_1 (3)	β_2 (4)	β_3 (5)	β_4 (6)	β_5 (7)	β_6 (8)	$\bar{R}^2$ (9)	F (10)
Variety: Varalakshmi									
Small	4·4503**	0·5788**	0·0555**	—0·0964	0·0116	0·1571**	0·1058**	0·7144	74·7961
(n=60)	(11·2949)	(4·1462)	(7·8646)	(—1·5892)	(0·5088)	(4·8393)	(12·0790)		
Medium	3·3082**	0·3172**	0·1217**	—0·3528**	0·1420**	0·4940**	0·1582**	0·7296	64·4209
(n=48)	(5·8088)	(7·2900)	(11·3175)	(—3·9999)	(11·3083)	(10·2331)	(11·0471)		
Large	3·5277**	0·5895**	—0·1394	0·0041	0·1112	0·2623**	0·1177**	0·9212	112·1182
(n=39)	(8·9071)	(3·5581)	(—1·6788)	(0·0960)	(0·6930)	(4·8415)	(11·4981)		
All	3·2985**	0·0801**	0·1421**	—0·0656	0·1677**	0·4828**	0·0847*	0·8092	310·6984
(n=147)	(13·0932)	(12·9170)	(24·9107)	(—1·8970)	(19·6340)	(14·5137)	(24·8881)		
Variety: MCU-5									
Small	2·4895**	0·1280**	0·0082	0·0312	0·1083**	0·1650	0·4646**	0·8211	85·1387
(n=56)	(5·3357)	(10·2127)	(0·0902)	(0·8158)	(4·1239)	(1·4172)	(3·3243)		
Medium	3·0118**	0·0873**	0·1210**	0·0832**	0·1495**	0·3254**	0·1542*	0·8478	123·5479
(n=45)	(7·0567)	(12·5014)	(8·2374)	(3·3212)	(12·8737)	(4·2707)	(2·3318)		
Large	2·9657**	0·1368**	—0·1488	0·0705**	0·1262**	0·5508**	0·1236**	0·8838	96·1031
(n=26)	(5·2531)	(6·3814)	(—1·9968)	(10·6780)	(7·3103)	(8·8593)	(8·6391)		
All	2·5794**	0·3933**	—0·0580	0·0496**	0·0559	0·1674**	0·3935**	0·9170	279·5686
(n=127)	(13·5581)	(5·2617)	(—1·9600)	(2·7777)	(0·7743)	(2·7036)	(6·8779)		
Varalakshmi and MCU-5									
Small	3·2808**	0·0826**	0·0484	0·0346	0·1321**	0·4531**	0·1085**	0·7097	94·7196
(n=116)	(8·4602)	(7·2785)	(1·2698)	(0·9104)	(10·1886)	(7·8580)	(11·7047)		
Medium	3·3664**	0·1602**	0·1179**	—0·0534	0·1483**	0·4349**	0·0646**	0·7108	114·0390
(n=93)	(8·1552)	(7·3360)	(15·0778)	(—1·2772)	(13·8016)	(13·7616)	(14·7626)		
Large	3·6219**	0·2100**	—0·1216	0·0616	0·4685**	0·6600**	0·1917**	0·8716	145·7591
(n=65)	(11·1321)	(6·8713)	(—1·8902)	(1·9125)	(7·0808)	(19·0999)	(5·8681)		
All	2·8899**	0·1978**	0·0618*	0·0336	0·4898**	0·5148**	0·1482**	0·9212	112·1181
(n=274)	(15·8056)	(28·2344)	(2·6266)	(1·6429)	(14·8753)	(21·0643)	(28·7857)		

Notes:— 'n' indicates number of observations.
Figures in parentheses indicate 't' statistic of regression coefficients.
* Indicates significance of regression coefficient at 5 per cent level.
** Indicates significance of regression coefficient at 1 per cent level.

TABLE VI—MARGINAL VALUE PRODUCTS OF INPUTS ESTIMATED FROM PRINCIPAL COMPONENTS REGRESSION

Size class of cultivators	MVP of area under cotton (per hectare)	MVP of pesticides (per rupee)	MVP of hired labour (per rupee)	MVP of fertilizers (per rupee)	MVP of manures (per rupee)	MVP of irrigation (per rupee)
(1)	(2)	(3)	(4)	(5)	(6)	(7)
Variety: Varalakshmi						
Small	7038·8213	0·3909	—0·8327	0·1838	3·9370	4·5736
(n=60)	(1697·6679)	(0·0497)	(0·5240)	(0·3613)	(0·8136)	(0·3786)
Medium	3790·6109	0·7366	—2·8189	2·0903	11·9645	6·7744
(n=48)	(520·0009)	(0·0651)	(0·7047)	(0·1848)	(1·1692)	(0·6132)
Large	9031·4055	—0·9502	0·0418	1·8698	9·2155	6·5531
(n=39)	(2538·2770)	(0·5660)	(0·4353)	(2·6983)	(1·9034)	(5·6999)
All	1029·5788	0·9446	—0·5784	2·6352	13·0882	3·9039
(n=147)	(79·7073)	(0·0379)	(0·3049)	(0·1342)	(0·9018)	(0·1569)
Variety: MCU-5						
Small	1217·4662	0·0455	0·2089	1·5114	3·2518	13·8383
(n=56)	(119·2109)	(0·5052)	(0·2560)	(0·3665)	(2·2945)	(4·1628)
Medium	917.1828	0·6423	0·6023	2·1157	7·9893	4·5709
(n=45)	(73·3665)	(0·0780)	(0·1813)	(0·1643)	(1·8707)	(1·9603)
Large	1379·4289	—0·6092	0·4794	1·5013	14·1058	3·3200
(n=26)	(216·1641)	(0·3051)	(0·0449)	(0·2054)	(1·5922)	(0·3843)
All	3921·7391	—0·3007	0·3421	0·7584	3·7625	11·4576
(n=127)	(745·3351)	(0·1534)	(0·1232)	(0·9795)	(1·3917)	(1·6658)
Varalakshmi and MCU-5						
Small	892·0156	0·3034	0·2644	1·9695	10·1118	3·9210
(n=116)	(122·5543)	(0·2389)	(0·2905)	(0·1933)	(1·2868)	(0·3350)
Medium	1799·6708	0·6697	—0·4068	2·1422	10·6028	2·3183
(n=93)	(245·3152)	(0·0444)	(0·3185)	(0·1552)	(0·7705)	(0·1555)
Large	2721·3668	—0·6909	0·5363	6·8579	2·0447	7·9727
(n=65)	(396·0468)	(0·3655)	(0·2804)	(0·9685)	(0·1071)	(1·3586)
All	911·4499	0·1304	0·0942	2·5604	4·5544	1·9649
(n=274)	(23·8384)	(0·0496)	(0·0573)	(0·1721)	(0·2162)	(0·0683)

Notes:—' n ' indicates number of observations.
Figures in parentheses indicate standard errors of marginal products.

The omission of family labour in the estimation of the production function constituted a limitation of the study. The omission was due to non-availability of data on this aspect. The exclusion of family labour has led to an under-statement of the labour input, especially on small farms. Though the output figures include the impact of the use of family labour, non-inclusion of family labour as an input leads to an upward bias in the estimates of marginal value products of other inputs in OLS regression. However, this bias is minimized in the principal components regression which is used for all further analysis in the study. In principal components regression, the estimates of marginal value products for the inputs are derived through factors, which are orthogonal to each other. Hence the exclusion of family labour may be reasonably expected to generate an upward bias in the estimates of marginal value products pertaining to the labour input alone and to leave the estimates pertaining to other inputs unaffected. The estimates of marginal value product of the labour input therefore need to be interpreted as being somewhat higher than that would prevail in the actual situation.

A perusal of Table V indicates that in general when the production function was estimated through principal components analysis, the specification provided a statistically satisfactory fit in terms of $\overline{R}^2$ and the F ratio for all categories of cultivators. The $\overline{R}^2$ was high ranging between 0.71 and 0.93 for all categories of cultivators. The output elasticities of inputs were generally positive and significant except for pesticides and labour inputs in the case of some categories of sample cultivators. The negative values of output elasticities were not significant except for hired labour input in the case of medium Varalakshmi cotton cultivators.

A comparison of the estimates obtained through OLS regression with principal components regression reveals that the estimates obtained through the latter method can be considered to be more reliable in view of the lower standard errors associated with them. We therefore take up the principal components regression results alone for interpretation.

The estimates of marginal value productivity of inputs derived from the principal components regression and presented in Table VI indicate that the marginal value productivity of pesticides is less than unity in all categories of cultivators. When all the sample cultivators were grouped together, the marginal value product (MVP) of pesticides was Re. 0.13. Probing further, we find that there was substantial variation in the MVP of pesticides across the two varieties. Each rupee's expenditure on pesticides yielded a return of Re. 0.94 in the case of all Varalakshmi cultivators in contrast to a return of Re. —0.30 for all MCU-5 cultivators.

The MVP of pesticides was markedly different for the three size-groups of cultivators. It was highest for medium cultivators in Varalakshmi, MCU-5, as well as for both varieties considered together, the value being Re. 0.74, Re. 0.64 and Re. 0.67 respectively. The small cultivators ranked next with the MVP of pesticides being Re. 0.39, Re. 0.05 and Re. 0.30 for Varalakshmi, MCU-5 and combined varieties respectively. In the case of large farmers, the MVP of pesticides was consistently negative being Re.

—0.95 in Varalakshmi, Re. —0.61 in MCU-5 and Re. —0.69 when both varieties were considered together. In general, the MVP for pesticides was positive though less than unity for small and medium categories of cultivators, while for the large cultivators it was negative.

IV

CONCLUSIONS AND IMPLICATIONS

The empirical analysis conducted above reveals that the MVPs of pesticides and hired labour are less than unity for all categories of the sample cultivators. If these figures are taken at their face value it would imply that pesticides and hired labour use by the sample cultivators is 'excessive.' It may also be observed that the MVPs of fertilizers, manures and irrigation are substantially higher than unity, implying sub-optimal levels of use of these inputs by the cultivators.

The 'excessive' use of pesticides by the sample cultivators thus implies that they are irrational in their pesticides use behaviour. This result, however, is to be understood in the context of the 'optimal' defined in the production function framework that is based on restrictive assumptions. The results are thus sensitive to the definition of the 'optimum' derived in the production function analysis.

The apparent 'irrationality' of the sample cultivators, as reflected in their tendency to use more than 'optimal' quantities of pesticides, may be explained if considerations such as complementarity of input use and uncertainty, which are outside the purview of the production function framework of analysis, are brought into the picture.

The pesticides use decisions of cultivators are based on their expectations regarding the timing and intensity of pest attack, the pest damage function and the effectiveness of pesticides. The expectations of the cultivators tend to go wrong in the absence of perfect information regarding the above factors. In the context of uncertainty, the pesticides use behaviour of cultivators depends on their attitude to risk taking. Assuming that the cultivators are in general risk-averse, the use of pesticides, which possess the unique characteristic of reducing yield uncertainty, tends to be higher. Risk aversion on the part of cultivators, and uncertainty regarding the intensity of pest attack and effectiveness of pesticides explain the general 'excessive' use of pesticides by the sample cultivators.

The tendency of larger cultivators to use more pesticides than the smaller cultivators may be explained by the fact that financial capital markets are imperfect. Under imperfect financial markets, the cultivators have differential access to financial capital depending upon their respective asset positions. The large cultivators who have greater assets are therefore in a better position to secure finance. Since pesticides are to be purchased from the market, the cultivators with easier access to financial capital may be in a position to use larger quantities of pesticides to achieve the goal of 'safe' or 'secured' profits.

It is thus evident from the above analysis that pesticides use decisions are influenced crucially by considerations of risk and uncertainty and by the fact of complementarity among inputs. The realisation of these decisions rests critically on the availability of finance. Given the real world situation of imperfect financial capital markets, the large farmers with higher asset positions get finance easily and thus realise their input use decisions to a greater extent than the smaller farmers.

The above analysis reveals the inappropriateness of the production function framework for the analysis of pesticides use behaviour of cultivators. The analysis in this framework revolves around the concept of 'optimum' levels of input use which is determined at the point where the ratio of marginal products of inputs is equal to their relative prices. The estimation of the production function implies an assumption that inputs are not related to each other.

It was argued earlier that the use of a yield-saving input like pesticides is closely related to the levels of use of yield-increasing inputs. This viewpoint is substantiated by the empirical analysis in which the expenditure on pesticides was found to be highly correlated with the expenditure on fertilizers, labour and irrigation. The 'independence' of inputs which is assumed in the estimation of the production function is not an empirically tenable proposition.

Furthermore, the presence of uncertainty in the real world vitiates the optimum input use levels defined in the production function framework which depends on perfect certainty. The presence of uncerainty induces risk-averse cultivators to use less than 'optimal' quantities of yield-increasing inputs and more than optimal quantities of a yield-saving input like pesticides. This is borne out by our empirical analysis wherein it was observed that the MVP of most of the yield-increasing inputs was higher than unity, indicating sub-optimal levels of use of such inputs, while the MVP of pesticides was much lower than unity implying more than optimal use of the input.

The production function framework rests on the assumption that financial capital markets are perfect and hence the 'optimal' levels of use of inputs are actually realised by the cultivators. It was argued that in the real world, financial capital markets are seldom perfect and that in imperfect financial capital markets the larger cultivators who have better access to finance are able to realise their input use levels to a greater extent than the smaller cultivators. The basic validity of this premise is demonstrated by the fact that total per hectare expenditure on inputs was higher on the larger farms.

Thus, it is evident that the condition of 'optimal' input use derived in the production function framework is not appropriate to analyse the pesticides use behaviour of cultivators in the real world. In the production function framework, the pesticides use behaviour of cultivators is sought to be explained solely in terms of marginal productivity, and change in relative prices and factors such as complementarity of input use, risk-preferences of cultivators, expectations regarding profits, asset positions of cultivators, availability of information, availability of finance, etc., are totally ignored. An alternative theoretical framework which can take account of these factors may be more appropriate for an analysis of pesticides use behaviour of the cultivators. The continued use of the inappropriate production function framework for the analysis of pesticides use behaviour of the cultivators serves only to blind the eyes of the policy makers to the complexities governing its use in the real world.

APPENDIX

MEASUREMENT OF VARIABLES USED IN THE PRODUCTION FUNCTION ANALYSIS

The variables used in the production function analysis were value of output, size of holding, area under cotton cultivation, labour, irrigation, manures, chemical fertilizers and pesticides.

The value of output was used as the dependent variable in the production function analysis. The variable included value of *kapas* produced plus the value of stalks. The physical production was converted into value terms by using cotton prices that were received by each cultivator. The value of cotton stalks as reported by the cultivators was then added to the value of cotton produced to obtain the value of output.

Land was measured in terms of area under cotton cultivation in unstandardised hectares. In the case of labour, the non-availability of data on family labour was a constraint. Hence only hired labour was used to represent the labour input. The hired labour may be measured either in terms of man-days employed or in terms of expenditure incurred. In order to measure labour in terms of man-days, female labour and male labour are usually converted to a standardised man-day, the measure for standardisation being their respective wage rates. In the absence of data on the prevailing wage rate for male and female labour in all the villages, this measures could not be used. Since expenditure on hired labour was reported by individual cultivators, this measure was used to represent the labour input.

Irrigation input was also measured in terms of expenditure on irrigation since data regarding number of waterings and average depth of each watering which were necessary to measure it in physical terms were not available. The use of expenditure on irrigation did not involve the problem of aggregating charges on heterogenous means of irrigation like canals and wells. The only means of irrigation prevalent among the sample cultivators was wells. The uniformity of the mode of irrigation used by the sample cultivators enabled us to treat the expenditure on irrigation as a fairly good measure of the irrigation input. Organic manures were measured in terms of expenditure incurred by the cultivators on this input. Chemical fertilizers were measured in terms of expenditure incurred on them. Pesticides were measured in value terms in order to overcome the problem of addition of heterogenous physical units in which they were measured. The expenditure on pesticides as reported by each individual cultivator was used to represent this input.