Vol XXXIX
No. 4

ISSN 0019-5014

OCTOBER-
DECEMBER
1984

INDIAN JOURNAL OF AGRICULTURAL ECONOMICS

INDIAN SOCIETY OF
AGRICULTURAL ECONOMICS,
BOMBAY

RESEARCH NOTES

ECONOMICALLY OPTIMAL FERTILIZER REQUIREMENTS FOR WHEAT AND PADDY CROPS IN DIFFERENT REGIONS OF UTTAR PRADESH

The significance of fertilization in the achievement of green revolution in India needs no mention any more. The individual farmer, however, still needs to know fairly precisely the response to the amount and timing of fertilizer applications of crop yield so that he may determine the optimal agronomic requirements for maximum economic efficiency of the farm.

The relationship between crop yields and fertilizer levels has been recognized as a necessary base for individual producer decision regarding the most profitable level of fertilizer application. Even if we do not exactly know the decision model used by individual farmers, improved estimate of the size of gap between the level recommended for agronomic reasons and the level considered economically optimal for individual farmer will be useful.[1] It will help in making better judgments regarding the strength of incentive needed to accomplish optimal level of fertilizer application.

The crop yields response to the levels of fertilizer application may be different from one location to another due to the differences in agro-climatic conditions and soil characteristics at each location. Also, the response of crop yields to the same level of fertilizer dose may not be the same from one year to another. The usual recommendations to the farmers for fertilizer levels are usually not based on the above considerations and as such are likely to lead to the misuse of this scarce resource.[2] This study was, therefore, undertaken with two objectives; (i) to examine the regional and yearwise variations in the crop yield responses to the levels of fertilization in four regions of the State of Uttar Pradesh, and (ii) to suggest the levels of N,P,K, which would optimize the yields of high-yielding wheat and paddy crops in the respective regions. The study period spans five crop years from 1970-71 to 1974-75 for wheat and the same years except 1971-72 for paddy. Only wheat and paddy crops were selected for analysis because of availability of data and their economic importance. These two crops dominate the cropping pattern of the State and occupy approximately 26 and

1. E. R. Swanson, E. R. Taylor and I. F. Welch, "Economically Optimal Level of Nitrogenous Fertilizer for Corn: An Analysis Based on Experimental Data, 1966-1971", *Illinois Agricultural Economics,* Vol. 13, No. 2, 1973, pp. 16-25.

2. A. K. Chaudhari and A. S. Sirohi, "Allocation of Fertilizers among Crops and Regions in Uttar Pradesh", *Indian Journal of Agricultural Economics,* Vol. XXVIII, No. 3, 1973, pp. 46-61.

19 per cent respectively of the total cropped area. Major achievements of the green revolution, in genral, ar also in these crops only.

THE DATA

The data for the present analysis were obtained from the four Regional Agricultural Research and Demonstration Centres at Varanasi, Hardoi, Jhansi and Bareilly located in the Eastern, Central, Bundelkhand and Western regions respectively of the State. At each centre, treatment levels of fertilizer with respect to nitrogen, phosphorous and potash were given in a ratio of 2:1:1 in both the crops over the entire period of experiments considered. Due to this perfect multicollinearity it was not possible to separate out the impact of individual nutrients on the yields. Therefore, the combination of the three nutrients was treated as a single variable.

In each region data were obtained from a single location. In cases where there were replications of a single fertilizer dose, each replication was treated as an obsrvation. This was done to make regressions possible and obtain sufficient degrees of freedom to increase the precision of estimate of the response coefficients. Unfortunately, each of the four locations could not participate each year in both the crops. The regions excluded and the number of observations for each crop and year are shown below.

Year	Number of observations		
	Wheat	Paddy	Exclusions
1970—71	72	70	Bundelkhand in both the crops
1971—72	74	—	Bundelkhand in wheat crop
1972—73	72	74	Bundelkhand in paddy and Central in wheat crop.
1973—74	101	96	—
1974—75	96	108	—

THE YIELD RESPONSE FUNCTION AND OPTIMAL FERTILIZATION

Form of the Response Function

A number of specifications of the functional form of crop yield response to fertilizer are available.[3] An ideal form should not only be biologically sound but such that it can provide useful economic information. Taking this fact into consideration, different functional forms were tested on the yield and fertilizer data. These included quadratic,

3. E. O. Heady and J. L. Dillon: Agricultural Production Functions, Iowa State University Press, Ames, Iowa, 1961.

cubic, square root, logarithmic and semi-logarithmic forms. To compare and select the best form representing the data at hand, we considered (i) the consistency of the sign of the coefficients with production theory; (ii) the significance of the coefficients, i.e., t-statistic; (iii) the standard errors of the estimates (SEE); (iv) the coefficient of multiple determination (R^2); (v) the standard deviation of the regression surface (STD); and (vi) a visual analysis of the residual plotted against the fertilizer variable and the predicted values of crop yields. Based on the above considerations, the quadratic form, by and large, fitted the data better than the other forms. The choice of the quadratic form was also supported from the fact that the levels of treatments in each region in each year were high enough indicating yield increases first at increasing rate and then eventually at decreasing rate. As is well-known, the best function to represent this kind of data is the quadratic one.[4]

To accomplish the objectives of the study, data of the four regions were pooled. To capture the regional variation in the yield responses, three sets of dummy variables, with a value of one for an observation pertaining to a location and zero otherwise, were included in addition to the linear and quadratic fertilizer terms in the quadratic function. The final equation was specified as below:

$$Y = a + b_1X + b_2X^2 + b_3C + b_4B + b_5W + b_6XG + b_7XB + b_8XW + b_9X^2C + b_{10}X^2B + b_{11}X^2W$$

where

Y is the yield of crops in quintals/hectare,
X is the level of fertilizer in kilograms|hectare,
C is the zero-one variable for location in Central region.
B is the zero-one variable for location in Bundelkhand region.
W is the zero-one variable for location in Western region.

To avoid the problem of dummy trap in a case of computer programme which automatically gives intercept term, one dummy variable (for location in the Eastern region) was dropped from each set.[5]

Input-Output Prices and Optimal Fertilization

The estimated response functions for both the crops were then used to calculate the optimal fertilizer requirements in each region

4. W. D. Hopper, "The Economics of Fertilizer Use—A Case Study in Production Economics", *Indian Journal Agricultural Economics,* Vol. XVII, No. 4, 1962, pp. 12-22.
5. J. Johnston: Econometric Methods, McGraw-Hill, New York, 1972.

and in each year. In calculating the optimum fertilizer requirements it was assumed that an economically optimal level is the one which results in maximizing the return over fertilizer cost.

RESULTS

The estimated response coefficients are presented in Table I for wheat crop and Table II for paddy crop along with their standard errors of estimates and coefficients of multiple determination (R^2). It can be seen from these tables that the signs obtained for fertilizer variables are according to the expectations, i.e., a positive linear term and a square negative term for each set of equation. This implies eventually decreasing absolute yields. As indicated by the magnitudes of coefficients of multiple determination, a large part of the variation in the yield of both the crops has been explained by the included explanatory variables. The fertilizer variables (in linear and quadratic expressions) alone are capable of explaining a large part of the variations in the yields of both the crops. These variables appeared highly significant (at 1 per cent level), in general, in all the estimated equations. However, the large number of statistically significant coefficients of interaction of fertilizer levels with locations need to be emphasized. Out of 44 such coefficients, 33 appeared to be statistically significant at very high probability levels. This indicates that the general conditions of production at each location, like organic matter and trace nutrients contents of soils, temperature, humidity, rainfall and other factors, play a major role in explaining the regional differences in response of crops to fertilizer levels.

This fact can further be verified by examining the significant intercept terms obtained by including dummy variables for locations in each region. There were 22 such terms and, in 20 cases, the coefficients appeared to be statistically significant with high probability levels indicating the spatial differences in the response of wheat and paddy crops to the fertilizer levels. So, the locational variables appear to have a significant effect on the yields of wheat and paddy crops both directly and through interaction with fertilizer levels.

Based on response functions at each location, marginal physical products of fertilizer were calculated. These calculations are based on the arithmetic mean level of fertilizer applications and are presented in Table III. The marginal physical products presented in the table indicate the additional output (in kg.) of a crop upon application of one additional kg. of fertilizer (half kg. of nitrogen, ¼ kg. of phosphorus and potash each). As can be seen from this table, the marginal productivities of fertilizer in both the crops are different in each region and in each crop year. The highest fertilizer productivity in either crop was observed in the Western region except in the year 1972-73 in

Table I—Coefficients for Wheat Yield Response to Fertilizer Nutrients, Locations and Interactions of Fertilizer Nutrients with Locations in Different Crop Years

Variables	Crop years				
	1970-71	1971-72	1972-73	1973-74	1974-75
Intercept	15.8227	17.2381	13.8967	22.0519	19.2080
X	0.1618*** (0.0088)	0.1283*** (0.0079)	0.1946*** (0.0083)	0.2198*** (0.0067)	0.2039*** (0.0090)
X^2	—0.00030* (0.00018)	—0.00023*** (0.00002)	—0.00046*** (0.00007)	—0.00037*** (0.00012)	—0.00035*** (0.00002)
C	2.1018*** (0.4062)	3.9623*** (1.3901)	-	—1.3930 (1.0583)	—3.0386*** (1.3042)
B	—	—	—3.1098** (1.2203)	—8.2381*** (1.1030)	—3.3123* (2.0021)
W	5.8228*** (1.3021)	6.0281*** (1.0892)	3.8321*** (1.1239)	3.2382*** (0.8928)	3.0632*** (1.1236)
XC	0.0016 (0.0011)	—0.0029 (0.0062)	—	0.0119*** (0.0042)	—0.0081 (0.0070)
XB	—	—	—0.0329** (0.0043)	—0.0639*** (0.0028)	—0.0283*** (0.0052)
XW	0.0160*** (0.0012)	0.0122*** (0.0020)	0.0228*** (0.0040)	0.0363*** (0.0051)	0.0129*** (0.0055)
X^2C	0.000021*** (0.000009)	0.000016 (0.000011)	—	0.000012** (0.000006)	0.000013 (0.000008)
X^2B	—	—	—0.000012 (0.000008)	0.000010* (0.000006)	—0.000051*** (0.000020)
X^2W	0.000053*** (0.000019)	0.000033*** (0.000012)	0.000018*** (0.000008)	0.000026*** (0.000009)	0.000031*** (0.000010)
R^2	0.97	0.94	0.96	0.99	0.97

Notes:— 1. Figures in parentheses indicate the standard errors of estimates of coefficients.

2. A single asterisk indicates significance at 10 per cent, a double asterisk at 5 per cent and a triple asterisk at 1 per cent level.

Table II—Coefficients for Paddy Yield Response to Fertilizer Nutrients, Locations and Interactions of Fertilizer Nutrients with Locations in Different Crop Years

Variables	Crop years			
	1970-71	1972-73	1973-74	1974-75
Intercept	16.2012	13.8990	18.8212	16.9502
X	0.1129*** (0.0152)	0.1138*** (0.0086)	0.1692*** (0.0063)	0.1655*** (0.0072)
X^2	—0.00026*** (0.00004)	—0.00029*** (0.00008)	—0.00033*** (0.00010)	—0.00027*** (0.00005)
C	2.1022* (1.0809)	3.2099* (1.7322)	—0.9837 (1.5092)	—2.0083** (1.0125)
B	—	—	—2.6389* (1.0233)	1.9610*** (0.6510)
W	4.0910*** (1.1229)	3.8290** (1.9536)	2.1639*** (0.9958)	3.6210** (1.3320)
XC	0.0116* (0.0006)	0.0395*** (0.0122)	—0.0133 (0.0092)	—0.0058 (0.0040)
XB	—	—	—0.0612* (0.0322)	0.0049*** (0.0011)
XW	0.0119*** (0.0053)	0.0260*** (0.0096)	—0.0112** (0.0056)	—0.0122*** (0.0060)
X^2C	0.000051*** (0.000021)	0.000012 (0.000008)	—0.000017* (0.000009)	—0.00006 (0.00005)
X^2B	—	—	0.000063** (0.000029)	—0.000011 (0.000008)
X^2W	0.000068*** (0.000021)	—0.000026*** (0.000011)	0.000096*** (0.000038)	0.000059*** (0.000025)
R^2	0.96	0.93	0.86	0.92

Notes:— As in Table I.

Table III—Marginal Physical Products of Fertilizer Nutrients in Different Regions Over Different Crop Years

(*kg. of product output*)

Crop years Crops/regions	1970-71	1971-72	1972-73	1973-74	1974-75	Average
Wheat						
Eastern	8.26	6.76	7.32	12.48	11.15	8.70
Central	9.38	6.89	—	13.72	10.68	10.17
Bundelkhand	—	—	6.99	6.08	7.00	6.70
Western	11.26	8.85	7.79	16.53	13.26	11.54
Paddy						
Eastern	5.57	—	5.00	9.66	10.61	7.71
Central	7.85	—	9.21	7.96	8.71	8.73
Buidelkhand	—	—	—	4.93	8.68	6.80
Western	8.26	—	7.03	10.65	10.69	9.16

the paddy crop where higher productivity was observed in the Central region. On an average, over the crop seasons, as high as 11.54 kg. of wheat output and 9.16 kg. of paddy output can be obtained with the application of one additional kg. of fertilizer in the Western region. The regional and temporal variations in the fertilizer productivity can be explained in the light of reasons already explained in the case of differences in yield response to fertilizer levels.

The results suggest that wheat and paddy crops have different response to the fertilizer levels and have different productivities which vary from one region to another. Consequently, the economically optimum fertilizer requirements to optimize crop outputs would be different from one region to another.

The price ratios of wheat and fertilizer nutrients and that of paddy and fertilizer nutrients fluctuated over years, particularly the price of fertilizer and also of paddy output fluctuated largely as can be seen from Table IV. A change in the price ratio of crop to fertilizer nutrients could be expected to require a change in the optimum quantities to maximize crop returns. Because of the different production functions at each location and in each year, a change in the product-input price ratio may necessitate a different change in the use of fertilizer nutrients. Using the input-output prices and the appropriate response function at each location, optimum levels of fertilizer nutrients were calculated and are presented in the same table.

The year to year variation in the optimum fertilizer levels in terms of nitrogen, phosphorous and potash can be noted from the table. The fluctuations in the optimum fertilizer requirements from one year to another may be due to (1) the different product-input price ratios used to attain the optimal levels; (2) the differences in the general climatic conditions which comprise rainfall, temperature, humidity and other natural factors varying from year to year; (3) differences in the number of treatments followed in each year, crop rotations, residual impacts of carriers and due to other factors. From recommendation viewpoint, however, average optimal fertilizer requirements, averaged over the crop years, seem to be more reasonable. These average optimum requiremnts are also presented in Table IV.

It can be seen from this table that average optimal requirements also varied from region to region. For wheat crop, it varied from 86 kg. of nitrogen and 43 kg. of phosphorous and potash each in the Bundelkhand region to 141 kg. of nitrogen, 71 kg. of phosphorous and potash each in the Western region. In the case of paddy crop, the average optimum requirements varied from 82, 41 and 41 kg. of nitrogen, phosphorous and potash respectively in the Bundelkhand region to 127, 63 and 63 kg. of respective fertilizer nutrients in the Western region. It was found profitable to use 117+58 + 58 kg. and 95 + 47 + 47 kg. of N,P,K. in the Eastern region and 129+65 +65 kg. and 102+51+51 kg. of respective nutrients in Central region for wheat and paddy crops respectively to optimize the crop outputs.

Thus, using the same product and fertilizer price ratios the variations in the optimal fertilizer requirements from region to region may largely be due to the differences in management practices followed at each experimental centre, the differences in general climatic conditions of production and due to soil characteristics. It can be noted that not much difference in average optimum fertilizer requirements was found between the Central and the Eastern region. This indicates that both the crops are grown in almost the same climatic conditions

Table IV—Optimum Requirements of Nitrogen, Phosphorous and Potash at Different Output and Fertilizer Prices, to Optimize the Wheat and Paddy Returns in Different Regions Over Different Years of Crop Production

(*kg./ha.*)

Crop years	Fertilizer output-price ratios (Rs./kg.)	Eastern region			Central region			Bundelkhand region			Western region		
		N	P	K	N	P	K	N	P	K	N	P	K
Wheat													
1970-71	1.55/0.76	118	59	59	128	64	64	—	—	—	149	75	75
1971-72	1.67/0.76	116	58	58	120	60	60	—	—	—	131	65	65
1972-73	1.73/0.76	93	46	46	—	—	—	73	37	37	110	55	55
1973-74	1.93/0.76	131	66	66	144	72	72	90	45	45	167	84	84
1974-75	2.54/1.05	128	64	64	126	63	63	95	47	47	150	75	75
Average		117	58	58	129	65	65	86	43	43	141	71	71
Paddy													
1970-71	1.55/0.54	82	41	41	114	57	57	—	—	—	125	62	62
1972-73	1.73/0.56	72	36	36	110	55	55	—	—	—	103	52	52
1973-74	1.93/0.67	106	53	53	92	46	46	74	37	37	138	69	69
1974-75	2.54/0.74	121	60	60	95	47	47	90	45	45	141	70	70
Average		95	47	47	102	51	51	82	41	41	127	63	63

Notes:— 1. The quantities of **N, P, K** have been obtained after breaking the optimum amount of fertilizer in the ratio of 2:1:1. As would be recalled from the data section, three nutrients were applied in experiments in this ratio.

2. The fertilizer price constitutes the prices of ½ kg. of nitrogen, ¼ kg. of phosphorous and potash each. These prices are the selling price of the respective nutrients. The transportation costs, cost of labour in fertilizer application and cost of interest in the purchase of fertilizer are not included.

and with the same soil quality in the two regions. The differences in optimal requirements existed largely between the Bundelkhand and other regions of the State. This seems due to the poor soil quality in the Bundelkhand region yielding a poor response to the levels of fertilization. Furthermore, a wide gap in optimal requirements existed between the Western and rest of the regions. This might have resulted due to a better crop response to fertilization and suitable climatic conditions for growing both the crops in the Western region.

CONCLUSIONS AND POLICY IMPLICATIONS

Crop yield response to fertilization varies from region to region and from year to year which results in differential marginal physical productivities of fertilizer input in the production of a particular crop. This may originate due to differences in the climatic conditions and soil compositions and other factors. All these lead to differential optimal fertilizer requirement to optimize the crop output in different regions. Fertilizer recommendations for high-yielding wheat and paddy crops should, therefore, be based on detailed economic analysis rather than recommending a uniform dose for a crop in all regions.

B. K. Singh and J. S. Sharma*

* Post-Doctoral Fellow, Faculty of Forestry, University of Toronto, Toronto, Ontario, Canada and Professor of Agricultural Economics, Department of Agricultural Economics, G. B. Pant University of Agriculture and Technology, Pantnagar, Nainital, Uttar Pradesh, respectively.

The authors are grateful to Dr. J. C. Nautiyal, Professor of Forest Economics, University of Toronto, and to two anonymous referees of this *Journal* for reading the revised manuscript at various stages and for suggesting a number of improvements. Uses of the University of Toronto facilities and some funds from Grant Number A6205 of the Natural Sciences and Engineering Research Council of Canada in completing the revision are also very much appreciated.