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## CONTENTS


| | | Page |
|---|---|---|
| Factors Responsible for Productivity Differentials on Small Farms | Bashir Ahmad | 1 |
| Improving Marketing of Mango Fruit in the Punjab Province | Qamar Mohy-ud-Din | 11 |
| Fertilizer Response in Irrigated Maize in the Swat Valley: A Synthesis of Five Years of On-Farm Research | Derek Byerlee and Kiramat Khan. | 23 |
| A Homogeneous Area Approach for Cotton Crop Insurance | Muhammad Aslam Chaudhry Khizra Aslam Syed and Razia Sultana | 39 |
| A Strategy for Poverty Alleviation Through Rural Development | K. M. Azam | 51 |
| Impact Evaluation of Focal Points Programme in Punjab | Mahmood Ali Saleem and Muhammad Jameel Khan | 63 |
| BOOK REVIEW | | |
| B.M. Bhatia. Pakistans Economic Development: 1947-1990 | Reviewed by: B. A. Azhar | 79 |
| RESEARCH NOTES | | 89 |


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# *Fertilizer Response in Irrigated Maize in the Swat Valley: A Synthesis of Five Years of On-Farm Research

**Derek Byerlee and Kiramat Khan**

## ABSTRACT

*This paper has demonstrated an integrated and interdisciplinary approach to establishing appropriate fertilizer recommendations for small farmers. The series of surveys and experiments over a five years period in Swat Valley indicate that the optimum dose of N is around 100 Kg per hectare and farmers are approaching that level. Capital scarcity appears to be the main factor limiting the use of N in this area. The overall response to phosphorus in maize in this area is small.*

## Introduction

Expenditures on fertilizer represent the major cash outlay in irrigated areas of Pakistan. The very small farmers (less than 1 ha) of the Swat Valley in North West Frontier Province (NWFP) spend on average over Rs.500/ha to purchase fertilizer for irrigated maize, and this represents over half of the variable cost of maize production and 80% of cash costs. Hence improvements in the efficiency of fertilizer use in the major crop has potentially large benefits to farmers of the area, as is the case for small farmers throughout Pakistan.

Despite the importance of fertilizer in the agricultural economy of Pakistan, agricultural research has failed to develop site-specific recommendations to suit the varying agro-climatic and socio-economic conditions of farmers. Usually, official recommendations are often made for large relatively heterogeneous areas. Moreover recommendations are often made on the basis of technical criteria and fail to reflect the economic circumstances of small farmers.

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The experience of fertilizer use on maize in the Swat Valley is no exception to these generalizations. During the 1970s, over 100 demonstrations were laid out in farmers' fields in the Swat Valley to popularize the use of improved varieties, fertilizer and other recommended production practices. Although many of the practices were not adopted and use of improved varieties was constrained by inadequate supply of seed, fertilizer was adopted by all farmers in the valley although well below the official recommendations of 115 Kg/ha of nitrogen and 57 kg/ha of phosphorus. Initially, nitrogenous (N) fertilizer was adopted, but by 1985, 55% of farmers also applied phosphorus (P) to maize (Byerlee et al., 1987).

Beginning in 1982, an extensive on-farm research program was initiated in order to develop recommendations more appropriate to the circumstances of farmers in the Swat Valley. One focus of this program was to develop more appropriate fertilizer recommendations for farmers of the area, based on on-farm surveys and experiments, and sound economic analysis of fertilizer response. This paper synthesizes the results of that program over the five-year period 1982-86 with respect to findings on fertilizer use and response. The methods and results from this experience have wider applications for small farmers elsewhere in Pakistan where there is a need for research to develop more efficient fertilizer recommendations in the light of government policy to remove fertilizer subsidies.

## Methods

A variety of methods were employed in the research program which followed the well-known sequence of steps in farming systems research from diagnostic surveys to understand farmers' problems and practices, on-farm experiments to measure responses to selected technologies, and on-farm verification trials to verify responses under farmers' management. The results reported here were obtained from the following activities:

1. From 1983-85, a survey was undertaken to obtain detailed information on specific fields and to estimate grain and fodder yields through a crop cut at harvest time, consisting of three samples per field of 2m x 4m each. A total of 214 fields were surveyed with the largest number of samples taken in 1984.

2. In 1982 and 1984, five experiments were conducted on farmers' fields to measure N and P response. N and P treatments were arranged in a factorial combination in each of three replications with the treatment levels shown in Table 1. The trials were managed by researchers using the recommended practices for maize production.

3. In 1985, three experiments were conducted under researcher management to measure response to phosphorus. Four levels of phosphorus were applied from 0 to 100 kg/ha (Table 1) and a standard dose of 100 kg/ha of N was applied to all plots.



4. In 1985, twelve verification plots were laid out under farmers' management. Two treatments compared the use of phosphorus at a level of 57 kg/ha with no phosphorus application.

5. In 1986, ten experiments were conducted to estimate response to $P_2O_5$ under farmer management.

Each experiment was subject to analysis of variance to determine if there was a statistically significant response at that site. Over all sites for a given set of experiments, statistical and economic response was conducted through fitting the quadratic response function of the form:

$$Y = a + bN + cN^2 + dP + ep^2 + fNP + \Sigma D_i + \Sigma M_j$$

where:

- N = nitrogen applied (kg/ha),
- P = phosphorus applied (kg/ha),
- $D_i$ = dummy variables for individual site effects, and
- $M_j$ = variables reflecting differences in management(i.e. density) in the case of farmer managed trials.

Since no significant N by P interaction was observed, economic optima for N were derived as follows:

$$N^* = (r_N - b)/2c \qquad (1)$$

where:

$$r_N = [m(P_N + t + g)]/[x(P_y - h - s)] \qquad (2)$$

and
- $P_N$ = price of N nutrient (Rs/Kg)
- t = transport cost of fertilizer nutrient (Rs/kg) from the village to the field (Rs/kg)
- g = application cost of fertilizer (Rs/kg)
- $P_y$ = farm gate price of maize (Rs/kg)
- h = harvesting cost of maize (Rs/kg)

s = shelling cost of maize (Rs/kg)

m = minimum acceptable rate of return on capital

x = adjustment factor to correct experimental yields to farmer yields in researcher managed trials.

Prices used corresponded to 1986, and except for m were readily estimated by interviewing farmers who hosted the trials.

The optimum level of P, P*, was derived in a similar manner, with one exception. Since phosphatic fertilizers were subsidized, and it was planned that this subsidy be removed, $r_P$ was computed based on an estimated unsubsidized price.

The estimated values of $r_N$ and $r_P$ for two different values of m are given in Table 2. For small capital-short farmers, such as in those in the Swat Valley, it is not unreasonable to expect a minimum acceptable rate of return on capital of 100% (i.e., m = 1) (CIMMYT, 1988). Note that because we have included realistic farmer costs of fertilizer use (transport costs, harvest costs and a minimum rate of return on capital), the resulting $r_N$ and $r_P$ range from 6 to 10, over double the simple grain-nutrient price ratio commonly used in Pakistan for economic analysis of fertilizer response.

## Results

### Farm Surveys

The farm surveys indicated that farmers in the Swat Valley use quite high levels of fertilizer (see Table 3). All nitrogen is usually applied at planting at an average rate of 60 to 80 kg/ha. Phosphorus is also applied by about half of the farmers -- a much higher proportion than elsewhere in NWFP (Byerlee and Hussain, 1986). Farm yard manure is extensively applied to shaftal (Trifolium persicum) but not to maize or wheat. Data on fertilizer use in the various years of the surveys are reasonably consistent for phosphorus but the amount of nitrogen increases sharply over time (Table 3).

The average figures hide considerable diversity among farmers in fertilization practices. A multiple regression analysis was conducted to explain variation in fertilizer practices. It was hypothesized that three sets of factors influenced farmers fertilizer practices:

1) Practices that complement fertilizer use such as improved variety and timely planting.



2) Orientation toward grain or fodder production. More fertilizer is expected to be used if farmers' main objective is grain production.

3) Location and year of survey.

In fact fertilizer use is significantly related to use of improved variety and timely planting (Table 4). The latter has a major impact on farmers' fertilizer use. The variables SEED (seed rate), SEEL (seel or interculture done), and TEN (share tenancy) were included to represent farmers' orientation toward fodder production.[1] Both SEEL and TEN had the expected effect although the latter was not significant. However, SEED has an unexpected positive relationship with fertilizer use. This probably reflects errors in measuring both seed rates and fertilizer rates due to difficulties in standardizing farmers' measures of land area.

It was hypothesized that some farmers might be applying phosphorus to the previous crop and relying on the carry-over for the maize crop. In the 1985 harvest survey, farmers were asked to recall fertilization of their maize fields over the last year. The results (Table 5) suggest that farmers either use phosphorus fairly regularly or they do not use it at all. Hence 70% of farmers who applied no phosphorus to maize also did not apply phosphorus to the previous crop. By contrast 82 percent of farmers who applied phosphorus to maize had also applied phosphorus to a crop sown in the field in the preceding year.

Finally, the survey data were used to analyze effects of N and P on maize yields. Various specifications of yield function were employed and only one is reported here (Table 6). All variables had the expected signs. Improved variety, nitrogen, density, and location, all have significant effects on yields. However the effect of P is small and not significant. Because the sample divides equally between those who use and those who don't use P, the variable for P is expressed as use of P or non-use of P (PUSER) to provide maximum discriminatory power.

The variables N and DEN are included in quadratic form to represent the expected non linear response to these variables. By setting $dY/dN = 0$, the maximum yield is calculated at 165 kg/ha of N. The economic optimum for N at N = 0.5 is 102 kg/ha compared to farmers' practice of 72 kg/ha.

At the same time, the response to phosphorus although positive is small and not statistically significant. Given the coefficient for PUSER, an average rate of application for users of 50 kg/ha and a value of $r_P$ of 7.16, it would not be economical to use P. Hence the survey data tend to support the official recommendation to apply 115 kg/ha of N but cast serious doubt on the official recommendation to apply 57 kg/ha of P.

1. Tenant farmers receive a higher share of fodder than grain and hence tend to have more of an orientation toward fodder production.

## On-Farm Experiments

The five on-farm experiments conducted from 1982 to 1984 that included both N and P were analyzed jointly. The estimated response function, given in Table 7, indicates a highly significant response to N of over 25 kg of grain for 1 kg of N for the first 40 kg/ha of N applied. The derived economic optimum for N was about 100 kg/ha. This confirmed the response derived from the survey data. As noted farmers used an average of 72 kg/ha and this appeared to be increasing. By setting $N^* = 72$ in Equation 1 above and solving for $r_N$, the implied minimum rate of return on investment for farmers' current fertilizer levels m, was calculated from Equation 2 as 230%. This indicates acute capital scarcity on the part of Swat farmers (CIMMYT 1988). However, since farmers were already moving toward the optimum and since the results from the surveys and experiments were highly consistent, there seemed little point in conducting further research on optimum N levels.

The situation for P was quite different. Of the five experiments conducted from 1982 to 1984 a response to P was observed in only two, and then only at the 10% level of significance. Over the five experiments there was no overall response to P as indicated by the F-ratio to enter P and $P^2$ in the equation (Table 7). In addition the economic optimum for P was calculated at 22 kg/ha for $m = 0.5$ and zero for $m = 1.0$ (Table 8).

Because of inconclusive response to P in 1984, the experiments assigned for 1985 focussed on P-response. Of the three experiments managed by researchers to measure response to different levels of P, a statistically significant response was observed in only one experiment. Although P previously applied in the field as well as FYM use were recorded, there was no correlation between these variables and P response. The economic analysis of the response function for 1985 (Table 8), indicated an optimum P dosage of 33-45 kg/ha (Table 9). At the same time, in the farmer managed verification trial in 1985, the plots with zero P yielded 5.63 t/ha compared to 5.44 t/ha for plots with 50 kg/ha of P, but this difference was not significant. Since the verification trial was not replicated, it was not possible to statistically test for P response in each site, although a visual response was observed in one or two sites.

In 1986, a much larger program was designed to measure P-response across 10 farmers' fields under farmer management. Again in only one site was a significant P-response observed. Over all 10 sites, the response was significant at the 10% level (Table 7), and the economic optimum was estimated at 23 to 38 kg/ha. Unfortunately, site history of P and FYM use was not recorded in 1986, so it was not possible to determine if P response in a given field related to fertilizer history of that field.



## Discussion

The series of surveys and experiments conducted over a five-year period in the Swat Valley indicate that the optimum dose of N is around 100 kg/ha and farmers are approaching that level. Capital scarcity seems to be the main factor limiting use of N in this area; there appears to be little need for further experimentation on N use.

The overall response to phosphorus in maize in this area is small. Both survey data and experimental results support this conclusion. Certainly the recommended level of P of 57 kg/ha is well above the economically optimum dosage. A more appropriate overall recommendation would be 25 kg/ha. Also since farmers on average use 30 kg/ha of P while the marginal return to higher levels of N is very high, most farmers could increase returns from applying more nitrogen rather than phosphorus.

It is likely that most of the observed overall response to phosphorus results from a significant response in a few fields while for most fields there is no response. Hence efforts to identify the conditions under which an economic response to phosphorus is observed could have high payoffs to farmers in more efficient utilization of cash spent on fertilizer. A research program looking at P application and response over the whole rotation, especially wheat-maize, and in relation to use of FYM is required to answer this question. Alternatively soil testing (appropriately calibrated by experimental data) may allow fields in which there is a P response, to be identified. However it is unlikely that small farmers of the Swat Valley will have access to reliable soil testing facilities for many years.

## Conclusions

This paper has demonstrated an integrated and interdisciplinary approach to establishing appropriate fertilizer recommendations for small farmers. Both surveys and experimental evidence suggest that farmers are approaching the optimal level of N use which is somewhat below the official recommendations. There seems little need for further investment in research on N response.

The evidence presented in this paper suggests that recommended phosphorus levels are well above the economic optimum and that many farmers could save considerable costs by reducing P doses. Phosphorus response in maize is likely to be a function of base soil fertility, use of farm yard manure and P application on other crops in the rotation. In the long run, researchers might attempt to develop appropriate P recommendations for the system as a whole, rather than for one crop alone.

Given the increasing levels of fertilizer, especially in irrigated areas, more research of this type is needed to develop site-specific recommendations to fit the varied circumstances of farmers. This research will also need to be closely linked to extension in order to transmit the improved information to target farmers.

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**Table 1**

**Summary of Fertilizer and Verification Experiments Conducted, Swat Valley, 1982-86**

| Type of experiment | Year | No.of sites | No.of replications | N Levels | P Levels | Management levels |
|---|---|---|---|---|---|---|
| 1. N x P | 1982 | 2 | 2 | 0 | 0 | Recommended |
| | | | | 68 | 34 | |
| | | | | 102 | | |
| | | | | 138 | | |
| 2. N x P | 1984 | 3 | 2 | 0 | 0 | Recommended |
| | | | | 50 | 40 | |
| | | | | 100 | 80 | |
| | | | | 150 | | |
| 3. P | 1985 | 3 | 3 | 100 | 0 | Recommended |
| | | | | | 33 | |
| | | | | | 66 | |
| | | | | | 100 | |
| 4. Verification | 1985 | 12 | 1 | 100 | 0 | Farmer |
| | | | | | 57 | |
| 5. P verification | 1986 | 10 | 2 | 100 | 0 | Farmer |
| | | | | | 50 | |
| | | | | | 75 | |
| | | | | | 100 | |

**Table 2**

**Estimated Values or $r_N$ and $r_P$ for Computing Economic Optimum Fertilizer Levels, Swat Valley, 1986.**

| | $r_N$ | $r_P$ |
|---|---|---|
| Researcher managed trial | | |
| m = 0.5 | 6.35 | 7.95 |
| m = 1.0 | 8.45 | 10.60 |
| Farmer managed trial[a] | | |
| m = 0.5 | 5.72 | 7.16 |
| m = 1.0 | 7.61 | 9.54 |

[a] In farmer-managed trials no adjustment is made to yields (i.e. x = 0).

**Table 3**

**Summary of maize fertilization practices, Swat Valley, 1983-85**

| | 1983 Survey | 1984 Survey | 1985 Survey |
|---|---|---|---|
| Percent farmers applied N | 89 | 89 | 95 |
| Percent farmers applied $P_2O_5$ | 60 | 45 | 52 |
| Percent farmers split N | *na* | 22 | 30 |
| Average dose (kg/ha) | | | |
| -N | 57 | 77 | 103 |
| -$P_2O_5$ | 28 | 28 | 36 |
| -Total | 91 | 105 | 139 |
| Percent farmers used farm yard manure on maize | na | 8 | 10 |

*na* = not available



**Table 4**

**Regression Analysis of Factors Affecting Farmers' Fertilizer Use, [a] Swat, 1984-85**

| Variable | Definition | Coefficient and t-value |
|---|---|---|
| LATEP | Dummy variable = 1 if planted after July 1st | 36.15 (2.73)*** |
| SEED | Seed rate (kg/ha) | 0.36 (1.88)* |
| SEEL | Dummy variable = 1 if seel done | 27.84 (2.21)** |
| IMPVAR | Dummy variable = 1 if improved variety used | 30.38 (2.17)** |
| TEN | Dummy variable = 1 if share tenant | - 29.46 (1.29) |
| LOC | Dummy variable = 1 if upper Swat | 32.22 (2.11)** |
| YEAR | Dummy variable = 1 if year is 1985 | 38.52 (2.65)** |
| Constant | | 8.43 |
| n | | 102 |
| $R^2$ | | 0.28 |

a Dependent variable is kg/ha for fertilizer nutrient applied.

Note: *, **, and *** denote significance at the 10%, 5%, and 1% levels, respectively.

**Table 5**

**Fertilizer History of Maize Fields, 1985**

| | Percent of fields |
|---|---|
| <u>Phosphorus</u> | |
| No phosphorus applied to maize, 1985 | 50% |
| Of these field: | |
| - phosphorus applied in previous *rabi* cycle | 12% |
| - phosphorus applied in previous *kharif* cycle | 17% |
| - no phosphorus applied in previous year | 71% |
| Phosphorus applied to maize, 1985 | 50% |
| Of these fields: | |
| - phosphorus applied also in previous *rabi* cycle | 58% |
| - Phosphorus applied in previous year | 82% |
| <u>Farm Yard Manure (FYM)</u> | |
| FYM applied in previous year | 49% |
| For maize after *shaftal*: | |
| FYM applied to *shaftal* | 80% |



**Table 6**

**Regression Analysis of Yields and Management Practices, Swat, 1983-85**

| Variable | Definition | Coefficient and t-value |
|---|---|---|
| IMPVAR | Dummy variable = 1 if used improved variety | 2383<br>(2.94)*** |
| NIT | Nitrogen level (kg/ha) | 14.5<br>(2.57)*** |
| NITSQ | $(NIT)^2$ | - .44<br>(1.53) |
| PUSER | Dummy variable = 1 if applied $P_2O_5$ | 130.3<br>(.67) |
| DEN | Harvest density (plants/ha) | 75.6<br>(3.09)*** |
| DENSQ | $(DEN)^2$ | - .451<br>(3.54)*** |
| VARDEN | VAR*DEN | - 21.1<br>(1.99)** |
| LOC | Dummy variable = 1 if upper Swat | 377<br>(1.88)* |
| Constant | | - 334 |
| n | | 180 |
| $R^2$ | | 0.29 |

Note: *,** and *** denote significance at the 10,5, and 1% level, respectively.

### Table 7

**Estimated Response Function for N and P Over Five Sites, 1982-84**

| | Coefficient and t-value |
|---|---|
| N | 32.87 |
| | (4.73)*** |
| $N^2$ | -.129 |
| | (3.14)*** |
| P | 9.05 |
| | (.71) |
| $P^2$ | -.0248 |
| | (.15) |
| F-ratio to enter P, $P^2$ | 1.44 |
| F-ratio for site dummies | 13.4*** |
| Constant | 4338 |
| $R^2$ | 0.71 |
| n | 49 |

Note: *, **, *** denote significance at the 10%, 5%, and 1% level, respectively



### Table 8

**Estimated Response Function for Phosphorus in On-farm Experiments in 1985 and 1986**

| | Three experiments in 1985 (Research management) | Ten experiments in 1985 (Farmer managed) 1 | 2 |
|---|---|---|---|
| P | 17.6 | 13.1 | 14.2 |
| | (1.27) | (1.65) | (1.18) |
| $P^2$ | - 0.106 | - 0.0776 | - 0.0775 |
| | (.80) | (.98) | (.65) |
| F-ratio to enter P and $P^2$ | 4.29* | 3.32* | 2.12 |
| F-ratio for site dummies | 6.80** | 10.9*** | |
| DEN[a] | | | 2.31 |
| | | | (2.45)** |
| $DEN^2$ | | | - 1.32 |
| | | | (1.97)* |
| Constant | 6396 | 5846 | - 4199 |
| $R^2$ | 0.76 | 0.79 | 0.44 |
| n | 12 | 40 | 40 |

Note: *, **, *** denote significance at the 10%, 5%, and 1% respectively.

[a] Plant density (plants x $10^{-3}$/ha)

**Table 9**

**Summary of Statistical and Economic Analysis of Fertilizer Response, Swat, 1982-86.**

| Type of experiment | No. of Years | No. of sites | Management[a] | No.of sites where response significant | Economic optimum[d] m = 0.5 | m = 1.0 |
|---|---|---|---|---|---|---|
| N x P | 2 | 5 | r | N - 4 | N• = 102 | 94 |
| | | | | P - 2[b,c] | P• = 22 | 0 |
| P | 1 | 3 | R | 1 | P• = 45 | 33 |
| P | 1 | 10 | F | 1[b] | P• = 38 | 23 |

a R = researcher F = farmer.
b Significant at the 10% level only.
c A significant N x P interaction was observed in one experiment.
d m = minimum acceptable rate of return on capital (CIMMYT, 1988).