AN ALTERNATIVE APPROACH FOR WORKING OUT FERTILIZER NEEDS OF CROPS BASED ON THE SOIL TESTS

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(Received : December, 1981)

SUMMARY

A modified approach for studying crop responses to the fertilizers in relation to soil tests, has been proposed. It consists of selecting the fields differing in native soil fertility. 4^3 confounded designs in the three nutrients in blocks of 16 and 8 plots are suggested. The design with 16 plots will utilize soil variation between as well as within blocks while the other design will use soil variation between blocks only. The quadratic model for working out the economic doses of the fertilizer nutrients on the basis of soil test values and improved technique for estimating the contributions and efficiencies of the nutrients from soil and fertilizer sources are described. The proposed methodology has been illustrated by actual data from a4^3 confounded experiment.

Two approaches are being followed for recommending fertilizer doses to crops. The first widely used approach consists of conducting multi-locational fertilizer trials on major soil types in a particular region for wider applicability. The second approach is site-specific and consists of conducting the trials in the same field after creating artificial fertility gradient and the applicability of the inferences is strictly location bound. The second approach has been designed by Ramamoorthy and co-workers [4], [5], [6] and [7] and is being used in Soil Tests Crop Response (STCR) project of ICAR. Recently, Raychaudhury [9], Randhawa [8], Sekhon and Tandon [10] have argued that results of little practical utility have emerged by adopting the site-specific design in experimentation. Keeping in view the above criticism, the artificial fertility gradient (AFG) technique was critically examined and the modified technique for recommending fertilizers in relation to soil tests is suggested.

Procedure for creating fertility gradient: A criticism to the AFG technique lies in the fact that how far the hastily built-up instable soil fertility with the application (one dressing) of the fertilizers is stable and will behave alike to native soil fertility. A modification of the AFG technique has been suggested to circumvent its criticism. It consists of selecting the fields in the same locality taking care that the fields differ only in fertility but belong to the same soil type of the series (unit of soil classification). Soils should be similar in stoniness, erosion, drainage and other characteristics etc. During selection, the emphasis should also be laid on the local factors. For instance, in the hills of Shimla, the yield potential of the fields facing the *southern aspects* of the hills is higher than fields facing *northern aspect* because of the less solar energy harvested by the crop in the latter aspect.

Statistical Design of the Experiment : Two different types of designs are suggested. First design considers only the variability between the blocks (variability w.r.t. the nutrients under consideration). In this design, the block size should be small but the number of blocks large. Soil within the blocks is homogeneous. A single composite basic soil sample is taken from each block before the planting for its analysis to co-rrelate with the yield. Second design considers the variability between as well as within the blocks. Soil variability, to an appreciable extent, is present within the blocks. In this design, block size is large but the number of blocks is less. Here, soil samples from each plot within each block are to be taken before planting.

The designs suggested have an edge over the one adopted in the STCR project in terms of economy in space and inputs and orthogonal estimation of unconfounded effects etc. For the first type a 4^3 factorial design is proposed. It confounds $N''P''$, $N''K''$, $N'P'K'$ and their interactions with the blocks of 8 plots (table 2.1). It is to be repeated twice. For the second type, a 4^3 factorial design confounding $N'P''K'''$, $N''P'''K'$ and $N'''P'K''$ with the blocks of 16 plots is suggested (Table 2.2) or a 5^3 factorial design confounding a three-factor interaction component with the blocks of 25 plots may be used. Fields differing in fertility are to be taken as blocks.

Larger net-plots, apart from increasing intra-block error, hamper the estimation of the yield-nutrient relationship due to averaging effect (soil variability within a plot and plot yield are represented by a single pair of values) while smaller net-plots estimate the plot yields less efficiently. Therefore, the net-plot size should be reasonable and must not exceed the optimum size determined statistically. When the variation within the blocks is to be utilized, it is advisable to keep gross plot size comparatively larger or one non-experimental plot may be kept between the two experimental plots. Compact blocks might be preferable for the first type of designs while the blocks of strip shape may prove useful for the second type of designs.

Statistical Analysis :

(*i*) *Testing of effects* : Yield data obtained from the experiment conducted according to these designs may be analysed for testing the main effects and unconfounded 2-factor interaction components. Unconfounded three-factor interaction components may be used for error.

(*ii*) *Fitting of Model* : The following quadratic model is chosen for explaining the crop response to the nutrients :

$$Y=\beta_o+\sum \beta_i X_i+\sum \beta_{ij} X_i^2+\sum_{i<j} \beta_{ij} X_i X_j,\ i, j=1 \text{ to } 6 \quad \ldots(A)$$

where Y is the yield, X_1, X_2, X_3 are the fertilizer nutrients *i.e.* N, P and K and X_4, X_5, X_6 are the soil nutrients *i.e.* N, P and K, in kg/ha, respectively. The model (A) omitting the linear, quadratic terms in the soil nutrients and the terms containing the interaction between the soil nutrients can be directly fitted to the yield data. This is because of the fact that these omitted portions are to some extent mixed up with the block effects. When the block effects are expected to be small the full model can be fitted. In case of doubt about the block effects or if one is interested in fitting the full model then one should first fit the following model:

$$Y_l=\eta_l+Y; \quad \ldots(B)$$

where Y_l is the yield in the l-th block, η_l is the effect of the l-th block with $\Sigma\eta_l=0$ and Y is the model (A). Block effects are now to be tested for significance. In case of significant block effects, the model Y fitted on the right-hand-side of (B) may be taken as the required model for subsequent purposes. Otherwise, refitting of the model (A) may be carried out while ignoring the block effects.

Fitting of the model (A) : The fitting of the model (*A*) is carried out by the 'Least Squares Method'. For convenience we rename the independent variables as follows :

$$1=Z_0,\ X_1=Z_1,\ X_2=Z_2,\ X_3=Z_3,\ X_1^2=Z_4,\ X_2^2=Z_5,\ X_3^2=Z_6,$$

$$X_1X_2=Z_6,\ X_1X_2=Z_7\ \ldots,\ X_3X_6=Z_{27}.$$

The 'β' coefficients may also be renamed as $\beta_0, \beta_1 \ldots \beta_{27}$. The normal equations for the estimations of the 'β's in the matrix form are given below :

$$M_{28\times 28}\, \underset{\sim}{b}_{28\times 1} = \underset{\sim}{w}_{28\times 1}\ ,$$

where (*i, j*)-the element of *M* is $=\Sigma Z_i Z_j$, $(i, j=0$ to $27)$; the *i*-th row of $\underset{\sim}{w}$ is $=\Sigma YZ_i$; 'Σ' is over all the 64 plots' values and $\underset{\sim}{b}$ is a column vector of unknowns to be determined.

The matrix equation can be solved by triangulation (*i.e.* by successive elimination of the unknowns) or by inversion of the matrix *M*. The later method will, additionally, provide the estimate of the dispersion matrix of the estimates of 'β's (for details *see* Kempthorne, [3]).

Denoting the estimate of 'β_i' by 'b_i', the regression

$$SS=\sum_{i=0} b_i \left(\sum YZ_i\right) - \frac{G^2}{64}\ ,$$

where *G* is the grand total. The regression *d.f.*=number of estimated β_i's$(i\neq 0)$. The deviation from regression *SS*=Total *SS*−Regression *SS* and has *d.f.*=63−regression *d.f.* Model (*A*) is adequate if regression *MS* is significant relative to the deviation from regression *MS* (by *F*− test).

Fitting of the Model (B) : The first type of designs do not provide information on the block effects. But in the designs of the second type, block effects can be estimated and tested for significance. So we assume under this heading that the design used for experimentation is of the second type. The model (*B*) is rewritten as follows :

$$Y_{lk}=\eta_l+\sum_{i=0}^{27} \beta_i^o Z_{ilk},\ k=1 \text{ to } 16,\ l=1 \text{ to } 4\ ;$$

where 'Y_{lk}' is the yield of the k-th plot in the l-th block at the level Z_{ilk} of the i-th independent variable Z_i ; 'β_i^o' is the regression coefficient and 'η_l' is the l-th block effect with $\Sigma\eta_l=0$. The matrix equation for estimating 'β^o' coefficients (excepting β_o^o) obtained after eliminating the block effects from the normal equations is given below :

$$M^o{}_{27\times27}\underset{\sim}{b}^o{}_{27\times1}=\underset{\sim}{w}^o{}_{27\times1}\ ;$$

where (i, j)-th element of M^o is

$$=\sum_{l,k}(Z_{ilk}Z_{jlk}-\bar{Z}_{il}\bar{Z}_{jl})$$

$(i, j=1, 2, \ldots, 27)$; the i-th row of $\underset{\sim}{w}^o$

$$\text{is } w_i^o=\sum_{l,k}(Y_{lk}Z_{ilk}-\bar{Y}_l\bar{Z}_{il})$$

and $\underset{\sim}{b}^o$ is a column vector of unknowns. Further,

$$\bar{Y}=\sum_{l,k}\frac{Y_{lk}}{64},$$

$$\bar{Y}_l=\sum_{k}\frac{Y_{lk}}{16}, \qquad \text{and}$$

$$\bar{Z}_{il}=\sum_{k}\frac{Z_{ilk}}{16}.$$

The matrix equation is solved by triangulation or by inversion of M^o. The estimate of 'β_o^o' is given by

$$b_o^o=\bar{Y}-\sum_{i}b_i^o\bar{Z}_i,$$

where 'b_i^o' is the estimate of β_i^o. The ANOVA—1 for testing regressions and ANOVA—2 for testing block effects are presented in table 5.

Firstly, the adequacy of the model (B) is established. The model is adequate if the Model (B) MS is significant relative to the deviation from Model (B) MS by F-test. Secondly, we test the block effects by comparing the blocks (eliminating regressions) *MS* from ANOVA-2 with the deviation from Model (*B*) *MS* by *F*-test when model (*B*) has been found to be adequate. Significant *F*-test implies the appropriateness of Model (*B*) and then the test of regressions is made from ANOVA-1 by comparing the regressions (eliminating blocks) *M.S.* with the deviation from Model (*B*) *M.S.* by *F*-test. Non-significance of block effects indicates the appropriateness of model (*A*).

The multiple correlation coefficient R^2 of the regressions are calculated for the models (*A*) and (*B*) as follows:—

$$\text{Model } (A) : R^2 = \frac{\text{S.S. due to Model } (A)}{\text{total SS}} \times 100$$

$$\text{Model } (B) : R^2 = \frac{\text{S.S. due to regressions (eliminating blcoks) from (ANOVA)}-1}{\text{total SS}} \times 100$$

Contributions of the nutrients from the soil and fertilizer sources: Ramamoorthy *et. al.* [6] considered the nutrient uptake by the crop in $N_oP_oK_o$ (control) plot as the contribution from the soil source. The methodology of Ramamoorthy for working out contributions of nutrients from the soil source can be improved by taking into account the interaction effects (effect of application of one nutrient on the availability of the other nutrients either from soil or fertilizer source), Table 1 illustrates that when *N* is applied to the crop, the contribution of soil *P* increases from 13.7 to 20.5 per cent and likewise with the application of both *N* and *P*, the contribution of the soil to supply *K* increases from 35.5 to 52.5 per cent. The contribution of nutrients from the soil and fertilizer sources have been assumed by these workers to be constant irrespective of the level of the nutrients. Actually, the per cent contribution of nutrients decreases with increasing doses as the law of diminishing returns operates.

Improved methodology for calculating the contribution af the nutrients from soil and fertilizer sources : Exact contributions of the nutrients from soil and fertilizer sources are possible only with the isotopic studies. However, in absence of isotopic studies, the following method may be adopted :

For a particular crop, let F $(X_1, X_2, \ldots X_n)$ be the response function of the fertilizer and soil nutrients $X_1, \ldots, X_n$. Assuming the existence and continuity of the first order partial derivatives of

TABLE 1

Contributions of P and K from the soil source as affected by the application of fertilizers*

Treatments	*Tuber uptake in kg/ha*		
	N	P	K
$N_0F_0K_0$	61	5.5(13.7)	71(35.5)
$N_1P_0K_0$	78	8.2(20.5)	103(52.5)
$N_1P_1K_0$	109	11.1	126(63.0)
$N_1P_1K_1$	118	14.0	193

Figures in the parenthesis represent percentage contributions form the soil source.

$N_1 : P_1 : K_1$ :: 100 : 44 : 84 kg/ha

Soil analysis: Organic carbon=2.2 per cent
Bray-P =40 kg/ha
NH_4OAc-K =200 kg/ha

* Method of computing contributions :

P uptake in the tubers *i.e.* P content of the tubers from a $N_0P_0K_0$ treated plot=5.5 kg/ha.

Soil P=40 kg/ha.

Therefore, per cent contribution of soil P in the absence of fertilizer treatments

$$=\frac{5.5}{40}\times 100=13.7\%$$

Similarly per cent contribution of soil P in the presence of only N_1

$$\text{is } =\frac{8.2}{40}\times 100=20.5\% \text{ etc.}$$

F *w.r.t.* $X_1, \ldots, X_n$ the point efficiency of the i-th nutrient at the point $X_i=x_i$, $i=1, 2, \ldots\ldots, n$ may be defined by the partial derivative

$$\frac{\partial F}{\partial x_i}\Big|_{x_i=x_i,\ x_2=x_n,\ \ldots,\ x_n=x_n.}$$

The contribution of x_i over the interval (x_i', x_i) is defined by the definite integral $\int_{x'_i}^{xi}\left(\frac{\partial F}{\partial x_i}\right) dx_i$.

The contribution of X_i over the interval $(0, x_i)$ is denoted by C_i. The efficiency of X_i over the interval (x_i', x_i) is defined by

$$\int_{x_i'}^{x_i} \left(\frac{\partial F}{\partial x_i} \right) dx_i \Big/ (x_i - x_j') \,.$$

When $x_i'=0$, it is denoted by E_i. E_i is, therefore, the average contribution per unit of X_i. The point $x_i'=0$, may fall outside the range of the values x_i actually tried (fertilizer nutrients levels) or observed (soil nutrients levels). The estimation of the response at such points would require extrapolation of the estimated response function (model A). This is not a good feature, but for our purpose, it will not matter, for the points $x_i'=0$ would serve only as fixed reference points provided we restrict the computations of C_i's and E_i's only within the range of independent variables actually found in the experiment. It may be pointed out that the contribution of the nutrients as calculated by Ramamoorthy *et al.* [6] is E_i in our analogy.

When $F=a+\Sigma F_i(X_i)$, where $F_i(X_i)$ is a function of X_i alone and 'a' is some constant then $F=a+\Sigma C_i$, ..., (*) at $X_i=X_i$, $i=1, 2, \ldots\ldots, n$. This is the case of no interaction among the factors.

In the present study, efficiencies and contributions will be worked out for the general quadratic response function (A). Fit the model (A) to the yield. Then

$$C_i=b_i x_i+b_{ii} x_i^2 - \sum_{\substack{j<j' \\ j \text{ or } j'=i}} b_{j,j'}\, x_j x_{j'}. \text{ ('}b\text{'s are estimates of '}\beta\text{'s)}$$

The above definition of C_i does not satisfy (*) for the model (A). However, the following modification will do :

$$C=b_i x_i+ b_{ii} x_i^2 +\tfrac{1}{2} \sum_{\substack{j<j' \\ j \text{ or } j'=i}} b_{jj'} x_j x_j^1$$

Interestingl $b_{jj'} x_j x_{j'}$ may be defined as the contribution of the interaction of the nutrients, X_j and X_i. The correspondingly modified definition of E_i is given by $E_i' = \frac{C_i'}{x_i}$. Priming of the symbols will be stopped in what follows. The C_i and E_i described above are *w.r.t.* yield. Soil Scienrist is often interested in knowing how much of a particular nutrient either from fertilizer or soil has been converted into yield by the plant. For doing this, we define:— Efficiency of X_i *w.r.t.* the *j*-th nutrient$=E_i$, r_j ; $j=N$, P, K, where r_j is a fraction of the nutrient *j* in the yield ($o \leqslant r_j \leqslant 1$). In this definition we have assumed that r_j'*s* are constants. On the contrary, model (*A*) has to be fitted to *N*, *P* and *K* contents in the yield separately in addition to the yield. The efficiencies E_i'*s* are calculated as for yield. Usually, four different E_i'*s* of the nutrient X_i can be determined *i.e. w.r.t.* yield, *N*, *P* and *K* contents in the yield.

Formation of fertilizer adjustment equations for targeted yield: Doses of the fertilizer nutrients for given soil nutrients values to achieve targeted yields of the crops may be worked out by the formula analogous to that used in *STCR* project but from the multiple regression equation (*A*).

$$\text{Dose of } X_i \text{ is given by : } X_i=\frac{T-b_o}{E_i}=\frac{\sum\limits_{j\neq i} E_j\, x_j}{E_i} \quad \text{for } i=1,2,3$$

where *T* is the targeted yield E_i is the efficiency of the *i*-th nutrient with respect to yield. On substitution for these values in the above formulae, we get:

$$bo+\sum b_i\, x_i+\sum b_{ii}\, x_i^2+\sum_{i<j} b_{ij}\, x_i\, x_j-T=0, \ldots \quad (C)$$

This relation can be solved as a quadratic equation in x_i giving a series of combinations of x_1, x_2 and x_3 providing the same targeted yield for the given soil nutrient levels. Out of these we may select one combination on the basis of balanced nutrition and other considerations. It can be seen that the relation (*C*) is nothing but the corresponding (*A*) model with *Y* substituted by *T*. So for targeting yield, we need not even calculate soil and fertilizer efficiencies but straightway solve the corresponding fitted model for the fertilizer nutrients for given soil test values.

Significance of constant (b_o) *in the multiple regression equations*: Singh and Sharma [12] have reported 'b_o' values of high as 1403.04 kg/ha for wheat (H.D. 1982) in the multiple regression equation.

What is the cause of such high values of yields 'b_o' when the contribution of N, P and K from soil as well as fertilizer source is zero ? This raises doubts regarding the validity or reliability of the estimates and the technique itself. Theoretically one can expect positive value of 'b_o' in the case of leguminous crops which fix nitrogen from the atmosphere. We believe that 'b_o' will have some negative value (Snedecor and Cochran, [13] due to the fact that some nutrients may be required just for the survival of the plants without any reflection on the increase in yield. It may be mentioned that 'b_o' value may be used to measure the *extravagence* or *lavishness* of a particular crop. When converted to dry matter or nutrient content or as the ratio of maximum response, it may also be used for comparison among different crops.

Formulation of fertilizer adjustment equations for optimum doses : Dev and Dhillon [1] and Dev *et al.* [2] have reported adjustment equations for working out optimum (economic) doses of nutrients for the different crops, some of which are not tenable because the adjustment equations in these cases do not exist as the coefficients of the square term of the fertilizer nutrients in the quadratic model fitted are positive.

The adjustment equations for the model (A) when they exist can be obtained by solving the matrix equation :

$$\begin{pmatrix} 2b_{11} & b_{12} & b_{13} \\ b_{12} & 2b_{22} & b_{23} \\ b_{13} & b_{23} & 2b_{33} \end{pmatrix} \begin{pmatrix} x_1 \\ x_2 \\ x_3 \end{pmatrix} = -\begin{pmatrix} b_1+\sum_{j=4}^{6} b_{1,j}\, x_j - R_1 \\ b_2+\sum_{j=4}^{6} b_{2j}\, x_j - R_2 \\ b_3+\sum_{j=4}^{6} b_{3j}\, x_j - R_3 \end{pmatrix},$$

$$\text{where } R_i = \frac{\text{Cost per kg of fertilizer nutrient' } X_i}{\text{Price per unit of yield}}$$

The conditions for the existence of adjustment equations are as follows :—

(a) b_{11}, b_{22} and b_{33} are all negative,

(b) determinant $\begin{vmatrix} 2b_{11} & b_{12} \\ b_{12} & 2b_{22} \end{vmatrix}$ is positive and

(c) the determinent of the 3×3 matrix on the left-hand-side of the above matrix equation is negative.

The solution to the above matrix equation provides fertilizer adjustment equations for the optimum yield. When the above matrix equation is solved while ignoring R_1, R_2 and R_3 fertilizer adjustment equations for the maximum yield are obtained.

Need for right interpretation of the results: Singh and Sharma [12] have worked out lower and upper critical limits of the soil test values. According to them there are certain soils (soils having the nutrient concentration below the lower critical limit) which are highly deficient but do not respond to the fertilizers. The conclusions drawn by these authors regarding the non-responsiveness of highly deficient soils to fertilizers are apparently due to the usage of incomplete models. It seems that they have worked out the lower critical limits from the models : (*a*) Cotton ($PS-10$) : $R=-16.38\ FN+0.0752\ FNSN$, and (*b*) Arhar (Pusa Ageti) : $R=0.174\ FK-0.0003\ FKSK$, where R is the response, FN, FK the fertilizer N and K and SN, SK the soil N and K. The complete model should have contained the additional term, *i.e.*, $0.38\ FN^2$ in (*a*) and $0.0212\ FK^2$ in (*b*). Thus the right interpretation of the data should be : Cotton ($PS-10$) will respond to FN for doses satisfying,

$$FN > \frac{16.38-0.0752\ SN}{0.038}$$

i.e. a higher dose of FN is needed (and expected too) for getting response in the highly deficient soils and Arhar (Pusa Ageti) will respond to FK if its dose is

$$> \frac{-0.174+0.0003\ SK}{0.0212}.$$

Thus for working out the fertilizer response all the terms in the model involving the given fertilizer nutrient should be considered.

Illustration: The data from $a4^3$ experiment conducted in 1981-82 (autumn) with the potato crop at the Central Potato Research Station, Patna has been used for illustrating the main points of the proposed methodology. The data are presented in Table 3. The experiment was conducted according to the design given in Table 2.2. The preliminary analysis (ANOVA, Table 4) showed that fertilizer N, fertilizer K and their interactions were significant whereas P, NP and PK effects were non-significant. Therefore, for fitting the model (A) to yield, the terms involving the nutrient (P) were dropped. For designs of first type, there is little meaning in

TABLE 2.1

Plan of the 4^3 design confounding $N''P''$, $N''K''$, $N'P'K'$ and their interaction with the blocks of 8 plots.

Treatments combinations				*(n, p, k) in the blocks*			
B1	*B2*	*B3*	*B4*	*B5*	*B6*	*B7*	*B8*
333	303	332	302	323	313	322	312
211	211	210	220	201	231	200	230
121	111	120	110	131	101	130	100
003	033	002	032	013	023	012	022
300	330	301	331	310	320	311	321
222	212	223	213	232	202	233	203
112	122	113	123	102	132	103	133
030	000	031	001	020	010	021	011

2.2 Plan of 4^3 confounded design confounding $N'P''K'''$, $N''P'''K'$ and $N'''P'K''$ in block of 16 plots.

The treatment combinations within the blocks are given in Table 3.

considering the terms in the soil nutrients in model (A) when the 'blocks (ignoring soil effects) *M.S.*' is insignificant relative to error *M.S.* (in an ANOVA similar to table 4). In our illustration, the soil variation in N and K both have been utilized for fitting the response surfaces. The ANOVA for fitting the model (B) has been computed in table 5. 'Blocks eliminating regressions (*i.e.* soil effects)' are not significant. (ANOVA-2) while 'regressions eliminating blocks' are significant (ANOVA-1). This and the highly significant blocks (ignoring soil effects) *M.S.* in table 4 indicate that the blocks contain useful variation in soil N and K which should be utilized by fitting the model (A). However, when blocks (eliminating regressions) are significant then model (B) having the ANOVA-1 in table 5 is the appropriate model. Model (A) is the right model in our illustration. ANOVA is presented in table 4 and the estimates of the regression coefficients in table 6. The model explained 92.56% of the total variation in yield.

TABLE 3

Experimental data from a4^3 experiment of Dr. J.P. Singh with potato conducted at Central Potato Research Station, Patna during (1981-82)

Block I			*Yield*	*Soil Nutrients (ppm)*		*Block II*			*Yield*	*Soil Nutrients (ppm)*		*Block III*			*Yield*	*Soil Nutrients (ppm)*		*Block IV*			*Yield*	*Soil Nutrients (ppm)*	
n	*p*	*k*	*kg/3.24 m²*	*SN*	*SK*	*n*	*p*	*k*	*kg/3.24 m²*	*SN*	*SK*	*n*	*p*	*k*	*kg/3.24 m²*	*SN*	*SK*	*n*	*p*	*k*	*kg/3.24 m²*	*SN*	*SK*
1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*	*13*	*14*	*15*	*16*	*17*	*18*	*19*	*20*	*21*	*22*	*23*	*24*
0	0	0	4.2	40	53	0	0	1	3.3	33	41	0	0	2	5.7	52	68	0	0	3	4.3	38	52
0	1	3	4.6	41	63	0	1	2	3.6	32	46	0	1	1	8.9	64	65	0	1	0	3.8	34	59
0	2	1	4.3	41	63	0	2	0	3.5	32	40	0	2	3	7.2	70	95	0	2	2	4.1	34	48
0	3	2	5.8	36	55	0	3	3	4.8	32	46	0	3	0	6.5	70	70	0	3	1	4.1	38	52
1	0	2	10.7	45	63	1	0	3	8.4	34	54	1	0	0	10.3	60	67	1	0	1	9.5	34	48
1	1	1	11.0	47	76	1	1	0	5.6	40	53	1	1	3	13.0	64	68	1	1	2	8.8	40	44
1	2	3	11.3	42	70	1	2	2	9.7	36	51	1	2	1	10.6	53	82	1	2	0	7.6	38	48
1	3	0	7.8	41	65	1	3	1	11.0	38	49	1	3	2	13.2	60	54	1	3	3	11.4	36	48
2	0	3	14.9	48	54	2	0	2	12.7	34	42	2	0	1	14.1	71	70	2	0	0	8.6	34	42

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
2	1	0	8.9	41	80	2	1	1	12.0	38	53	2	1	2	15.0	54	65	2	1	3	15.6	38	66
2	2	2	15.6	40	63	2	2	3	16.5	38	52	2	2	0	14.8	59	101	2	2	1	12.5	40	54
2	3	1	14.2	40	77	2	3	0	5.3	32	50	2	3	3	14.0	67	89	2	3	2	15.8	33	54
3	0	1	16.0	38	59	3	0	0	9.1	34	48	3	0	3	16.7	59	68	3	0	2	15.2	38	50
3	1	2	16.0	40	77	3	1	3	13.8	38	51	3	1	0	11.5	64	79	3	1	1	12.2	33	55
3	2	0	12.3	43	70	3	2	1	12.4	34	46	3	2	2	17.0	62	87	3	2	3	17.9	35	48
3	3	3	18.6	38	57	3	3	2	13.4	34	52	3	3	1	17.2	67	99	3	3	0	6.7	33	45
Average			11.0	41	65		—		9.1	35	48		—		12.2	62	77		—		9.9	36	51

1 *ppm*=2.24 kg/ha ; Levels of fertilizer *N* (nitrogen) and $K(K_2O)$ in kg/ha are :—0 : Nil, 1 : 100, 2 : 200, 3 : 300 and of $P(P_2O_5)$ in kg/ha are :—*O* : Nil ; 1 : 70 ; 2 : 140 and 3 : 210 ;
$SN = NO_3-N$ in surface soil (0–15 cm) by Chromotropic acid. *SK* : 0.7*N* warm H_2SO_4 extractable *K* from the soil.

TABLE 4

Analysis of variance $(kg/3.24m^2)^2$

Source	*D.F.*	*Sum of squares*
(1) Blocks (ignoring soil effects)**	3	90.9092*
(2) *Fertilizer Effects :*		
N	3	825.4967*
P	3	7.4692
K	3	161.0892*
NP	9	19.4564
NK	9	46.2764*
PK	9	30.4189
(3) Error for testing (1) & (2)	24	39.0638
(4) Total	63	1230.1798
(5) Regression (Model *A*)	14	1138.5962*
(6) Deviation from Regression [error for testing (5)]	49	91.5836

* Significant at 1% level.

** Soil effects considered here are : Soil *N*, *P* and *K*.

The equation giving the efficiency of fertilizer N is given by

$$E^1=\frac{1.481109FN-0.002868FN^2+\frac{1}{2}(0.002071FNFK-0.006570FNSN+0.004514FNSK)}{FN}$$

where FN, FK, SN and SK denote the fertilizers N, K, soils N and K respectively. E_1 at $FN=50$, 100, 150, 200, 250, 300 kg N/ha at different levels of other nutrients is presented in table 7. The efficiency of FN decreased as the dose of FN was increased but it increased as the level of other nutrients (FK, SK) was increased. Efficiencies of FK, SN, SK can be similarly computed.

The yield targeting has been illustrated at the soil levels of $SN=71$ and $SK=90$ kg/ha. The yield targeting equation which is obtained after substituting the values for SN and SK is given below :

$$T=-87.680658+1.420899FN-0.002868FN^2+0.733413FK$$
$$-0.001645FK^2+0.002071FNFK$$

TABLE 5

ANOVA for Model (B) (for designs of second type)

ANONA-1 : Testing of Regressions		*D.F.*	*ANOVA-2 : Testing of Block Effects*	
Source	*Sum of squares*		*Sum of squares*	*Source*
(1) Blocks (ignoring regressions)	$\frac{B_l^2}{16}-\frac{G^2}{64}$ (90.9092.)+	3 (3)	By subtraction (10.4073 NS)	Block (eliminating regressions)
(2) Regressions (eliminating blocks)	$\sum_{i=1}^{27} b_i^0 w_i^0$ (1058.0943)*	26 (14)	Model (A) S.S. (1138.5962)	Regressions (ignoring blocks)
(3) Model (B)	(1)+(2) (1149.0035)	29 (17)	→ (1149.0035)	Model (B)
(4) Deviation from Model (B)	Total SS—Model (B) S.S (81.1763)	34 (46)	→ (81.1763)	Deviation from Model (B)*
Total	$\sum_{l,k} y_{lk}^2-\frac{G^2}{64}$ (1230.1798)	63 (63)	→ (1230.1798)	Total

+ :—Figures in the parenthesis are the values obtained in the illustration; B_l is the block total ; NS : non-significent at 5% ;
* : significant at 1%.

TALBE 6

Estimates of the constants in Model (*A*)*

Constants	*Estimates*
β_0	−167.732308
β_1 (*FN*)	1.481109
β_2 (*FK*)	1.048730
β_3 (*SN*)	4.427441
β_4 (*SK*)	−0.550359
β_{11} (F^2N)	−0.002868
β_{22} (F^2K)	−0.001645
β_{33} (S^2N)	−0.008835
β_{44} (S^2K)	0.002602
β_{12} (*FN FK*)	0.002071
β_{13} (*FN SN*)	−0.006570
β_{14} (*FN SK*)	0.004514
β_{23} (*FK SN*)	−0.002167
β_{24} (*FK SK*)	−0.001794
β_{25} (*SN SK*)	0.002200

R^2=92.56 (%)

* Dependable variable yield is in *Q*/ha and all the independant variables are in kg/ha.

TABLE 7

Efficiency of *N* at different levels of other fertilizer and soil nutrients

Level of other factors (kg/ha)			*Efficiency of N at different doses of N (kg/ha) in (q/ha)/kg N*					
FK	*SN*	*SK*	*50*	*100*	*150*	*200*	*250*	*300*
0	90	100	1.2678	1.1244	0.9810	0.8376	0.6942	0.5508
50	120	150	1.3338	1.1904	1.0470	0.9036	0.7602	0.6168
100	150	200	1.4000	1.2565	1.1131	0.9697	0.8263	0.6829

Now FN or FK is fixed at some level and the resulting quadratic equation is solved for a root for given targeted yields (T). The different combinations of FN and FK giving the same targeted yield T=250, 300, 350, 400, 450 q/ha are presented in Table 7.

Nextly, the condition of existence of the fertilizer adjustment equations arc satisfied, for b_{11}, $b_{22}<o$ & the determinant

$$\begin{vmatrix} 2b_{11} & b_{12} \\ b_{12} & 2b_{22} \end{vmatrix} > o.$$

TABLE 8

Fertilizer needs for yield targeting of potato at SN=71 and SK=90 kg/ha of soil nutrients

Targeted yield (q/ha)	*Fertilizer need in Nitrogen*	*kg/ha K_2O*
250	0	114.25
	10	77.17
	20	50.69
	30	29.84
	48.63	0
300	20	174.16
	40	89.87
	60	48.02
	98.72	0
350	60	138.89
	100	57.86
	178.68	0
400	80	213.65
	120	102.11
	160	60.50
450	120	208.13
	180	106.94
	243	78.55

The fertilizer equations for the maximum yield are given by :

$$N=483.100788-1.790045SN+0.763638SK$$

$$K=622.866788-1.785466SN-0.064591SK.$$

Taking the cost of FN as Rs. 6.40/kg as calcium ammonium nitrate, FK as Rs. 2.17/kg as muriate of potash and price of potato as Rs. 50/q, we have, $R_1=0.128$, $R_2=0.0434$. The fertilizer adjustment equations for optimum yields are :

$$N=448.058447-1.790045SN+0.763638SK,$$

$$K=587.616731-1.785466SN-0.064591SK.$$

The range of validity of the above equations is given by : FN, $FK \leqslant 300$, $71 \leqslant SN \leqslant 160$ and $90 \leqslant SK \leqslant 224$ in kg/ha.

ACKNOWLEDGEMENT

Authors are thankful to Mr. J.P. Singh, Scientist S-1, (Soil Science), Central Potato Research Station, Patna for providing the data of the experiment for illustration of the proposed technique.

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