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Fertiliser Response Functions and Optimum Levels for Bean Cultivation in Badulla District

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ABSTRACT. Application of levels of fertiliser higher than the recommended levels is a common occurrence with up country vegetable crops. The obvious reason for this has been the response to fertiliser even at higher levels. This study focuses on determination of the correct optimum levels for bean grown in the up country.

The non-linear functional relationships with respect to all three main nutrients were investigated in this study. Standard fertiliser response functions are usually for one nutrient and thus the interaction between nutrients cannot be taken into account. Therefore, determination of optimum levels of fertiliser should be based on the models with all three nutrients together. This paper focuses on the possibility of including all three nutrient effects in fertiliser response and to estimate the optimum fertiliser levels.

Based on these response models, we found that the Mitcherlich – Baule model can be extended to the three nutrient situation and the Box-Cox transformation showed an improvement in Mitcherlich - Baule model. For the extended model, the λ value for Box-Cox transformation was around 0.8. The best models were selected based on the R^2, separately for basal dressing and top dressing. Survey data collected from 125 farmers in Badulla district were used to fit the models. Cluster sampling technique was adopted in data collection. According to the best fit models, we found optimum levels to be, Nitrogen around 100 kg/ha, Phosphorus around 200 kg/ha and Potassium around 90 kg/ha and the optimal rates for top dressing were Nitrogen around 80 kg/ha and Potassium around 80 kg/ha.

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INTRODUCTION

The key to maximising the profit in crop production is by applying the optimum levels of fertiliser. Although, fertiliser recommendations are available for most of the crops in Sri Lanka, farmers do not adhere to these recommendations. In the up country (Nuwara Eliya and Badulla) especially, farmers use higher amounts of fertiliser for their vegetable crops. Wijewardene and Amarasiri, 1990, 1997 and Marikar *et al.*, 1996 also stated that the level of fertiliser applied by the farmers to potato and vegetables in up country were higher than the recommended rates.

Crop response analysis is recognised as an important area of research for developing fertiliser recommendation. Optimum level of fertiliser is determined by studying the functional relationship between fertiliser levels and yield, by means of fitting models. With one nutrient, Mitscherlich (1909) showed that an exponential function fits well the relationship between fertiliser level (x_i) and yield (Y_i) and is of the form,

$$Y_i = \alpha\left(1 - \beta e^{-\delta x_i}\right) + \varepsilon_i \text{ ------------ (1)}$$

Where, α, β and δ are the parameters and ε_i is the error term. The extension of the analytical specification of crop response to more than one nutrient is attributed to Baule (1918). He proposed a multiplicate relationship among nutrients ($x_{1i}, x_{2i}, \ldots, x_{ki}$) and yield ($Y_i$) in the form,

$$Y_i = \left\{\alpha\left(1 - \beta_1 e^{-\delta_1 x_{1i}}\right)\left(1 - \beta_2 e^{-\delta_2 x_{2i}}\right)\ldots\left(1 - \beta_k e^{-\delta_k x_{ki}}\right)\right\} + \varepsilon_i \text{ --- (2)}$$

where α, β_1, ..., β_k and δ_1, ..., δ_k are the parameters. This function (equation 2) is known as Mitscherlich – Baule function (Paris, 1992). This function is non-linear in parameters. Therefore, it was rarely used in the empirical analysis of crop response.

In Sri Lanka, the fertiliser recommendations have been made on the basis of the information obtained from the field trails, representing the major Agro-ecological region (Seneviratne, 1992). The common analysis used to identify these optimal levels was the Analysis of Variance (ANOVA) procedure, which does not correctly locate the optimum. Therefore an appropriate statistical technique should be adopted in the determination of optimum levels of fertiliser. The objective of this study is to find the optimum levels of fertiliser for bean cultivation in Badulla district using the most appropriate fertiliser response functions. Since, the data collection by means of establishing a field trail is expensive and time consuming, a survey was carried out to collect the data in Nuwara Eliya and Badulla district. Since, bean is mostly grown in Badulla, the data collected from Badulla district was used in this study.

METHODOLOGY

A survey of 125 farmers from Badulla district was conducted to obtain information on levels of different fertilisers used for bean cultivation. The survey was carried out during January to June 1997. The sampling design used to select the farmers is given in Figure 1.

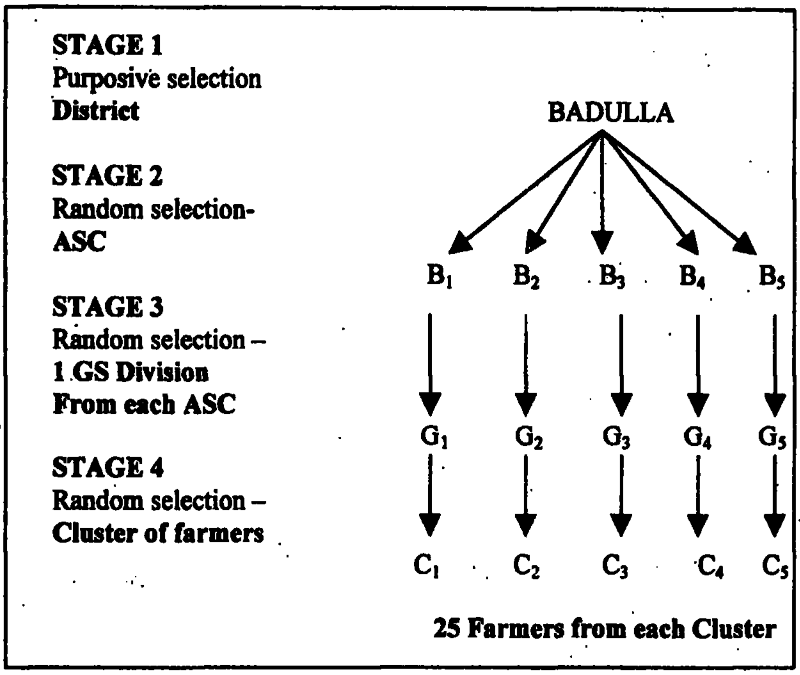

Figure 1. Multistage sampling scheme for the survey.

Five Agrarian Service Centres (ASC) were randomly selected from the district. One GS division was randomly selected from each ASC. From each GS division 25 farmers were selected using Cluster Sampling Technique (Sukhatme and Sukhatme, 1970). They were interviewed and relevant information was collected using a pre-tested questionnaire. In order to check the validity of the data, five farmers were selected randomly in each cluster and the amounts of fertiliser applied by them were measured on the day of application. In addition, one square meter plot bean was also harvested from each of these five farmers. Soil test values were collected from the Regional Agricultural Research and Development Centre, Bandarawela.

The data were tabulated and scatter diagrams were made to select possible models to determine fertiliser response. For preliminary model analysis several linear models such as square root, polynomial (Colwell, 1994), and non-linear models (Ratkowsky, 1983) were fitted to the collected data. The R^2 values and residual plots of these models were looked at and it was found that the Mitcherlich-Baule function was the best to model fertiliser response. In order to make recommendations specific to farmer's field, it is desirable that the initial level of nutrient be included in the mathematical model in a form which is additive to the fertiliser rates (Mombiela *et al.*, 1981). Therefore, two reparameterised models (equations 3 and 4) of equation 2 were used for basal dressing and top dressing respectively.

$$Y_i = \left\{\alpha\left[1-e^{a}\right]*\left[1-e^{b}\right]*\left[1-e^{c}\right]\right\}+\varepsilon_i \quad \text{--------(3)}$$

$$Y_i = \left\{\alpha\left[1-e^{a}\right]*\left[1-e^{c}\right]\right\}+\varepsilon_i \quad \text{--------------(4)}$$

where,

$$a=\left(-\beta_N\left(N_i+\delta_N\right)\right) \qquad b=\left(-\beta_P\left(P_i+\delta_P\right)\right) \qquad c=\left(-\beta_K\left(K_i+\delta_K\right)\right)$$

β_N, β_P, β_K, δ_N, δ_P and δ_P are parameters and N_i, P_i and K_i are the applied amount of nitrogen (kg/ha), phosphorus (kg/ha) and potassium (kg/ha) and Y_i is the yield (kg/ha).

The soil test phosphorus and potassium values are seem to be low (Table 1) and the number of times pesticides applied were for a season in each cluster also ranging from 12-15 times. Therefore, they were not included in this analysis.

Table 1. **The average soil test phosphorus and potassium values for each cluster.**

Cluster	P (ppm)	K (ppm)
Cluster 1	20.41	140.64
Cluster 2	18.90	135.80
Cluster 3	19.75	130.15
Cluster 4	18.08	125.85
Cluster 5	17.95	138.25
Low	<20	<160

Several transformations were used for equation 3 and 4 and we found that the Box –Cox transformation (Zarembka, 1974), which is in the form,

$$Y_t = \frac{(Y_i^{\lambda} - 1)}{\lambda} \quad ; \quad \lambda \neq 0$$

$$Y_t = \ln Y \quad ; \quad \lambda = 0$$

where, Y_t is the transformed yield values and λ is the parameter, which controls the shape of the transformation, to be more appropriate. The transformation was applied to all variables (*i.e.*, dependent as well as independent). The Mitcherlich - Baule function was fitted for the transformed data. The fitted functions for basal dressing were in the form of equation 3.1 and 4.1 and for top dressing, in the form of equation 3.2 and 4.2.

$$\frac{(Y_i^{\lambda} - 1)}{\lambda} = \left\{\alpha\left[1 - e^{a}\right] * \left[1 - e^{b}\right] * \left[1 - e^{c}\right]\right\} + \varepsilon_i \text{-----}(3.1)$$

$$\frac{(Y_i^{\lambda} - 1)}{\lambda} = \left\{\alpha\left[1 - e^{a_1}\right] * \left[1 - e^{b_1}\right] * \left[1 - e^{c_1}\right]\right\} + \varepsilon_i \text{----}(4.1)$$

$$\frac{\left(Y_i^{\lambda}-1\right)}{\lambda}=\left\{\alpha\left[1-e^{a}\right]*\left[1-e^{c}\right]\right\}+\varepsilon_i\text{ ---------(3.2)}$$

$$\frac{\left(Y_i^{\lambda}-1\right)}{\lambda}=\left\{\alpha\left[1-e^{a_1}\right]*\left[1-e^{c_1}\right]\right\}+\varepsilon_i\text{ ---------(4.2)}$$

where,

$$a_1=\left(-\beta_N\left(\frac{\left(N_i^{\lambda}-1\right)}{\lambda}+\delta_N\right)\right) \qquad b_1=\left(-\beta_P\left(\frac{\left(P_i^{\lambda}-1\right)}{\lambda}+\delta_P\right)\right)$$

$$c_1=\left(-\beta_P\left(\frac{\left(K_i^{\lambda}-1\right)}{\lambda}+\delta_K\right)\right)$$

The SAS Statistical Software Package (SAS, 1995) was used to fit the above mentioned functions. The procedure PROC MODEL was used for the fitting of models. Maximum likelihood method with Marquarat – Levenberg iterative minimisation technique was used.

The optimal fertiliser rates were computed based on equation 5 (Cerrato and Blackmer, 1990),

$$\pi = P_y Y - P_N N - P_P P - P_K K \text{ ---------(5)}$$

where, P_Y, P_N, P_P and P_K are the prices of bean, N, P and K respectively and Y is the yield where π is the profit (Rs/ha) and N, P, and K are levels of N (kg/ha), P (kg/ha), and K (kg/ha) applied respectively. Y is substituted in the form of crop response functions. The solutions (levels of N, P and K) were obtained by differentiating equation 5 with respect to N, P and K, and equating them to zero, and solving the resulting system of equations.

RESULTS AND DISCUSSION

Based on the coefficient of determination (R^2 value - It is an indicator of how much the variation in the data is explained by the model), the best-fitting model for each cluster was obtained. In the selected functions, all the parameters are significant at $p<0.05$. The estimates of the best fitting functions for each cluster are given in Tables 1 and 2. The R^2 values range from 0.959 to 0.999.

Best fitted model for basal dressing

The model (4.1), where, Box - Cox transformation was used for both independent and dependent variables was the best fitted model to clusters 1, 3 and 5. The function (3.1), where Box - Cox transformation was done only for dependant variable, was the best-fitted model for cluster 2 and 5.

Table 2. Estimates of parameters of the fitted functions (basal dressing).

Cluster	α	β_N	δ_N	β_K	δ_K	β_P	δ_P	log L	R^2
Cl- 1	3893.64	0.04	18.90	0.06	-12.27	0.12	-43.16	-71.52	0.999
Cl- 2	5215.56	0.01	48.43	0.01	182.52	0.01	-34.89	-80.72	0.990
Cl- 3	5246.72	0.01	26.47	0.09	-11.65	0.04	-42.44	-97.81	0.988
Cl- 4	8208.96	0.05	–28.92	0.004	54.79	0.002	166.49	-99.36	0.959
Cl- 5	5443.22	0.02	12.76	0.017	81.99	0.02	-21.03	-84.31	0.984

Best fitted model for top dressing

The function (4.2), where for both variables the Box-Cox transform was used, gave the best-fit model for all clusters.

Table 3. Estimates of parameters of the fitted functions (Top dressing).

Cluster	α	β_N	δ_N	β_K	δ_K	log L	R^2
Cl- 1	6116.63	0.01	91.91	0.01	16.99	-104.63	0.983
Cl- 2	4257.48	0.01	-17.03	0.01	-10.35	-83.99	0.985
Cl- 3	4443.57	0.02	-6.77	0.02	66.52	-106.94	0.967
Cl- 4	3860.87	0.01	19.19	0.02	33.17	-98.85	0.962
Cl- 5	8106.50	0.01	-11.85	0.01	17.60	-82.05	0.988

Log L = Maximum likelihood estimates

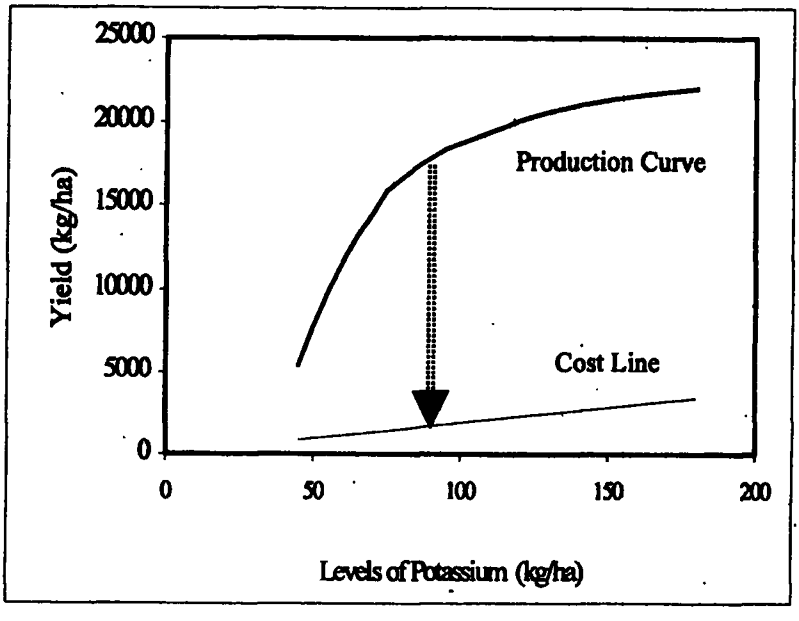

Figure 2. The fitted curve of K with cost line for basal dressing to cluster 1.

The predicted yield values were plotted against the levels of fertiliser with cost line. The Figures 2, 3 and 4 are the curves obtained from fitted functions separately for each fertiliser along with the cost for cluster 1. Since, all the curves are similar in shape all plots are not given in the text.

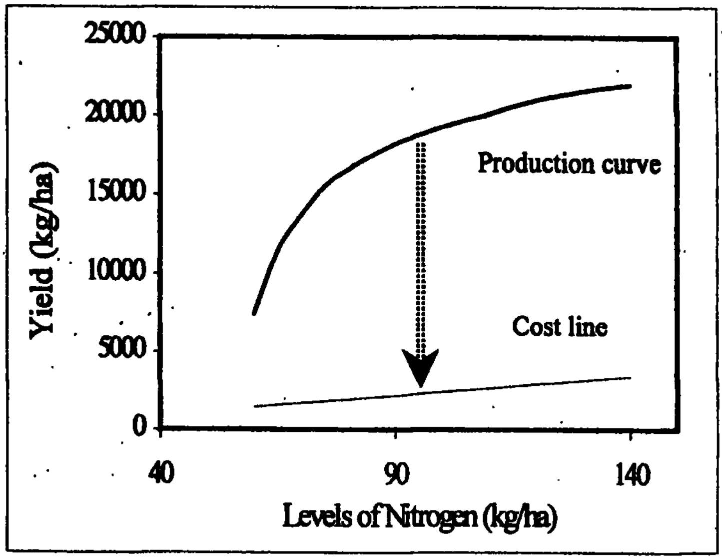

Figure 3. The fitted curve of N with cost line for basal dressing to cluster 1.

Residual plots of the fitted curves to different fertiliser were studied and it was found that the scatters are random and thus, selected models are best fitted models for the data. The estimated optimum levels of fertiliser for different clusters are given in Table 4 along with average values and current recommended rates. Since, there are not much differences between the estimated optimum levels of fertiliser for each cluster; the average value can be taken as the optimum level of each nutrient.

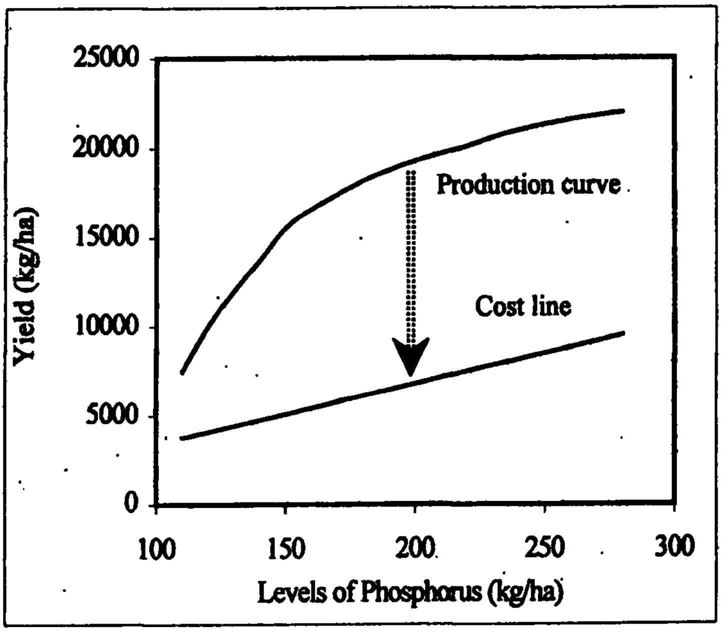

Figure 4. The fitted curve of P with cost line for basal dressing to cluster 1.

Table 4. Optimal levels of N, P and K for basal dressing (B/D) and top dressing (T/D), along with average values and current recommended values.

Cluster	N(B/D)	P(B/D)	K(B/D)	N(T/D)	K(T/D)
Cluster 1	92.61	205.06	93.70	80.32	72.53
Cluster 2	96.52	190.02	95.81	84.61	76.45
Cluster 3	98.10	185.06	90.18	79.61	80.23
Cluster 4	95.72	201.13	91.25	86.05	79.60
Cluster 5	90.80	195.08	98.25	78.54	79.20
Average values	94.75	195.27	93.98	81.82	77.60
Recommended rates	50.00	125.00	45.00	50.00	45.00

CONCLUSIONS

From the fitted models, we found the Misterlich -Baule function with Box-Cox transformation to be the best to model the response function. The best fit was obtained with $\lambda = 0.8$. The optimal rates for basal dressing are Nitrogen 100 kg/ha, Phosphorus 200 kg/ha and Potassium 90 kg/ha and the optimal rates for top dressing are Nitrogen 80 kg/ha and Potassium 80 kg/ha. The optimum rates are higher than the current recommended levels. In fact, the estimated optimum levels are, on average, 1.75 times higher than the current recommended levels. This results show that while the current recommendations are on the lower side, the farmers use higher levels than the optimum levels found by this study.

REFERENCES

Baule, B. (1918). Zu Mitscherlichhs gesetz der physiologischen beziehungen. *In*: Paris, Q. The return of von Liebig's "Law of minimum". Agron. J. 84: 1040-1046.

Cerrato, M.E. and Blackmer, A.M. (1990). Comparison of models for describing corn yield response to nitrogen fertiliser. Agron. J. 82: 138-143.

Colwell, J.D. (1994). Estimating fertiliser requirements: A quantitative approach, Cab International, Wallingford, U.K.

Maraikar, S., Wijewardena, J.D.H. and Amarasiri, S.L. (1996). Improving productivity of vegetable cultivation on ultisols of Sri Lanka. pp. 1-5. *In*: Managing soil fertility for intensive vegetable production system in Asia. Proc. Symposium 4-10 Nov. 1996. AVRDC, Tainan, Taiwan.

Mitscherlich, E.A. (1909). Das gesetz des minimums und das gesetz des abnehmenden bodenertrages. *In*: Paris, Q. The return of von Liebig's "Law of minimum". Agron. J. 84: 1040-1046.

Mombiela, F., Nicholaides, J.J. and Nelson, A. (1981). A method to determine the appropriate mathematical form for incorporating soil test levels in fertiliser response models for recommendation purposes. Agron. J. 73: 937-940.

Paris, Q. (1992). The return of von Liebig's "Law of the minimum". Agron. J. 84: 1040-1046.

Ratkowsky, A.D. (1983). Non-linear regression modelling, CSIRO Division of Mathematics and Statistics, Tasmanian Regional Laboratory, Hohart, Tasmania.

SAS Institute. (1995). SAS/ETS user's guide, Version 6, 2nd edition, SAS Inst. Cary, NC.

Seneviratne, R. (1992). Basis for fertiliser recommendation. Present and future research activities, paper presented in national seminar on fertiliser use in agricultural development, Gannoruwa, 28-29 October.

Sukhatme, P.V. and Sukhatme, B.V. (1970). Sampling theory of surveys with applications, Iowa State University Press, U.S.A.

Wijewardena, J.D.H. and Amarasiri, S.L. (1990). Comparison of phosphate on growth of vegetables on an acid soil. Tropical Agriculturist. 6(1): 57-61.

Wijewardena, J.D.H. and Amarasiri, S.L. (1997). Long-term use of potassium fertiliser for vegetable crops in the upcountry intermediate zone. J. Nat. Sci. Sri Lanka. 25(1): 59-68.

Zarembka, P. (1974). Transformation of variables in Econometrics, Frontiers of Economics, New York: Academic Press. pp. 81-104.