The “Law of Optimum” and Soil Test Based Fertiliser Use for Targeted Yield of Crops and Soil Fertility Management for Sustainable Agriculture

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I am honoured to deliver the first Dr.B.Ramamoorthy Memorial lecture under the auspices of Tamil Nadu Agricultural University on 28th Dec 2011. I am most grateful to the Vice-Chancellor, Dr. P. Murugesan Boopathi for instituting Dr. B. Ramamoorthy Memorial lecture and inviting me for delivering the first memorial lecture.

The “Law of Optimum” is propounded as the unifying concept in Plant Nutrition for realizing “Targeted yield of Crops” through soil test based Nutrient management, as calibrated from a novel factorial field experiment technique, designed and used under the All India Coordinated Soil Test Crop Response (STCR) project investigations, on a range of soils and crops, in India over four decades and validated through hundreds of demonstration trials in farmers fields. Early studies under the project established that the relationship between yield of wheat, Sonora-64, grain and total uptake of nutrients by the whole plant followed a linear relationship, implying that for obtaining a given yield, a definite quantity of nutrients must be absorbed by the plant (Ramamoorthy et al., 1967). The “Law of Optimum” is defined as the concept of soil test based major plant nutrients (N, P and K) application to crops, by taking into account the percent contribution from the soil available nutrients as estimated by chemical soil tests and the percent contribution of nutrients from added fertilizers and manures and the nutrient requirement of the crop as estimated from plant uptake, for obtaining a specific yield target. Over 2000 demonstration trials in Farmers’ fields conducted so far have validated this Law on the Targeted yield concept by realizing the yield target (s) within 10% deviation by following soil test based fertilizer use and adopting all other best Agronomic management practices. Operationally this Law harmonises the much debated approaches namely, ‘Fertilising the soil’ versus ‘Fertilising the crop’ ensuring for real balance (not apparent balance) between the applied fertilizer nutrients among themselves and with the soil available nutrients. The principles underlying the “Law of Minimum”, “Law of Diminishing returns” and the “Law of the Maximum” governing plant nutrition are not only embedded in the “Law of Optimum” but this Law also provides a basis for soil fertility maintenance consistent with high productivity and efficient nutrient management in “Precision Farming” for sustainable and enduring Agriculture.

Key words: The Law of Optimum, Plant nutrition, Targeted yield of crops and soil testing.

The relationship between crop yield and nutrients : Historical perspectives

Quantitative relationship studies on plant growth factors and their effect on growth and yield of plants dates back to Sprengel (1832) and Justus Von Liebig (1843). The well known Liebig’s “Law of Minimum”, says that “every field contains a maximum of one or more and a minimum of one or more nutrients. With this minimum, be it lime, potash, nitrogen, phosphoric acid, magnesia or any other nutrient, the yields stand in direct relation. It is this factor that governs and controls the yield. With this minimum, the yield will remain the same and not increase even though amounts of other nutrients be increased a hundred fold”. When the most limiting factor at minimum is corrected, yields are then regulated by the next important limiting factor. In Production Agriculture, this process is managed with step-wise yield increases until there are no remaining growth limiting factors. Paris (1992) has demonstrated the applicability of this law in two crop response experiments.

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Mitscherlich (1909), in his “Law of Diminishing Returns” stated that crop yields are influenced by all limiting factors simultaneously and the influence of each such factor is proportional to the severity of its limitation. His equation, \( \frac{dy}{dx} = (A-Y) C \) provided a basis for optimising fertiliser doses from fertiliser rate trials, where \( dy \) is the yield increase from increment \( dx \) of the growth factor (nutrient) \( x \), \( A \) is maximum possible yield, \( y \) is the yield after a given amount of \( x \) has been added and \( c \) is a constant, which can be taken as efficiency factor. Mitscherlich yield equation was widely used in the Great German Soil Fertility Survey conducted during 1934-38. In four years a total of 27,069 well replicated field tests with 12 crop plants were made. Wilcox (1955) has commended on the meaning of the Great German Soil Fertility Survey. Although Mitscherlich concluded that the efficiency constants \( K \) or \( C \) are constant in his model, it was rejected by Boyd (1956) who found that the efficiency constants were decreasing with increasing levels of applied N and K nutrients as given in Table 1.

Table 1. The effect of N and K levels on the constants in the Mitscherlich equation

<table>
<thead>
<tr>
<th>Level of N</th>
<th>( K_1 )</th>
<th>Level of K</th>
<th>( K_2 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.95</td>
<td>0</td>
<td>1.71</td>
</tr>
<tr>
<td>1</td>
<td>0.68</td>
<td>1</td>
<td>1.43</td>
</tr>
<tr>
<td>2</td>
<td>0.15</td>
<td>2</td>
<td>0.73</td>
</tr>
</tbody>
</table>

Boyd (1956)

Alivelu et al. (2003), reported that the fertilizer recommendations estimated by linear response plateau (LRP) and quadratic response plateau (QRP) models were considerably lower than that given by modified Mitscherlich equation and also the systematic bias with Mitscherlich’s model was higher. Between the two plateau models, the QRP based recommendations were lower than those of LRP. Due to its simplicity and applicability to only single nutrient studies, the Mitscherlich model is seldom used for optimisation of fertiliser doses, as required in multinutrient studies.

Balmukand (1928) proposed the “resistance formula”, capable of a direct and physical interpretation; for each nutrient there are two constants; one represents the importance of the nutrient concerned to the crop concerned, expected to vary from crop to crop and variety to variety and so to afford a direct comparison between varieties of their manural needs, while the second represents the amount of nutrient available in the unmanured soil.

Percent sufficiency concept: Based on his nutrient mobility concept, Bray (1945) modified Mitscherlich equation as follows:

\[
\log (A-Y) = \log A - C_1 b - CX
\]

A = maximum yield when all nutrients are present in adequate quantities

\( Y \) = yield obtained with nutrient ‘b’ in soil, when it is less than adequate

\( C_1 \) = efficiency factor of the nutrient supplied by the soil

\( X \) = quantity of fertiliser added

\( C \) = efficiency factor for the method of applying fertilizer

The exponential function of Mitscherlich - Bray yield curve never reaches an absolute maximum. Regardless of the level of nutrient present in the soil, the indicated yield never reaches 100%. The computational basis for calculating maximum yield vital to the percent yield sufficiency concept has thus been questioned. The exponential curve will never indicate yield depression from excess or toxic level of a nutrient. This method also does not take into account nutrient interactions, their effect on yield and hence on the fertiliser requirement for “balanced fertilisation”.

Colwell (1978) proposed orthogonal polynomial model for calculating fertilizer requirement from multilocation fertilizer rate trials. Similar experiments and data generated under STCR Project did not meet with success in optimizing fertilizer requirement. In this model, the role of soil test values is reduced and are being used only to refine the fertiliser response coefficients as computed in an orthogonal polynomial model.

Wallace (1993) proposed the “Law of the Maximum”, having two major characteristics. First, the effect of a given input is progressively magnified as other limiting factors are corrected. The final result is greater than the sum of the effects of the individual inputs, because of the way in which they interact. The interaction multiplies the effects of each. Second, yields can be highest or maximum only if there are no remaining limiting factors; the fewer limiting factors that remain, the higher will be the yield. How closely this can be approached and attained, of course, depends on relative economics. When dealing with Mitscherlich-type limiting factors, those most economical to use can be chosen first.

He has shown how the law operates with examples of multinutrient rate trials. If 100 per cent were the yield attainable (Agronomic yield potential) and all factors except one were optimal, the final yield would be whatever the one factor represented, whether it be 50 or 80 or 90 per cent. Two such factors each at 90 per cent effect would give 81 per cent of the yield attainable. For five such factors the yield would be 59% and for 10, it would be only 35%. A farmer may do everything to 90% of perfection and yet get only 35% the maximum yield possible. This underlines the need for best management practices and precision nutrient management with soil testing for high yields and sustainable agriculture.
Soil testing research and Advisory service

The usefulness of soil testing service as a vital part of the expanding fertiliser use programme was recognised by the Government and 24 soil testing laboratories were first established in 1955-56 with assistance from the USAID. With the initial research work carried out at the Indian Agricultural Research Institute (IARI), with the then tall varieties of rice and wheat, the fertiliser doses arrived at for different crops on the basis of agronomic experiments in the states were taken as applicable to the ‘medium’ soil fertility status. Those doses were either reduced or increased by 30 to 50% empirically for soils tested as ‘high’ or ‘low’ respectively (Muhr et al., 1965). Ramamoorthy and Velayutham (1971) reported an average increase in yield of 11% when the fertilisers were applied based on such recommendation over the general recommendation without soil testing. With the introduction of the high yielding varieties and hybrids of crops during the mid 1960’s, Green revolution era, the need for more precise soil test-fertiliser requirement calibration was an urgent requirement for expanding fertiliser use to increase Food Production.

Soil Test Crop Response Correlation: A novel field design

Recognising the reported lack of correlation between soil test and crop response to fertiliser in multi-location agronomic trials in the past and the need for refinements in fertiliser prescriptions for varying soil test values for economic crop production in the wake of Green Revolution era, Ramamoorthy (1968) designed a novel field experimentation methodology for Soil Test Crop Response (STCR) correlation studies and initiated the All India Coordinated Research Project of the Indian Council of Agricultural Research (ICAR) in 1967 - 1968.

The principle of the methodology is that to develop a quantitative relationship between different measured levels of any one component (e.g. fertiliser N) of a crop production system and the yield obtained from that system, it is necessary to conduct a field experiment with different measured levels of that factor and to measure the resultant yield. When more than one factor influences the yield (e.g. fertiliser N, P, K etc) and there are interaction between the different variables, a factorial experimental design is necessary to describe the desired relationship. If factors other than those included in the design (e.g. climate, soil types, management) also influence the yield, it becomes necessary to develop the relationship at a ‘standard level’ of these other factors. Otherwise it becomes necessary to conduct additional studies to determine the effects of those other factors also.

In soil test crop response studies, it is necessary to have data covering the appropriate range of values for each controlled variable (fertiliser dose) at different levels of the uncontrolled variable (e.g. soil fertility). Since different levels of the uncontrolled variable (e.g. soil fertility) cannot be expected to occur at one place, normally different sites are selected to represent the different levels of soil fertility (soil test values) and the fertilizer requirement inference is deduced and applied in general (Deductive approach).

In the “Inductive Approach” of STCR field experimentation, all the needed variation in soil fertility level is obtained not by selecting soils at different locations as in earlier Agronomic trials, but by deliberately creating it in one and the same field experiment in order to reduce heterogeneity in the soil population (types and units) studied, management practices adopted and climatic conditions. Ramamoorthy and Velayutham (1971, 1972 & 1974) have elaborated this Inductive approach and the STCR field design, which is also quoted by Black (1993).

A field, representative of the major soil type in the region, having low soil fertility level is selected and divided into four equal strips. While the first strip receives no fertiliser, the second, third and fourth receive half, one and two times the standard dose of N, P and K respectively. The standard dose of P and K are fixed taking into account the P and K fixing capacities of the soil. A short duration ‘exhaust crop’ is grown so that the fertilisers undergo transformations in the soil with plant and microbial activity. After harvest of this exhaust crop, each of the strips is divided into sub-plots. Twenty one selected treatment combinations from 5x4x3 levels of N, P and K, in addition to 6-8 controls are randomly allotted in each of the four strips and the test crop for which soil test calibration is required is grown to maturity, following standard agronomic practices. Before the application of fertilisers, soil samples are collected from each sub-plot and analysed for available nutrients by different soil test methods. After harvest, grain and straw yield and total nutrient uptake are also determined plot wise.

Statistical processing of the STCR field data

Selection of suitable soil test method: The first step in the processing of data is to establish a significant relationship between the yield and the chemical soil tests employed to assess the available nutrient status in the soil. Using the yields from the control (unfertilised) plots and the corresponding soil test values this relation is established through multiple regression. A significant value of the co-efficient of determination ($R^2$) with high order of predictability (above 66%) and significant partial regression co-efficients (b) indicate the choice of soil test methods for their suitability for advisory purpose. The results from the numerous STCR field data indicate that organic carbon and alkaline KMnO$_4$ method for N, Olsen’s method for non-acidic soils and Bray I method for
acids for P and neutral N. Ammonium acetate method for K are the most suitable soil test methods. In soils with Illitic clay, and where the contribution to plant from non-exchangeable K is considerable, selection of suitable testing procedure, which could integrate the extraction from the different sources for improving the soil test calibration for K in such soils has been pointed out by Sekhon and Velayutham (1978).

From significant multiple regressions of the quadratic form established between the soil tests, the added fertiliser levels, the interaction term for the soil and fertiliser nutrients and crop yield, fertiliser calibration for varying soil test values for obtaining maximum economic yield (MEY) and maximum profit ha$^{-1}$ have been derived, where the response to added nutrients follow the Law of Diminishing Returns (Ramamoorthy et al., 1974).

An example of such a soil test calibration for wheat, HD-2204 grown in alluvial soils of Delhi is as follows:

\[
\begin{align*}
FN &= 293 - 0.53 SN - 6.58 R \\
FP_2O_5 &= 115 - 0.67 SP - 16.67 R \\
FK_2O &= 386 - 1.00 SK - 16.67 R
\end{align*}
\]

where, F and S stand for fertiliser and soil nutrient in kg ha$^{-1}$ and

\[
R = \frac{\text{Cost of fertiliser nutrient (Rs./ kg)}}{\text{Value of economic produce (Rs./ kg)}}
\]

**Targeted yield concept**

Truog (1960) illustrated the possibility of ‘Prescription method’ of fertiliser use for obtaining high yields of Maize using empirical values of nutrient availability from soil and fertiliser. However, Ramamoorthy and his associates established during 1965-67 the theoretical basis and field experimental proof and validation for the fact that Liebig’s Law of Minimum of Plant nutrition operates equally well for N, P and K for the high yielding varieties of wheat, rice and pearl millet, although it is generally believed that this law is valid for N and not for P and K which were supposed to follow the percentage sufficiency concept of Mitscherlich and Baule and Mitscherlich and Bray. Their work, Ramamoorthy et al. (1967), Ramamoorthy et al. (1969a), Ramamoorthy et al. (1969b), Ramamoorthy and Aggarwal (1972) and Aggarwal and Ramamoorthy (1978) showed the importance of the associated nutrients in determining the value of response to N and the need for balanced nutrition in making efficient use of fertilisers and laid the basis for fertiliser recommendation for targeted yield of crops.

Table 2, taken from their work (Ramamoorthy et al., 1967), shows the effect of balanced nutrition on efficiency and economy in fertiliser use on wheat.

The high response of 14.8 at 50 kg ha$^{-1}$ of N was associated with 25 kg each of $P_2O_5$ and $K_2O$. For obtaining a similar response (14.5), at a higher level of N application viz 90 kg ha$^{-1}$, the requirement of the associated $P_2O_5$ and $K_2O$ also has to be increased to 75 and 50 kg ha$^{-1}$ respectively. This table also shows that response to absorbed N, is varying within narrow limits than the response to added N, indicating that the varied response to applied fertilisers is primarily affected by factors which influence the uptake of the nutrient concerned, but when once taken up, the efficiency of applied nutrients is nearly the same. They also showed that the relationship between yield of grain and uptake of nutrient followed the same linear relationship, irrespective of the method of application - whether the P and K were placed or broadcast or applied partially to soil and the remaining as foliar application, although the response to fertiliser applied changed with method of application.

**Table 2. Effect of balanced nutrition on efficiency and economy in fertiliser use at Delhi with wheat Sonora 64 (1965-1966)**

<table>
<thead>
<tr>
<th>Level of added N (kg/ha)</th>
<th>Associated treatment</th>
<th>Yield in kg ha$^{-1}$</th>
<th>Response to added N (kg grain per kg N)</th>
<th>Response to absorbed N (kg grain per kg N)</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>$P_{25}K_{50}$</td>
<td>5.047</td>
<td>14.5</td>
<td>38.7</td>
</tr>
<tr>
<td></td>
<td>$P_{50}K_{50}$</td>
<td>4.779</td>
<td>11.8</td>
<td>38.9</td>
</tr>
<tr>
<td></td>
<td>$P_{50}K_{25}$</td>
<td>4.760</td>
<td>11.7</td>
<td>40.3</td>
</tr>
<tr>
<td></td>
<td>$P_{50}K_{75}$</td>
<td>4.588</td>
<td>9.9</td>
<td>42.0</td>
</tr>
<tr>
<td>50</td>
<td>$P_{25}K_{50}$</td>
<td>4.665</td>
<td>10.7</td>
<td>40.2</td>
</tr>
<tr>
<td></td>
<td>$P_{50}K_{50}$</td>
<td>4.330</td>
<td>14.8</td>
<td>43.1</td>
</tr>
<tr>
<td></td>
<td>$P_{50}K_{75}$</td>
<td>4.302</td>
<td>14.2</td>
<td>43.5</td>
</tr>
<tr>
<td>Control</td>
<td></td>
<td>3.590</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

**Needed parameters**

The essential basic data required from soil test crop response correlation field experiment for formulating fertiliser recommendation for targeted yield of crops for a given soil type-crop-Agro-climatic conditions are: (1) Nutrient requirement in kg quintal$^{-1}$ (100 kg) of grain or other economic produce (2) the per cent contribution, the availability of ‘soil available nutrients’ as measured by soil test method and (3) the per cent contribution from the applied fertiliser nutrients. The linear relationship between yield and uptake implies that for obtaining a given yield, a definite quantity of nutrients (both from soil and fertilisers) must be taken up by the plant. This is also borne out by the near constancy when the response is expressed in the form of units of grain production per unit of nutrient absorbed by the plant. It is the reciprocal of this form viz response to absorbed nutrient which is expressed as nutrient requirement. Once this requirement is known for a given yield, the quantity of fertiliser needed can be estimated.
taking into account the efficiency of contribution from the soil available nutrients and that from the fertiliser nutrients.

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The “Law of Optimum” is defined as the concept of soil test based major plant nutrients (N, P and K) application to crops, by taking into account the percent contribution from the soil available nutrients as estimated by chemical soil tests and the percent contribution of nutrients from added fertilizers and manures and the nutrient requirement of the crop as estimated from plant uptake, for obtaining a specific yield target.

Operationally this Law harmonises the much debated approaches namely, ‘Fertilising the soil’ versus ‘Fertilising the crop’ ensuring for real balance (not apparent balance) between the applied fertilizer nutrients among themselves and with the soil available nutrients. The principles underlying the “Law of Minimum”, “Law of Diminishing returns” and the “Law of the Maximum” governing plant nutrition are not only embedded in the “Law of Optimum” but this Law also provides a basis for soil fertility maintenance and efficient Nutrient management in “Precision Farming” for sustainable and enduring Agriculture.

It has been shown that the nutrient requirement per quintal of grain production is nearly the same for a given variety, although variations between varieties of a crop and variations in the same variety grown in different seasons have also been observed from field experiments. The percent contribution from the soil is essentially influenced and varied by the type of soil, the texture, nutrient release characteristics of the soil and rooting pattern of the plant. The per cent contribution from fertiliser depends on the form, solubility, method and time of application of the fertiliser and other parameters viz. the soil type, plant type, climate and water management.

From the above mentioned three parameters obtained from STCR field experiment, the fertilizer dose required for specific yield target is derived as given below.

\[
FD = \frac{NR}{100 \times T} - \frac{CS}{STV}
\]

where,

- \( FD \) = Fertilizer dose of N or \( P_2O_5 \) or \( K_2O \) (kg ha\(^{-1}\))
- \( NR \) = Nutrient requirement of N or \( P_2O_5 \) or \( K_2O \) (kg\(^{-1}\) quintal (100 kg))
- \( CF \) = Per cent contribution from fertilizer N or \( P_2O_5 \) or \( K_2O \)
- \( CS \) = Per cent contribution from soil N, P, K.
- \( STV \) = Soil test value of N or P \times 2.29 or K \times 1.21 (kg ha\(^{-1}\)).

The fertilizer adjustment equations, in the simplest form, become,

\[
FN = 4.96 T - 0.63 SN
\]
\[
FP_2O_5 = 3.83 T - 4.63 SP
\]
\[
FK_2O = 2.66 T - 0.22 SK
\]

for soil test based calibration of wheat var. WH – 157 at Hisar, for targeted yield. F and S stand for fertilizer and soil nutrient in kg ha\(^{-1}\) and T is yield target in q ha\(^{-1}\).

Santhi et al. (2010a) documented in a handbook soil test and yield target based integrated fertilizer prescriptions, for a range of 41 crop situations in Tamil Nadu. One such example from this hand book, for integrated nutrient management for Rice on Noyyal Soil Series is given below:

\[
FN = 4.39 T - 0.52 SN - 0.80 ON
\]
\[
FP_2O_5 = 2.22 T - 3.63 SP - 0.98 OP
\]
\[
FK_2O = 2.44 T - 0.39 SK - 0.72 OK
\]

where ON, OP and OK are the N, P&K nutrients supplied through organic source.

Subba Rao and Srivastava (2001) have documented the soil test based fertilizer recommendations for targeted yields of crops in the Coordinated STCR project. Such documents for advisory use by the concerned soil testing laboratories have been updated by the 17 cooperating centres of the STCR project in the country. After generating the basic data, the applicability of these calibrations are tested for their validity, by conducting simple follow-up trials in farmer’s fields on similar soils (taxonomic group). The results from more than 2000 follow-up trials in farmers’ fields over the four decades indicated that by following the soil test based fertilizer use for targeted yield and adopting the recommended best Agronomic management practices, it is possible to achieve the yield targeted within a variation of ± 10 per cent, provided the targets are within the range of yields obtained in the STCR calibration field experiment conducted at the research station.

The dimensions, scope and prospects of fertilizer recommendation based on the concept of yield targeting were documented by Randhawa and Velayutham (1982).
Yield targeting for a fixed cost of fertiliser investment

The relevance and value of soil testing increases by choosing the yield target at such a level so that the cost of fertiliser requirement becomes more or less same as what was being practised by the farmer already. The results of such demonstration trials conducted in Delhi villages as given in Table 3 reveal that the response per unit fertiliser is higher than that from other practices, when balanced fertilisation is adopted for targeted yield (Velayutham, 1979).

Yield targeting under resource (fertiliser/credit) constraints

When fertiliser availability is limited or the resources of the farmers are also limited, planning for moderate yield targets, which are at the same time higher than the yield levels normally obtained by the farmers or the average yield of the district, provides means for saturating more areas with the available fertilisers and ensuring increased total production also. The consequence of this approach - Ramamoorthy and Velayutham, (1973); Velayutham et al. (1975); Ponnamperuma (1979) and Velayutham (1979) are given in Table 4, which shows that fertiliser use efficiency and the total production are higher when the available fertilisers are applied for low or moderate yield targets rather than arbitrary reduction in fertiliser dose. The average response ratio obtained in six replicated experiments conducted in Delhi villages was 10 from the general fertiliser dose (120-60-40) as against 16.9 for yield target of 4.5 tons ha⁻¹ in case of wheat, Sonalika.

<table>
<thead>
<tr>
<th>Place and farmer's name</th>
<th>Variety</th>
<th>Soil test value (Kg ha⁻¹)</th>
<th>Fertiliser dose (kg ha⁻¹)</th>
<th>Yield obtained (kg ha⁻¹)</th>
<th>Cost of fertiliser (Rs. ha⁻¹)</th>
<th>Net profit (Rs. ha⁻¹)</th>
<th>Per cent profit</th>
<th>Response per unit of fertiliser</th>
</tr>
</thead>
<tbody>
<tr>
<td>N or OC (%)</td>
<td>P₂O₅</td>
<td>K₂O</td>
<td>N</td>
<td>P₂O₅</td>
<td>K₂O</td>
<td>N</td>
<td>P₂O₅</td>
<td>K₂O</td>
</tr>
<tr>
<td>Pindwala</td>
<td>0.28</td>
<td>20.6</td>
<td>112</td>
<td>i) 23</td>
<td>58</td>
<td>0</td>
<td>i) 1,930</td>
<td>180</td>
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<tr>
<td>Khurd</td>
<td>0.40</td>
<td>45.3</td>
<td>146</td>
<td>i) 70</td>
<td>10</td>
<td>10</td>
<td>i) 2,520</td>
<td>178</td>
</tr>
<tr>
<td>Rao Ranjeet</td>
<td>0.32</td>
<td>34.6</td>
<td>95</td>
<td>ii) 60</td>
<td>60</td>
<td>60</td>
<td>ii) 2,460</td>
<td>355</td>
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<tr>
<td>Shiv Lal</td>
<td>0.40</td>
<td>16.5</td>
<td>151</td>
<td>i) 23</td>
<td>58</td>
<td>0</td>
<td>i) 1,610</td>
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<td>Hari Ram</td>
<td>0.32</td>
<td>10.3</td>
<td>168</td>
<td>i) 23</td>
<td>58</td>
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<td>i) 1,250</td>
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<td>Goela</td>
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<td>16.5</td>
<td>140</td>
<td>i) 60</td>
<td>0</td>
<td>0</td>
<td>i) 1,630</td>
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<tr>
<td>Dharam Singh</td>
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<td>26.8</td>
<td>123</td>
<td>ii) 60</td>
<td>0</td>
<td>10</td>
<td>ii) 1,800</td>
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<td>160.00</td>
<td>14.4</td>
<td>179</td>
<td>iii) 80</td>
<td>60</td>
<td>60</td>
<td>iii) 2,100</td>
<td>355</td>
<td>720</td>
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<tr>
<td>Rachpal Singh</td>
<td>148.00</td>
<td>28.9</td>
<td>241</td>
<td>i) 60</td>
<td>0</td>
<td>0</td>
<td>i) 1,800</td>
<td>130</td>
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<td>154.00</td>
<td>29.2</td>
<td>201</td>
<td>ii) 50</td>
<td>10</td>
<td>10</td>
<td>ii) 2,150</td>
<td>136</td>
<td>690</td>
</tr>
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<td>148.00</td>
<td>41.2</td>
<td>321</td>
<td>iii) 80</td>
<td>60</td>
<td>60</td>
<td>iii) 2,350</td>
<td>355</td>
<td>810</td>
</tr>
</tbody>
</table>

Yield targeting and maintenance of soil fertility

Fertiliser recommendation for realising greater fertiliser use efficiency in the short term on the one hand and for upgradation / maintenance of soil fertility in the long term on the other seem to have two opposing dimensions. If soil fertility is to be

Table 3. Profitability of fertiliser use for targeted yields of bajra on Delhi Territory 1973*

<table>
<thead>
<tr>
<th>Place and farmer's name</th>
<th>Variety</th>
<th>Soil test value (Kg ha⁻¹)</th>
<th>Fertiliser dose (kg ha⁻¹)</th>
<th>Yield obtained (kg ha⁻¹)</th>
<th>Cost of fertiliser (Rs. ha⁻¹)</th>
<th>Net profit (Rs. ha⁻¹)</th>
<th>Per cent profit</th>
<th>Response per unit of fertiliser</th>
</tr>
</thead>
<tbody>
<tr>
<td>N or OC (%)</td>
<td>P₂O₅</td>
<td>K₂O</td>
<td>N</td>
<td>P₂O₅</td>
<td>K₂O</td>
<td>N</td>
<td>P₂O₅</td>
<td>K₂O</td>
</tr>
<tr>
<td>A=1 ha having standard fert.dose and other unfertilised; B=each ha fertilised with half the standard dose ; C=each ha fertilised on the basis of low yield target; *=calculated values</td>
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</table>

Table 4. Comparison of different strategies of fertiliser application for wheat and rice under conditions of fertiliser / credit shortages

<table>
<thead>
<tr>
<th>Location/ crop and variety</th>
<th>Fertiliser doses (kg ha⁻¹)</th>
<th>Control Yield (kg ha⁻¹)</th>
<th>Yield obtained (q ha⁻¹) with fert. distribution pattern</th>
<th>Cost of fert. (Rs.2 ha⁻¹)</th>
<th>Net profit on fert. use (Rs./2 ha)</th>
<th>Per cent profit</th>
<th>Response yard stick</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.Delhi:Barthal wheat sonalika 1972-73</td>
<td>120</td>
<td>60</td>
<td>40</td>
<td>2,700</td>
<td>70.1 A</td>
<td>422</td>
<td>828</td>
</tr>
<tr>
<td>2. Delhi: Barthal Hira 1972-73</td>
<td>120</td>
<td>60</td>
<td>40</td>
<td>3,484</td>
<td>52.6 A</td>
<td>422</td>
<td>1,942</td>
</tr>
<tr>
<td>3.Ludhiana farm:wheat kalyansona 1972-73</td>
<td>120</td>
<td>60</td>
<td>30</td>
<td>2,744</td>
<td>87.4 A</td>
<td>438</td>
<td>1,066</td>
</tr>
<tr>
<td>4.Delhi IARI farm : rice IR-8, 1972</td>
<td>120</td>
<td>60</td>
<td>60</td>
<td>2,744</td>
<td>87.4 A</td>
<td>438</td>
<td>1,066</td>
</tr>
</tbody>
</table>

Velayutham (1979)
maintained or even increased, heavier doses of fertilisers have to be used to take into account the inevitable losses in the availability due to leaching, volatilization and fixation. Therefore, to get the best out of fertiliser investment, the turnover from it must be very quick. This is ensured when fertilisers are applied for low / moderate yield targets. Under such situations, according to the “Law of Optimum”, the excess native soil nutrients will make a greater contribution to increase the yield. This would lead to low doses of application of fertilisers and exhausting of the unutilised excess nutrients from the soil. The soil fertility, would, therefore deplete at a faster rate as a result of this exhaustion. Thus, these two approaches seem to be pulling in different directions and it will be prudent to adjust the fertilizer practices over seasons in such a way so as to strike a balance between the two and monitor the soil fertility level (through soil health card) by periodic soil testing of the farm.

The generation of basic data for targeted yield of crops in a crop rotation would hence enable application of fertilizer for appropriate yield targets in multiple cropping for maintenance of soil fertility. Ramamoorthy (1975) showed that the yield target and the required fertilizer dose for maintenance of soil fertility can be calculated from the equation.

$$T = \frac{n.s}{(m-r)} \quad \text{and} \quad F.D = \frac{r.n.s}{(m-r)} \quad \text{where}$$

$$T = \text{yield target in q ha}^{-1}$$
$$n = \text{ratio between the percent contribution from soil and fertiliser nutrient}$$
$$r = \text{nutrient requirement in kg q}^{-1} \text{of grain production}$$
$$m = \text{ratio between nutrient requirement and contribution from fertiliser nutrient}$$
$$s = \text{soil test value in kg ha}^{-1}$$
$$F.D = \text{fertiliser nutrient dose in kg ha}^{-1}$$

Velayutham and Rani Perumal (1976) have shown the consequences of three types of fertiliser use viz. for 1) continuously lower yield targets 2) yield targets consistent with the maintenance of soil fertility level and 3) succession of one and two over years. The results of this field experiment, given in Table 5, shows that when fertiliser is applied continuously for lower yield target of 30 q ha\(^{-1}\) of rice for three seasons the soil fertility status decreases to 228-49-107 kg ha\(^{-1}\) of available N,P,K from 256-59-170, although the output / input ratio is the highest. The fertility status is maintained when required fertiliser is applied for an yield target meant for this purpose, although the output / input ratio is the lowest. However, greater profit consistent with maintenance of soil fertility status (256-46-162 kg ha\(^{-1}\)) is realised when fertiliser is applied for appropriate yield targets in succession over years. Velayutham and Singh (1981) have shown similar advantage of this approach in Rice-wheat and Pearl millet – wheat rotation system in the alluvial soil at Delhi.

The yield targeting Block demonstration at a field site from 1998 at Tamil Nadu Agricultural University is an eye-opener for demonstrative value and study-ground for further research and refinement in long-term soil fertility management based on the dynamics of yields, soil fertility changes, nutrient management and agronomic practices adopted over years.

The soil test summaries and Nutrient Index based area-wise soil fertility maps at different levels, provide the means for area wise soil fertility information and their interpretation for scientific fertilizer use promotion. Singh et al. (2004, 2005, 2007 a & b) have shown the possibilities of extending soil test information for area wise fertilizer recommendation and use. Naidu et al. (1999 & 2008) have shown the level of economic loss in misapplication of fertilizers to crops following general recommendation and the value of soil type and soil test based fertilizer application.

<table>
<thead>
<tr>
<th>Yield Target q ha(^{-1})</th>
<th>I(^{\text{rd}}) year</th>
<th>II(^{\text{nd}}) year</th>
<th>III(^{\text{rd}}) year</th>
<th>Value of total produce (Rs)</th>
<th>Cost of total fertilizer (Rs)</th>
<th>Output / input ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>(i) Fertiliser doses (kg ha(^{-1}))</td>
<td>N P K</td>
<td>N P K</td>
<td>N P K</td>
<td>N P K</td>
<td>N P K</td>
<td>N P K</td>
</tr>
<tr>
<td>(ii) P.H.S.T.V. (kg ha(^{-1}))</td>
<td>N P K</td>
<td>N P K</td>
<td>N P K</td>
<td>N P K</td>
<td>N P K</td>
<td>N P K</td>
</tr>
<tr>
<td>1.30(L)</td>
<td>i35 0 19</td>
<td>30(L)</td>
<td>44 0 27</td>
<td>30(L)</td>
<td>49 0 31</td>
<td>6750 721 9.36</td>
</tr>
<tr>
<td></td>
<td>i242 57 135</td>
<td>234 53 118</td>
<td>228 49 107</td>
<td>9000 1693 5.32</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.43(M)</td>
<td>i117 20 44</td>
<td>40(M)</td>
<td>88 21 33</td>
<td>37(M)</td>
<td>68 20 26</td>
<td>8250 1358 6.07</td>
</tr>
<tr>
<td></td>
<td>i273 54 194</td>
<td>276 50 198</td>
<td>271 46 188</td>
<td>6750 721 9.36</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3.43(M)</td>
<td>i117 20 44</td>
<td>30(L)</td>
<td>25 0 14</td>
<td>37(M)</td>
<td>82 20 35</td>
<td>8250 1358 6.07</td>
</tr>
<tr>
<td></td>
<td>i273 54 194</td>
<td>252 50 159</td>
<td>256 46 162</td>
<td>6750 721 9.36</td>
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</table>

L=low yield target; M=medium yield target for maintenance of soil fertility; PH.S.T.V.=Post-harvest soil test values

Velayutham and Rani Perumal (1976)
Refinements in the estimation of the basic data for yield targeting

In apportioning the total nutrient uptake (in grain and straw) between the soil nutrient and fertilizer nutrient sources by the conventional deduction method, the priming effect and interaction effect of the fertilizer nutrient enhance the percent efficiency of fertilizer nutrient indirectly to values more than 100 per cent. Similarly, in case of legumes the bacterial N fixation confounds the fertilizer N contribution. Maruthi Sankar et al. (1983) proposed a new method for better estimation of soil and fertilizer efficiencies from the STCR factorial field experiment, by solving a simultaneous equation for the uptake of nutrient for two plots at a time from the 16 selected treated plots out of 84 treated plots, as given below.

\[ \begin{align*} \text{Un}_1 &= \text{Cs} \times S_1 + \text{Cf} \times F_1 \\ \text{Un}_2 &= \text{Cs} \times S_2 + \text{Cf} \times F_2 \end{align*} \]

Solving the above,

\[ \begin{align*} \text{Cs} &= \frac{(\text{Un}_1 F_2 - \text{Un}_1 F_1)}{(S_1 F_2 - S_1 F_1)} \quad \text{and} \\ \text{Cf} &= \frac{(\text{Un}_1 S_2 - \text{Un}_2 S_1)}{(F_1 S_2 - S_1 F_2)} \end{align*} \]

Ramamoorthy (1993) proposed that the values of Cs and Cf may be obtained by regressing the uptake of nutrients from all the 16 plots with the soil test values S (1-16) and fertilizer dose of the particular nutrient F (1-16) of the 16 treated plots (chosen for their significant yield response) and identifying the two regression coefficients, Cs and Cf.

Influence of varietal differences on the basic data for targeted yield of crops and a method for deriving them

With the release of a large number of varieties from time to time, the experimental evaluation of the varieties will be cumbersome each time. Ramamoorthy (1993) advocated a short-cut methodology for deriving the basic data for new variety (ies) by the procedure proposed, as given below:

There are three possibilities of commonness amongst the varieties: (A) with all the three components of the basic data being the same for a group of varieties (B) only one of the components being the same way, \( b_1 \) in NR, \( b_2 \) in Cs and \( b_3 \) in Cf and (C) with two out of the three being common. In the case of (A), all varieties in this group will have the same fertilizer dose at all targets. In the case of (B), there will be only one target at which any two varieties indicated by subscript 1 and 2 will have the same fertilizer dose. In the case of (C) there is no possibility of same fertilizer dose at any target of yield.

Since nutrient uptake from soil is Cs S and fertilizer is Cf F and the targeted yield is total uptake divided by the nutrient requirement, the general equation for targeted yield and fertilizer dose for a given target yield become

\[ \begin{align*} T &= \frac{\text{Cs} S + \text{Cf} F}{\text{NR}} \quad \text{or} \\ F &= \frac{T \times \text{NR}}{\text{Cf} - \text{Cs} S / \text{Cf}} \end{align*} \]

By conducting 5 or 6 target trials with two varieties and fitting a regression equation for them, the basic data can be derived depending on the shape of the relative response of the two varieties as given in Fig 1, 2 and 3. In all varieties which have response curves like those in Fig 1 or 2, if the yield of any variety is plotted on a graph against the fertilizer dose tried in the STCR field trial, the intercept on the Y axis is the control yield. Dividing this value by the soil test value, we get ideal Cs / NR value for that variety, which will be better than the value obtained by the difference method. The regression coefficient for the fertilizer dose is the response \( \frac{dT}{dF} = \frac{\text{Cf}}{\text{NR}} \). This method helps in determining not only the basic data for the unknown variety but also for correcting the existing data for even the known variety. Fig 3 is for varieties which do not have any of the components in common but have the ratio of Cf / NR the same. That is Cf and NR of the unknown variety either increases or decreases simultaneously but in each case proportionately. Fig 2 is for varieties not covered by 1 and 3.

Screening crop varieties for their nutrient extraction power

Ramamoorthy (1993) showed that by testing a number of varieties in one and the same soil (reverse...
procedure adopted by Bray for determining availability of a nutrient in the soil) and using two fertiliser treatments, namely, (1) with full and sufficient doses of all the three nutrients (N+P+K) and (2) same as (1) but omitting the particular nutrient in question. The % yield (yield obtained under treatment (2) as % of that under treatment (1) of each variety represents its extracting power or capacity for utilisation of the soil nutrient. Higher the percent yield of a variety, higher is its capacity for utilisation of soil available nutrients. In their studies (R.S. Dinesh 1971, Ph.D. thesis, Agra University), the % yield of rice varieties TN-1, IR -8, NP-130, and BC – 5 were respectively 42.5, 33.4, 54.6 and 52.5 for Nitrogen; 50.6, 64.5, 95.0 and 85.3 for P and 77.3, 77.9, 124.0 and 102.5 for K.

Similarly, Dinesh and Ramamoorthy (1968) showed that properties of plants at flowering stage such as equilibrium phosphate potential (EPP) (Ramamoorthy and Subramanian, 1960) and equilibrium potassium adsorption ratio (EKAR) (Ramamoorthy and Paliwal, 1965), which are genetically controlled and which would be easily determined in sand culture provided a good indication of the relative response of the different varieties to these nutrients. The lower the equilibrium phosphate potential of a crop variety, lower the % yield to P and higher the P₂O₅ requirement of that variety for production of one quintal of grain. The analogy is also similar with respect to EKAR of the variety. Thus there is need for potassic fertiliser so long as the equilibrium KAR of the soil is less than that of the plant variety.

Field experimentation design for determining the basic data for targeted yield of crops under Integrated Nutrient Management (INM)

Ramamoorthy devised the field design for creating simultaneously soil fertility gradient and organic manure gradient. As in the case of the two component system (Soil and fertiliser nutrient), a soil fertility variation (gradient) is created in a field in one direction by increasing the four levels of fertilisers as L₀, L₁, L₂, and L₃, with the levels randomised in that direction. The exhaust crop is then sown and harvested. The manure variation (organic sources) is then created in a perpendicular direction to the previous one and again randomised by applying M₀, M₁, M₂, and M₃, levels of manure (FYM or slurry or compost) about one month before sowing of the test crop. These manure levels are so chosen as to contain 0, 25, 50 and 75 kg N ha⁻¹. Thus the field (60 x 40 metres) is divided into 16 sub-blocks as shown in Fig 4 (Ramamoorthy, 1994).

Each of these sub-blocks is divided into six plots, three in one direction and two in the other, with the usual irrigation channels and soil samples are taken for analysis from all the 96 plots before sowing.

24 Fertiliser treatments (till 2004)

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<tbody>
<tr>
<td></td>
<td>L₀</td>
<td>L₁</td>
<td>L₂</td>
<td>L₃</td>
<td>L₀</td>
<td>L₁</td>
<td>L₂</td>
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Fig. 4. Creation of Soil Fertility and Manure Gradients

of the crop. The 24 fertiliser treatments are given, with nitrogen in the usual splits and all P placed and all K applied before sowing of the test crop in such a manner that the full set of 24 fertiliser treatments occur in the four consecutive sub-blocks whether taken in the north to south or west to east direction.

The plant and grain samples are taken for nutrient uptake studies from only 16 plots selected as follows: One plot for each of the strips of the manure gradient giving the highest yield as well as another which gives sufficient response to the additional increment in the nutrient level. Thus with two plots for each of the four manure levels, eight plots are chosen for plant analysis. Similarly another eight plots are chosen with two for each soil of the four fertility gradient strips. NR for each nutrient is determined by averaging the quotient obtained by dividing the uptake of the nutrient by the crop from
each of the 16 selected plots by the yield of the crop in the plot concerned. The other three parameters Cs, Cf and Cm are obtained as the regression coefficients of soil (S), fertiliser (F) and manure (M), when the uptake of the nutrient is regressed with the following model equation.

\[ U = S \cdot (C_s) + F \cdot (C_f) + M \cdot (C_m) + R, \]

where U is the uptake of the nutrient and R is the absolute constant equal to the nutrient content of the seed.

The yields from the 96 plots are regressed with the sum of the rates of nitrogen applied and similar values for P and K in each plot both from the fertiliser and manure (N1), (P1) and K1, (C1 / N1) and the C / N which are respectively the C / N ratios of the combination of the manure and fertiliser applied and the C / N ratio of the soil of each plot before the application of the fertiliser and manure, on the following regression model.

\[ Y = R + a \cdot N_1 + b \cdot N_1^2 + d \cdot \frac{S \cdot N + g \cdot (C_1 / N_1)}{C(N_1)} + i \cdot P_1 + m \cdot (P_1)^2 + q \cdot K_1 + r \cdot (K_1)^2 + t \cdot (P_1) \cdot S \cdot P + V \cdot (K_1) \cdot S \cdot K \]

From this equation, the optimum levels of N1, P1 and K1 and (C1 / N1) ratio can be calculated. The optimum value of C1 / N1 value can be estimated using a quadratic regression model, with the increase in yield due to the addition of organic manure to a fertiliser treatment regressed with C1 / N1.

\[ \Delta Y = R + a \cdot (C_1 / N_1) - b \cdot (C_1 / N_1)^2 + d \cdot (C_1 / N_1) \cdot (C / N), \]

where \( \Delta Y \) is the increase in yield (with the appropriate algebraic sign of the yield \( Y_{m+} \) with manure over \( Y_{m-} \) the yield of the corresponding fertiliser treatment without the manure (Ramamoorthy, 1994).

The integrated nutrient management for a given yield target (T) is calculated from the equation.

\[ F = \frac{T \cdot N_R}{M \cdot C_m} \cdot \frac{C_s \cdot S}{C_f} \cdot \frac{C_m}{C_f} \]

gives the efficiency of the manure in terms of the fertiliser, Cs / Cf is the efficiency of the soil nutrient in terms of the fertiliser.

From 2005 the revised treatment schedule developed by AICRP-STCR project in consultation with Indian Agricultural Statistical Research Institute, New Delhi is being followed by all the cooperating centres of AICRP-STCR. In the new design, the gradient L1/2 is omitted and L0, L1 and L2 are retained with OM1, OM2 and OM3 blocks for the test crop experiment (Fig 5).

Ramamoorthy et al. (1975) showed from such integrated INM studies that if a suitable C/N ratio is maintained at the time of application of fertilisers and manure, the effect of the latter can be positive without any ‘nitrogen effect’ as occurs when the N mineralised from manure is immobilised by the microbes. This value is about 9.9 for cotton (H14) at Hisar, 9.3 for potato (C3805) at Pantnagar and less than 10.7 for rice (Jaya) at Nalhatti (W.B.).

### Table 1: Fertiliser treatments (since 2005)

<table>
<thead>
<tr>
<th>No.</th>
<th>N1</th>
<th>P1</th>
<th>K1</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>N0</td>
<td>P0</td>
<td>K0</td>
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<tr>
<td>2</td>
<td>N0</td>
<td>P0</td>
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<td>3</td>
<td>N0</td>
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<td>7</td>
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<tr>
<td>17</td>
<td>N1</td>
<td>P1</td>
<td>K2</td>
</tr>
</tbody>
</table>

**Fig. 5. Creation of Soil Fertility and Manure Gradients**

Reddy et al. (1989) have documented the integrated nutrient management prescriptions derived from the above mentioned approach for wheat, sunflower, rapeseed, cotton and jute grown in different soils.

### Epilogue

Soil testing is the first entry point to the farmers’ field for extending Agro-technology transfer to the farming community, including long-term soil fertility management. The soil testing service through nearly 600 soil testing laboratories in the country, to be of potential value for the farming community needs to be continuously backed up by soil test crop response research at all research stations. Dr. M. S. Swaminathan, Chairman, National Commission on Farmers in his third report (2005) has ranked soil fertility upgradation and soil health maintenance as the first strategy for Ever - Green Revolution. The country is delineated into 265 Agricultural zones, each zone being endowed with a Regional Research Station. Soil fertility (Physical, chemical microbiological aspects) and integrated nutrient management should form the core research programme at all research stations on a continuing basis, with bench mark sites chosen at the research stations and representative farmers’ holdings (small, medium and big) in the zone for monitoring of ‘soil health’ in the context of intensive and sustainable agriculture.
From static soil testing laboratories, the advice on fertilizer use by post in earlier times has come now 'on line', thanks to the advances in Information Communication Technology. The DSSIFER software developed by Tamil Nadu Agricultural University and updated as DSSIFER 2010 (Santhi et al., 2010b) and the web based (http://www.stcr.gov.in) online fertilizer recommendations developed by the STCR project and National Informatics Centre (NIC), Pune are potent examples of such advances in 'knowledge delivery' to the farmers.

All the stakeholders have a role to saturate the concept of soil based and soil test based fertilizer use just as the very saturation of the cultivated areas under high yielding varieties and hybrids of crops is necessary for increased agricultural production so that agrotechnology transfer in the future will be not only 'seed centered' but also 'soil driven'.

Karamanos and Cannon (2002) have shown that it is even possible for 'virtual soil testing' through mechanistic model predicted soil test levels, for western Canadian soil testing laboratories to offer supplemental information for those fields that are not soil tested on a yearly basis.

Ramamoorthy envisaged the creation of a “National Soil Datamatics Centre” for storing, processing and retrieving soil test information from all soil testing laboratories and Agricultural Universities in the country for assessing, monitoring and upgrading the soil health of the Nation. The Indian Institute of Soil Science, Bhopal, is well placed for undertaking this challenging operational and coordinating task. This will be a tribute and homage to the memory of Dr. B. Ramamoorthy, who once told me that “Soil Testing is Testing Soil Science”.

Acknowledgement

Grateful acknowledgement is made for the support given to the All India Coordinated STCR Project by the ICAR, by Dr.B.P.Pal, Director-General and the successive Director Generals; by Dr.J.S. Kanwar, Deputy Director-General and the successive Deputy Director Generals of the ICAR.


The statistical context and content and processing of the data of the Project was greatly enriched by Dr. Daroga Singh, Shri. S.K.Raheja, Dr.S.S.Pillai, Dr.R.C. Garg, Dr. N. Saxena, Dr. V.K. Mahajan, Dr.K.N.Mathur, Dr.G.R. Maruthi Sankar and Dr.Alok Dey.

Scores of Scientists at different cooperating centres and the Project Coordinators of the Project over years, have put in their devotion and dedication to this project.

I thank Dr. R. Santhi, Professor, STCR project, Tamil Nadu Agricultural University and her staff for help in the preparation of the lecture and the article.

References


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### About the Memorial Lecture

This memorial lecture was instituted in 2011 by the Tamil Nadu Agricultural University and the Coimbatore Chapter of Indian Society of Soil Science in memory of Dr. B. Ramamoorthy who passed away on February 1, 2006.

Dr. Bharatula Ramamoorthy was born on 22nd October, 1913 in Ongole, Andhra Pradesh. He completed his postgraduate and doctoral studies specializing in Physical Chemistry from Allahabad University. He has also earned the Assoc. IARI (Soil Science and Agricultural Chemistry) and ARIC (London) associateships and Fellow of the National Academy of Sciences. Dr. B. Ramamoorthy joined the Indian Agricultural Research Institute as a Research Assistant in the year 1939 and rose to Head of the Division of Soil Science and Agricultural Chemistry in which capacity he retired on 20th October, 1972. During 1954, he was deputed to the MaCaulay Institute for Soil Research, Aberdeen as Colombo Plan Scholar. He initiated and guided the All India Coordinated Research Project on Soil Test Crop Response Correlation (AICRP-STCR) as Project Coordinator from 1967 till 1975. Subsequently he worked as Emeritus Scientist of ICAR till 1977. During his academic career spanning over 39 years, Dr. B. Ramamoorthy was actively involved in Teaching and Research and has held several important assignments. He visited USA and Canada as an Indian delegate to attend International Scientific Conferences. He presided over the session VI at the International Symposium on Soil Fertility Evaluation held at New Delhi in 1971 and participated in the FAO Sub Committee Meeting on Plant Nutrients held at Frankfurt in 1974. He was a Member of several Scientific and Expert Committees of ICAR, Ministry of Food and Agriculture, Indian Standards Institution, Planning Commission and others. He did pioneering research on Soil Chemistry and introduced several concepts like equilibrium phosphate potential and equilibrium potassium adsorption ratio of soils. He evolved a new energy concept for determining the gypsum requirement of soils and evaluated the role of soil factors in determining the quality of irrigation water.

In Soil Fertility and Fertiliser use research, Dr. B. Ramamoorthy has evolved the Inductive cum Targeted yield Concept suited to our Indian soil and climatic conditions. This methodology of research took the shape of the All India Coordinated Research Project on Soil Test Crop Response Correlation by ICAR in 1967 with Dr. B. Ramamoorthy as its first Project Coordinator. The first publication in the May issue of Indian Farming in 1967 brought out the theoretical basis and sound experimental proof for balanced fertilization. This has revolutionised the concepts relating to economic and efficient fertiliser use. These studies have also made it possible to rationalise fertilization practices for targeted yield of crops through Integrated Plant Nutrition System, for cropping sequences based on initial soil test values and also for farmers' resource constraints. His research has demonstrated that fertilizer use in rainfed agriculture can be made profitable by adjusting the rates of application of fertilizers to availability of moisture in soils and other soil physical properties. He has guided a number of Doctoral and Masters Degree students in their academic programmes and research work. He has published 85 papers in both National and International Journals. In recognition of his meritorious work and service to the country, the prestigious Raj Ahmed Kidwai Memorial Award was presented to him by the Government of India in the year 1975. One of his students received the Jawaharath Nehru Award for outstanding research contributions for his doctoral thesis.

### About the Speaker

Dr.M. Velayutham was born on 7th April 1942 at Sivagiri, Tirunelveli District, Tamil Nadu. He graduated from the Agricultural College and Research Institute, Coimbatore in 1962 and M.Sc (Ag) in Soil Science in 1964. He was a recipient of many gold medals for his academic distinction in the College. He worked as a Research Assistant at AC & RI during 1964 - 65.

As a Commonwealth Scholar, he obtained Ph.D degree in Soil Science from the University of Aberdeen, U.K. during 1965 - 68. He joined the Indian Agricultural Research Institute, New Delhi in 1969 and worked closely with Dr.B. Ramamoorthy in the Coordinated Soil Test Crop Response Project. In his career with the Indian Council of Agricultural Research, he rose to the positions of Project Coordinator (STCR Project), Assistant Director General (Soils), Acting Deputy Director General (NRM) and Director, National Bureau of Soil Survey and Land Use Planning, Nagpur. He worked as a consultant at the Regional office of FAO, Bangkok during 2001. From 2002 - 07, he worked at the M. S. Swaminathan Research Foundation, Chennai as National Coordinator and Executive Director.

He was the President of the Indian Society of Soil Science and Indian Society of Soil Survey and Land Use Planning, both during 1999 and 2000. Widely traveled, he has served as member / Chairman in several National and International Committees and technical sessions of conferences. He is the Chairman of Bhooovigyan Vikas Foundation (Foundation for Earth Sciences Development), New Delhi.

Dr. Velayutham has published 143 titles in the form of papers, chapters and coauthor of 32 books and presented 122 papers in National / International Seminars and Conferences. The Indian Society of Soil Science conferred on him the highest recognition of “Honorary Membership” of the Council of the Society in 2008 for his significant contributions and advancement of Soil Science.