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# The Law of Optimum - A Unified Concept in Plant Nutrition Bridging the Law of Minimum and the Law of the Maximum

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**A unique methodology of two-directional creation of fertility gradient with chemical fertilizers in one direction and organic manures in the opposite direction of the experimental field (60 x 40 m) was devised by Dr. B. Ramamoorthy for soil test - crop response (STCR) correlation research. This unique methodology has been adopted in the All India Coordinated Soil Test - Crop Response Correlation project of the Indian Council of Agricultural Research (ICAR) for over 4 decades at 25 Cooperating centres in the country at present on a range of soils and crops and validated through hundreds of demonstration trials in farmers' fields. The "Law of optimum" propounded by Ramamoorthy and Velayutham (2011) as the unifying concept in plant nutrition, is an experimentally proven concept for soil test based major plant nutrients (N, P and K) applications to crops for desired targeted yields, based on the derivation of three parameters from standard soil test - crop response factorial field experiments, namely 1) per cent contribution (efficiency) from the soil available nutrients (Cs) as estimated by chemical soil tests in soil testing laboratory, 2) per cent contribution of nutrients from added fertilisers (Cf) and manures (Cm) and 3) nutrient requirement of the crop (kg/ton) as estimated from yield and plant nutrient uptake data from STCR field experiments. The principles underlying the "Law of minimum", "Law of diminishing returns" and "Law of the maximum" governing plant nutrition are not only embedded in the "Law of optimum" but also provides a basis for "Balanced fertilisation". The scope for extensive use of the "Targeted yield" approach on the basis of derivation of the efficiencies of soil and fertilizer nutrients is discussed.**

**Key words**: Law of Optimum, STCR, Balanced fertilization, Soil health

The "Law of optimum" provides the approach for soil test based soil fertility maintenance and management, by efficient nutrient management through use of manures and fertilizers for high crop productivity and profitability for ensuring sustainable and enduring agriculture. A number of limiting factors relating to soil, plant, climate and management domains regulate crop production and the level of yield obtainable. The limiting factors interact with each other and the interaction responses are important for obtaining maximum yield/ maximum economic yield. Sinha and Swaminathan (1979) gave an estimate of the absolute maximum food production potential in India. Sinha (1989) estimated the maximum productivity potential of some crops in India as given in Table 1. As against the maximum production potential, only 30 -35% has been realised so far.

### *Limiting nutrients and crop yield*

Historically, two laws, namely, Liebig's "Law of minimum" (1843) and Mitscherlich's (1909) "Law of diminishing returns" have guided the principles and practices of nutrient application to crops and soil fertility management in farming, avoiding nutrient(s) deficiency in soils and in crops.

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### *Liebig's "Law of minimum"*

Liebig's "Law of Minimum" (1843) states 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, magnesium or any other nutrient, the yields stand in direct relation. It is this limiting 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". If the most limiting factor such as soil nitrogen can only provide 60% adequacy of the yield, yield will never be more than 60%, even if there are no other remaining limitations. When that factor is corrected, the next factor in most limitation determines the yield. In production agriculture, this process is managed and regulated with step wise inputs and attendant yield increases until there are no remaining growth limiting factors.

### *Mitscherlich's "Law of diminishing returns"*

Mitscherlich (1909), 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, $dy/dx = (A-Y) C$, 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 to soil and C is constant, which can be taken as efficiency factor. Based on the nutrient mobility concept in soil, Bray (1945) modified the Mitscherlich equation, incorporating efficiency factor for soil nutrient and for fertiliser as per its method of application.

***Wallace's "Law of the maximum"***

Taking together the above two different laws of the minimum, as how limiting factors relate to crop production, Wallace (1993) proposed "The Law of maximum" for diagnostic nutrient management by identifying and eliminating both Liebig type and Mitscherlich type limiting factors in crop production along with considerations of economic returns and environmental realities. Fig. 1 taken from the paper of Wallace (1993) gives the increase in relative yield in relation to multiple action yield fraction (due to the function of inputs made to overcome stresses). Zone 'A' corresponds to little or no response to factors (inputs) which are under high stress, *i.e.* Liebig type. When those factors are corrected, there is an apparent synergistic zone, 'B'.

When the yield curve reaches zone 'C', sequentially additive interactions occur and accurate predictions can be made for use of inputs to obtain desired targeted yield underlying the concept of the law of optimum, by soil and plant testing diagnostic analyses. Efficiency for each individual input (nutrient) progressively increases with the use of other inputs (nutrients) having positive interaction effect on yield. Zone 'D' represents the potential yield when there are no remaining limiting factors of any kind. Zone 'E' represents yield depression beyond maximum yield, due to excessive inputs or toxicity levels of some nutrients/elements.

According to Wallace (1993), 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 effect of the individual inputs, because of the way in which they interact. Yield can be the highest or maximum only if, there are no remaining limiting factors; the fewer limiting factors that remain, the higher will be the yield. When dealing with Mitscherlich - type limiting factors, those most economical to use can be chosen first.

***National soil test crop response correlation research***

Fried (1964) discussing E, L and A values as measures of soil available nutrient, stated that "each is an attempt to make a quantitative measurement and our science, in so far as *nutrient supply* is concerned will be retarded unless qualitative observations can be made quantitative. The first phase of soil testing laboratories advisory service in India was initiated in 1955-56 under the TCM-USAID Programme. The soil test calibrations (low, medium and high) and fertilizer recommendations advocated to the then tall varieties of food crops were qualitative in nature. With the introduction of high yielding varieties and hybrids of crops triggering green revolution, a new phase of quantitative soil test - crop response correlation (STCR) studies were conceived and implemented through an All India Co-ordinated STCR Project by Dr. B.Ramamoorthy in 1967 under the aegis of the Indian Council of Agriculture Research (ICAR). A novel field experimentation methodology was devised and soil test - based fertilizer dose calibrations were derived by creating a macrocosm of soil fertility variability within a microcosm of the experimental field. Details of fractional factorial multi-nutrient field experiment and the unique "inductive approach" envisaged in this project were outlined by Ramamoorthy and Velayutham (1971).

The various aspects of soil test calibration and soil fertility management themes covered under the project include (1) efficient fertilizer recommendation according to the investment capacity of the farmer ( 2) fertilizer allocations under conditions of fertilizer/credit shortage (3) fertilizer recommendation for targeted yields and maintenance of soil fertility in a cropping system (4) prediction of post- harvest soil test values from initial soil test values in multiple cropping system (5) apportioning the fertiliser application between crops in a multiple cropping system for increased fertiliser use efficiency (6) area wise fertiliser recommendation based on yield targeting and nutrient index of soil fertility (7) limitations to extensive use of fertilisers and the possible methods of overcoming them and (8) the need for maintenance of optimum C/N ratio for increased nutrient efficiency, when both organic manures and fertilisers are used.

The soil test based fertiliser recommendation for (1) targeted yield of crops under fertilizer resource constraints and (2) on the shape of eight different types of crop response curves for nutrient management were elaborated by Ramamoorthy, *et al.* (1974) and Velayutham (2017). At the inaugural address of XIV$^{th}$ annual workshop (1994) of the STCR project, I observed the publication of Ramamoorthy *et al.* (1967) brought out the theoretical basis and experimental proof of what I may now designate as the underlying "Law of optimum" - optimum nutrient supplies from soil and fertiliser sources for definite yield targets. This concept harmonises the contrasting view points of "Are we to fertilise the soil or fertilise the crop? and provides a sound basis for soil test based balanced fertilisation.

In the last 50 years, a large data base on soil test - fertiliser calibration has been generated in the project by the 24 co-operating research centres covering various soil types and crops, as documented in the publications of Velayutham (1979), Randhawa and Velayutham (1982), Velayutham *et al.* (1985), Muralidharudu *et al*. (2010, 2011 and 2012), Dey and Santhi (2014). and Santhi *et al*. (2017). Maji (2014) have documented the use of GPS and GIS tools in preparing soil fertility maps and making site-specific on-line fertiliser recommendations. Based on the large volume of field experimental data on soil test - crop response calibration covering a range of soil types and crops and over 2000 demonstration trials validated in Farmers' fields, the "Law of optimum" was propounded (Ramamoorthy and Velayutham, 2011) as the unifying concept in plant nutrition for realizing targeted yield of crops through soil test based integrated nutrient management. The "Law of optimum" as propounded by Ramamoorthy and Velayutham (2011) is an experimentally proven concept of soil test based major plant nutrients (N, P and K) applications to crops for desired targeted yields, based on the derivation of three parameters from standard soil test - crop response factorial field experiments, namely 1) per cent contribution (efficiency) from the soil available nutrients (Cs) as estimated by chemical soil tests in soil testing laboratory, 2) per cent contribution of nutrients from added fertilisers (Cf) and manures (Cm) and 3) nutrient requirement of the crop (kg $ton^{-1}$) as estimated from yield and plant nutrient uptake data from STCR field experiments. Velayutham *et al.* (2016) have elaborated the application of the "Law of optimum" for realizing targeted yields in India.

***Efficiencies of soil and fertilizers, targeted yield of crops and maintenance of soil fertility***

It is generally believed that the law of diminishing returns operates with increasing levels of production and that lower the level of production greater is the benefit cost ratio (BCR). This conclusion is generally arrived, because the effect of going in for low level (s) of production on the fertility status of the soil, following the crop growth is not taken into account. Therefore, there is no wonder that in subsequent years more fertilizer is required to compensate for the lower fertility level of the soil for producing even the same level of production.

According to the law of optimum (Ramamoorthy, 1993 and 1994), the uptake of nutrients by the plant from the soil will cause a depletion of soil available nutrient equal to Cs.S. This is counteracted by the addition to the soil, fertiliser nutrient left unutilized by the plant, which is equal to F (1-Cf).

As a first approximation, therefore,

Cs. S = Fm (1-Cf) (1)

or Fm = Cs. S/(1-Cf) (2), where Fm is the fertiliser dose for maintenance of soil fertility

The minimum yield target (Tm) for maintenance of soil fertility at initial level of soil test, S, will be Tm/NR = Cf.Fm + Cs.S (3)

Substituting the value of Fm in equation 2 and simplifying, the target yield for maintenance of soil fertility,

Tm=Cs.S x NR (1-Cf) (4) and the fertiliser dose for Tm will be

Fm=Tm x NR / Cf-Cs.S /Cf (5) and for integrated nutrient supply

Fm=Tm x NR /Cf-Cs.S / Cf-M.Cm / Cf, where Tm and Fm represent target yield and the fertiliser dose required for maintenance of soil fertility; S is soil test value; M is the amount of manure added; Cs, Cf and Cm are efficiencies of soil nutrient and nutrient in the fertiliser and manure, respectively.

The efficiency of soil nutrient in terms of fertiliser is given by the coefficient of S in the equation above. A value less than one signifies that the soil nutrient is less efficiently utilized than the fertiliser nutrient measured in the same unit. Similarly, a value greater than 1 means that the soil nutrient is more efficiently used. Therefore, for economic turnover of fertilisers in multiple cropping system, crops or varieties with less value for the above coefficient should be followed by those with high values. The term Cm / Cf gives the efficiency of the nutrient in the manure in terms of the nutrient in the fertilizer.

A long term field experiment on targeted yield of rice-rice rotation and maintenance of soil fertility being demonstrated at a fixed site since 1998 at the Tamil Nadu Agricultural University significantly brings out the application of law of optimum" for realising the desired yield target and maintenance of soil fertility in the long run (Velayutham and Santhi, 2013).

***Real and apparent efficiencies of applied fertilizers***

Response curve from a field STCR experiment on sugarcane conducted as illustrated by Ramamoorthy (1994) by Rani Perumal at Palur is given in Fig. 2. Curve 1 represents yield of sugarcane to different levels of fertiliser Nitrogen. Curve 2 is drawn between actual yield obtained and the balanced fertiliser dose for targeted yield with only the N dose represented on X-axis. The fertiliser equivalent of soil nutrient is given by Fes =S.Cs/Cf. Curve No.2 in Fig.2, when extrapolated cuts the Y axis (yield) at, Ysf = 66 t $ha^{-1}$ for zero level of fertiliser, whereas the actual yield obtained without any fertiliser, $YS_0$ = 54 t $ha^{-1}$. The lowering extent of the extrapolated value (12 t $ha^{-1}$), denoted as Ysf - $YS_0 = Y_P$ (7), represents the priming effect ($Y_p$) of the fertiliser on the availability of soil nutrient.

**Table 1. Maximum productivity potential of various crops**

| Crop | Duration (Days) | Biomass (t $ha^{-1}$) | Harvest (%) | Yield (t $ha^{-1}$) |
|---|---|---|---|---|
| Wheat | 150 | 28.1 | 40 | 11.2 |
| Barley | 135 | 20.4 | 35 | 7.1 |
| Mustard | 150 | 24.3 | 25 | 6.1 |
| Chickpea | 180 | 27.8 | 25 | 7.1 |
| Rice | 120 | 26.1 | 40 | 10.4 |
| Maize | 100 | 22.3 | 35 | 7.8 |
| Pigeonpea | 150 | 23.4 | 25 | 5.8 |

Source: Sinha (1989)

The priming effect of fertiliser and the use of apparent efficiencies of soil and fertiliser nutrient in the fertiliser recommendation equations for targeted yield, results in the actual yields obtained being higher than the targets in the range of lower targets, with the difference decreasing as the targets become higher till a point is reached when the fertiliser dose Fx and the target Tx obtained is the same as the one targeted. At higher fertiliser doses than this, the actual yields obtained become progressively less than those targeted, as illustrated from STCR project results (Fig. 3) by Black (1993) and Ramamoorthy (1994).

An improved procedure for derivation of more realistic Cs and Cf values than from the usual subtraction method is by regressing the uptake of nutrients from the 16 selected plots with their soil test values and fertiliser dose of the particular nutrient and identifying the two regression coefficient, Cs and Cf, respectively and averaging the set of 16 values (Ramamoorthy, 1993). Maruthi Sankar *et al.* (1983) proposed a statistical method for selection of 16 plots from the STCR field experiment for the estimation of nutrient requirement and Cs and Cf values.

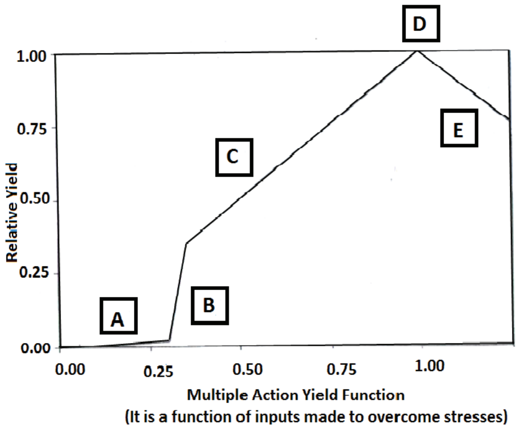



**Fig 1. Yield curve according to Multiple Action Yield Fraction plot**

A is the high-stress zone with Liebig-type limitations;

B is the synergistic response zone with Liebig synergism;

C is the zone of sequentially additive interactions with Mitscherlich-type limitations;

D is the attainable yield for a given situation; and

E is the zone of the yield losses due to excessive inputs.

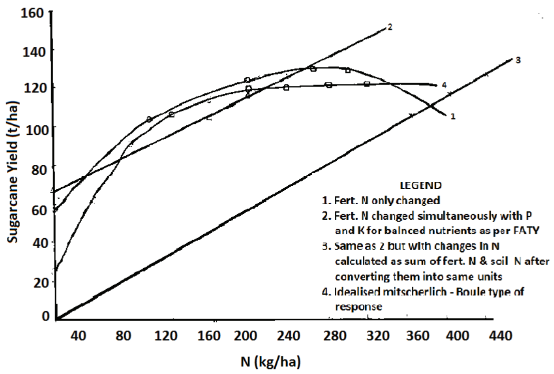
Source: Wallace and Wallace (1993)

***Plant tissue testing***

For long duration crops such as sugarcane, banana and perennial fruit crops, the soil test based fertiliser management can be complemented and supplemented with plant tissue testing and use of ion selective electrodes (Kim *et al.,* 2007) at important physiological growth stages of the crop and the adequacy levels of nutrients in the plant sap can be monitored and corrected for adequacy (Dev *et al*., 1980; Bhargava, 2002; Ganeshamurthy and Raghupathi 2014).

***The law of diminishing returns - its avoidance and the way forward***

The National Soil Testing Advisory Service consists of 876 static and 135 mobile laboratories and the fertiliser industry has 54 static and 24 mobile laboratories, with an annual analysing capacity of 12 million soil samples, with a capacity utilisation of 73% (Ramesh Sharma, 2014). Government of India has initiated in 2015, the soil health card scheme based on soil testing of the farm holdings. An estimated 25.3 million soil samples will be collected and 140 million soil health cards will be distributed in a cyclic programme. The fertiliser recommendations for targeted yield of crops from the 24 agricultural university SAU research centres, uploaded in the software provided for this scheme *viz., http://soil.health.dac.gov.in*, will get disseminated to the farmers in the respective areas to adopt soil test based fertiliser use for enhancing the productivity, profitability and soil fertility and promote through horizontal learning of this knowledge by fellow farmers (Vandana Dwivedi, 2016). It is a paradox that against the large number of soil test results, there are at present, disproportionately only a few number of research stations experimental data on Soil Test-Crop Response calibration being generated through 24 co-operating research centres. Based on the soil survey and mapping programme carried out by the



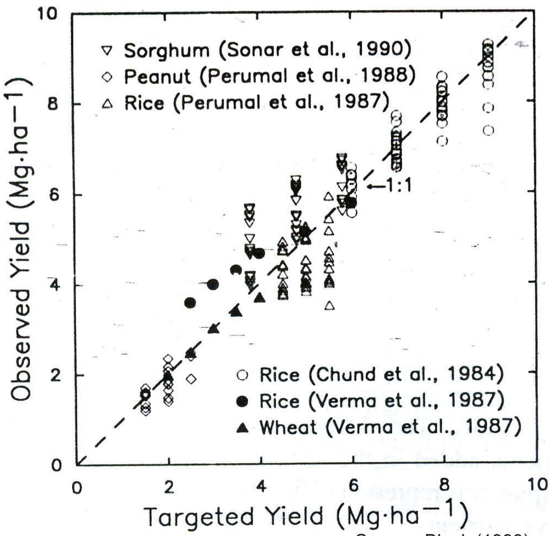

Source: Ramamoorthy (1994)

**Fig.2 Changing response curves to N of Sugarcane 6304 at Cuddalore with the way changes in N are made**

National Bureau of Soil Survey and Land Use Planning at 10 Km interval, Bhattacharyya *et al.* (2013) have delineated 1247 kinds of "soil families" in the country, as per USDA soil taxonomy.

There are about 265 agricultural research stations in the National Agricultural Research System (NARS) of the country. Soil test-crop response calibration studies must form one of the continuing core research programmes of majority of the research stations so that appropriate soil test calibrations, interpretation and recommendations may be given to the farmers by the soil testing laboratories for the locally important major crop varieties, for ensuring sustainable soil fertility management underlying the concept of the law of optimum and adopting integrated nutrient management by the 130 million farm holdings for the required targeted levels of production over years. The great German soil fertility survey during the late 1930s is a relevant analogy (Wilcox, 1955), for triggering soil health revolution to support food security, in the years to come. The soil test calibration recommendations derived from the standard STCR field experiments at majority of the 265 research stations covering major agricultural production zones, can be transferred through soil testing laboratories, to similar soils in the neighbouring districts using the concept of "soil family" as the unit from the soil map.

Extended application of these calibrations to dissimilar soil types in the region could lead to lesser reliability and applicability of the calibrations; where the applicability of the calibrations does not fit, due to local pedological differences, a few verification trials on about 8 levels of targeted yields in farmers fields may be conducted and the calibration for the targeted yield may be revised with new values for nutrient requirement per ton of produce (NR) and coefficients of efficiencies of soil and fertiliser nutrients (Cs and Cf). Hence, STCR studies will have to form a core and dynamic research endeavour with emerging new varieties and hybrids of crops, cropping systems and soil variants in the agricultural landscape of the region(s).




Source: Black (1993)

**Fig 3.Targetted and observed yields of crops in tests of the fertiliser prescription procedure**

Swaminathan (2005) has ranked soil fertility upgradation and soil health maintenance as the first strategy for ever green revolution and sustainable agriculture. Under the Digital India paradigm, an equally dynamic web-based technology transmission and advisory service and effective knowledge delivery (distance education) to the farming community on soil-crop-land management can be accomplished (Bhattacharyya *et al.*, 2016 and Velayutham, 2016). ICT aided, locally owned and manned "Village Knowledge Centres" as being demonstrated through M.S. Swaminathan Research Foundation model villages and knowledge delivery systems being promoted in Australia and New Zealand (*www.landcareonline.com.au; www.soilhealthknowledge.com.au)* and the National Soil Health card project are good such examples for triggering soil health rejuvenation in the country .

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