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Boundary-Line Approach in Specifying Nutrient Diagnosis Ranges for Vegetatively Propagated Tea in Sri Lanka

[1]G P Gunaratne, [1]L S K Hettiarachchi and [2]A N Jayakody
[1]Soils and Plant Nutrition Division, Tea Research Institute of Sri Lanka, Talawakelle, Sri Lanka
[2]Department of Soil Science, Faculty of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka

ABSTRACT

A relatively new approach, the 'boundary line' approach, for objectively assessing cause-and-effect relationships in biology, was made to a systematically-collected set of data, representing climates, soils, ownerships and management practices, from the present distribution of vegetatively-propagated tea plantations in the corporate sector of Sri Lanka. This was primarily to investigate whether this technique could be used to study tea nutrition and determine nutrient sufficiency or deficiency, and to investigate whether diagnosis ranges for vegetatively-propagated tea could be upgraded with a view to using leaf analysis as an effective diagnostic tool.

Accordingly, nutrient diagnosis ranges were arrived at for nitrogen (N), phosphorus (P), potassium (K), sulphur (S) and magnesium (Mg), and rated as 'optimum', 'deficient', 'low' and 'excess'. The optimum nutrient ranges are 2.78 - 3.39, 0.12 - 0.15, 0.91 - 1.24, 0.23 - 0.37, and 0.13 - 0.22, respectively. An attempt was also made to compare the diagnosis ranges with those ranges currently in use in Sri Lanka, and other tea-growing countries. It is apparent that the 'optimum' leaf-nutrient ranges for tea in Sri Lanka had been fixed using a limited set of information, representing a limited number of areas. Hence, the nutrient diagnosis ranges established using the boundary line approach, can be used to improve the utility of plant testing in tea when more precise interpretation and/ or more narrow ranges of critical values are warranted.

Key words: boundry line approach, nutrients critical values

INTRODUCTION

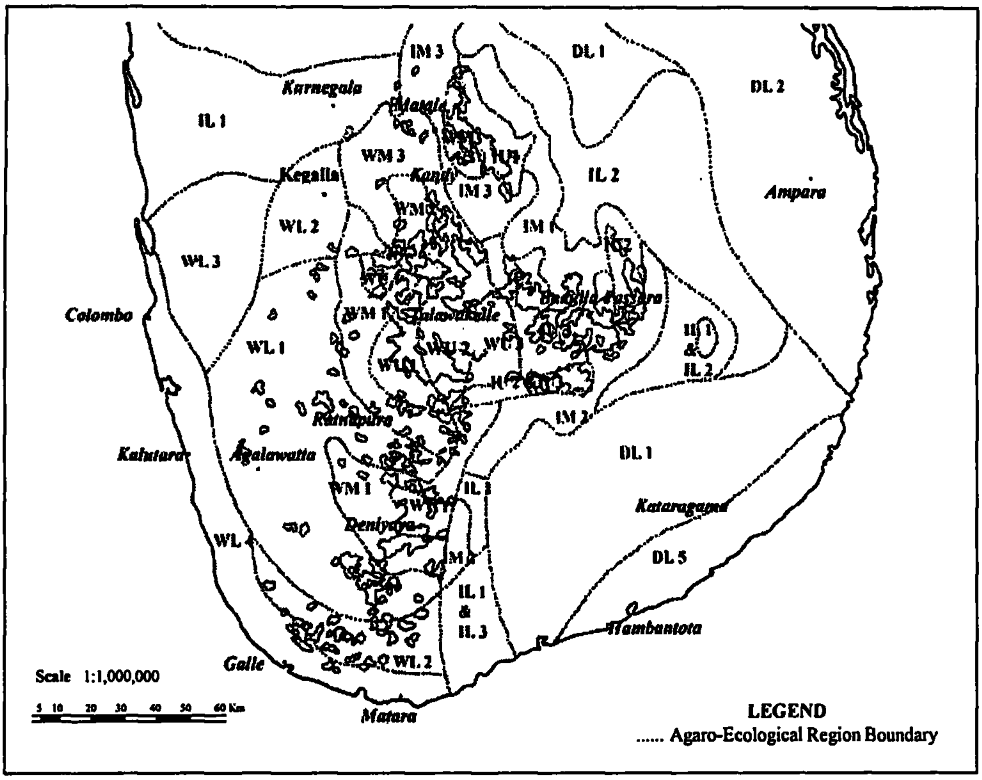
Tea in Sri Lanka is planted from almost mean sea level to around 2200 metres above mean sea level, in the wet and intermediate zones of the country. Of the tea extent, approximately 46% are under old seedling while the rest is vegetatively propagated (VP) tea with high yield potential. The tea lands are classified as high- (above 1200 m), medium- (between 600-1200 m) and low- grown (below 600 m), depending on the elevation of the green leaf-processing factories. This classification originated in the early days of tea production, and is primarily to help consumers to recognize the characteristics of made tea available for sale.

The soils present in the tea-growing areas fall into three large groups, namely Red Yellow Podzolic (RYP), Reddish Brown Latasolic (RBL) and Immature Brown Loam (IBL) (Moorman and Panabokke, 1961). According to the USDA soil taxonomic classification (Anon., 1975), the RYP and RBL groups are regarded as an order Ultisol while IBL is regarded as Inceptisol.

Besides these large groups, the soils of the wet zone have been provisionally characterized and classified into series levels, using both the USDA and FAO/UNESCO systems (Mapa et al., 1999). Accordingly, 13 main series have been recognized from the following tea-growing areas: Mattakelle, Maskeliya, Nuwara Eliya, Kandy, Ukuwella, Akurana, Malaboda, Pallegoda, Weddagala, and Dodangoda, Ragala, Badulla and Mahawalatenne.

Annual rainfall, mean temperature and the duration of mean annual sunshine vary widely within the tea-growing areas in Sri Lanka. The climatic conditions, together with the soil properties at a given location, determine the land use and management requirements. Following this criterion, the areas with similar climatic and soil conditions were identified and demarcated as agro-ecological regions (AER) (Panabokke and Kannangara, 1975). Accordingly, 12 AERs have been identified within the tea-growing areas (see Fig.1). However, the rate of growth, and in turn the production of harvestable shoots from a given site, primarily depend on the interactive rôle of climate, soil and plant factors, together with a host of management practices.

Generally, there is a basic relationship between the concentration of a plant nutrient and the growth rate, or yield, of the plant (Dow and Roberts, 1982; Mengel and Kirkby, 1987). Over the range of this relationship, the critical nutrient range of concentration (CNR) or sufficiency range is a narrow range, above which, with a reasonable confidence, the plant is amply supplied, and below which the plant is deficient (Dow and Roberts, 1982). Plant-tissue analyses provide a satisfactory basis for determination of the relative proportion of nutrients present in plants and/or available in soils. In Sri Lanka, the mother leaf, in whose axil a pluckable shoot has developed, has been shown to be the most



suitable for most plant nutrient analyses, and also for the diagnosis of most nutrient deficiencies and excesses (Hasselo, 1965; Wickremasinghe and Krishnapillai, 1986). However, for foliar analysis the first and/or third leaf of the pluckable shoot from the bud is sampled in East Africa (Tolhurst, 1972; Willson, 1974), while the uppermost mature leaf is sampled in Kenya (Othieno, 1988).

Leaf analysis is being increasingly used as a diagnostic tool for perennial crops. The concentration of nutrients in the plant tissue reflects what the plant has obtained from the soil, in relation to its growth up to the time of sampling. It is based on the principle that the nutrient levels reflect fertility factors affecting the growth of the plant.

Leaf-nutrient criteria can also be developed from the relationship between plant-nutrient concentration and plant performance, or yield, in fertilizer treatments. However, several years are often required before crops respond to added fertilizer, and many years of field data, collected over a range of conditions, are required to develop critical concentrations or ranges. Apart from the time duration, in the case of vegetatively-propagated tea in Sri Lanka, there exist variations among the cultivars or clones owing to clonal characteristics, and wide variations in soil and climatic conditions.

A relatively new approach to the study of crop productivity has been developed, in which the performance of the best in the sample examined is taken as a standard against which to judge the remainder (Webb, 1972). This is on the assumption that there exist reasons other than chance, which accounts for the inferior performance of part of the population. As an example, when the points in relation to nutrient status and crop yield, or relative yield, are plotted in a scatter diagram, there is always a line on the upper edge of the data range. It represents the highest yields observed over the range of nutrient values measured, and is called the 'boundary line'. The boundary line also describes the response to variation in the test parameter, where all the other factors do not limit crop yield (Lark, 1997; Schnug et al., 1996; Webb, 1972).

Walworth et al. (1986) and Evanylo and Sumner (1987) opined that it is possible to use the boundary-line approach to quickly derive sufficiency ranges for nutrients and other parameters. Surveying tissue composition in highly productive fields has been recognized as a tool in establishing sufficiency nutrient ranges (Poovarodom and Chatupote, 2002). Several researchers have effectively used this technique for various crops (Haneklause and Schnug, 1994; Khiari et al., 2001; Poovarodom and Chatupote, 2002; Sullivan et al., 1996; Walworth and Kilby, 2002; Zhenmin et al., 1999).

Optimum or critical nutrient levels, or norms, or standards, and even ranges, have been established in tissues from survey databases using this technique: for S in oilseed rape grown in Northern Germany (Haneklause and Schnug, 1994), for P in potatoes grown in Quebec (a critical nutrient diagnostic index, Khiari et al., 2001), and for N, P, K, Ca, Mg and Zn in durian grown in eastern Thailand (Poovarodom and Chatupote, 2002). However, hardly any information was found on the application of this technique for crops grown in Sri Lanka.

The objective of this study was to find out whether nutrient sufficiency, or diagnosis ranges, for vegetatively-propagated tea could be established using a large body of survey data, collected from the entire tea-growing area in the country.

MATERIALS AND METHODS

Survey methodology

An island-wide survey was carried out during July 2001 - March 2003 to collect detailed information from VP tea fields in 200 corporate-sector estates, out of a total of about 400, representing different climate factors, soil, ownership, and plantation management practices. High-yielding fields, not more than 10 to 15 years after first canopy pruning, were chosen. In general, no nutrient deficiency symptoms were observed in the chosen fields. The survey was primarily to identify the factors affecting responses to applied fertilisers, with special emphasis on potash and sulphur.

A multi-stage sampling method was used to select the estates, as shown in Fig. 2. Detailed information, on field management practices, bush characteristics, pest and disease records, yield data, and climate and site characteristics, was collected from a selected VP tea field on each estate.

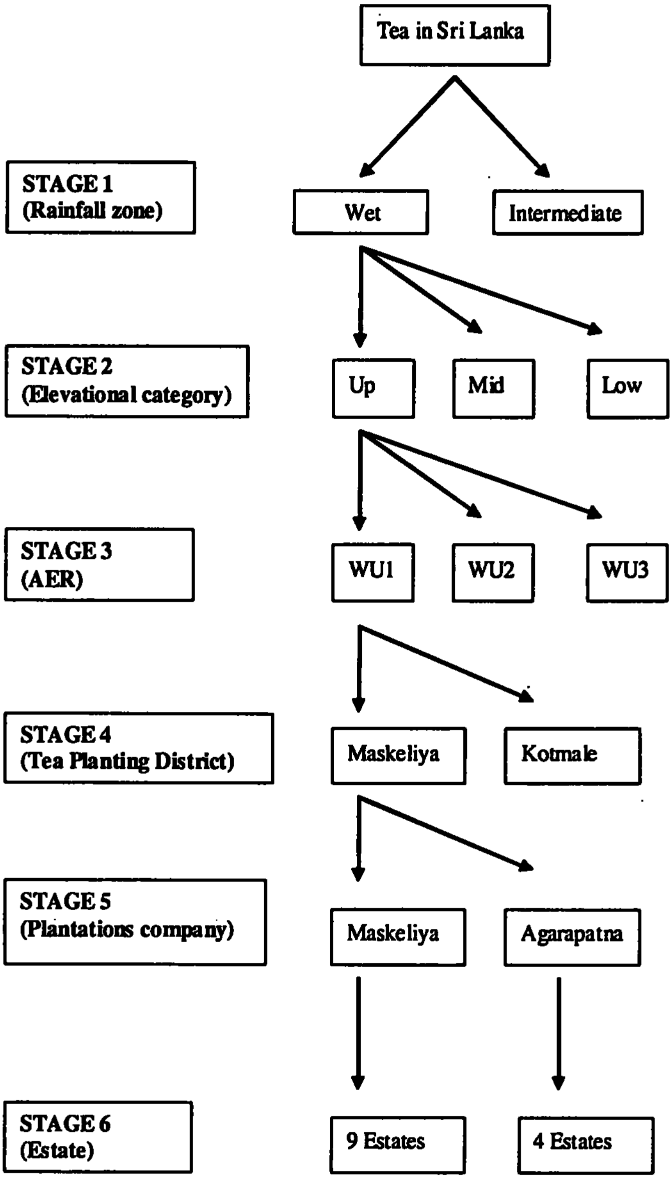


Fig 2. Multistage sampling scheme for the Islandwide survey

Sampling procedure

The first mature leaf, from whose axil the pluckable shoot emerges, was sampled for leaf-nutrient analysis. The sampled leaves were dried overnight at 80 °C, and ground in a leaf-grinding mill.

Leaf nutrient analysis

A ground leaf sample (0.2 g) was placed in a digestion tube, and ashed in a muffle furnace overnight at 480 °C. The ash content was dissolved in 0.5 ml of digestion mixture ($HCl: HNO_3: H_2O$ in the proportion 1:1:2), and dried again over a hot plate.

Ten ml of 0.05 M HCl solution was added to the dried ash, and mixed well. Suitable aliquots were used to determine K and Mg using a flame photometer, and atomic absorption spectrophotometer, respectively. Phosphorus was determined by the vandamolybdate method (Jackson, 1958), and sulphate by the $BaCl_2$ method (Butters and Chenery, 1959), using an UV/visible spectrophotometer. The nitrogen content was determined by the Kjeldhal method (Bremner and Malvaney, 1982).

Statistical analysis

The yield data collected and leaf-nutrient concentrations estimated were tabulated, and the highest yields observed over the range of nutrient concentrations (the boundary-line points) were selected for plotting scatter diagrams. Models (linear, reciprocal, logarithmic, exponential and polynomial) were fitted using the Statistical Analysis System (SAS), version 6 (Anon., 1995 a) and Microsoft Excel (Anon., 2000) packages. The coefficient of determination (R^2) was used to select the best-fitted model.

Using the mathematical equation of the best-fitted boundary line, yield ranges representing low, deficient and optimum were estimated as < 60%, 60 - 90%, and 90 - 100%, respectively. Excessive nutrient ranges, which presumably cause decline in yield, were taken to be the concentration beyond the maximum point of the sufficiency range.

RESULTS AND DISCUSSION

The coefficients of determination (the R^2 values), which is an indicator of the degree of variation in a data set (the 'goodness'), and explained by the regression models on the highest yields over the range of leaf nutrient concentration, are given in Table 1, along with their respective probability values. The R^2 values, explained by the regression models fitted conventionally to select the best regression on yield over the nutrient ranges, are also given, along with their respective probability values, in Table 2.

The best-fitted models for the highest yield observed over the nitrogen (N), phosphorus (P), potassium (K), magnesium (Mg) and sulphur (S) ranges, which are in fact the best-fitted boundary lines, are shown in Figs. 3 to 7, along with their respective distributions of total sample populations, as scatter diagrams.

The R^2 values have been significantly improved, following the elimination of inferior performances by a part of the population (compare values given in Tables 1 and 2). Based on the R^2 values of models tested for determining best-fitted boundary lines, and their P values, it was found that the polynomial models satisfactorily describe the variations in diverse sample populations accounting for 18 to 47 % (Table 1). This is particularly so, as the goodness of fit (the R^2 value) primarily indicates the possible cause-and-effect relationship existing between two variables, despite the poor level of significance for a given model of regression as P values indicate the degree of probability for repetition. In fact, the degree of variation accounted for in the case of K was 25%, which was even higher than for S, although their P values were 0.4291 and 0.0431, respectively (Table 1).

Table 1. Coefficient of determination for different models fitted to select the best boundary-line regression on the highest yields over the nutrient ranges.

	Model; [Yield = *f* (plant nutrient concentration)]				
	Linear	Reciprocal	Logarithmic	Exponential	Polynomial
Nutrient	Co-efficient of determination (R^2)				
N	0.138 *(0.1421)*	0.226 *(0.0536)*	0.183 *(0.0867)*	0.031 *(0.4994)*	0.474 *(0.0112)*
P	0.039 *(0.5003)*	0.002 *(0.8808)*	0.014 *(0.6829)*	0.044 *(0.4742)*	0.340 *(0.0661)*
K	0.082 *(0.4547)*	0.031 *(0.6513)*	0.056 *(0.5416)*	0.110 *(0.3824)*	0.246 *(0.4291)*
S	0.107 *(0.0591)*	0.050 *(0.2033)*	0.079 *(0.1075)*	0.117 *(0.477)*	0.184 *(0.0431)*
Mg	0.237 *(0.0185)*	0.082 *(0.1859)*	0.154 *(0.0645)*	0.257 *(0.0135)*	0.311 *(0.0023)*

* Probability values (or level of significance) are given in parenthesis

Table 2. Coefficient of determination for different models fitted conventionally to select the best regression on the yields over the nutrient ranges.

	Model; [Yield = *f* (plant nutrient concentration)]				
	Linear	Reciprocal	Logarithmic	Exponential	Polynomial
Nutrient	Co-efficient of determination (R^2)				
N	0.004 *(0.5016)*	0.008 *(0.3355)*	0.006 *(0.4114)*	0.001 *(0.8177)*	0.002 *(0.6010)*
P	0.190 *(0.0001)*	0.143 *(0.0001)*	0.169 *(0.0001)*	0.193 *(0.0001)*	0.205 *(0.0001)*
K	0.024 *(0.0947)*	0.026 *(0.0828)*	0.025 *(0.0869)*	0.022 *(0.1102)*	0.023 *(0.1065)*
S	0.078 *(0.0022)*	0.067 *(0.0049)*	0.074 *(0.0021)*	0.079 *(0.0022)*	0.079 *(0.0021)*
Mg	0.003 *(0.5640)*	0.002 *(0.6379)*	0.002 *(0.6038)*	0.003 *(0.5512)*	0.003 *(0.5212)*

* Probability values (or level of significance) are given in parenthesis

Nutrient diagnosis ranges for the VP tea distribution were established for the first time from a single data set systematically collected, using the best-fitted polynomial boundary line equation with respect to standardized yield categories, as defined and given in Table 3. An attempt was also made to compare the diagnosis ranges with the range or ranges currently in use both in Sri Lanka (Table 3), and in other tea growing countries (Table 4), with a view to upgrading leaf-nutrient standards.

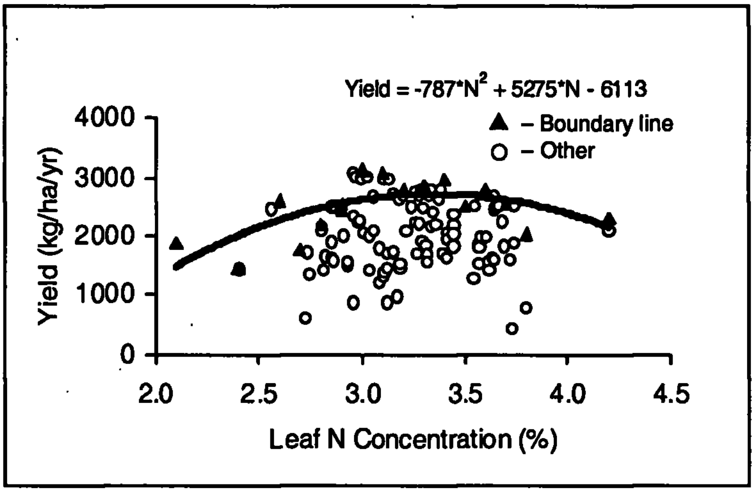


Fig 3. The best fitted boundary line for N concentration and yield.

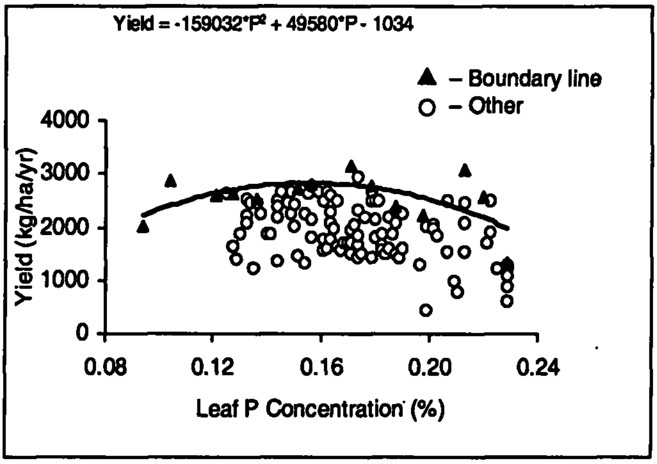


Fig 4. The best fitted boundary line for P concentration and yield.

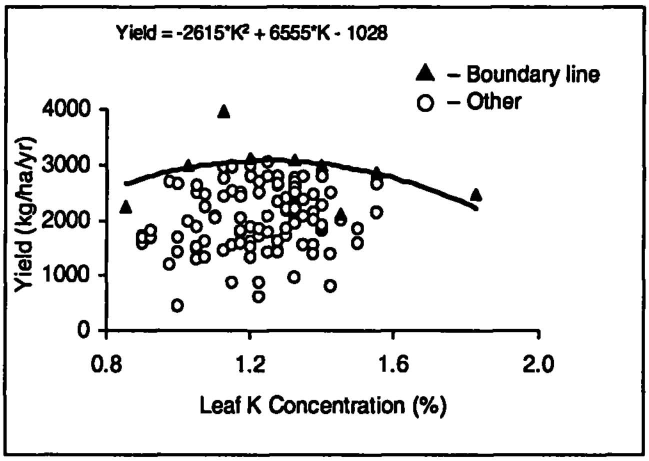


Fig 5. The best fitted boundary line for K concentration and yield.

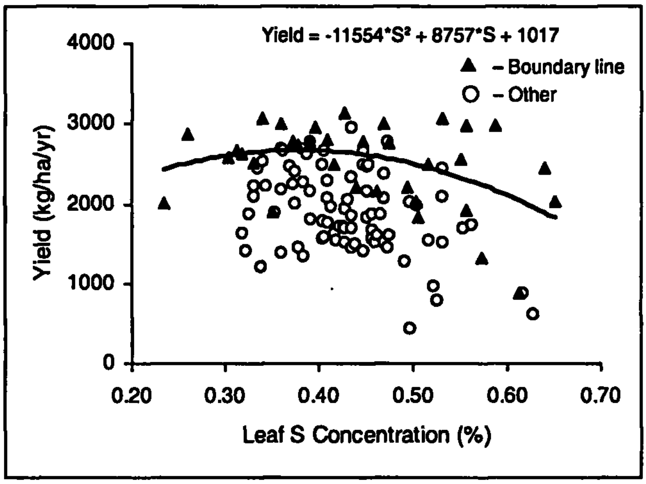


Fig 6. The best fitted boundary line for S concentration and yield.

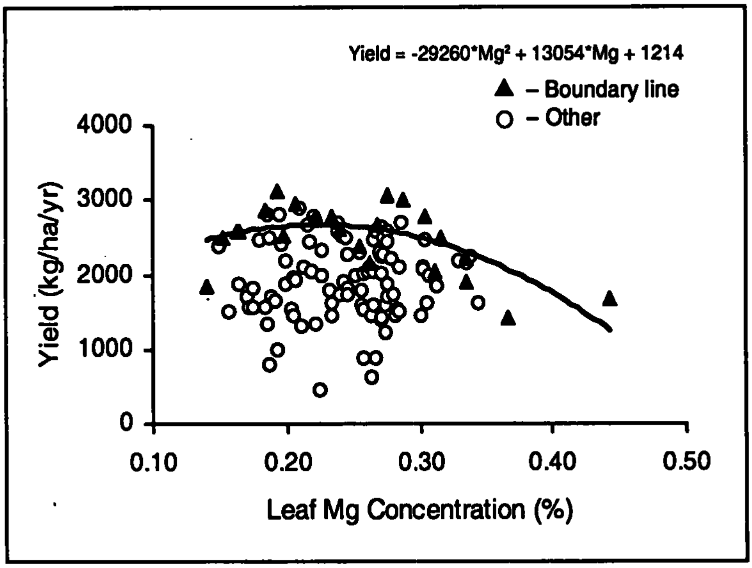


Fig 7. The best fitted boundary line for Mg concentration and yield.

Table 3. A comparison between the 'optimum' nutrient ranges currently in use in Sri Lanka, and nutrient diagnosis ranges obtained from the boundary-line technique.

	Plant nutrient (%)				
	Nitrogen	Phosphorus	Potassium	Sulphur	Magnesium
Nutrient diagnosis ranges obtained from boundary line technique					
Low	< 2.19	< 0.07	< 0.56	< 0.08	< 0.04
Deficient	2.19 – 2.78	0.07 – 0.12	0.56 – 0.91	0.08 – 0.23	0.04 – 0.13
Optimum	2.78 – 3.39	0.12 – 0.15	0.91 – 1.24	0.23 – 0.37	0.13 – 0.22
Excess	3.39 >	0.15 >	1.24 >	0.37 >	0.22 >
Nutrient ranges currently in use*					
	3.00 – 4.00	0.2 – 0.30	1.50 – 2.00	0.20 - 0.30	0.20 >
Anon, (1995b)*					

Source: Anon. (1995b)*

In spite of the heterogeneous nature of seedling tea and variations among the cultivars owing to varietal characteristics, and the wide variations in soil and climatic conditions, a range for each nutrient supposedly 'optimum' (Table 3) have been arrived at.

These ranges appear to have been developed from a large body of data on growth and yield responses to nutrient status under different experimental conditions over a long period of time, along with the analytical data generated on soil- and leaf- samples and submitted by plantations for the last two to three decades (Jayman and Sivasubramanium,

Table 4. Critical levels of nutrients in the uppermost mature and third leaf of the pluckable shoot, established by Kenya and East Africa respectively

	Plant nutrient (%)				
	Nitrogen	Phosphorus	Potassium	Sulphur	Magnesium
Critical levels of nutrients in the uppermost mature leaf *					
Deficient	< 3.0	< 0.15	< 1.20	-	< 0.10
Borderline	3.0 - 3.5	0.15 - 0.17	1.20 - 1.50	-	-
Adequate	3.5 >	0.17 >	1.50 >	-	-
Critical levels of nutrients in the third leaf of a shoot **					
Deficient	3.00	0.35	1.60	-	0.05
Subnormal	4.00	0.40	2.00	0.05	0.10
Normal	5.00	0.50	3.00	0.50	0.30

Sources; Owuor and Wanyoka (1983)*; and Bonheure and Willson (1992)**

1980; Pethiyagoda and Krishnapillai, 1970; Sivasubramanium and Jayman, 1976; Wettasinghe and Watson, 1980). Contrary to the optimum N and K ranges given, results from a recent trial, over a five-year pruning cycle, showed that the sufficiency range for leaf N varied from 3 to 3.5%, and for leaf K from 1.25 to 1.5% (Hettiarachchi et al., 2003).

The maximum concentrations of the best-fitted polynomial boundary lines, as shown in Figs. 3 to 5, were 3.39, 0.15 and 1.24 % while the optimum ranges were 2.78 – 3.39, 0.12 – 0.15 and 0.91 – 1.24, for N, P and K, respectively. These ranges are lower than the optimum ranges currently used in Sri Lanka, except for S and Mg (Anon., 1995 b).

A study was carried out by Pethiyagoda and Krishnapillai (1970) on the mineral nutrition of tea by inducing major nutrient deficiencies in sand culture. They did this by excluding from the supplied solution a single nutrient at a time, and were able to establish the leaf N, P, K, Ca and Mg concentrations associated with deficiency symptoms. Recovery to normalcy followed restoration of nutrient supply.

The results of nutrient analyses of soil- and leaf-samples from the first-ever designed 3^3 NPK factorial trial on low jat seedling tea, taken in conjunction with the corresponding yields following long-term fertilization, showed that leaf K reached a maximum value of approximately 1.8% when the water-soluble soil K content was around 12 ppm, with the yield response at 84 kg K_2O ha^{-1} yr^{-1} (Sivasubramanium and Jayman, 1976). Similarly, P reached approximately 0.24% when the borax-extractable soil P was around 20 ppm, with the yield response at 33 kg P_2O_5 ha^{-1} yr^{-1} (Jayman and Sivasubramanium, 1980). It appears that these values may also have been taken into consideration when the optimum nutrient ranges currently in use were arrived at, in spite of obvious differences between seedling and VP tea.

Wettasinghe and Watson (1980) studied the effect of three levels of N, P, K and Mg on leaf-nutrient composition, using long-term fertiliser trials with VP teas grown in low country conditions. They found that increasing the rate of N fertiliser resulted in an increase in leaf-N concentration. Although the leaf-N concentration increased with increasing levels of N fertiliser at each location, the relationship was not quite clear when the data were pooled, indicating the possible influence of other factors such as climate, soil type and clone, on the leaf-N content. The authors opined that there appeared to be a fine balance between N, K and Mg, but felt it was premature to attempt to define critical values for the various nutrients from these results.

Lately, a pot trial carried out to test the agronomic effectiveness of increasing rates of P using Eppawala rock phosphate and Triple super phosphate on assessing the growth of 8-month old tea plants from TRI 3072 in an Ultisol over a period of 10 months showed that the P concentration of the first mature leaf corresponding to 95% of the maximum dry matter yield was approximately 0.18% (Zoysa, 2000).

No attempt was made to compare the diagnosis ranges arrived at from the mother leaf, with the critical levels of nutrients in the third leaf of the shoot (Bonheure and Willson, 1992), as the concentration of N, P and K in the foliage decreases significantly with leaf maturity (Hettiarachchi et al., 1997). Also, there exist significant differences between the critical levels of nutrients in the uppermost mature leaf when compared to diagnosis ranges in the mother leaf, although they appeared to be quite similar.

In general, soil properties are related to climate, parent material, land relief and changes in use pattern. As the soils were also collected simultaneously with leaf samples from each field in this survey, an attempt will be made to correlate all the plant-available soil nutrient levels with leaf-nutrient concentrations, and yield data, in due course for a subsequent publication.

It is evident that the boundary-line approach can be used to upgrade nutrient-deficiency diagnosis in tea plantations. It is worthwhile considering the nutrient diagnosis ranges established for VP teas for implementation.

Another advantage of this technique is the identification of incipient nutrient-deficiency prior to the presentation of symptoms, and the possibility of early correction of such deficiencies to prevent a deleterious effect on the optimum rate of growth in VP tea plants.

CONCLUSION

It is apparent that the so-called optimum leaf-nutrient ranges for tea in Sri Lanka have been developed with limited information from only certain areas. It is now necessary to revise the standards, and the nutrient diagnosis ranges, established using the boundary-line approach, can be used to improve the utility of plant-testing in tea, when a more precise interpretation and narrower ranges of critical values are warranted.

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