FOLIAR DIAGNOSIS OF OIL PALM IN PENINSULAR MALAYSIA

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ABSTRACT

Optimum leaf nutrient levels corresponding to maximum yield were calculated from fitted leaf nutrient response equations derived from the date obtained over three to five years in 40 oil palm fertilizer trials carried out in Peninsular Malaysia. On all soils the optimum levels of leaf N and P were found to increase with annual rainfall, whilst palm age and planting density further influenced N and P respectively. On inland soils optimum leaf N levels also increased with silt content, whilst on all soils optimum leaf K levels declined with the silt content. On coastal soils the optimum leaf K levels also declined with the soil cation exchange capacity.

The prediction of yield response to individual fertilizers from leaf nutrient data in 32 trials on inland soils and 20 trials on coastal soils was only moderately improved by taking into account predicted variation in the optimum leaf nutrient levels. On the other hand, prediction of yield response was much improved by taking into account the variation in the level of total leaf bases (or leaf Ca alone in the case of P response). The level of total leaf bases, which is a fundamental leaf property representing total positive charge, varies considerably with soil type and was found to be significantly negatively correlated with the available water-holding capacity of the soils.

Equations have been developed to predict, from leaf nutrient data, the yield responses which can be expected from an increase in individual fertilizers, taking into account both the level of total leaf bases and environmental factors. These predictions can be used to adjust the existing fertilizer rates to optimum levels.

The objective of foliar diagnosis in oil palm is to quantify the deficiency of individual nutrients so that fertilizer adjustments can be calculated. In commercial practice in Malaysia, the concentration of nutrients in the central leaflets of frond 17 is usually measured annually for this purpose. In a previous review of the usefulness of foliar diagnosis in oil palm, based on limited trial data, Foster and Chang (1977) concluded that the main shortcoming of the method was the lack of knowledge concerning the variation in the optimum leaf nutrient levels which correspond with maximum yields in different situations. Since then results of many more oil palm fertilizer trials have become available, providing information on optimum nutrient levels over a wide range of environments in Peninsular Malaysia. Data from these trials have been used to compare various approaches in estimating potential fertilizer response from the concentration of nutrients in frond 17 and the findings are presented in this paper.

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METHODS AND APPROACH

The data used in this paper are from approximately 50 oil palm fertilizer trials carried out by different organizations in Peninsular Malaysia, previously used to relate yield responses to N and K fertilizers to site characteristics (Foster *et al.*, 1985). Details of the individual trials, including palm information, soil survey scores, soil analysis results, rainfall data and water balance calculations are given in a latter paper. The yield and leaf nutrient data used are average results obtained over three to five years. Within a trial, yield can be related to individual leaf nutrient levels, but only if all other nutrients are non-limiting (Foster and Chang, 1977). In this paper all yields and leaf levels have therefore been calculated from fitted response equations, at non-limiting levels of all nutrients except the one under consideration (as described in Foster, 1976). This means that the results cannot be used to interpret all the leaf nutrient levels at the same time. However, the results are relevant to the most deficient nutrients, which can therefore be corrected, whilst, if no nutrients are deficient, excessive levels can be identified and corrected.

At a particular site, the relationship between yield and an individual leaf nutrient (for example N) is typically as shown in *Figure 1*. The potential yield response at any leaf level is proportional to the slope of the response curve and the difference between the optimum leaf level (corresponding to maximum yield) and the current leaf level. As shown by Foster and Chang (1977), within a similar environment, the response slope and the optimum leaf level are similar and hence response is approximately proportional to the current leaf level alone. However, the response slope and the optimum leaf level are not the same in different environments and it is this variation which causes difficulty in interpreting leaf analysis data.

In this paper attempts have been made to improve the foliar diagnosis procedure by taking into account variation in the environment. The improvements in the procedure have been measured by the increased success in predicting yield response to individual fertilizers.

RESULTS

Variation in Optimum Leaf Nutrient Levels

Trials which had inadequate fertilizer rates were omitted by excluding those in which the maximum fresh fruit bunch (FFB) yield did not reach 24 tonnes per hectare per year. For the remaining trials, the leaf nutrient levels corresponding to maximum yield were calculated from fitted response equations, and the mean values of these optimum levels and of the ratios between them are shown separately for the 21 inland and 19 coastal alluvial soils in *Table 1*. Since the values from each trial were calculted from a number of plots sampled over several years, the sampling errors are small and the coefficients of variation are therefore a reasonable indication of the true variation in the optimum leaf nutrient levels. The variance of both the control plot leaf levels and these optimum leaf levels were calculated and the ratios of their variance are shown in *Table 1*. Only if a ratio is significant is it likely that samples from the two populations can be distinguished. The results indicate that the most promising ratios generally include the level of total leaf bases.

To investigate the variation in the optimum level of the leaf nutrients, they were regressed on the palm, soil and climatic properties of the different trials. The independent variables found to account for an appreciable amount of variation ($F > 2$) are shown in *Table 2;* first, when only palm parameters were included, and, second, when soil and climatic properties were also included. The order of the independent variables indicates the order of their significance. In more than half the cases over 60% of the variation in the leaf optimum levels could be accounted for and the coefficients of variation for the residual error were substantially reduced.

In *Figures 2* and *3*, the individual optimum leaf levels from each trial are plotted against the most significant independent variable. The fitted regression lines also indicate the variation due to the next most significant variable. In general, the remaining variables accounted for less than 10% additional variation. On all soils, annual rainfall accounted for the most amount of variation in the optimum levels of N and P, whilst palm age and planting density had a further appreciable influence of N and P, respectively. On inland soils, the combined concentration of all the leaf bases (expressed in milligramme equivalents) showed the highest correlation with the optimum levels of both K and Mg, whilst on coastal soils the optimum levels of these nutrients were most strongly (negatively) correlated with the level of soil total extractable bases. On all soils the silt content was also significantly negatively correlated with the leaf K optimum levels.

Possible improvement in the foliar diagnosis method, by taking account of the variation in optimum leaf levels predicted from environmental data as above, was next investigated using the data from all available trials. The amount of variation in the maximum FFB response to individual fertilizers observed in the trials, which was accounted for by the simple concentration of the relevant nutrient in frond 17, is shown in *Table 3*. On inland soils, leaf N, P and K show a moderate correlation with FFB response, accounting for about 40% of the variation in the latter, but leaf Mg on inland soils and all the leaf nutrients on coastal soils are much less successful. When FFB response was correlated instead with a leaf nutrient index representing the difference between the predicted optimum leaf level and the current leaf nutrient level, first using only palm data and then using palm plus environmental data, coefficients of determination were obtained (*Table 3*). There are some slight improvements when optimum levels are predicted from palm data alone and marked improvements in the case of P on inland soils and K on coastal soils when optimum levels based on enviromental data are used to derive the leaf nutrient indices. In particular, it appears that inclusion of annual rainfall considerably improves the correlation with P response on inland soils and soil total extractable cations (TEC) when taken into account allows a significant correlation with K response to be obtained on coastal soils.

Variation in the Level of Other Nutrients

The higher variance ratios obtained in *Table 1,* when comparing leaf nutrient ratios from control and optimum yield populations, indicates that the balance between leaf nutrients may be more important than their absolute levels. This concept of the prime importance of balance between nutrients has been strongly developed by Beaufils (1973) in his Diagnosis and Recommendation Integrated System (DRIS). Essentially, this method involves computation of all the ratios between the major leaf nutrients, which are then compared with the ratios previously calculated from an optimum yield population (in the present case shown in *Table 1*), taking into account the average errors indicated by the coefficients of variation. Following this method, DRIS indices were calculated from the leaf nutrient data in the present trials, and their correlations with FFB response are shown in *Table 3*. Although the correlations for most of the nutrients were appreciably better than those obtained with the simple nutrient concentrations (particularly for K on inland soils), the improvement is hardly sufficient to justify the tedious calculations. An even more complicated approach was tried, in which the DRIS indices were calculated by comparing the observed leaf nutrient ratios with optimum ratios predicted by environmental data, but this only improved the correlation with K response on coastal soils (*Table 3*).

The variance ratios in *Table 1* indicate that the single leaf nutrient ratio, which most effectively distinguishes control and optimum yield situations, is the ratio of total leaf bases to individual nutrients. FFB yield responses were therefore correlated with these leaf ratios alone and the results show that this index is generally more successful than the DRIS index which integrates several ratios (*Table 3*). A large number of multiple regressions were then carried out to determine the best relationships between FFB responses and leaf nutrient levels expressed in various ways, including all possible leaf nutrient ratios, and all possible combinations of individual leaf nutrients expressed in linear, quadratic and compound form. In general, the only measurements which were found to be significantly related to FFB responses were the leaf level of the nutrient supplied in the fertilizer and the level of the total leaf bases. One exception was observed on inland soils where leaf Ca showed a strong negative correlation with response to P fertilizer. A quadratic polynomial, including the level of the leaf nutrient corresponding to the fertilizer nutrient and the level of the total leaf bases, was generally most satisfactory and the variation in FFB response accounted for by the fitted equations is shown in *Table 3*. In the case of response to Mg fertilizer on inland soils, a strong correlation was obtained only when trials having a maximum FFB yield below 24 tonnes per hectare per year were omitted, presumably because some unidentified factor was limiting response in the low-yielding trials. The potential FFB yield response to individual fertilizers predicted by the fitted equations at different levels of the corresponding leaf nutrient and total leaf bases is illustrated in *Figures 4–6*.

TABLE 1. MEAN OPTIMUM LEAF NUTRIENT LEVELS AND RATIOS

Leaf Nutrients	Inland Soils (n = 21)			Coastal Soils (n = 19)		
	Mean	C.V. (%)	Variance ratio ×	Mean	C.V. (%)	Variance ratio ×
N	2.763	5.9	1.78+	2.603	4.5	1.85+
P/N	0.06081	4.7	1.98*	0.06227	5.7	1.21
N/K	2.594	14.9	1.03	2.927	12.9	1.20
Mg/N	0.09759	21.5	1.58	0.1106	20.0	2.98**
TB/N	31.40	8.1	2.40*	27.55	7.6	3.34**
P	0.1678	5.5	1.41	0.1620	5.7	0.80
P/N	0.06081	4.7	1.74	0.6227	5.7	0.69
P/K	0.1575	14.0	1.22	0.1818	11.9	0.78
P/Mg	0.6462	18.6	1.26	0.5865	22.2	1.92+
TB/P	516.5	6.9	2.06*	443.8	14.2	1.33
K	1.087	15.4	1.38	0.903	13.0	0.59
N/K	2.594	14.9	4.22***	2.927	12.8	0.57
P/K	0.1575	14.0	6.77***	0.1818	11.9	0.62
K/Mg	4.215	26.3	0.96	3.323	31.7	0.67
TB/K	81.01	13.1	8.98***	80.67	15.0	0.85
Mg	0.2690	20.7	0.74	0.2876	19.6	1.05
Mg/N	0.09759	21.5	0.58	0.1106	20.0	0.87
P/Mg	0.6462	18.6	7.55***	0.5865	22.2	0.94
K/Mg	4.215	26.3	5.17***	3.323	31.7	1.09
TB/Mg	331.6	16.1	5.72***	257.5	19.6	0.59

TB = leaf total bases = leaf (Ca + Mg + K) expressed in mg equivalents per 100g dry matter

***, **, *, + = Significant at P = 0.001, 0.01, 0.05 and 0.10 respectively

x = Ratio of the variance of the control plot leaf levels to the optimum leaf levels

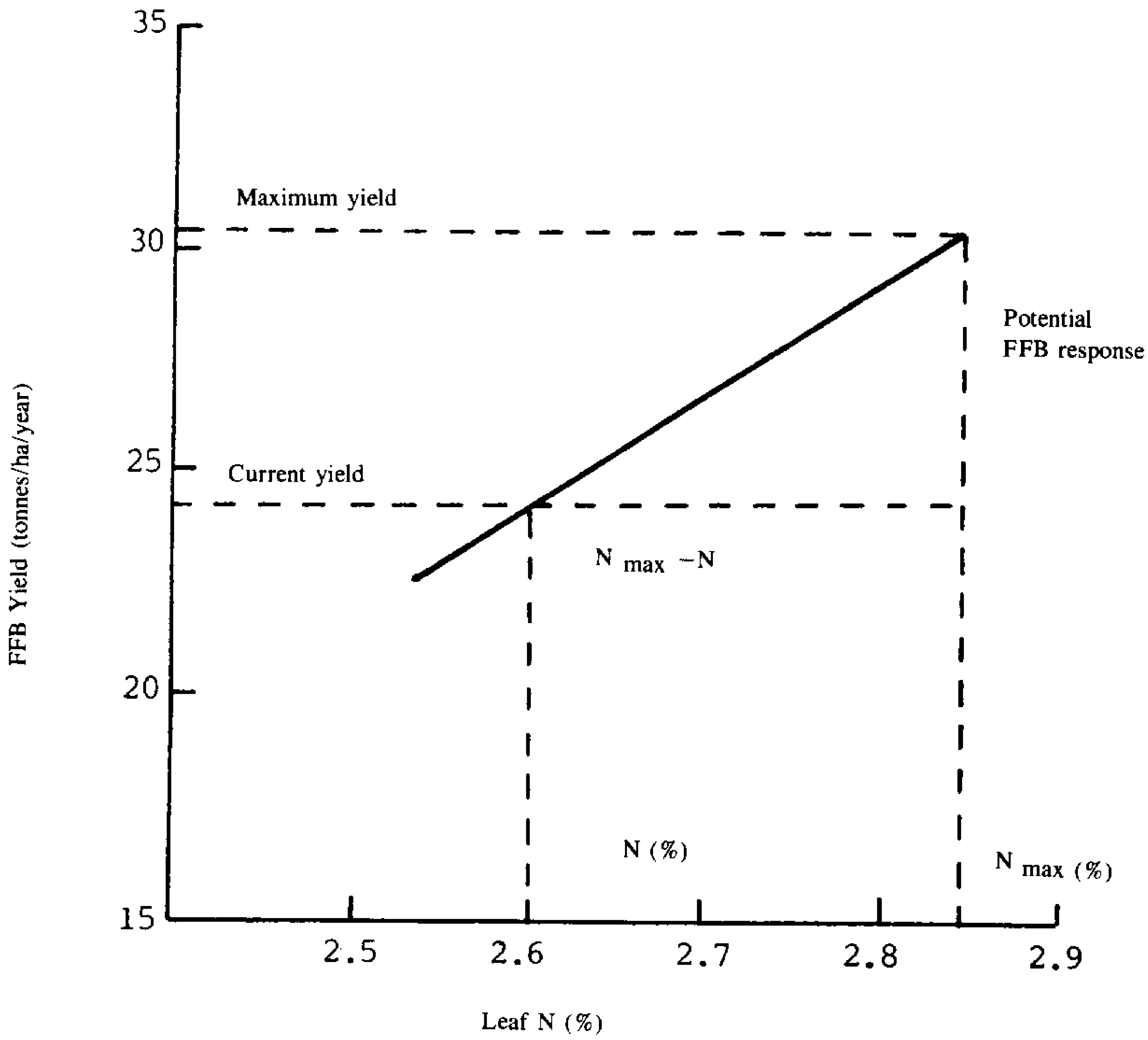

Figure 1. Typical relationship between FFB yield and leaf N concentration at non-limiting levels of other nutrients — (a slight positive curvature near maximum yield is sometimes observed).

TABLE 2. REGRESSION OF OPTIMUM LEAF NUTRIENT LEVELS ON PALM AND SITE CHARACTERISTICS

Optimum Leaf Nutrient	Independent variables (palm factors only)	R^2	Error C.V. (%)	Independent variables (palm and site)	R^2	Error C.V. (%)
	INLAND SOILS (n = 21)					
N	Density, age	24.4	5.31	Rainfall, silt, age, density	63.7	3.59
P	Density, leaf TB, age	51.2	4.28	Rainfall, density, age	69.1	3.50
K	Leaf TB, age, density	39.1	13.09	Leaf TB, silt, age	42.4	12.16
Mg	Leaf TB, age, density	57.0	14.59	Leaf TB, age, density, rainfall	64.7	13.86
	COASTAL SOILS (N = 19)					
N	Age, leaf TB	37.0	3.46	Age, rainfall, leaf TB, silt	65.1	2.96
P	Density, leaf TB	21.4	5.31	Rainfall, density	63.5	3.77
K	—	—	—	Soil TEC, silt, leaf TB	57.7	9.19
Mg	Leaf TB	12.6	17.39	Soil TEC, leaf TB, silt	73.5	10.78

(Leaf TB = Total leaf bases.
Soil TEC = Soil total extractable cations)

TABLE 3. PERCENTAGE VARIATION (R^2 %) IN FFB RESPONSE TO INDIVIDUAL FERTILIZERS ACCOUNTED FOR BY DIFFERENT LEAF NUTRIENT INDICES

Leaf Nutrient Index	N Inland (n = 64)	N Coastal (n = 40)	P Inland (n = 36)	P Coastal (n = 64)	K Inland (n = 40)	K Coastal (n = 56)	Mg Inland (n = 34)	Mg Coastal
1. Nutrient (%)	41.1	26.1	47.5	0.3	37.8	3.1	15.7	0.2
2. Critical value (%) (P) — Nutrient (%)	35.7	34.4	46.8	1.5	42.4	3.1	26.0	0.5
3. Critical value (%) (PS) — Nutrient (%)	26.9	30.0	61.8	0.2	43.5	32.2	22.1	1.2
4. DRIS Index	38.8	30.5	55.5	2.1	53.5	0.6	12.8	0.5
5. DRIS Index (PS)	14.3	21.9	41.5	0.1	51.5	30.3	23.0	2.5
6. Leaf TB/% Nutrient	51.0 (n = 44)	38.7	38.1	4.4	57.1	0.2	16.0 (n = 40)	0.1
7. Nutrient (%), Nutrient ^{2} (%), Leaf TB, Leaf TB^2	63.3	47.8	76.4+	4.8	63.5 (n = 44)	2.0	48.6	3.7
8. Nutrient (%), $Nutrient^2$ (%), Leaf TB, Leaf TB^2 (PS)	67.6	55.4	79.4+	12.8	68.1	35.1	69.2	3.8

P : Calculated using palm data (Age, density, leaf TB)

PS : Calculated using palm and site data (Rainfall, silt, soil TEC)

+ : Including leaf percentage Ca as an independent variable

n : No. of observations, consisting of two from each trial representing control and optimum situations. The lower numbers of observations (in lines 7 and 8) were obtained after excluding trials in which maximum FFB yield 24 tonnes/ha/year.

Coefficients of determination (R^2 %) are shown in bold print where a significant improvement in the variation accounted for has been obtained.

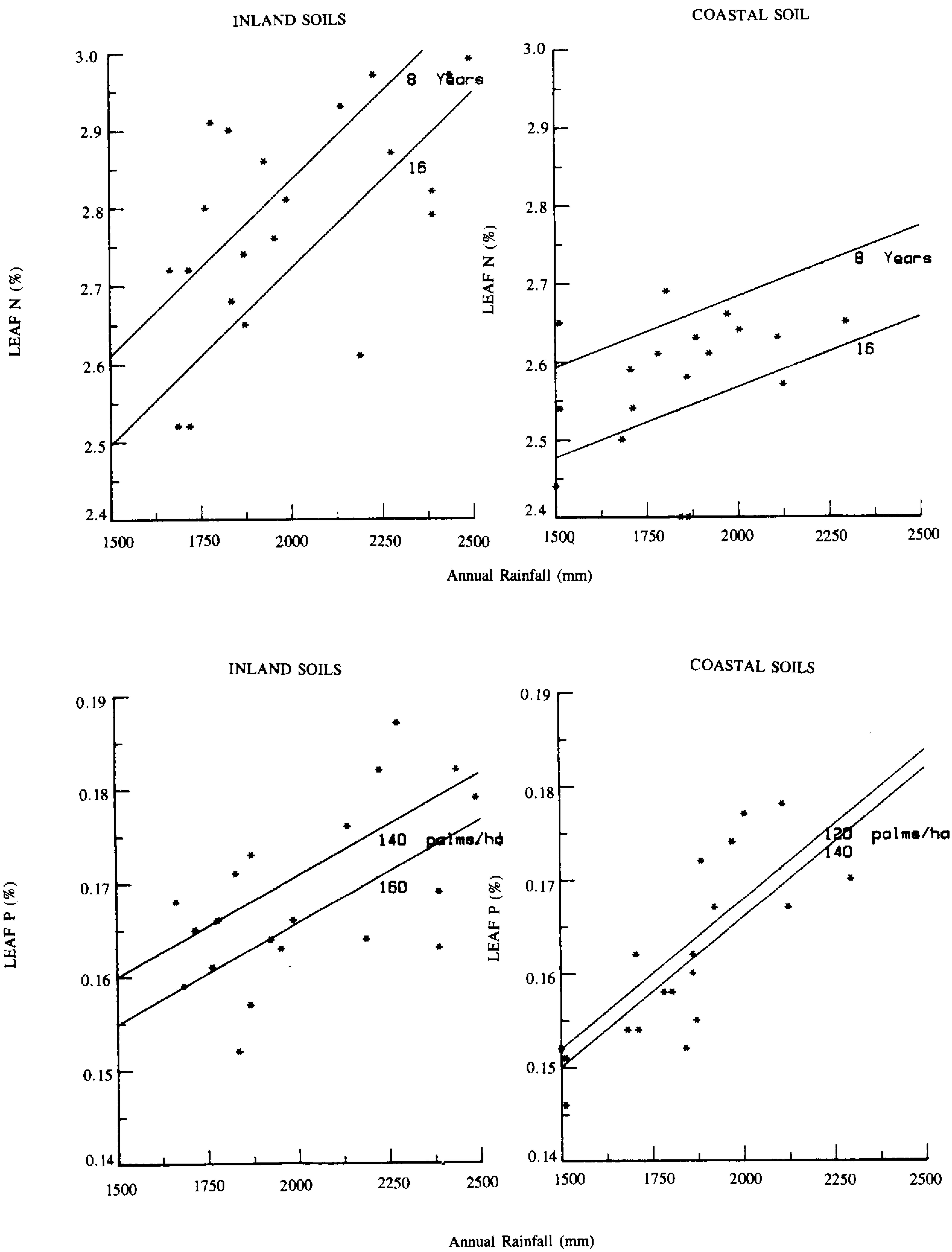

Figure 2. Optimum leaf N and P levels determined in individual trials in relation to annual rainfall, palm age and planting dens·

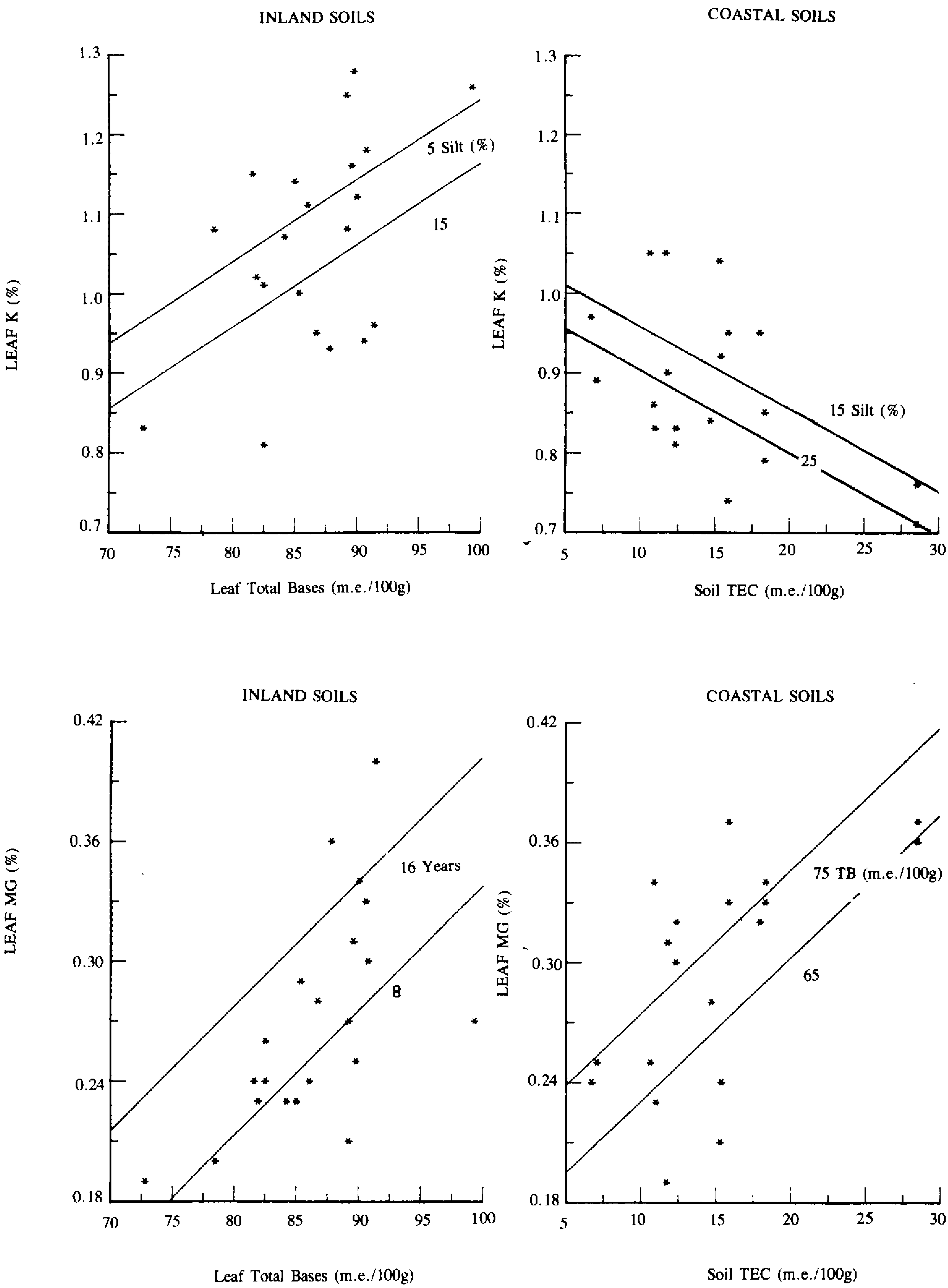

Figure 3. Optimum leaf K and Mg levels determined in individual trials in relation to leaf total bases, soil TEC, silt content and palm age.

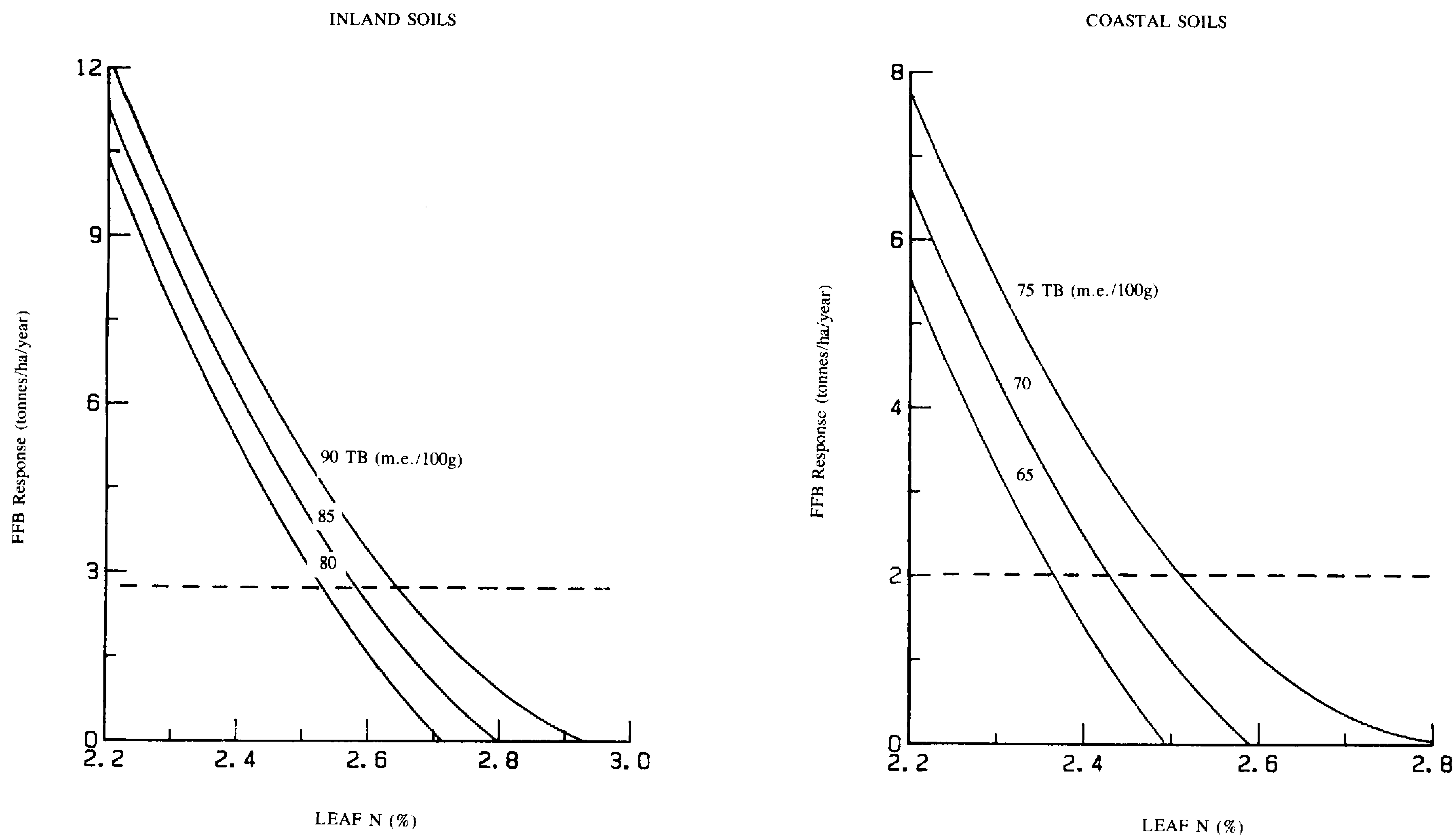

Figure 4. Predicted maximum potential FFB yield response to N fertilizer at different levels of leaf N (%) and total leaf bases. (Broken lines indicate the residual standard error).

Influence of Variation in Environment

As shown above, the potential yield response to fertilizers is very significantly related to the level of total leaf bases. The site characteristic found to account for the most amount of variation in the latter was the available water-holding capacity of the top metre of soil. Inland soils generally have an available water-holding capacity of less than 150 mm/m (*Figure 7*). The total leaf bases on these soils invariably exceed 80 m.e./100g, whilst coastal alluvial soils typically have much higher water-holding capacities ranging from 150 mm/m to 300 mm/m, the latter being associated with total leaf bases as low as 65 m.e./100g.

The direct influence of palm factors and the environment on yield response at a particular leaf nutrient level was investigated by including trial site characteristics in the equations developed above. The coefficients of determination obtained are shown in *Table 3*. Although inclusion of average annual rainfall did not markedly improve the prediction of response to N and P fertilizers on inland soils, the partial correlation of rainfall with yield response was significant in both cases. The predicted variation in response to P fertilizer for different rainfall regimes is illustrated in *Figure 5b*, which confirms the variation in the critical level of P reported earlier. The inclusion of palm age slightly improved the prediction of response to N, the effect rather surprisingly being positive. Response to K and Mg fertilizers on inland soils was found to be significantly related to the soil silt content (*Figure 6*). The response to N fertilizer on coastal soils was also positively related to the silt content. Lastly the level of soil total exchangeable cations and the silt content was found to dominate the response to K on coastal soils as shown by the predicted responses at different leaf K levels (*Figure 8*).

DISCUSSION

The results reported in this paper show that there is considerable variation in potential yield response to fertilizer at any particular leaf nutrient level. If this variation is not taken into account, foliar diagnosis cannot be an accurate procedure. This variation is due to environmental differences; in particular the difference between coastal alluvial and inland soils is so marked that they have been considered separately in this paper.

The greatest influence of the environment is through its effect on the level of total leaf bases, which is significantly correlated with the water-holding capacity of the soils. The more water a soil contains, the lower will be the concentration of the cations — in particular as the soil solution becomes more dilute, the concentration of the divalent cations falls sharply in relation to the concentration of monovalent cations. Since most of the leaf bases are divalentions, this dilution effect in the soil solution would seem to offer a plausible explanation for the variation in the level of total leaf bases. However, other soil factors, particularly the level of exchangeable cations and the nature of the clay complex, must also be involved. Conveniently, it is not necessary to measure these site factors, since it is only the level of leaf bases that we need to know.

The level of total leaf bases is crucial, because it determines the total positive charge which must be balanced by the leaf anions. It has also been suggested that it is important that K and Mg should be in balance with Ca (Foster and Chang, 1977), which means in effect that these two nutrients must individually be in balance with the total level of bases. Variation in total leaf bases appears to account for much of the variation in optimum leaf levels, due not only to the environment but due also to palm factors such as age. In fact, after adjustment for the level of total leaf bases, response to N fertilizer was found to be positively related to palm age (rather than negatively as would be expected from the correlation of optimum leaf N levels with age).

The direct influence of environmental factors on the relationship between potential response to fertilizers and leaf nutrient levels appears to be less important than initially expected. Annual rainfall accounts for a large amount of the variation in leaf P optimum levels, as expected for a nutrient which moves through the top-soil almost entirely by diffusion — a process highly dependent on the soil moisture content. However, variation in rainfall gave only a modest improvement in the prediction of P response, after adjustment for the level of leaf bases. The soil silt content accounts for a significant amount of the variation in the optimum level of leaf K on both inland and coastal soils. This is presumably because the silt content is closely correlated with the soil K buffering capacity of most soils in Malaysia (Foster *et al.*, 1985), which limits palm uptake of K. However, the silt content gave only a small improvement in the prediction of K response on inland soils. The only large direct effects of the environment appear to be the influence of soil factors on the response to Mg on inland soils and the response to K on coastal soils. In particular, the response to K on coastal soils showed no relationship with leaf K levels until the limiting effect of the K buffering power of the soils, indicated by the silt content and the level of total extractable cations, was taken into account.

PRACTICAL CONCLUSIONS

The major factors which cause variation in the optimum leaf nutrient levels of oil palm in Peninsular Malaysia were identified. Fitted regression equations including these factors allow the optimum leaf nutrient levels which correspond to maximum yield to be predicted for any environment in Malaysia. This should be of help to the agronomist in determining if optimum leaf nutrient levels have been achieved.

However, taking account of optimum leaf nutrient levels only improves the prediction of yield response to P on inland soils and the response to K on coastal soils. Lack of improvement in the prediction of response to other nutrients in all other cases is attributed to variation in the slope of the yield versus leaf nutrient response curve. Because they also take account of the latter, reasonably accurate predictions of fertilizer response can be made from fitted quadratic polynomial equations which include only the level of the corresponding leaf nutrient and the level of total leaf bases. Inclusion of palm age, annual rainfall and the soil silt and exchangeable cation content improves these predictions in some cases.

However, the above equations apply only to an individual nutrient when all other nutrients are non-limiting. It is suggested that the expected yield responses to all the

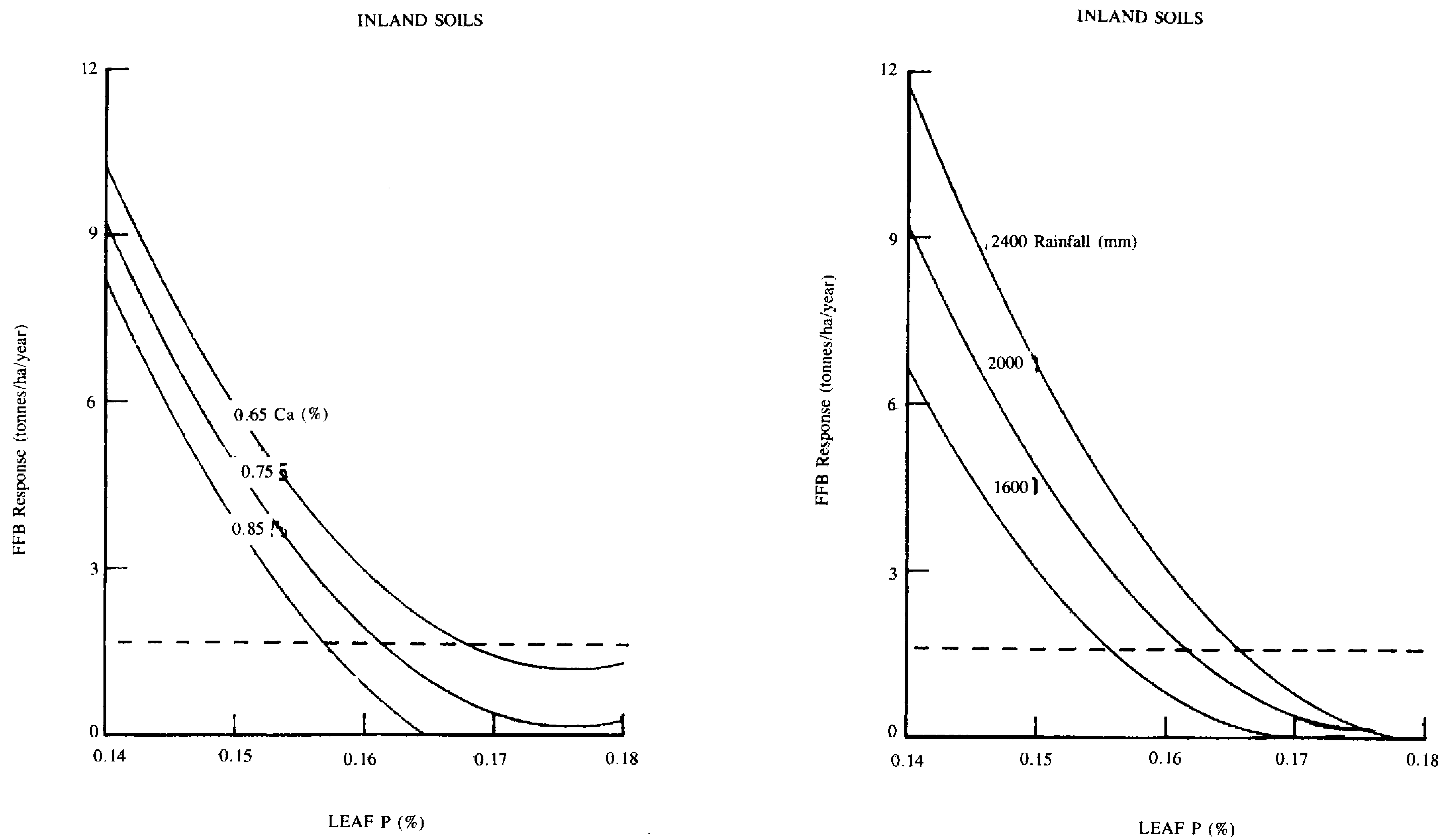

Figure 5. Predicted maximum potential FBB yield response to P fertilizer on inland soils at different levels of leaf P (%) and either leaf Ca (%)and a fixed rainfall of 2000 mm/year or rainfall and a fixed leaf Ca level of 0.75%. (Broken lines indicate the residual standard error).

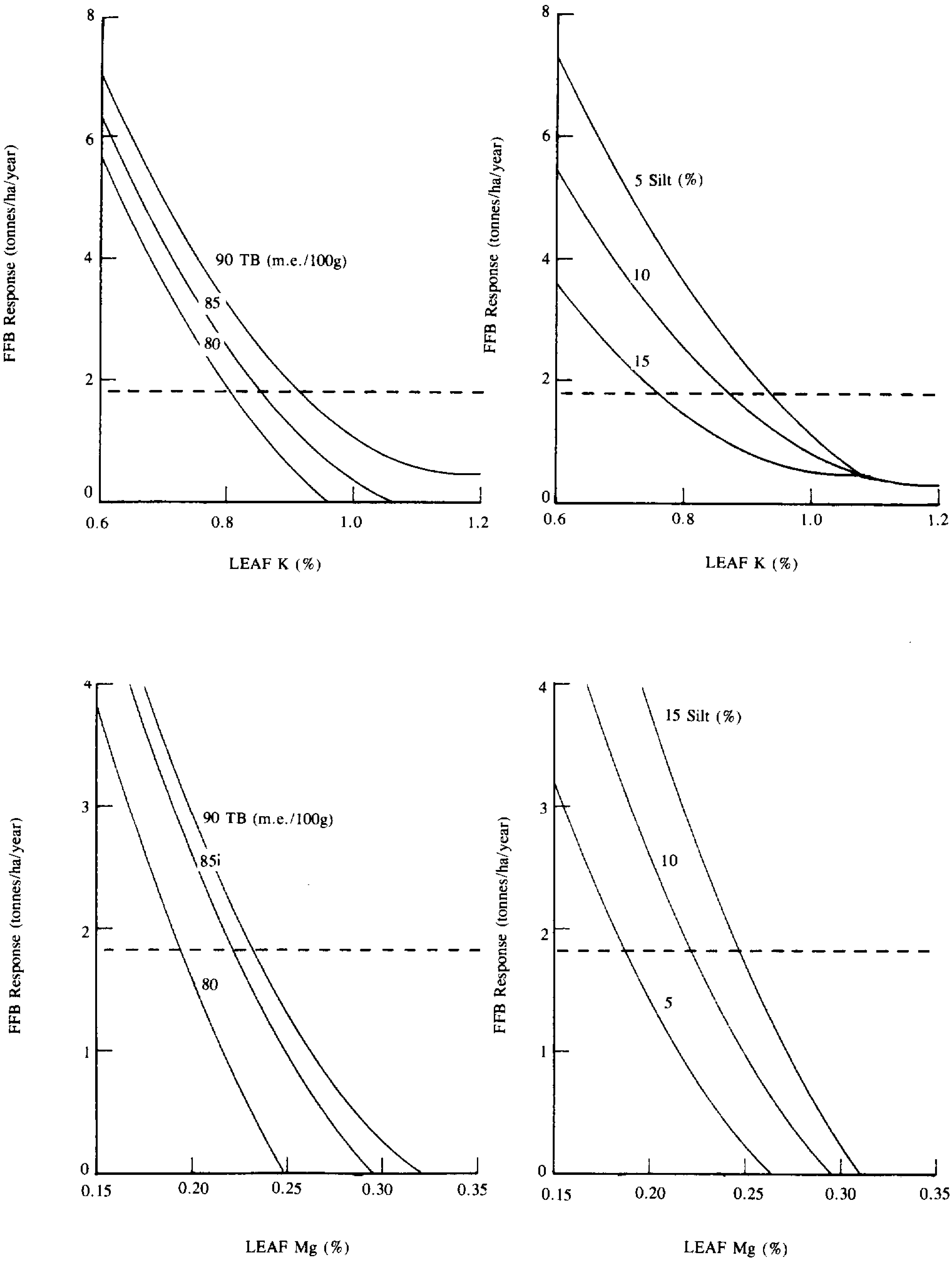

Figure 6. Predicted maximum potential FFB yield response to K and Mg fertilizer on inland soils at different levels of the corresponding leaf nutrient and either total leaf bases and a fixed silt content of 10% silt content and a fixed leaf TB level of 85 m.e./100g. (Broken lines indicate the residual standard error).

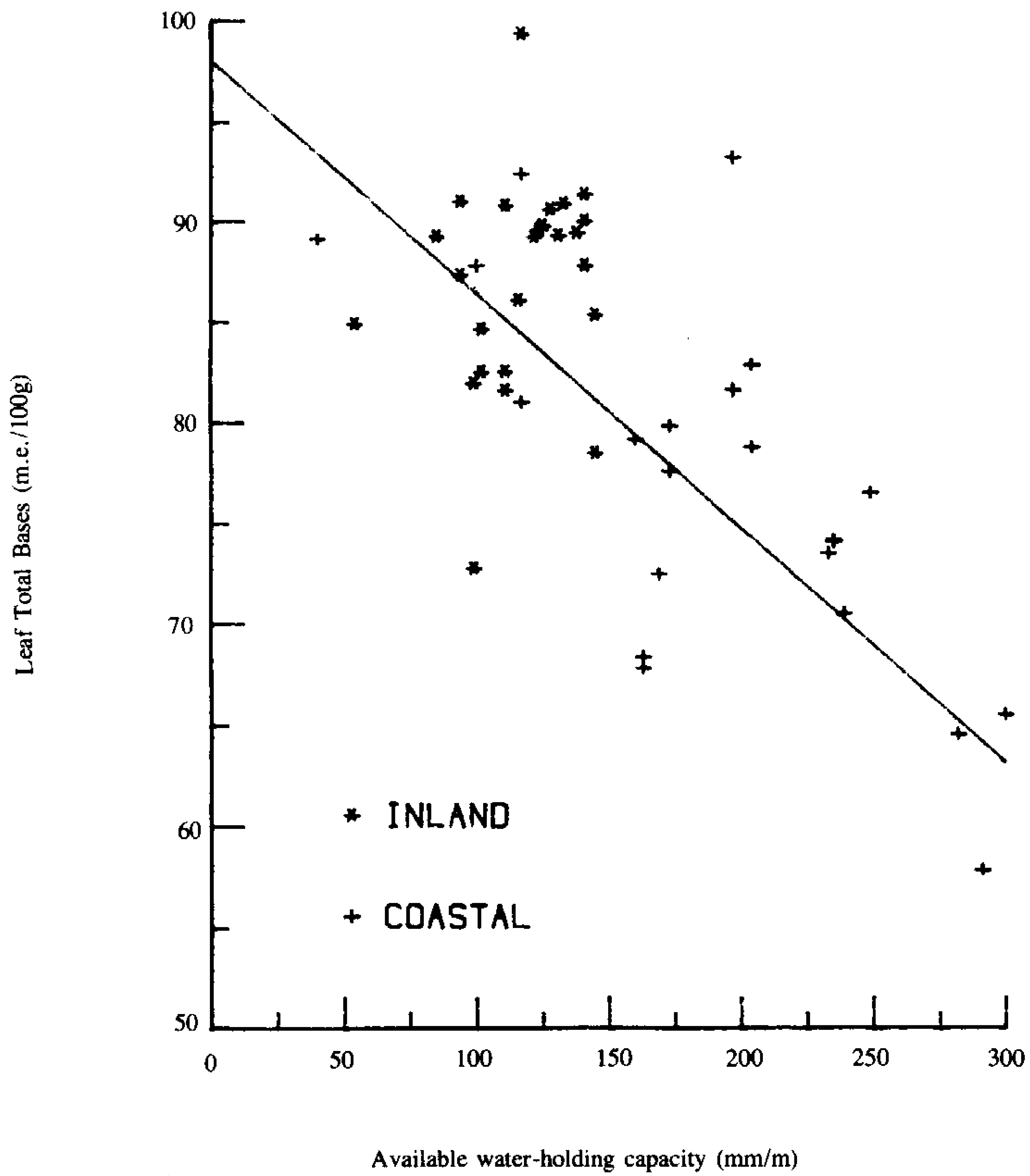

Figure 7. Average level of leaf total bases in individual trials in relation to soil available water-holding capacity.

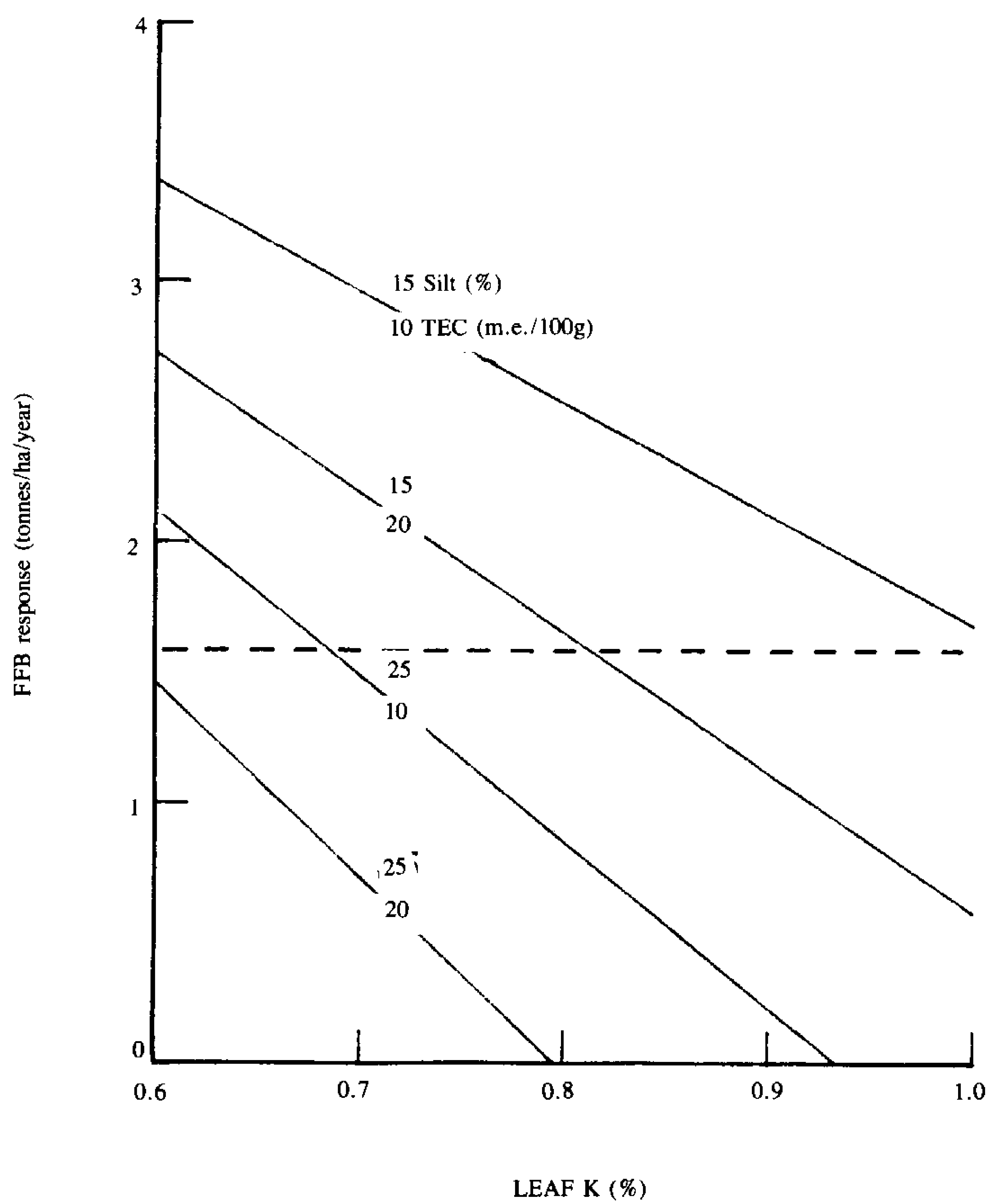

Figure 8. Predicted maximum potential FFB yield response to K fertilizer on coastal soils at different levels of leaf K (%), soil silt and soil total extractable cations.

major nutrients be predicted from the relevant equations in order to determine the most deficient nutrient.

The fertilizer rate for the most deficient nutrient can then be adjusted according to the size of the yield response predicted. If the expected response does not exceed the standard error, then an increase in the fertilizer rate is unlikely to be very profitable. If, however, a larger response is predicted, then the amount of fertilizer required can be calculated from the appropriate yield versus fertilizer response curve (Foster *et al.*, 1985).

In later years, another nutrient may become the most deficient, when it in turn can be corrected.

The equations developed in this paper were derived from yield and leaf nutrient data averaged over several years thus avoiding the problem of seasonal variation. In the practical application of these equations, mean leaf data from several seasons should be used, if possible. Seasonal fluctuation in leaf nutrient levels is currently being investigated in several experiments to determine how to overcome this problem.

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