THE SOIL DIAGNOSTIC METHOD FOR FORMULATING FERTILIZER REQUIREMENTS ON COCOA IN GHANA

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ABSTRACT

In Ghana, cocoa is grown in the entire forest belt. This belt which covers the mid-south of the country from East to West is made of a variety of soils. The potential of the soils to support cocoa production is varied and, therefore, there is a need to formulate fertilizer recommendations to suit cocoa production in the different soils.

The fertilizer requirements for the various soils were estimated by using the Soil Diagnostic method developed by Jadin and Snoeck (1985) and validated by Snoeck *et al*. (2006) for soil conditions in Ghana. Soil samples were taken from cocoa growing areas and the Soil Diagnostic method was used to establish general fertility recommendations for each region.

Sample calculations are described and the recommendations obtained with the Soil Diagnostic method for the cocoa growing areas in Ghana are discussed.

The results indicate a negative gradient of soil fertility from East to the West. Soils of the Eastern and Central regions have higher total exchangeable bases and percentage base saturation than soils of the Western region. In the Eastern and Central regions, it would be costly to correct the ratios between the nutrients, and the fertilizer recommendations must just be enough to compensate for losses in nutrients due to cocoa pod harvests. In the Western region, however, it will be necessary to first restore the ratios between the soil exchangeable bases (K, Ca and Mg) before being able to improve the cocoa yields. The results obtained by the model confirm the recommendations by Cocoa Research Institute of Ghana (CRIG) for the soils of the Eastern Region in a long-term fertilizer trial.

INTRODUCTION

Optimum productivity of any cropping system depends on an adequate supply of plant nutrients. Although one or more nutrients are commonly applied to most crops, the quantity of nutrients removed in the harvested crop is generally much greater than the quantity added. Continued removal of nutrients with little or no replacement will increase the potential for future plant-nutrient related stress and subsequent loss and yields.

Most soils do not supply sufficient nutrients for normal plant development and optimum productivity. Therefore, application of supplemental nutrients is required. The proper rate of plant nutrients is determined by soil testing.

Soil analyses are routinely carried out in cocoa plantations in Ghana, but are not often used for fertilizer recommendations, because they are difficult to interpret. A soil diagnostic model was developed to help the agronomist to easily understand and interpret soil chemical data (level of nutrients, N/P and K-Ca-Mg ratios) in order to formulate adequate fertilizer recommendation for cocoa plantation.

The purpose of this work is to investigate the potential of soils in the Southern part of Ghana to support cocoa production and to recommend the fertilizer requirements for the different areas.

The cocoa soil diagnostic method was used to determine the actual needs in soil nutrients. The model, developed by Jadin and Snoeck (1985), allows calculating the requirements (fertilizer formulae and doses) of the major nutrients from the actual chemical soil analyses.

MATERIALS AND METHODS

We used the soil and climate maps to define the nutrient needs per major groups of soils and climatic conditions for the main three cocoa growing regions. Then, we took soil samples in the various areas to determine the actual fertilizer recommendations per zone. The areas which have unsuitable soils (too acidic or with too low total exchangeable bases) or insufficient rainfall were eliminated.

Calculation of the fertilizer requirements

Soil analytical data from the Soil Research Institute Memoirs (Adu**,** 1992; Adu and Asiamah, 1992; Adu, 1995; Ahn, 1961) were used to evaluate the overall potential of the major groups of soils.

One hundred and twenty soil samples taken from the three principal cocoa areas (Eastern, Central and Western regions) were analysed.

Each soil sample consists of a composite of thirty samples taken randomly from the top-soil (0 to 20 cm). Total nitrogen (Kjeldhal method), total and available phosphorus (Truog-Bray method), exchangeable bases and Cation Exchange Capacity (CEC) using the ammonium acetate method and soil acidity (pH H_2O) were determined.

To facilitate the interpretation of the analytical data, a diagnostic software programme was developed under Ms Excel™ and tested in various situations in Ghana (Snoeck *et al.*, 2006). The soil diagnostic method was used to calculate the fertilizer requirements. The software evaluates the types and amounts of nutrients needed for the optimum growth and yields of cocoa from the levels of nutrients in the soil and the ratios between them (Jadin and Snoeck, 1985).

Principles of the model

The amounts of fertilizer are calculated to reach the optimal balances described below by taking into account the coefficients of utilisation, immobilisation or movement in the soils of the various fertilizers. The main required ratios are:

Nitrogen / Phosphorus ratio: The optimal ratio represented by the line: N = 2 x $_{tot}$ P_2O_5 (both units in %). It makes it possible to identify the soils in which it is initially necessary to correct the levels of P from those not requiring it (Figure 4).

Total Exchangeable Bases (TEB) / Nitrogen ratio: The optimal TEB / N ratio is represented by the regression line: TEB = 8.9 x N – 6.15 (Figure 5). The soils whose dots are located on the left of this line will need N fertiliser either because the nitrogen is a limiting factor, or because the other nutrients are sufficient, and therefore, the nitrogen will have a beneficial effect in terms of increase yields.

Exchangeable Bases (K, Ca, Mg): The optimal values are: 8% of K, Ca 68% and Mg 24% (in % of the total of these three elements). The amounts of fertilizer are calculated to reach this triple ratio.

Once the levels of nutrients and their ratios are corrected, fertilizers will continue to be required to compensate for the nutrients exported by the products of harvests (pods). But this will require lesser quantities of fertilizers.

Other criteria used to select the potentially favourable zones

The areas suitable for cocoa were selected according to the rainfall patterns and minimum allowable levels of nutrients in the soils. These two elements are indeed important since they can influence the soil fertility and the effectiveness of fertilizers.

Climate: When the rainfall is insufficient (lower than 1400 mm per annum), the effect of fertilizer will be decreased due to moisture deficit in the soil which negatively influences the development and the nutrition of the cocoa-trees.

Threshold levels of soil nutrients: FAO Standards recommend the elimination of soils which have total exchangeable bases lower than 1.6 $cmol \cdot kg^{-1}$ soil; the pH lower than 4.6; bases saturation below 20%; and organic matter content below 0.8% or %N below 0.06% (FAO, 1996).

RESULTS AND DISCUSSION

Chemical potential of the soils

We eliminated the soils with very low Total Exchangeable Bases and Nitrogen. If cocoa is grown in these inherently poor soils, it would be necessary to strongly invest in fertilizers to render the soils productive and favourable for the production of the crop.

The groups of soils not suitable according to FAO standards are located in the Tikobo area (N < 0.08% or TEB < 1.6 $cmol.kg^{-1}$). Some other soils located in the Central region were also eliminated because the pH was lower than 4.5.

Fertilizer Requirements

We calculated the fertilizer requirements using the "Soil Diagnostic" model for each site.

For soils having a base saturation lower than 30%, we calculated the amounts of nutrients to increase the Base Saturation to 60%, keeping the ratios between K, Ca and Mg to the optimum recommended by the software (Figure 1).

Country	Ghana				19/04/2006
Title	Crig NK3 Amazon				
Clay + fine silt (%)	4		Expected values after fertilization		
Carbon (%)	1,67	C/N = 12,3			
Nitrogen (%)	0,136				
P total (ppm)		$\frac{N}{P_2O_5}$	-		
P available (ppm)	0,85		75,0		Truog-Br2
K (meq%)	0,295	10,0%	1,126	8,0%	0,83
Ca (meq%)	1,485	50,3%	9,574	68,0%	8,09
Mg (meq%)	1,170	39,7%	3,379	24,0%	2,21
Al^{3+} (meq%)					
C.E.C. (meq%)	35,200				
pH (H_2O)	4,70				
Sum of Exch. Bases	2,95		14,08		
Base Saturation	8,38		40,00		
∑ (exch. Bases) / N	6,72		14,93		

Comments

Test (exch. B.) / N => increase bases *After modif. => increase nitrogen*
N / P_2O_5 (optimum = 1,5)

Fig. 1: Soil sample with low Base Saturation. Ca is the limiting nutrient

For the soils having a base saturation between 30% and 80%, the amounts of nutrients were calculated to reach the optimal K-Ca-Mg ratio using least possible amount of fertilizer; i.e. we tried not to increase the nutrient in excess (Figure 2).

Country	Ghana				19/04/2006
Title	Kumasi				
Clay + fine silt (%)	30		Expected values after fertilization		
Carbon (%)	2,88	C/N = 15,8			
Nitrogen (%)	0,183				
P total (ppm)	198	$\frac{N}{P_2O_5}$ = 4,0	531		
P available (ppm)			75,0		Truog-Br2
K (meq%)	0,135	3,7%	0,389	8,0%	diff = 0,25
Ca (meq%)	2,565	71,2%	3,309	68,0%	0,74
Mg (meq%)	0,905	25,1%	1,168	24,0%	0,26
Al^{3+} (meq%)					
C.E.C. (meq%)	8,110				
pH (H_2O)	4,50				
Sum of Exch. Bases	3,61		4,87		
Base Saturation	44,45		60,00		
∑ (exch. Bases) / N	5,35		6,04		

Comments

Test (exch. B.) / N => increase bases *After modif. => increase bases*
N / P_2O_5 (optimum = 1,5) ==> P is low ; increase P

Fig. 2: Exchangeable ratios are almost correct in the original soil.

For soils having a base saturation higher than 80%, it is almost impossible to keep the optimum ratios between exchangeable bases recommended by the software. It would bring the base saturation over 100%. Therefore, in these soils, the fertilizers are calculated to compensate for nutrients exported through the harvest of pods (Figure 3).

Country	Ghana				19/04/2006
Title	Adzintam				
Clay + fine silt (%)	30		Expected values after fertilization		
Carbon (%)	1,76	C/N = 9,0			
Nitrogen (%)	0,195				
P total (ppm)	200	$\frac{N}{P_2O_5}$ = 4,3	568		
P available (ppm)	1,00		75,0		Truog-Br2
K (meq%)	0,250	2,1%	0,644	5,0%	0,39
Ca (meq%)	8,365	69,2%	8,752	68,0%	0,39
Mg (meq%)	3,475	28,7%	3,475	27,0%	0,00
Al^{3+} (meq%)					
C.E.C. (meq%)	12,650				
pH (H_2O)	6,73				
Sum of Exch. Bases	12,09		12,87		
Base Saturation	95,57		101,74		
∑ (exch. Bases) / N	9,35		9,75		

Comments

Test (exch. B.) / N => increase nitrogen *After modif. => increase nitrogen*

N / P_2O_5 (optimum = 1,5) ==> P is low ; increase P

Fig. 3: Soil with high Base Saturation, K% is low compared to %Ca and %Mg.

In the Eastern Region, Base Saturation is already high and, even though the ratios between the exchangeable bases are not optimal, it will be too costly to try to reach the optimum ratios. In this region, the normal recommendations will be to apply fertilizers solely to compensate for the nutrients exported by the crop; i.e. mainly P and K, as already recommended by CRIG.

On the other hand, in the Western region, fertilizers were calculated to increase the base saturation whilst correcting the optimum ratios between K, Ca and Mg.

Application to Ghana

The "Nitrogen / Phosphorus" ratios of the soil samples were computed and compared to the optimum ($N/P_2O_{5\ tot}$ = 2) regression line. Figure 4 represents the soils for all the areas studied.

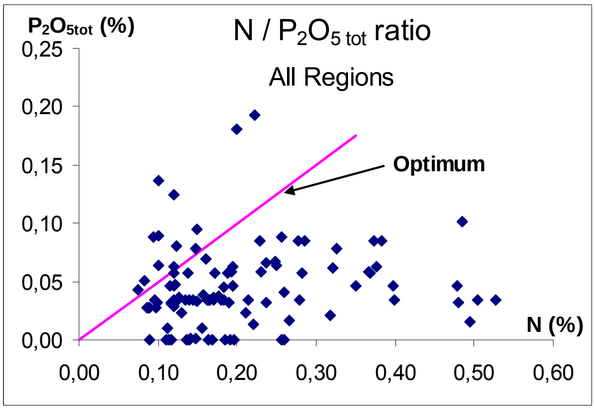

Fig. 4: Comparison of the ratios $N/P_2O_{5\ tot}$ of soils with the optimal value ($N/P_2O_{5\ tot}$ = 2)

All soils below the optimum line will need a phosphorus correction. Phosphorus fertilizers will be necessary in almost all of the studied soils, except for thirteen of them, which are above the optimum N/P_2O_5 line. These 13 soils mainly are located in Eastern Region.

The N / TEB ratio of soil samples were computed in order to determine which soils will require K, Ca and Mg fertilizers and those in which a nitrogen fertilizer will be effective. Figure 5 shows the ratios computed separately for the three main cocoa growing areas.

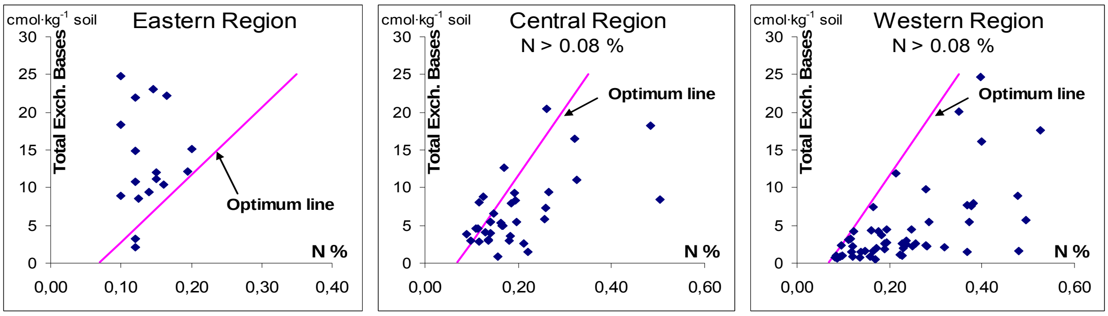

Fig. 5: Test of relation TEB /N to define the nitrogen needs per region.

The soils represented by the dots located below the optimal regression line need a correction in exchangeable bases. The soils whose dots are located above the regression line will respond favourably to nitrogen fertilization.

The results show that there is a negative fertility gradient in the soils from East to West:

- In the Eastern Region, the soils are often above the optimal line. They have balanced exchangeable levels of bases and a nitrogen fertilizer will be effective.
- In the Central Region, a rather large number of soils are located along the optimal line. These soils will have to receive a formula balanced in K, Ca and Mg. Once the optimal ratios are reached, the contribution of fertilizer of only one type can easily make the soils to switch above the optimum line and a nitrogen fertilizer will be necessary to correct the soils.
- In the Western Region, the soils are low in exchangeable bases. Soils having equilibria close to the optimal line are generally depleted and will require a complete fertilizer.

Figures 6 and 7 compare the relations between Mg – K and Ca – Mg expressed in % of the sum of total exchangeable bases.

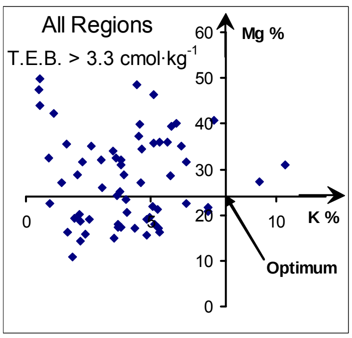

Fig. 6: %K and %Mg ratios in the soils

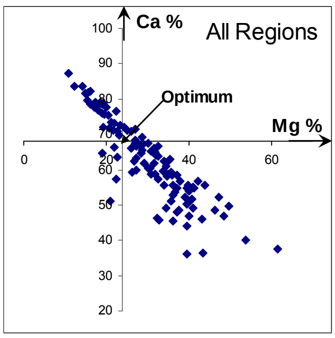

Fig. 7: %Ca and %Mg in the soils

The Figures show that, all areas taken together:

- If the TEB levels are higher than 3.3 $cmol \cdot kg^{-1}$, the formula of fertilizer will have to contain K (Figure 6).
- The soils rich in Ca are low in Mg and vice-versa (Figure 7). Most of the soils will require Ca, and Mg in less amounts under Ghanaian conditions.

The analysis of Figures 4 to 7 makes it possible to indicate the following tendencies:

- Negative fertility gradient from Eastern to Western regions,
- K fertilizer is required in almost all the soils,
- K and Ca fertilizers are required in half of the soils studied.

CONCLUSIONS

Almost all of the soils sampled were low in phosphorus; thus P fertilizer is recommended. Depending on the soil pH, we will recommend the following:

- If pH > 6.4: use ammonium phosphate because of its leaching tendency.
- If pH < 6.4: use TSP or SSP depending on whether the soil requires Ca fertilizer.

On the average, the formulae will depend of the region:

- Eastern Region: P and K to compensate for the nutrients removed by crop yields.
- Central Region: P and K to compensate for the nutrients removed by crop yields, plus Ca and Mg where required.
- Western Region: average amounts of K, Ca and Mg fertilizers will be advised by the software because the soils are depleted and have low CEC. In these soils, the recommendations will allow reaching the optimum ratios.

The results obtained with the model confirmed the recommendations given by CRIG after long term fertilizer trials for the Eastern region. The use of the model makes it possible to extend the fertilizer recommendations to areas where CRIG has not done any fertilizer trials. Without the model, long term fertilizer trials would be necessary in these areas, which are newly planted with cocoa trees and for which, farmers are now requiring advices.

The quantities of fertilizers are expressed in kg/ha. Normal application is done by spreading fertilizers all over the field. Farmers could reduce their expenses by doing localised applications, i.e. only around the cocoa trees.

Some differences could be observed on a local scale, because of differences between soil types and farming practices. But these differences are less important than the gradient observed from Eastern to Western regions.

The results show that the Soil Diagnostic Method can be a powerful tool to better understand the soil analyses and calculate the fertilizer requirements in cocoa farms.

The model has been observed to work well on cocoa plantations in Côte d’Ivoire and Togo. It is also applicable under the Ghanaian conditions.

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