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# Investigations on the nutritional status of *Hevea brasiliensis* plantations in the humid forest zone of Cameroon Part 2: Establishment of macro nutrient norms

Untersuchungen zum Nährstoffstatus von *Hevea brasiliensis*-Plantagen in der Feuchtwald-Zone von Kamerun Teil 2: Ableitung von Makronährstoff-Richtlinien


## Abstract

Standard nutrient values are needed for the assessment of optimum nutrient concentrations for improved and sustained yields. The aim of this study was to establish optimum soil and plant nutrient values for *Hevea brasiliensis* in the humid forest region of Cameroon. A nutrient survey was carried out during August 2010 and August 2011 in some rubber growing zones of Cameroon. Both soil and leaf samples were collected for the determination of their macronutrient contents. Using the macronutrient concentrations and yield data, boundary lines were calculated. These boundary lines were described by second degree polynomials. Equating the first derivative of the second degree polynomial equations to zero, the following optimum nutrient values 3.5%, 0.31%, 1.53%, 0.28% and 0.83% were obtained for N, P, K, Mg and Ca, respectively, for *Hevea* leaves. On the other hand, the optimum soil nutrient levels were 3.1% for organic carbon, 0.18% for N, 5.9 mg/kg for P, 262. mg/kg for K, 432 mg/kg for Ca and 16 mg/kg for soil Mg. The optimum soil and plant nutrient ranges were obtained by solving the boundary line equation at 95% of the optimum yield. The optimum nutrient values for *Hevea brasiliensis* obtained in this study were to a large extent different from those obtained in studies elsewhere. This is an indication that for effective nutrient diagnosis, locally derived norms should be used. Those local nutrient norms will be used for nutrient assessment in *Hevea* plantations in Cameroon.


**Key words:** Boundary line, *Hevea brasiliensis*, Humid forest, optimum nutrient levels/ranges


## Zusammenfassung

Zur Bewertung optimaler Nährstoffkonzentrationen für bessere und nachhaltige Erträge werden Nährstoffstandards benötigt. Ziel dieser Arbeit war die Ableitung von optimalen Nährstoffkonzentrationen in Böden und Pflanzen für *Hevea brasiliensis* in der Feuchtwaldzone von Kamerun. Zwischen August 2010 und August 2011 wurde eine Bestandsaufnahme der Nährstoffgehalte in mehreren Gummibaum-Anbaugebieten Kameruns durchgeführt. Boden- und Pflanzenproben wurden zwecks Untersuchung der Makronährstoffgehalte gesammelt. Unter Verwendung der Makronährstoffkonzentrationen und Erträge wurden „boundary lines“ kalkuliert und mittels polynomischer Funktionen 2. Ordnung beschrieben. Durch Gleichsetzung der ersten Ableitung der errechneten Gleichungen mit null wurden folgende optimal Blatt-Nährstoffgehalte für *Hevea brasiliensis* ermittelt: 3,5% N, 0,31% P, 1,53% K, 0,28% Mg und 0,83% Ca. Für Böden



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ergaben sich optimale Gehalte von 3,1% organisches C, 0,18% N, 5,9 mg/kg P, 262 mg/kg K, 432 mg/kg Ca und 16 mg/kg Mg. Diese Gehalte wurden errechnet, inem die „boundary line"-Gleichung bei 95% des optimalen Ertrages gelöst wurde. Die ermittelten Optimalgehalte für *Hevea brasiliensis* unterschieden sich größtenteils deutlich von jenen, die Studien in anderen Regionen ergeben hatten. Dies zeigt, dass für eine effective Nährstoffdiagnose lokal ermittelte Richtlinien verwendet werden sollten. Die hier ermittelten Richtlinien werden zukünftig zur Bewertung des Nährstoffstatus von *Hevea brasiliensis*-Plantagen in Kamerun verwendet.

**Stichwörter:** Boundary line, *Hevea brasiliensis*, Feuchtwald, optimale Nährstoffstufen

## Introduction

Natural rubber remains an important component of the Cameroonian economy being one of the major export crops (FAO, 2006). However, the actual productivity is still low compared to other countries. The mean annual yield in most estates ranges around 1,500 kg dry rubber/hectare/year (Njukeng and Ehabe, 2009). This is still quite low compared to 1,737 kg of dry rubber/hectare/year obtained by farmers in Thailand who use their own fertilization scheme, or 1,894 kg/hectare/year for farmers who follow the fertilizer recommendations of the Rubber Research Institute of Thailand (Saichai et al., 2012). Thus Cameroon has a potential to improve yields through proper fertilization.

The first step in developing any fertilization recommendation is to derive standards which serve as a reference (Abira et al., 2009; Rahman et al., 2007). Till date in Cameroon, standards used for nutrient assessment have been based on those derived in other *Hevea* growing countries like Malaysia and India. Nutrient standards derived in one region may not be suitable in another region, but if they have to be applied, they should be calibrated (Elwali et al., 1985). The risk of applying standards from other regions without calibration is that nutrients may be over or under applied. When over applied, nutrient losses from soil into surface and ground water may occur (Isermann, 1990; Isherwood, 2000). When under applied, the yield potential may not be attained especially as the nutrients have to be balanced for the yield potential to be obtained.

The critical leaf nutrient value can be derived from the relationship between nutrient concentration and tree growth or yield as a result of different fertilizer treatments. For the diagnosis of the nutrient status of plants, nutrient addition experiments providing response curves to define critical nutrient limits are used. This is often the case for annual crops. However, the disadvantage of using this method for perennial crops is that many years often elapse before trees respond to added fertilizer and many years of field data collected over varying plantation conditions are required to develop critical concentrations. Thus nutrient concentrations in samples from a survey of crops in the field are collected and used for nutrient assessment (Poovarodom and Chatupote, 2002; Robinson and McCarthy, 1985). Due to the effect of multiple factors such as soil and climate, nutrient concentrations and girth or yield from the survey do not often correlate significantly. Thus in analyzing this relationship it is assumed that for a given concentration of any nutrient element, the fields which have the best growth or most productivity are the maximum potential yielders in the absence of any other limiting factors (Saichai et al., 2012). After selecting the maximum yield at the increasing levels of each nutrient a line is drawn to fit the boundary-line curve. Several methods have been used to fit the boundary-line curves; by eye (Webb, 1972), drawn by hand (Schnug et al., 1996), or fitted according to statistical models, such as linear regression (Casanova et al., 1999; Poovarodom and Chatupote, 2002) or quadratic polynomials (Schnug et al., 1996; Schnug et al., 1995). The disadvantages of linear regression models are that a large number of observations are required and the construction of the accurate boundary line is difficult (Saichai et al., 2012). The objective of this study was therefore to establish optimum nutrient norms for *Hevea brasiliensis* in the humid forest zone of Cameroon using the boundary line approach.

## Materials and Methods

*The study area*

95 composite topsoil samples and composite leaf samples were collected from 11 rubber estates belonging to the Cameroon Development Corporation of Cameroon and 35 samples were also collected from Sociètè Forestiere Agricole du Cameroon (SAFACAM) rubber estate (Fig. 1). The climate of the study site is characterized by high temperatures and seasonal rainfall. The mean temperature is between 25–28°C and rainfall between 700–1250 mm. The soil depths were from shallow to deep and the texture from sandy loam through clay loam to sandy clay. Fertilizer application in the sampled fields was site specific.

The choice of the number of samples per estate was determined by the field size, the types of clones (different varieties) planted as well as the age of the plantation. The *Hevea* fields sampled were all mature fields (at least 8 years old) in tapping.

*Soil sampling and analysis*

Soil sampling. Soil sample collection involved removal of surface organic debris and augering to a depth of 0–15 cm. Each sample consisted of at least 10 sub-samples from the entire sampled area. In the field, soil samples were stored in properly labeled polythene bags and taken to the laboratory where they were air-dried separately on shelves in the soil drying room in order to avoid contamination. The dried samples were passed through 2-mm sieves prior to analysis.

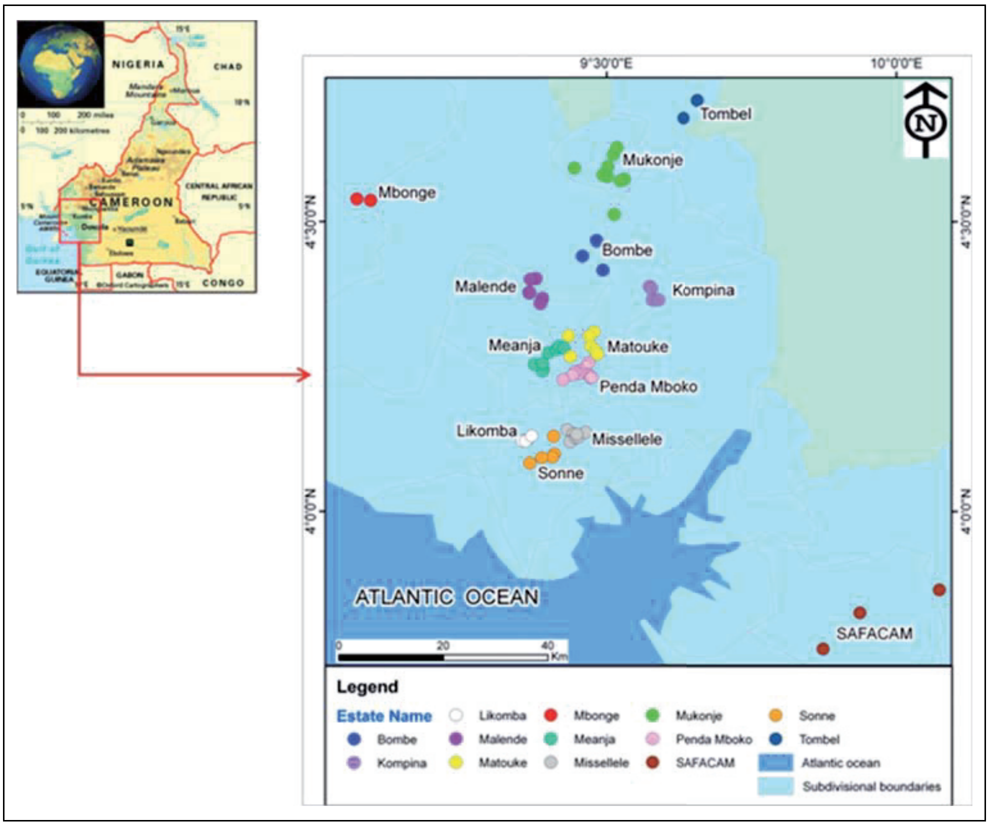


**Fig. 1.** The Map of Cameroon showing the study site.

Soil analysis. The determination of total carbon and total nitrogen was done by dry oxidation at 1,200 °C with a vario MAX CNS Elemental Analyzer. Conversion of total carbon to organic carbon was done by using the factor 1.724, which represents the mean C concentration in soil organic matter.

Soil pH was measured using a pH-meter with a glass electrode in a suspension of 1:2.5 soil and 0.01 M $CaCl_2$ (DINISO, 2005). The available macro nutrients P, K, Ca and Mg were determined by Inductively Coupled Plasma Optical Emission Spectrometry (ICP – OES) after extraction with Acidic Ammonium Acetate – Ethylenediaminetetraacetic acid (AAAc-EDTA) solution (Lakanen and Erviö, 1971).

*Leaf sampling and analysis*

Leaf sampling. Leaves from the shaded canopy were sampled from 15 trees per site and all samples were mixed together to make a composite sample. The samples were washed in running water to remove dirt, followed by the removal of the leaves stalk. The leaves were cut into smaller pieces and placed in paper bags for oven drying at 70 to 75 °C for 48 hours. After drying, the leaves were crushed into a powder using a home use blender (Mulinex) and sealed in polythene bags for later analysis.

Leaf analysis. Leaf N was analyzed using a vario MAX CNS Elemental Analyzer. For the determination of the macro nutrients P, K, Ca and Mg, the plant samples were digested in a mixture of nitric acid and hydrogen peroxide in a microwave oven. The digest was then filtered into a volumetric flask (250 ml) which was filled up to the mark with distilled water and used for the determination of the elements by Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES).

*Yield recording*

Harvested latex from the various blocks/sites was subjected to various durations of maturation to obtain field coagula (cuplumps). The dry rubber from each block was collected by their respective managements, weighed and the annual yields recorded in kilogram per hectare (kg/ha).

*Methodology for the construction of the boundary line and the determination of the optimum nutrient values and ranges*

The leaf and soil nutrient data were used for the establishment of the boundary lines and the determination of the optimum nutrient values and ranges. The boundary line was established following the steps below:

- The first step consisted of plotting rubber yield data versus nutrient concentration (scatter plot), analyzing the distribution pattern, followed by identification and elimination of outliers;
- The second step involved the selection of points located on the upper limit of the scatter diagram and which appeared to be more or less equidistant to the x-axis (Schmidt et al., 2000);
- The third step consisted of fitting a second degree polynomial function ($Y = ax^2 + bx + c$) to the selected points while recording the equation determination coefficient ($R^2$ value).

The optimum nutrient concentration was obtained by calculating the value corresponding to a slope of zero for the second degree polynomial regression (Saichai et al., 2012). That is the derivative of the polynomial equation (2ax + b = 0). The optimum nutrient range was obtained by solving the derivative of the second-degree polynomial regression for the nutrient concentrations corresponding to 95% of relative yield.

## Results

*Physico-chemical properties of the soils in the study site*

The physico-chemical properties of the soils of the study sites are presented in Tab. 1. The soils were all acidic with a pH less than 6. The mean soil organic carbon was 1.77%, and the mean N-concentration in the studied soils was 0.16%. The soils ranged from 2 to 69 mg/kg in P and from 220 to 1753 mg/kg in K. The average values of soil Ca and Mg were 417and 39 mg/kg, respectively.

**Tab. 1. Descriptive statistics of soil parameters of Cameroon *Hevea brasiliensis* plantations sampled**

| Parameter | Mean | Min | Max | Std Dev |
|---|---|---|---|---|
| Total C (%) | 3.05 | 0.96 | 14.05 | 1.62 |
| Organic C (%) | 1.77 | 0.56 | 8.15 | 0.94 |
| Total N (%) | 0.16 | 0.05 | 0.85 | 0.09 |
| Ca (mg/kg) | 417 | 34 | 3144 | 588 |
| K (mg/kg) | 220 | 93 | 1753 | 164 |
| Mg (mg/kg) | 39 | 7 | 616 | 65 |
| P (mg/kg) | 8.8 | 2.0 | 69 | 11 |
| pH | 4.3 | 3.7 | 5.7 | 0.5 |

Min = Minimum, Max = Maximum, Std Dev = Standard deviation from the mean

*Scatter plots and boundary line equations for soil nutrients*

The scatter plots and the boundary line equations relating soil data to *Hevea brasiliensis* yields as well as the corresponding $R^2$ values are presented in Fig. 2a–c. Most data points are clustered around low soil parameter values with few cases being very high. In the case where very high values were obtained, they were considered as outliers and therefore eliminated. Data for Mg are clustered along a very narrow range showing that the Mg content of the sampled sites did not vary much.

The equation representing the boundary line was drawn using at least ten data points (Fig. 2a–c). All the boundary line equations were second degree polynomials. The coefficient of determination ($R^2$) values for most of the representative equations was high with minimum being 0.5 for soil K relationship with yield and the maximum being 0.9 obtained for the equation relating soil Ca content to *Hevea brasiliensis* yields.

*Optimum soil nutrient concentrations and ranges*

The optimum nutrient concentrations obtained by equating the second degree polynomial equation of the boundary line to zero are summarized in Tab. 2 below. The optimum nutrient values were 3.1%, 0.18%, 5.9 mg/kg, 262 mg/kg, 432 mg/kg and 16 mg/kg respectively for organic carbon, N, P, K, Mg and Ca, respectively. The optimum yield values for the various nutrient elements were found to be very close to each other (Tab. 2). The lowest optimum yield was 1,815 kg/ha associated with soil Ca content.

*Scatter plots and boundary line equations for leaf nutrients*

The scatter plots and the boundary line equations relating plant data to *Hevea brasiliensis* yields are presented in Fig. 3a–c together with the corresponding $R^2$ values. A scatter plot shows the spatial distribution of the whole data set so that the points for the construction of the boundary line can be chosen. The leaf N ranged from 2.6–4.6%, P (1504–4521 ppm), K (6194–21187 ppm), Ca (2152–16386 ppm) and Mg (1341–6050 ppm). At least ten points were used to represent the boundary line and to generate the equation (Fig. 3a–c). The coefficient of determination ($R^2$) values for most of the representative equations was very high. The minimum value was 0.7 relating leaf Ca concentration to yield and maximum was 0.91 relating leaf Mg concentrations to relative yields.

**Tab. 2. Optimum nutrient values and ranges for *Hevea brasiliensis* soils**

| Nutrient | Optimum nutrient value | Optimum relative yield (%) | Optimum yield (kg/ha) | Optimum nutrient range (95% of maximum yield) |
|---|---|---|---|---|
| Organic C (%) | 3.1 | 149 | 2096 | 2.9 – 3.2 |
| N (%) | 0.18 | 147 | 2068 | 0.17 – 0.19 |
| P (mg/kg) | 5.9 | 161 | 2265 | 5.6 – 6.2 |
| K (mg/kg) | 262 | 157 | 2209 | 248.9 – 275.1 |
| Ca (mg/kg) | 432 | 129 | 1815 | 410.4 – 453.6 |
| Mg (mg/kg) | 15.8 | 136 | 1914 | 14 – 16.5 |

Originalarbeit

379

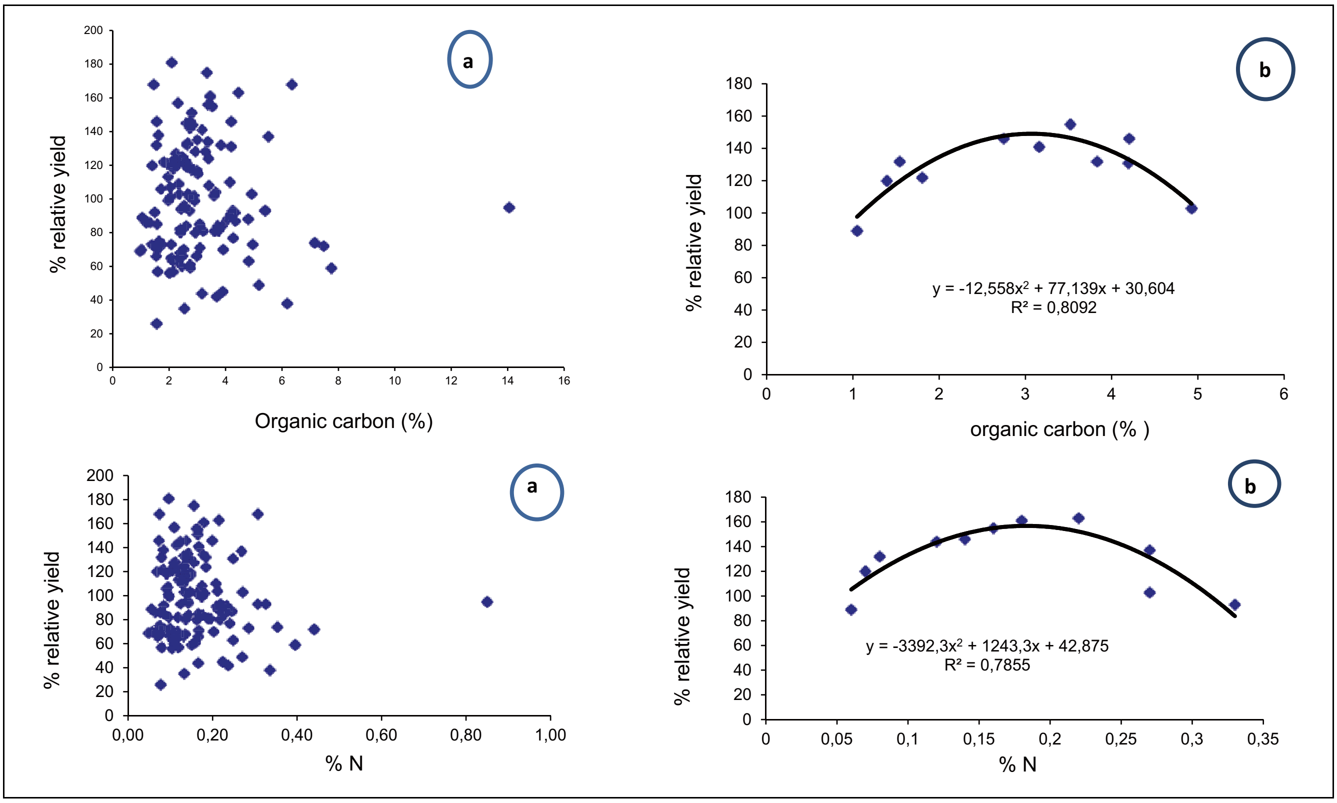


**Fig. 2a.** Scattered diagrams (a) and boundary lines (b) for *Hevea brasiliensis* yields vs soil nutrient (organic C and N) concentrations.

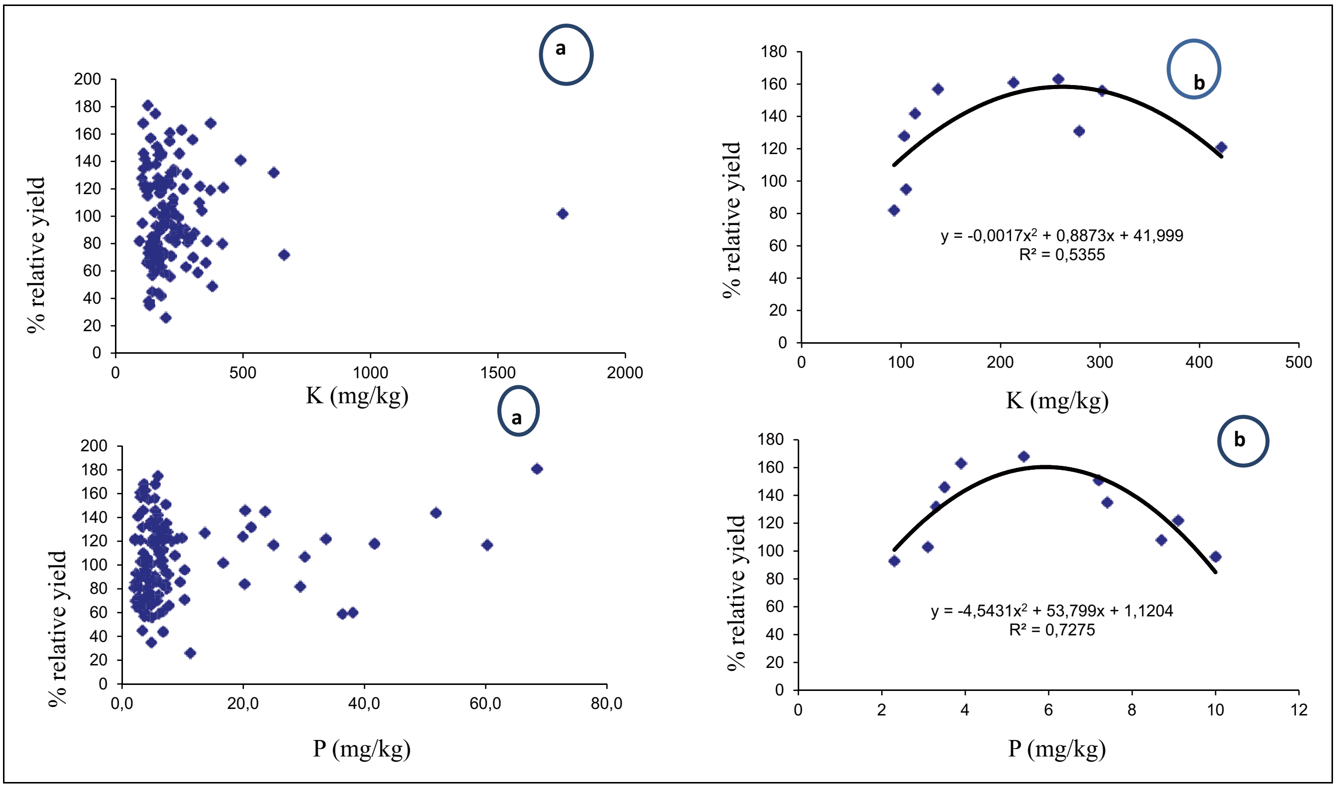


**Fig. 2b.** Scattered diagrams (a) and boundary lines (b) for *Hevea brasiliensis* yields vs soil nutrient (K and P) concentrations.

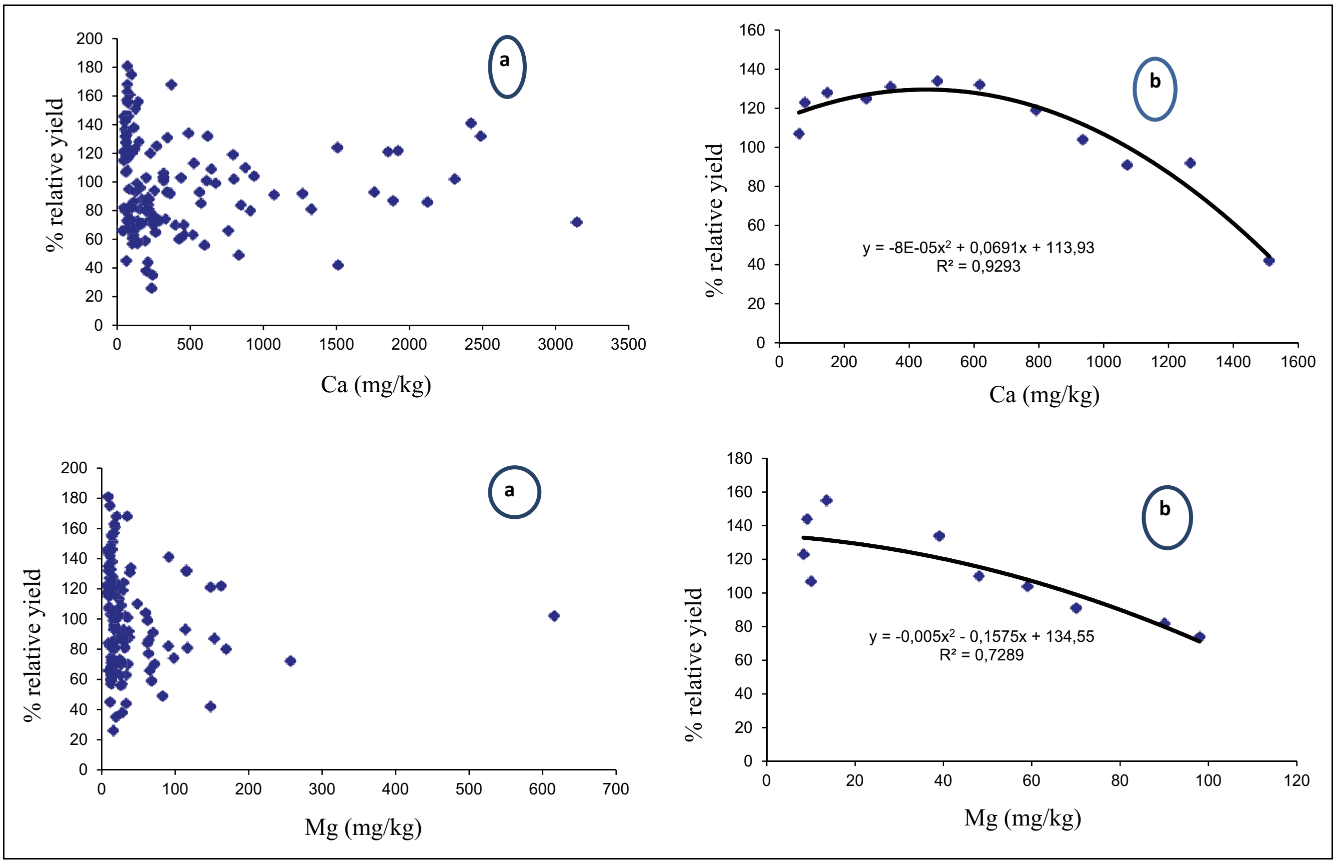


**Fig. 2c.** Scattered diagrams (a) and boundary lines (b) for *Hevea brasiliensis* yields vs soil nutrient (Ca and Mg) concentrations.

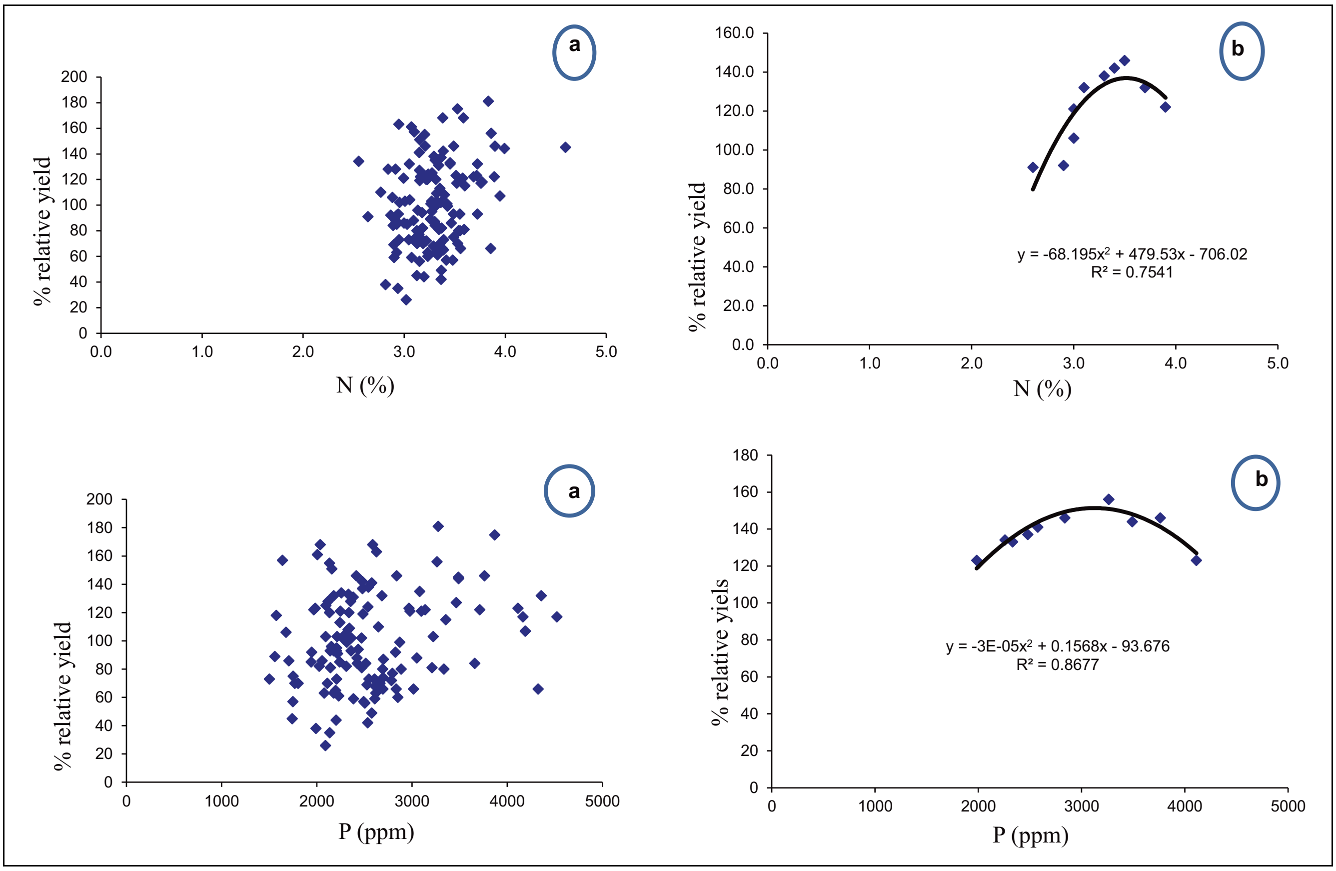


**Fig. 3a.** Scattered diagrams (a) and boundary lines (b) for *Hevea brasiliensis* yields vs leaf nutrient (N and P) concentrations.

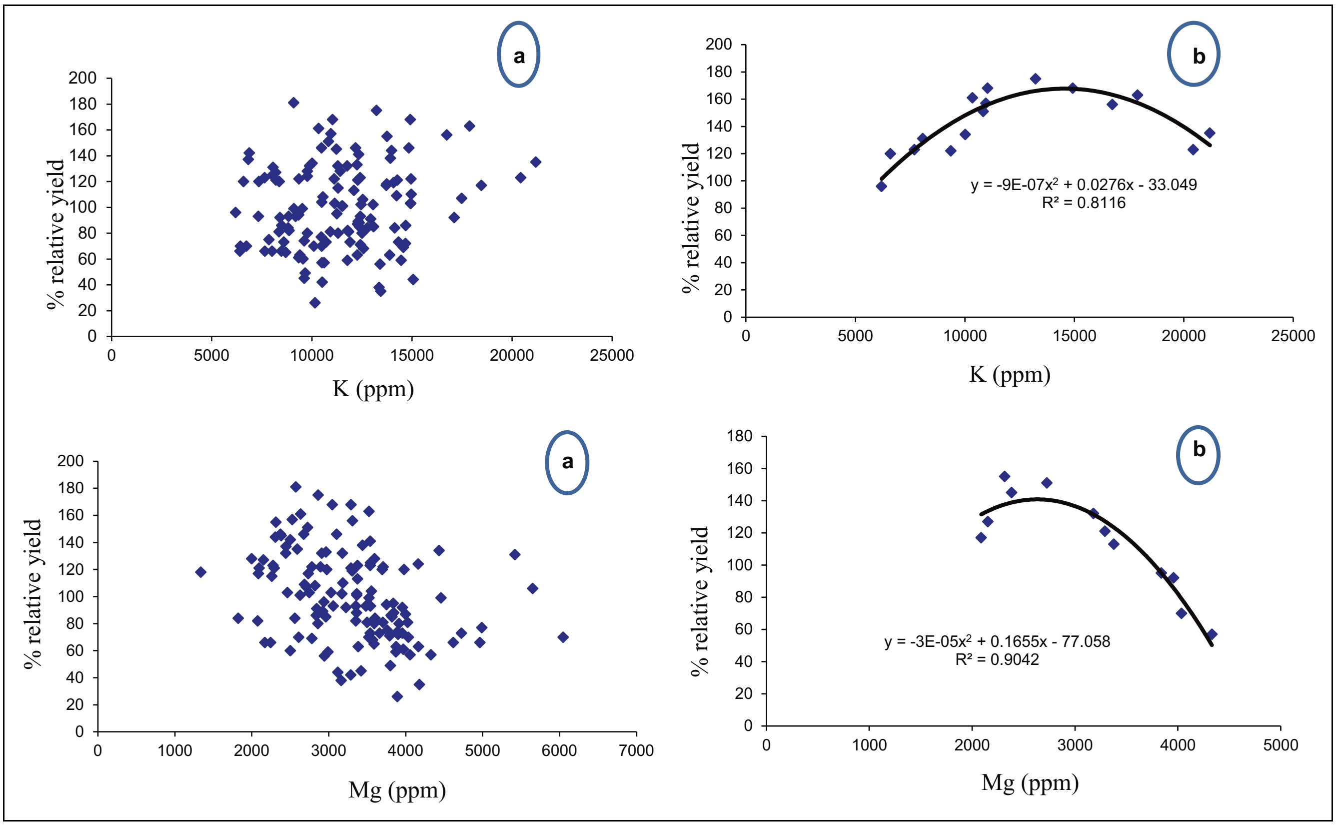


**Fig. 3b.** Scattered diagrams (a) and boundary lines (b) for *Hevea brasiliensis* yields vs leaf nutrient (K and Mg) concentrations.

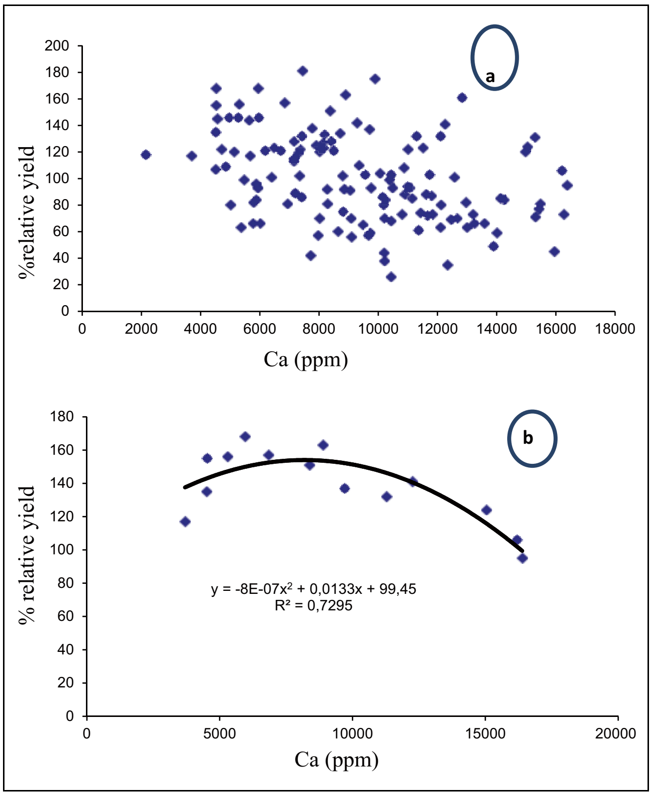


**Fig. 3c.** Scattered diagrams (a) and boundary lines (b) for *Hevea brasiliensis* yields vs leaf nutrient (Ca) concentrations.

*Optimum leaf nutrient concentrations and ranges*

The optimum nutrient concentrations obtained by equating the second degree polynomial equation of the boundary line to zero are summarized in Tab. 3 below. The optimum yield ranged between 2,035 and 2,126 kg/ha. This value is obtained with optimum nutrient concentrations of 3.5% N, 0.3% P, 1.5% K, 0.28% Mg and 0.83% Ca. The results for the optimum range calculated using the boundary line equation at 95% optimum relative yield are also presented in Tab. 3.

## Discussion

The main objective of this study was to establish the critical nutrient levels for *Hevea brasiliensis* plantations. This was done through establishing soil and leaf nutrient critical values. Though the soils of the study area were acidic, they were within the suitable range for rubber without any need for liming (Ugwa et al., 2006). The mean organic carbon about 2% under *Hevea brasiliensis* was high (George and Jacob, 2000). As mature *Hevea brasiliensis* usually sheds it leaves once a year, their accumulation over time could account for the high soil organic carbon (Njar et al., 2011). The plant available soil P and Mg ranged between deficient and excess levels while soil K content was in excess (George and Jacob, 2000).

Most soil data points clustered around low soil parameter values with few cases being very high. In the case

**Tab. 3. Optimum nutrient values and ranges for *Hevea brasiliensis* leaf**

| Nutrient Element | Optimum nutrient value | Optimum relative yield (%) | Optimum yield (kg/ha) | Optimum nutrient range (95% of maximum yield) |
|---|---|---|---|---|
| N (%) | 3.5 | 144.6 | 2035 | 3.33 – 3.68 |
| Ca (%) | 0.83 | 154.7 | 2177 | 0.79 – 0.87 |
| K (%) | 1.53 | 178.6 | 2513 | 1.46 – 1.61 |
| Mg (%) | 0.28 | 151 | 2126 | 0.26 – 0.29 |
| P (%) | 0.31 | 150.5 | 2178 | 0.29 – 0.32 |

where very high values were obtained, they were considered as outliers and therefore eliminated. Data for Mg clustered along a very narrow range suggesting that there were very slight variations in Mg levels in the fields sampled. The optimum range for organic carbon and soil K at 1–2.6% and 40–80 mg/kg, respectively, are higher than those suggested by SAICHAI et al. (2012). However, the variation in soil optimum values could be due to variation in the methods of determination because soil nutrient parameters vary with the method of analysis (LANDON, 1984). Thus soil nutrient data can only be directly compared if obtained by similar methods. The lowest optimum yield associated with soil Ca level was very close to the average yields obtained in Thailand (SAICHAI et al., 2012).

Coupled soil and tissue testing provides a more complete determination of nutrient levels affecting yield and performance of the plant than soil or plant analysis alone (CARDON et al., 2009). This is because there may be instances where the plant uptake of nutrient shows inadequate levels while the uptake of a particular soil nutrient may be inhibited by the lack of another limiting element. The optimum nutrient range is preferred to the critical value because a hidden deficiency at concentrations below the critical deficient level as well as an indication of excess concentration beyond the upper critical value can be more easily identified (CAMPBELL and PLANK, 2000).

The results of the present study clearly suggest that the boundary line approach is useful for the establishment of nutrient norms for *Hevea brasiliensis* as this method derived highly significant ($R^2 > 0.7$) second degree polynomial response curves and quadratic equations. When the $R^2$ value is low, it can be improved by increasing intervals (VIZCAIN-SOTO and COTE, 2004) for the boundary line equation. Thus, the high $R^2$ value obtained shows that the intervals were adequate.

The optimum leaf nutrient values were compared with literature values and are presented in Tab. 4 below. Most of the nutrient ranges differed in the different studies. The optimum range of N and Ca in *Hevea* leaf obtained in this study fell within the optimum range presented by THIAGALINGAM (2000). On the other hand, the lowest and highest optimum values for N in this study were higher than the optimum range of values obtained by GEORGE and JACOB (2000) who studied *Hevea* nutrition in India. The lowest and the highest optimum K nutrient levels obtained in this study were higher than what was obtained by GEORGE and JACOB (2000) and THIAGALINGAM (2000)

**Tab. 4. A comparison of obtained optimum nutrient range with literature values**

| Nutrient Element | Optimum nutrient value | Obtained optimum nutrient range (95% of maximum yield) | Literature optimum value or range | Reference |
|---|---|---|---|---|
| N (%) | 3.5 | 3.33 – 3.68 | 3 – 3.5 | GEORGE and JACOB, 2000 |
| | | | 3.31 – 3.90 | THIAGALINGAM, 2000 |
| Ca (%) | 0.83 | 0.79 – 0.87 | 0.6 – 1.00 | THIAGALINGAM, 2000 |
| | | | 1.0 – 1.50 | GEORGE and JACOB, 2000 |
| K (%) | 1.53 | 1.46 –1.61 | 1.21 – 1.36 | THIAGALINGAM, 2000 |
| Mg (%) | 0.28 | 0.26 – 0.29 | 0.20 – 0.25 | GEORGE and JACOB, 2000 |
| | | | 0.18 – 0.20 | THIAGALINGAM, 2000 |
| P (%) | 0.31 | 0.29 – 0.32 | 0.20 – 0.25 | GEORGE and JACOB, 2000 |
| | | | 0.17 – 0.19 | THIAGALINGAM, 2000 |

who compiled data on *Hevea* nutrient needs in Malaysia. This shows that the K needs for the plants investigated in this study were higher than for those of the previous studies. The optimum Mg and P nutrient ranges obtained in this study were higher than the ranges obtained by George and Jacob (2000) and Thiagalingam (2000).

The variation in optimum nutrient ranges in different countries could be attributed to the variation in soils, climate and the clones studied. This confirms the idea of Elwali et al. (1985) that standard norms should be locally derived or calibrated for optimum benefit. Some of the nutrient ranges obtained in this study were within those obtained in literature. This shows that the quadratic polynomial equations as mathematical models for fitting the boundary line can be used to establish the standard values. It further suggests that the results of optimum nutrient ranges and values obtained in this study are reliable. The results of this study will help in the assessment of fertilizer needs in rubber plantations in Cameroon by comparing obtained nutrient levels to critical levels established in this study. This is usually described as the critical value method (Lteif et al., 2008). Where the obtained nutrient levels are lower than the established optimum values, the fields will be diagnosed deficient and when the obtained values are higher than the established nutrient norms the fields will be diagnosed to be in excess of the particular nutrient. In that case no fertilizer application will be necessary but toxicity signs could be verified. On the other hand, fields are diagnosed to have adequate nutrient levels if the obtained levels are within the established optimum range. In this case no fertilization will be recommended. Because of the localized fertilizer application in the sampled fields, collection of typical representative soil samples in rubber plantations was difficult. Thus, it is suggested to use leaf nutrients for the assessment of tree nutritional status and fertilizer requirements, while soil nutrients serve as a reference indicator.

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**Abbreviations:** CDC – Cameroon Development Cooperation, SAFACAM – Sociètè Forestiere Agricole du Cameroon

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