SOIL MAPPING PROJECT
FINAL REPORT

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Executive Summary / Foreword:

Mapping soil fertility in Côte d'Ivoire

In Côte d'Ivoire, after more than 50 years of cocoa (*Theobroma cacao*) cultivation, soil fertility has declined. As a result, cocoa plantations now have a lower productivity. To mitigate this declining soil fertility and encourage cocoa productivity, farmers must use organic and mineral fertilizer according to best fertilization practices: which require in-depth knowledge of soil composition.

Many producers do not typically apply fertilizer. It is often the case that cocoa has been cultivated on historically fertile forest soils to which, for a long time, fertilizer application was unnecessary. And cocoa farmers generally have a widespread reluctance to invest in fertilizer due to high costs and associated risk. However, the decline in fertility of cultivated soils requires farmers to change their behavior.

A good fertilization program must consider both the plant and the soil. Each plant species has its own nutritional requirements and its own way of taking up nutrients from the soil. For example, some plants thrive in calcium-rich soils, while others don't. The soil is the nutritional counterpart to the plant, and it can supply only what it contains; different soils contain different nutrients. The soil nutrient levels depend on several factors, among which are the geology (relating to the "parent rock" or "parent material"—the baseline geological material from which soil is formed, and by which soil chemistry is influenced), environment, climate, soil development, farming practices, associated crops, etc.

The Cocoa Fertilizer Initiative is a public-private consortium that aims to return soil fertility to key cocoa-growing regions in Côte d'Ivoire: thereby ensuring the long-term viability of Côte d'Ivoire's cocoa industry. Launched in Abidjan on November 21, 2012, the Initiative's partners include the cocoa industry, fertilizer industry, cocoa traders, civil society organizations, and government. These partners provide the Initiative with the knowledge, resources, infrastructure, and networks that allow it to support cocoa farmers in developing healthy yields and following agricultural practices that will allow the longevity of their farms.

To help the Ivorian farmers in the most effective way, the Initiative's members commissioned a soil map of the country's cocoa growing regions. The current fertilizer recommendations for cocoa in Côte d'Ivoire date from the 1970s and are based on soil maps from that period. Yet there have been significant changes in the Ivorian cocoa landscape, in terms of the location of the farms and their age. An updated soil map will allow the sector to give farmers precise guidance on the fertilizers necessary to improve their soils—and achieve greater productivity in their cocoa harvests. The map will be a fundamental building block of the sector's efforts to assist farmers in increasing their harvests, generating more income, and ensuring the long-term viability of their farms. To produce the new map, the Initiative commissioned the Ivorian National Agronomic Research Center (CNRA).

CNRA took soil samples from different cocoa growing regions of Côte d'Ivoire. Each sample was tagged with GPS information that indicated the precise location where it was removed. The samples were analyzed for their physical, chemical, and organic compositions. CNRA then assembled existing information and the newly gathered data into maps that show which areas would benefit from the addition of specific nutrients.

As part of the Initiative's efforts to support Ivorian cocoa farmers, other key actions include:

- Bringing cocoa fertilizer to farm level using the existing value chains and delivery mechanisms in the cocoa and fertilizer industry.
- Making fertilizer financially accessible to cocoa farmers, thus stimulating competition and economies of scale.
- Ensuring proper training and guidance for fertilizer use at farm level.
- Promoting shared knowledge, such as studies on yield response, the farmer business case, and farmers' readiness for fertilizer uptake.
- Engaging the Ivorian government through the administration's national cocoa platform.

Each organization involved with the Initiative has helped to implement these different goals. By helping farmers improve harvests on their existing farms, the Initiative has had an impact on limiting farm expansion and deforestation. It has also enabled the farmers involved to improve their livelihoods by helping them see how cocoa farming can be a profitable and sustainable business.

This report outlines the methodology and results of the new soil map.

1. Project Overview

1.1. Objectives

The general objective of this research project was to produce an up-to-date map showing the soil fertility status in Côte d'Ivoire's cocoa growing regions. This updated map can serve as a basis for the development of adapted cocoa fertilizer formulas.

1.2. Growing regions for this study

Côte d'Ivoire's cocoa growing regions are located in the southern part of the country, in 13 administrative districts (See page 8, figure 1). The climate is tropical, characterized by small temperature amplitudes (26–30 °C), and high humidity (80–90%). There are two rainy seasons, from March to July and September to October. The rainfall has a mean annual range of 1200–2000 mm.

1.3. Brief review of methodology used to build the map

Using the geologic and pedologic maps of Côte d'Ivoire, the CNRA team first created a "base map" of the cocoa growing areas. To correlate the base map to soil nutrient parameters, the researchers took soil samples from a large variety of cocoa plots located within selected "land units." These land units represent areas that have the same climate, the same type of soil, and the same geological substratum. For the entirety of the cocoa growing zones, CNRA took 575 soil samples and 480 cocoa-leaf samples from different regions. Then, the researchers conducted analyses to assess the current physical, chemical, and organic properties of the soil. To do this analysis, CNRA used the "Soil Diagnostic Method."[1]

Once the analysis was complete, CNRA overlaid the data from the soil diagnosis onto the base map. Since the researchers had established that specific land units had the same soil properties, they were able to generalize the results of the limited number of sampled data points to the whole set of cocoa growing land units. Through this process, CNRA created a soil map that presents a geospatial inventory of soil fertility.

[1] Described for Côte d'Ivoire and recently used in Ghana by Snoeck et al (2010)

2. Activities

2.1. Overview

This section explains how CNRA gathered data and then assembled it into a map that shows the recommended fertilizer application for different areas. First, the organization created a map that integrated information about soil and climate. Regions that had similar traits of soil, temperature, and rainfall were assembled together into “land units.” Next, researchers took soil samples from 575 different cocoa growing sites throughout Côte d’Ivoire, and then analyzed those samples for their physical, chemical, and organic properties. Once the analysis was complete, CNRA developed a coding system that indicated the fertilization method necessary for specific land units. That information was integrated into the map, creating a comprehensive soil map of Côte d’Ivoire’s cocoa growing regions.

2.2. Materials and methods

Creation of the base map

CNRA obtained the pedological and geological maps in the form of geolocalized image maps (raster) produced by the cartography service of the France-based Institute for Development Research (IRD). The CNRA team then vectorized the maps using QGIS (Qgis.org), an open source geographic information system. Using the QGIS software, CNRA outlined each pedological unit and integrated it with data gathered from the areas. In the same way, the climatic maps were vectorized so the different climate regions could be outlined, and the maps could convey information about the temperature and pluviometry of those regions.

The regions having a similar climate (temperature and pluviometry) and identical soil properties were collected together into an individual “land unit,” a zone where the soil properties and climate remain consistent. CNRA ultimately identified a total of 132 land units, and the research team created the cocoa thematic map from the combination of the individual areas.

Collecting soil samples

To establish the nutrient requirements for each land unit, the CNRA researchers needed to know the condition of the soil there. With that in mind, the team collected soil samples from cocoa plantations located in different land units throughout the cocoa producing regions. In each cocoa plantation, the researchers gathered 30 elementary samples; they used those to generate a composite sample. The selected plots were geolocalized using GPS, and the points were placed on the base map. Considering the number and size of land units, CNRA determined that a total of 575 points were required to cover the full cocoa growing region.

Analysis of soil samples

To establish the nutritional needs for the cocoa trees in specific land units, the researchers discarded oversaturated soil samples. In addition, they did not include samples from areas where farmers had recently used fertilizer or other materials that could affect the diagnosis (e.g., if they had applied chicken manure).

The soil samples were analyzed to assess their macronutrient and micronutrient requirements. CNRA determined these requirements based on their interpretation of the soil's physical and chemical characteristics.

In addition, for each sampled cocoa plot, the CNRA team recorded additional agronomic parameters to help understand the chemical results. Those factors included the associated trees (to assess possible competition for the cocoa trees), litter height, planting density, the cocoa trees' ages, and the farmer's estimate of the cocoa yield.

Creation of the nutrient requirement maps

CNRA used the analysis of the soils' physical and chemical characteristics to determine the amounts of nutrients currently available. The team then computed the nutrient requirements—by determining the soil's nutrient content and ratios—to bring the current soil levels to those that are most beneficial for the cocoa trees. For this computation, the researchers used the Soil Diagnostic Method developed by Jadin et al (1985).

3. Main Results of Soil Mapping

3.1. Overview

This section summarizes the CNRA findings relating to the types of soils in different cocoa growing regions of Côte d'Ivoire, the overall assessment of the nutrient levels in the soils, and specific recommendations—given for each nutrient—to improve the soil quality and cocoa harvests.

3.2. Description of the main climatic zones

The most favorable zones for cocoa cultivation were identified based on the two main parameters of the climate: temperature and pluviometry. The regions are mapped in Figure 1.

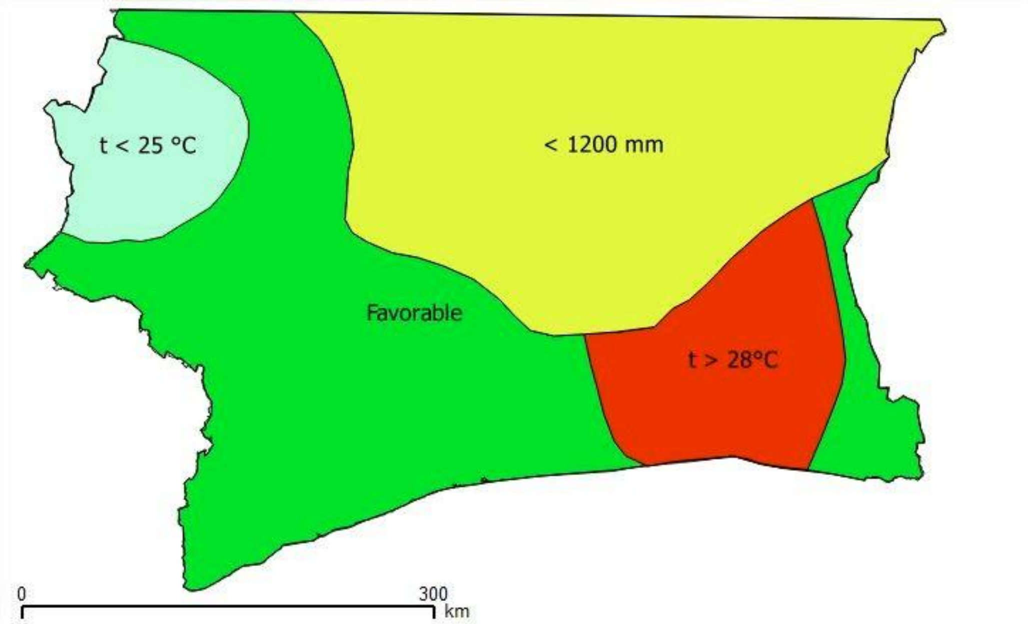

Figure 1: Map showing the favorable climatic zones for cocoa production.

The most favorable zone is generally in the southern part of Côte d'Ivoire, though there is a section in the south where the temperature is higher than 28 °C, which is unfavorable for cocoa cultivation. There is a section in the western part of the country that is not favorable due to an average temperature lower than 25 °C. And the zone in the north appears to be too dry, with a yearly rainfall less than 1200 mm. Notwithstanding these limitations, the cocoa growing zones stretch outside of the optimal zone and encroach on the drier zone, thus covering the whole south of the country.

The climatic and soil maps were combined to build the land units map (Figure 2).

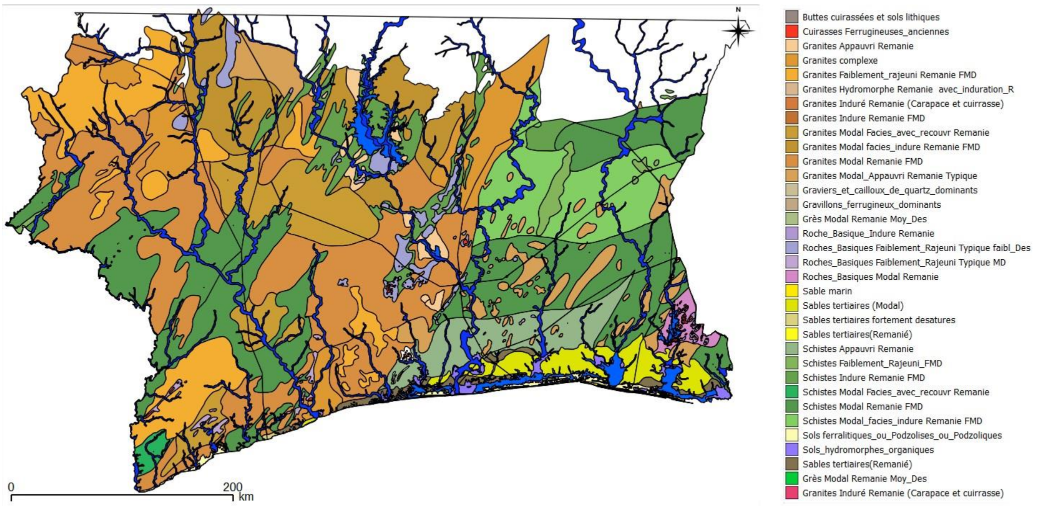

Figure 2: Map showing the land units resulting from the pedogenetic and climatic combination.

The units are colored according to the pedogenetic (soil type) units (Figure 2, legend, and Table 1). A colored unit can be divided into sub-units due to the intersection with the climatic parameters. Finally, the support map contains 128 land units.

The results shows that approximately 72% of the cocoa trees grown in Côte d'Ivoire are cultivated on six major soil types[2] that belong to two geological origins: granite and schist. The following six soil types represent the areas above 6% of land use in the cocoa belt:

Granites slightly rejuvenated, altered
Granites modal with overlaped facies, altered
Granites modal with hardened facies, altered
Granites modal, altered
Schist modal with hardened facies, altered
Schist modal, altered

3.3. Main results of the soil diagnosis

Macronutrients

CNRA used the analysis of the soils' physical and chemical characteristics to determine the amounts of nutrients currently available. The team then computed the nutrient requirements—by determining the soil's nutrient content and ratios—to bring the current soil levels to those that are most beneficial for the cocoa trees. For this computation, the researchers used the Soil Diagnostic Method[3] developed by Jadin et al (1985).

[2] According to the French classification (CPCS, 1967)

[3] Koko et al, (2011) in Agronomie Africaine 23 (3) : 217 – 225 & Presentation by CIRAD

Concerning only the macronutrient thresholds required for better cocoa growing, we observed that:

82% of the soils are poor in nitrogen
57% of the soils are poor in organic carbon
81% of the soils are low in phosphorus
34% of the soils are low in potassium
61% of the soils are low in calcium
37% of the soils are low in magnesium

Because cocoa trees benefit from having a certain ratio of macronutrients in the soil, the team also needed to consider the balance between the nutrients—to determine the actual needs.

Nitrogen:

The ratio between the sum of exchangeable bases, which constitute the main positive ions in the soil, and nitrogen (Σ (exchangeable bases)/N) is the main indicator used to determine the nitrogen requirement. The distance of the various Σ (EB)/N points to the optimum line is shown in Figure 3.

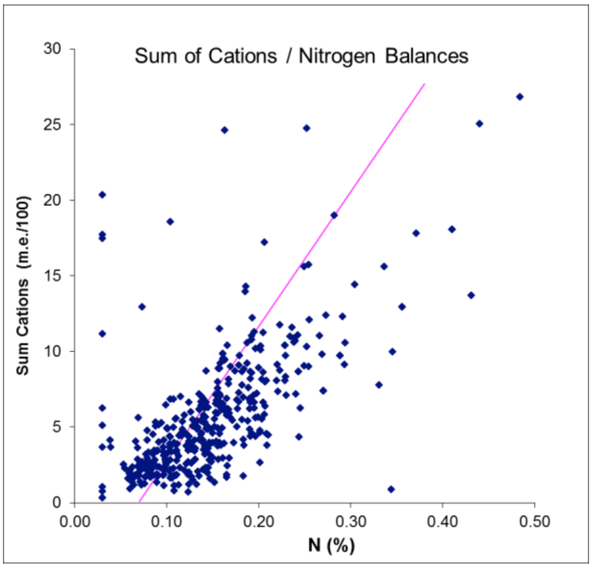

Figure 3: Balance between the exchangeable bases and nitrogen.

37% of the points are under the optimum and will likely respond to nitrogen fertilization. The points above the optimum must be fertilized with cations to approach the optimum line as indicated in Figure 3.

The results show that 23% of the soils will respond positively to nitrogen fertilizer.

The graph also shows that for most of the sampled points, except for 20 of them, quite low doses of nitrogen will be enough to reach the optimum.

The land units that would respond, or wouldn't, to nitrogen are presented in Figure 4.

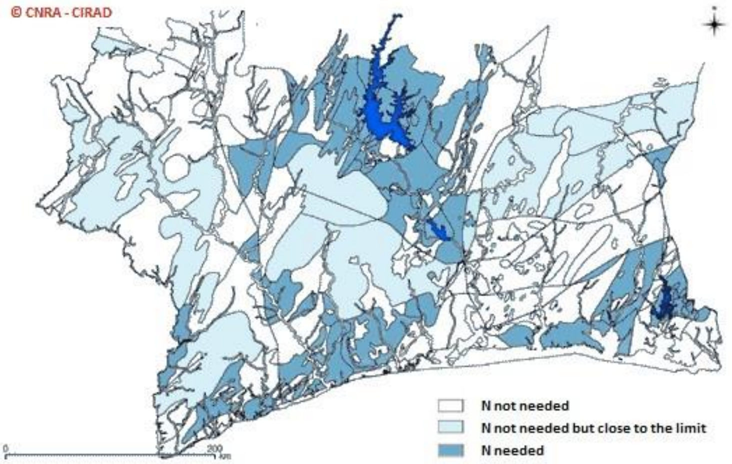

Figure 4: Map of the zones responding to nitrogen fertilization (dark blue) or not (light blue and white).

The figure shows that the cocoa plots on tertiary sands and granite require less nitrogen than the plots on schist.

The map shows nitrogen requirements in the east and in the area extending down in a V-like shape. These are logical, because the plantations are old in these regions. Similarly, in the southwest and south, the nitrogen requirement is linked to the fact that the soils are strongly leached in these areas (e.g., in Grand Béréby). Thus, it is important to favor the nitrate form of the nitrogen inputs.

Phosphorus:

The ratios of nitrogen and phosphorus as well as the ratio of the sum of exchangeable bases and phosphorus are used to determine the phosphorus requirements. The map of the land units responding to phosphorus is presented in Figure 5. The colors differentiate the level of phosphorus necessary.

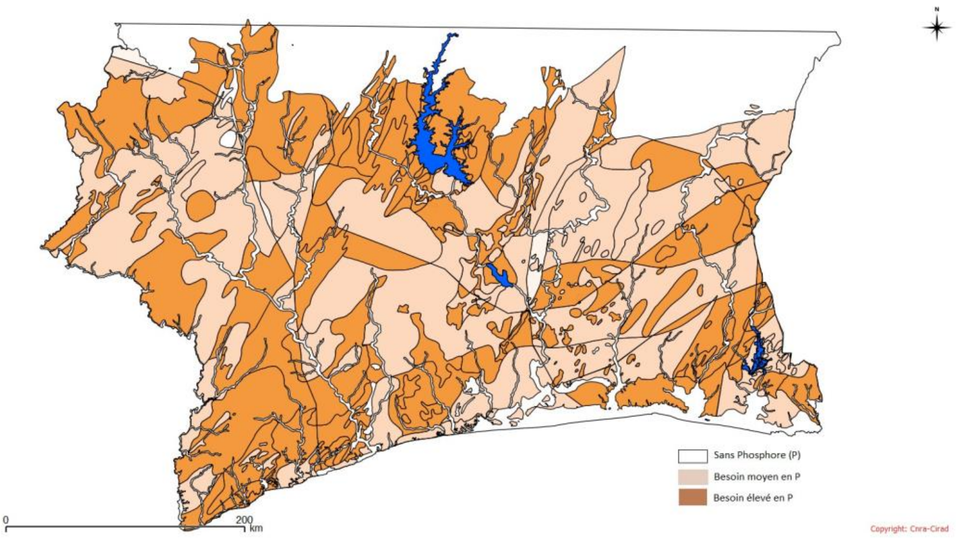

Figure 5: Map of the zones responding to phosphorus or not (white). Light orange indicates the need is low; in dark orange areas, the need is high.

The results show that 96% of the soils will respond to a phosphate-enriched fertilizer favorably.

Potassium, Calcium, Magnesium:

To determine the requirements of cations, the researchers considered both the thresholds and the balance between them. The determination of the threshold levels alone is not sufficient to determine what the soil needs and what corrections should be applied; it is essential to maintain an optimal balance between the bases (potassium, calcium, and magnesium) that are most favorable to cocoa. For each sampled point, CNRA compared the base ratios to the ideal balance (8:68:24) to determine the needs for potassium, calcium, and magnesium. These points are depicted in Figure 6.

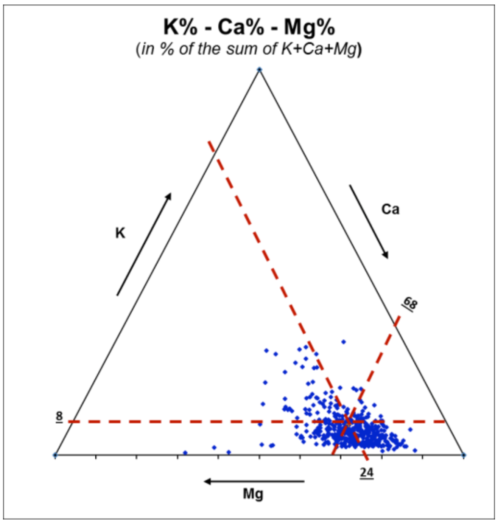

Figure 6: The Potassium:Calcium:Magnesium values of the sampled points as related to the optimal balance for cocoa cultivation.

The figure shows that 68% of the sampled soils have a balanced K:Ca:Mg ratio, which could easily be corrected with adapted fertilization.

The observation of saturation in exchangeable bases shows that approximately 11% of the soils have a base saturation lower than 40%. The location of the land units that would favorably respond to potassium, calcium, and magnesium—classified by the amounts needed—is presented in Figures 7, 8, and 9.

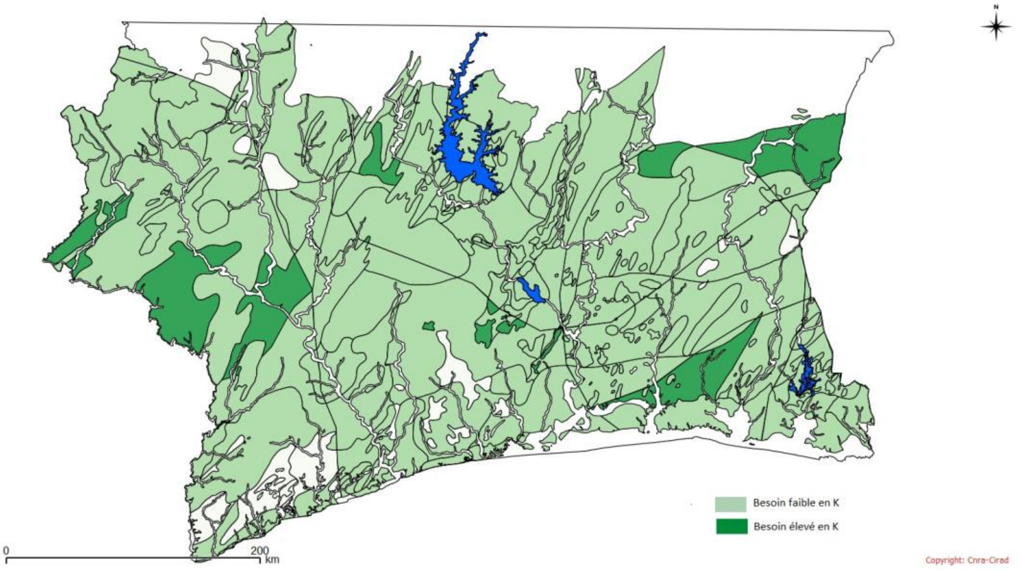

Figure 7: Map of the zones responding to potassium. The light green color indicates the need is low; dark green indicates the need is high.

The results of the soil diagnosis show that 69% of the soils are deficient in potassium.

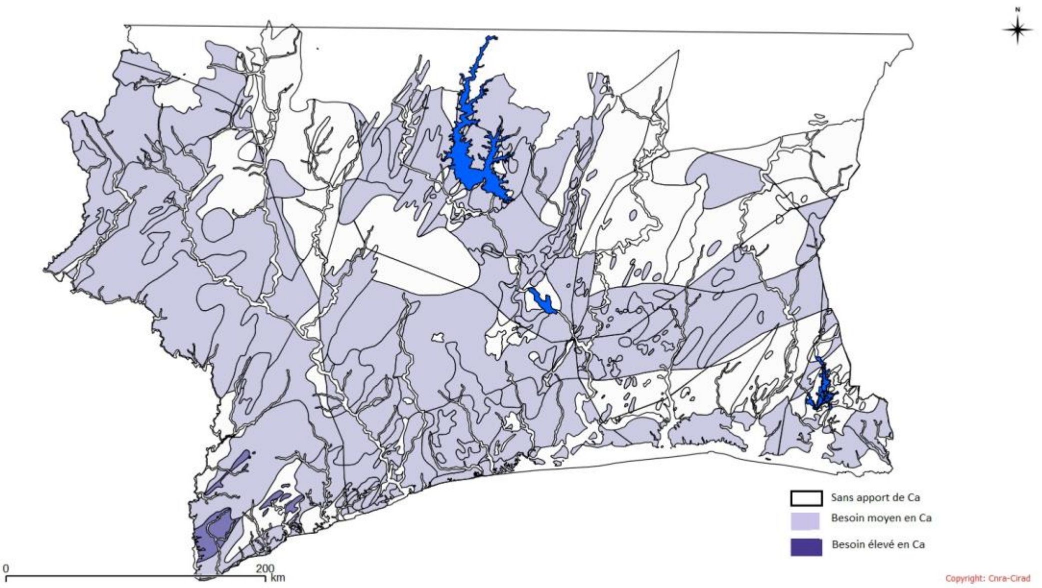

Figure 8: Map of the zones responding to calcium (blue) or not (white). Light blue indicates the need is low; dark blue indicates the need is high.

The results of the soil diagnosis show that 46% of soils are deficient in calcium.

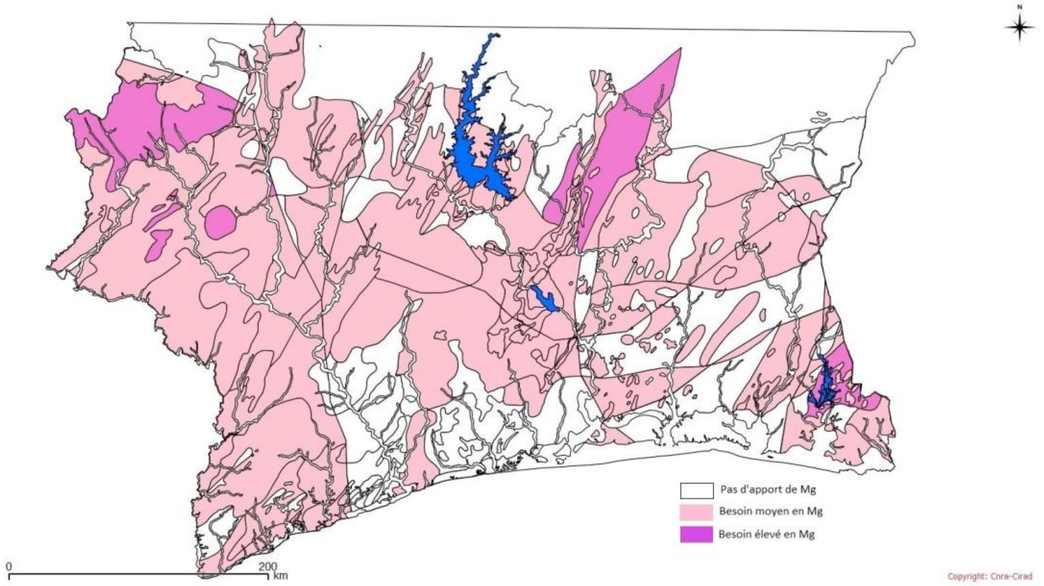

Figure 9: Map of the zones responding to magnesium (pink) or not (white). Light pink indicates the need is low; in dark pink areas, the need is high.

The results of the soil diagnosis show that 55% of the soils are deficient in magnesium.

Micronutrients

Regarding the micronutrients, we found that:

11.3% of the sampled soils were deficient in boron
1.4% in manganese
2.6% in copper
4.0% in zinc
0.0% showed iron deficiency

Figure 10 shows the land units in which we found boron deficiencies.

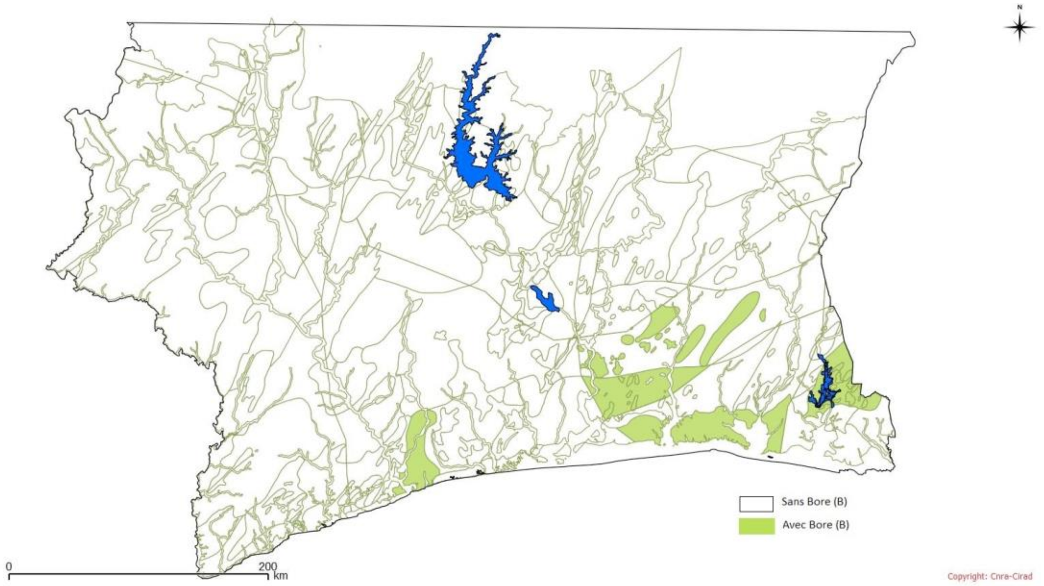

Figure 10: Map of the zones presenting possible boron deficiencies (green) or not (white).

For a better understanding of the soil conditions, CNRA also considered the soil acidity, as shown in Figure 11. This shows that about 22.7% has a pH of lower than 5.5 and as such are too acidic for cocoa.

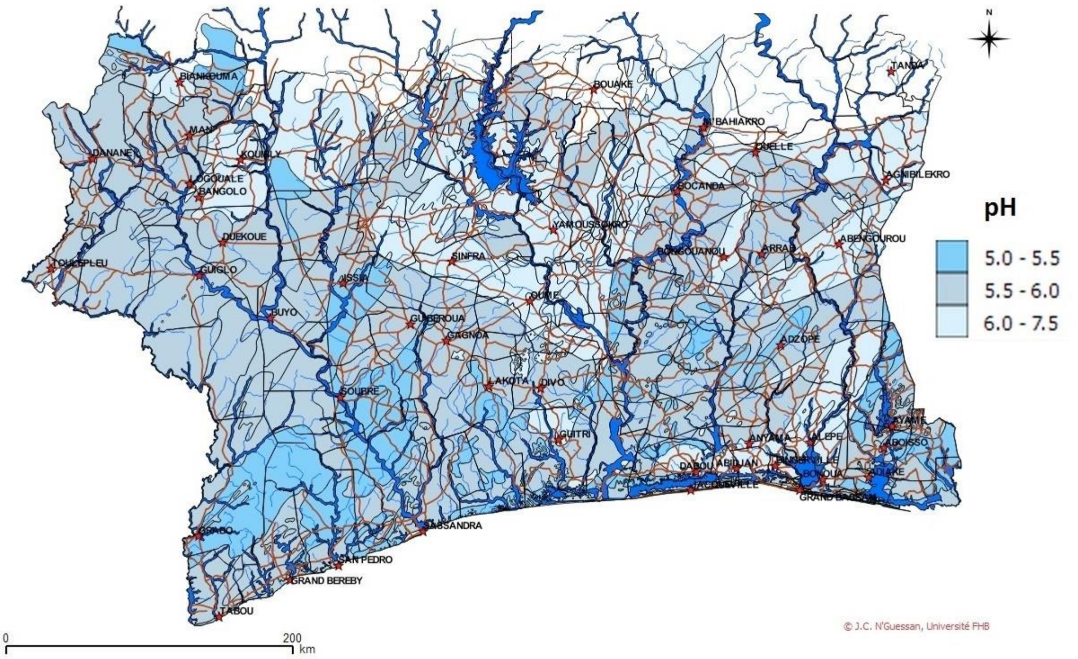

Figure 11: Map showing the soil acidity (pH).

3.4. Discussion of these maps

These maps show that the nutrient requirements have evolved, and are not fully consistent with the current fertilizer recommendations dating back from the 1970s. CNRA also noted an evolution of the nutrient requirements compared to those recommended by P. Jadin in 1975 (Jadin, 1975). In particular, although CNRA used the same soil diagnosis method that was used in 1975, the previous diagnosis did not emphasize any nitrogen requirement. But the diagnosis of the 2015 samples showed that 23% of the samples require a nitrogenized fertilization. This result appears consistent with CNRA's observations, which show that more than 86% of the samples are deprived of nitrogen and also of organic matter. However, it is known that 90% of the nitrogen measured in the topsoil of a cocoa plantation come from the organic matter (Harteminck and Donald, 2005). This suggests that nitrogen would better be introduced to the soil through organic matter rather than mineral fertilizers.

The requirements for potassium, calcium, and magnesium have increased. This result is consistent with a generalized soil impoverishment because of the very rare use of fertilization during the last 30 years. This depressive effect had similarly been shown in previous soil research done in Ghana (Appiah, 1997; Afrifa, 2006).

On the other hand, the phosphorus requirements are rather similar as those observed in 1975 by Jadin, thus indicating that the needs of this nutrient remain constant.

4. Conclusion

The soil diagnosis commissioned by the Initiative and undertaken by CNRA provided a robust data set that gives insights to update the recommendations for how farmers can increase their cocoa harvests. The research generated actionable data about levels of macronutrients and micronutrients, and how to achieve the most beneficial balance between them.

The maps, numbers, and data sets compiled by CNRA have been vital to the sector's goals: to help farmers increase yields on their cocoa farms, implement practices that support the general well-being of their farms, and ensure the long-term viability of the cocoa industry in Cote d'Ivoire.

As the Conseil du Café-Cacao takes over the lead within its national cocoa platform, the groundwork laid by the Initiative will be of immense value in helping to convey updated recommendations to farmers. The partnerships and networks set up can help farmers gain access to resources, and the education that allows them to implement the necessary fertilization practices. Combined, these measures can help cocoa farmers thrive while also supplying a valued resource to businesses, food producers, and consumers all around the world.

4. References

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