

Nutritional Status of Soils Under Cassava Cultivation Using the Diagnosis and Recommendation System (DRIS) in the Savanna Zone of the Central African Republic

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Abstract

Cassava is an important crop that ensures food security for the population in the Central African Republic (CAR). It also significantly

contributes to improving farmers' incomes. Unfortunately, there is no specific data on soil nutrient status that would allow for informed management of the crop's nutritional condition and yield improvement, despite existing potential. The Diagnosis and Recommendation Integrated System (DRIS) is an approach used to interpret plant tissue analysis results and helps assess the nutritional status of crops. It focuses on comparing paired nutrient ratios and concentrations of nutrients in leaf tissues with norms developed from high-yielding crop populations. The objective of this study is to apply the DRIS model to determine the nutritional status of cassava cropping systems in the savanna forest zone of CAR. In total, 126 leaf samples were collected from cassava fields in the region. Nitrogen (N), Phosphorus (P), Potassium (K), Calcium (Ca), Magnesium (Mg), and Zinc (Zn) contents were analyzed. Root yields were also recorded. Significant differences ($p = 0.001$) were observed between the root yields of the low and high-yielding sub-populations. Based on the Nutritional Balance Index, nutrient requirements for cassava in this savanna zone were ranked as: $Ca > Mg > N > K > P > Zn$. The study recommends the implementation of Integrated Soil Fertility Management (ISFM) technologies in cassava cultivation systems in each zone, with emphasis on Nitrogen and Calcium supplementation.

Keywords: Food security, root crops, nutrient requirements, soil fertility management, use of secondary elements

Introduction

Optimizing agricultural productivity in the savanna zones of the Central African Republic (CAR) inevitably requires a deep understanding of pedological constraints, particularly nutrient deficiencies that limit crop yields (Agbangba et al., 2011; Bationo & Waswa, 2011). Mvondo et al. (2003) emphasized the importance of such knowledge for the development of targeted and effective fertilization recommendations. Nutritional diagnosis is an essential means of increasing both yield and quality of agricultural products through efficient fertilizer management (Mourão, 2004; Carneiro et al., 2015). Traditionally, fertilizer recommendations in agriculture are based on soil and plant analyses (Pacheco et al., 2010; McCray et al., 2013). However, the soil-based approach presents certain limitations, as soil samples may not accurately represent the portion of soil actually explored by plant roots, and there is some uncertainty in evaluating the nutrients truly available to plants (Coleman et al., 2003; Pacheco et al., 2010; Horneck et al., 2011). Moreover, critical nutrient concentrations in leaves have often been used to diagnose the nutritional causes of poor crop performance (Ramakrishna et al., 2009). The DRIS model (Diagnosis and

Recommendation Integrated System) is a method used to identify limiting nutrients in production, based on nutrient contents determined in leaf samples and high yields from the population on which the leaves were collected. DRIS is often less sensitive than the sufficiency range approach to differences caused by leaf position, tissue age, climate, soil conditions, and cultivar, as it uses nutrient ratios rather than absolute values (Sanchez et al., 1991). The DRIS approach was designed to provide valid diagnosis regardless of plant age, tissue origin (Sumner, 1977a; Meldal-Johnson & Sumner, 1980; Bailey, 1997; Jones, 1993; Sumner, 1977b), cultivar, local conditions (Payne et al., 1990), or changes in sampling methods or timing (Moreno et al., 1996). DRIS has been successfully used to interpret foliar analysis results for a wide range of crops, including annuals (Meldal-Johnson & Sumner, 1980; Elwali & Gascho, 1984; Mackay et al., 1987; Szücs et al., 1990; Singh et al., 2000; Ramakrishna et al., 2009; Dagbénonbakin et al., 2010) as well as perennials (Raj & Rao, 2006; Carneiro et al., 2015). The present study aims to develop DRIS norms for cassava cultivation using data on root yield and nutrient content in cassava leaf tissues in the savanna zones of the Central African Republic (CAR). This will help identify the nutrient status in cassava cropping systems in this region, taking into account the specific environmental conditions that influence plant nutrition (Lianderal et al., 2018; Bangroo et al., 2010). In CAR, cassava is the most important crop due to its contribution to food security and its widespread presence in local diets, making it the staple food (Mallouhin, 2002). Cassava alone accounts for 70% of food crop production in the country (MDRA, 2011). The national annual production of cassava roots is estimated at 2.6 million tons. Its leaves, an important source of dietary protein, are also a highly valued legume (Zinga et al., 2013). Beyond its food value, various parts of the plant are used in traditional medicine (Sinsin, 2013). Following the collapse of global coffee and cotton prices, the country's main cash crop, cassava, has become a major source of income and livelihood for the population (Kafara, 2003; Zinga et al., 2013). This crop is identified as a priority in the fight against hunger and poverty in the country's development policies (Roose et al., 1992; Pretty, 1997; DSRP2, 2011). Despite its importance, yields remain far below the potential of improved varieties, mainly due to declining soil fertility and climatic hazards (Chabi et al., 2019; Tittonell & Giller, 2013). Therefore, integrating nutritional diagnostics both at the soil and plant levels is crucial to address soil fertility challenges in the Central African Republic. Through a methodical and targeted approach, it is possible to increase agricultural yields and promote sustainable agriculture in the face of growing environmental challenges.

Materials and Methods

Study Area

The cassava leaf samples analyzed in this study were collected from various sub-prefectures within part of the pedoclimatic savanna zone of the Central African Republic. The Central African Republic (CAR) is characterized by a mosaic of pedoclimatic zones, among which savannas hold a predominant position. These ecosystems are strongly influenced by complex interactions among climatic, pedological, and ecological factors. Annual rainfall in the savanna zones ranges between 900 and 1600 mm, depending on geographic location. The northern savannas, typical of the Sahelian region, receive modest annual rainfall, between 900 and 1100 mm, whereas the more humid southern savannas often record values exceeding 1500 mm. The dominant soils in these regions are tropical ferruginous soils, generally reddish or brown in color, and known for their low organic matter content. Although limited in fertility, these soils are notably well adapted to savanna vegetation. Their texture is mainly sandy to sandy-loamy in the plains, while hilly areas are characterized by rocky soils. Chemically, these soils are slightly acidic to neutral, with a pH ranging between 5.5 and 7.0. Spatially, savannas cover a vast portion of the Central African territory, encompassing the central and northern regions primarily. They represent about 60% of the country's total land area, or nearly 380,000 km² out of a total of 623,000 km². These ecosystems thus constitute a major component of the landscape and ecological dynamics of the Central African Republic.

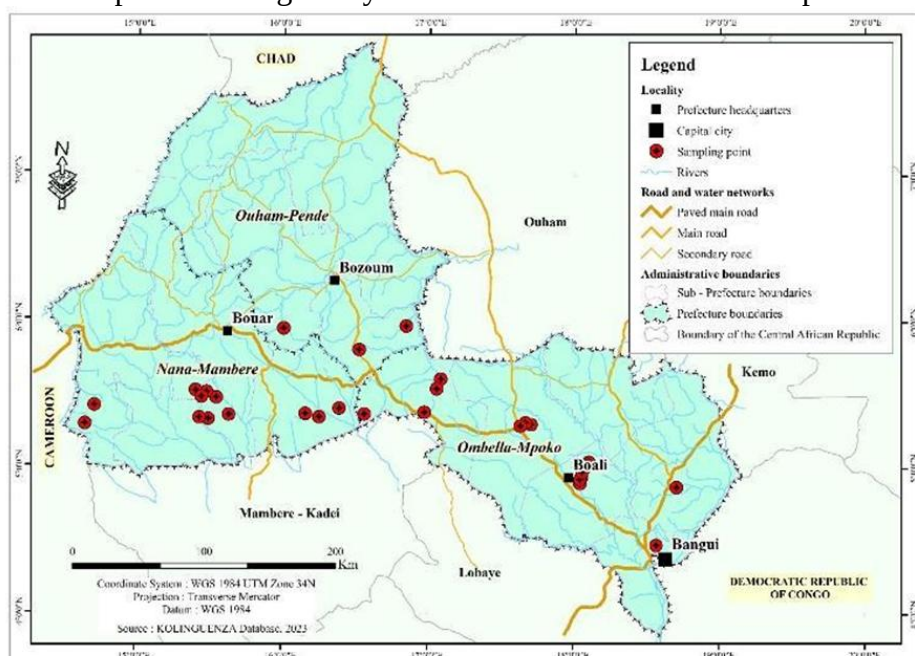


Figure 1: Map of the study area and Sampling Points

Leaf Sampling and Chemical Analyses

The leaf samples used in this study were collected along two diagonals in each field, maintaining a distance of 10 meters from the field borders (Gott et al., 2017). In total, 125 samples were collected, with an average of 45 cassava plants per field. From each plant, three fully developed and healthy leaves were taken from the top of the plant. All leaves from each field were mixed to form composite samples. After drying at 65°C in the Laboratory of Science and Technology at the École Normale Supérieure of Bangui until reaching a constant weight in an oven, the samples were ground using a Brabender mill, then labeled before being sent for analysis at the Laboratory for Soil Health Improvement and Environmental Protection Support (L2A2S2E). The analyses focused on the determination of N, P, K, Ca, Mg, and Zn. Leaf samples of 1 g were digested with H₂SO₄ and H₂O₂ using a nitrogen catalyst composed of 5 g K₂SO₄, 5 g CuSO₄, and 0.25 g selenium. Nitrogen was determined using the Kjeldahl method (Page et al., 1982). The dried samples were ashed in porcelain crucibles at 550°C in a muffle furnace. The ashes were dissolved in concentrated nitric acid to precipitate the silicates; then concentrated nitric acid was added again before final analysis. The solutions were transferred to volumetric flasks and rinsed multiple times with deionized water. An atomic absorption spectrophotometer (brand “AGILENT”) was used to determine Ca, Mg, and Zn contents (Page et al., 1982; Kalra, 1997). Phosphorus was determined using the molybdo-vanadate blue method (Page et al., 1982). The filtrate was reacted with ammonium molybdate in the presence of ascorbic acid, and the color intensity was measured colorimetrically at a wavelength of 600 nm. For yield estimation, a 25 m² yield plot was established in each field. The yield estimation was carried out according to the formula proposed by Kamau et al. (2010):

$$\text{RTY (t/ha)} = \text{Root weight (kg/m}^2\text{)} \times 10,000 / 1,000 \text{ kg}$$

$$\text{RTY} = \text{Root Tuber Yield}$$

Calculation and Interpretation of Nutrient Indices

The procedures of Walworth and Sumner (1987) for establishing DRIS norms and coefficients of variation were used in this study. Cassava root yields were divided into two yield subpopulations using the mean yield plus the confidence interval as the subdivision criterion (Dagbénonbakin, 2005; Agbangba et al., 2011). This resulted in one subpopulation with high yields and another with low yields for the DRIS procedure. The ratio of nutrient pairs was calculated for each subpopulation, with each element appearing both as numerator and denominator (e.g., Zn/P and P/Zn). For each of these ratios, the variance in both subpopulations was calculated. This was done by dividing the variance of the ratio in the low-yielding population

by the variance in the high-yielding population for the same ratio form (Elwali et al., 1985; Amundson & Koehler, 1987; Payne et al., 1990). For each nutrient pair, the ratio showing the highest variance ratio was selected for the establishment of DRIS norms. The means and standard deviations of the reference parameters from the high-yielding subgroup were then used in the formula below to calibrate the model (Hallmark & Burger, 1987; Rathfon & Burger, 1991; Bailey et al., 1997), following the generalized equations developed by Jones (1981) and Rathfon & Burger (1991): $X_{indices} = [f(X/A) + f(X/B) + \dots - f(M/X) - f(N/X) - \dots]$ where : $f(X/A) = 100 \times [(X/A) / (x/a) - 1] / CV$ when $(X/A) > (x/a) - SD$; $f(X/A) = 100 \times [1 - (X/A) / (x/a)] / CV$ when $(X/A) < (x/a) - SD$; X/A is the ratio of the concentrations of nutrients X and A in the sample; and x/a , CV , and SD are respectively the mean, the coefficient of variation, and the standard deviation for the parameter X/A in the high-yield population. To interpret the DRIS indices, the concept of potential response to fertilization was used (Wadt et al., 1998; Serra et al., 2013). This method compares the nutrient index or its absolute value to the Nutritional Balance Index (NBI). The NBI is the mean of the absolute deviations of all nutrient indices from zero. The index for a nutrient is obtained for each nutrient in the high-yield subpopulation. The average of all individual nutrient indices in the high-yielding subpopulation then constitutes the index for that nutrient. According to Wadt et al. (1998), for n indices: $NBI = (|Index A| + |Index B| + \dots + |Index n|) / n$. In the case of this study, $NBI = (|Indice N| + |Indice P| + |Indice K| + |Indice Ca| + |Indice Mg| + |Indice Zn|) / 6$. According to Wadt et al. (1998) et Serra et al. (2013), when the index of a nutrient (IN) : IN is negative and $|IN| > NBI$ and that IN is the smallest DRIS index, we say that the nutrient is deficient and limiting;

- $IN < 0$ et $|IN| > NBI$, the nutrient is probably deficient ;
- $|IN| \leq NBI$, we will say that the nutrient is sufficient;
- $IN > 0$ et $|IN| > NBI$, the nutrient is probably in excess;
- $IN > 0$ et $|IN| > NBI$ and IN is the highest DRIS index, we say that the nutrient is in excess.

Statistical Analyses

Descriptive statistics were calculated for cassava root yield, nutrient concentrations in leaves, and nutrient ratio expression data using Microsoft Excel 2016. The descriptive statistics included means, minimum and maximum values, variances, and coefficients of variation. Cassava root yields from the two subpopulations were subjected to a one-way analysis of variance (with subpopulation as the factor). Comparison of the means of nutrient concentrations and gross root yields was carried out using the Student's t-test. The normality of the data was first checked using the Shapiro-Wilk test (Shapiro and Wilk 1965).

Results

Nutrient Concentrations in Cassava Leaf Samples

Table 1 presents the root yields and nutrient concentrations in the leaves of cassava plants grown in the savanna zone of the Central African Republic. The root yield data show an average value of 7.4 t/ha (Table 1). Forty-two (42) out of the 126 data points are assigned to the low-yield subpopulation (yield ≥ 2.1 t/ha). However, the predominance of data from the high-yield subpopulation is not necessarily relevant for establishing the parameters of the DRIS model. Furthermore, root yields between the two subpopulations differ significantly ($p = 0.0001$). The average concentrations of N, P, K, Ca, and Mg in the leaves of the high-yield subpopulation are higher than those of the low-yield subpopulation. However, the Zn concentration is the same in both subpopulations ($p = 0.52$). In general, the levels of N, P, K, Ca, Mg, and Zn are relatively symmetrical between the two subpopulations, with high variance ratios (≥ 1), which appears suitable for the development of the DRIS model. Overall, the data on N, P, K, Ca, Mg, and Zn contents are relevant for the parameterization of the DRIS model in the savanna zone of the Central African Republic.

Table 1: Descriptive statistics (mean, coefficient of variation and variance) for cassava leaf nutrient concentrations in the two yield sub-populations.

Variables	Low-yield subpopulation [n=84]					High-yield subpopulation[n=42]					Variance Ratio
	Mean	Variance	CV	Min	Max	Moyenne	VAR	CV	Min	Max	
Yields (t/ha)	5,4	1,3	21,6	2,1	6,5	8,1	1,0	12,0	6,7	11,1	1,4
N	4,8	0,1	6,5	3,9	5,6	4,8	0,1	6,9	4,0	5,4	0,9
P	0,2	0,0	16,3	0,1	0,3	0,2	0,0	22,8	0,2	0,4	0,5
K	1,0	0,1	26,2	0,4	2,7	0,9	0,0	18,7	0,7	1,4	2,0
Ca	1,0	0,0	20,5	0,6	1,7	1,0	0,0	21,2	0,4	1,5	0,9
Mg	0,3	0,0	15,5	0,2	0,5	0,3	0,0	16,1	0,2	0,5	0,9
Zn	0,0	0,0	21,7	0,0	0,0	0,0	0,0	33,4	0,0	0,1	0,4

VAR=Variance; CV=Coefficient of variation; Min=Minimum; Max=Maximum

Nutrient Ratios and DRIS Norms to Improve Cassava Production

Descriptive statistics of nutrient pair ratios derived from the combinations of the six nutrients were calculated and are presented in Table 3. DRIS norms were established for each reciprocal nutrient pair ratio (e.g., K/P and P/K) based on the highest variance ratio between the two subpopulations. As a result, 15 nutrient ratios from the high-yield subpopulation, involving all essential nutrients, were selected as DRIS norms for cassava cultivation in this climatic zone (Table 4). The selected nutrient pair norms for the savanna zone are: N/P, N/K, Ca/N, Mg/N, N/Zn, K/P, Ca/P, Mg/P, P/Zn, Ca/K, K/Mg, K/Zn, Ca/Mg, Ca/Zn, and Mg/Zn (Table 4). Magnesium (Mg), nitrogen (N), potassium (K), phosphorus (P), and zinc

(Zn) were frequently involved in the binary ratios associated with a good nutritional balance for cassava.

Table 4 : Descriptive statistics (mean, coefficient of variation, variance) for nutrient ratio peers of cassava root yield sub-populations

Variables	Low yielding sub-population [n=172]					High yielding-sub population [n=172]					Ratio VAR	Selected Ratio
	Moy	VAR	CV	Min	Max	Moy	VAR	CV	Min	Max		
N/P	23,5	14,2	16,0	14,8	33,6	22,8	15,1	17,1	12,5	29,2	0,9	X
P/N	0,0	0,0	16,8	0,0	0,1	0,1	0,0	21,0	0,0	0,1	0,6	
N/K	5,3	1,8	25,1	1,7	13,9	5,2	0,7	15,9	3,5	6,8	2,6	X
K/N	0,2	0,0	27,0	0,1	0,6	0,2	0,0	17,3	0,2	0,3	2,4	
N/Ca	5,1	1,2	21,9	2,3	9,0	5,1	2,1	28,2	2,9	11,5	0,6	
Ca/N	0,2	0,0	23,2	0,1	0,4	0,2	0,0	22,9	0,1	0,3	1,0	X
N/Mg	16,0	6,3	15,6	8,1	21,1	16,2	6,7	16,0	8,8	20,8	0,9	
Mg/N	0,1	0,0	19,3	0,1	0,1	0,1	0,0	19,3	0,1	0,1	1,0	X
N/Zn	214,8	2429,7	23,0	117,2	397,4	207,2	2342,7	23,4	80,1	328,0	1,0	X
Zn/N	0,0	0,0	22,8	0,0	0,0	0,0	0,0	33,6	0,0	0,0	0,3	
P/K	0,2	0,0	20,3	0,1	0,5	0,2	0,0	12,4	0,2	0,3	2,6	
K/P	4,6	1,2	23,8	2,1	12,2	4,4	0,3	12,2	3,4	5,4	4,1	X
P/Ca	0,2	0,0	38,7	0,1	0,9	0,2	0,0	51,7	0,1	0,9	0,5	
Ca/P	4,8	1,5	25,6	1,1	7,8	4,8	1,8	27,9	1,1	7,4	0,9	X
P/Mg	0,7	0,0	22,4	0,5	1,7	0,7	0,0	28,3	0,5	1,7	0,6	
Mg/P	1,5	0,1	19,3	0,6	2,2	1,4	0,1	22,4	0,6	2,1	0,8	X
P/Zn	9,2	3,2	19,6	5,6	15,9	9,1	3,2	19,6	6,2	12,8	1,01	X
Zn/P	0,1	0,0	18,9	0,1	0,2	0,1	0,0	19,4	0,1	0,2	0,96	
K/Ca	1,0	0,2	43,9	0,4	4,6	1,0	0,2	40,2	0,6	3,2	1,2	
Ca/K	1,1	0,1	29,8	0,2	2,7	1,1	0,1	26,4	0,3	1,7	1,3	X
K/Mg	3,2	1,0	31,3	1,4	12,0	3,2	0,5	22,2	2,1	5,8	2,0	X
Mg/K	0,3	0,0	22,2	0,1	0,7	0,3	0,0	19,8	0,2	0,5	1,3	
K/Zn	41,0	76,5	21,4	15,6	68,9	40,0	66,0	20,3	22,3	56,9	1,2	X
Zn/K	0,0	0,0	25,2	0,0	0,1	0,0	0,0	23,9	0,0	0,0	1,1	
Ca/Mg	3,3	0,3	16,4	1,8	4,7	3,3	0,3	17,4	1,8	4,5	0,9	X
Mg/Ca	0,3	0,0	17,7	0,2	0,6	0,3	0,0	20,3	0,2	0,6	0,8	
Ca/Zn	44,0	190,0	31,4	7,0	91,1	43,2	170,6	30,3	7,0	69,9	1,1	X
Zn/Ca	0,0	0,0	52,1	0,0	0,1	0,0	0,0	72,4	0,0	0,1	0,5	
Mg/Zn	13,5	11,8	25,5	3,9	24,7	13,1	12,3	26,7	3,9	22,8	1,0	X
Zn/Mg	0,1	0,0	32,1	0,0	0,3	0,1	0,0	41,4	0,0	0,3	0,5	

VAR=Variance; CV=Coefficient of variation; Min=Minimum; Max=Maximum

Nutritional Status of Cassava Plants

The nutrient indices calculated based on the selected norms from the data in Table 2 are presented in Figure 2. These indices range from negative to positive values depending on the nutrient levels (relatively deficient or excessive). Nutrient requirements for cassava production were ranked as follows: Ca > Mg > N > K > P > Zn for the savanna zone of the Central African Republic, with a Nutritional Balance Index (NBI) of 13.3. Analysis of the figure reveals that Ca is deficient and constitutes the limiting nutrient for cassava yields in the soils, while N, P, K, and Mg are sufficient. Zinc (Zn) is in excess in the soils of cassava cropping systems in the savanna zone of the Central African Republic.

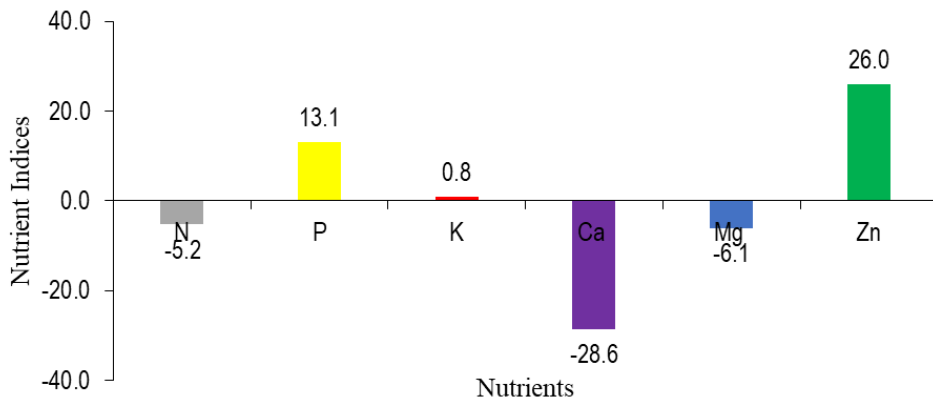


Figure 2: Nutrient indices

Discussion

The means and variances of nutrient ratios in cassava subpopulations in the savanna zone reveal significant differences in crop nutritional status depending on observed yields. These results confirm the validity of the DRIS (Diagnosis and Recommendation Integrated System) norms for diagnosing nutritional imbalances in this area of the Central African Republic. High-yielding crops exhibit symmetrical nutrient concentrations with a low coefficient of variation (<15%), indicating a nutritional balance favorable to optimal productivity, consistent with previous studies by Ramakrishna et al. (2009) and Agbangba et al. (2011). This balance is reflected in nutrient ratios such as P/Mg, P/K, and Ca/K, whose balanced values (between 0.6 and 0.9) align with DRIS norms (Jones et al., 1990; Kelling & Matocha, 1990). The study's results reveal a complex dynamic of nutrients in savanna soils of the Central African Republic with important implications. The phosphorus index in this zone (13.1) is relatively low compared to other regions, reflecting pedological dynamics typical of savannas. This low concentration may result from limited availability in the upper soil layers, although the deep root systems of plants can exploit deeper phosphorus reserves (Sanchez, 2002). Furthermore, savanna soils show a notable excess of zinc (26), attributed to edaphic conditions favoring its mobility and accumulation. This excess can negatively affect the uptake of other nutrients due to persistent nutritional imbalances, particularly through ionic competition mechanisms where excessive zinc concentration may limit the availability and absorption of elements such as iron (Fe) or copper (Cu) necessary for optimal plant growth. Nitrogen (N) deficiency is less pronounced in this savanna zone (-5.2), thanks to the frequent presence of nitrogen-fixing legumes. These legumes contribute to maintaining a natural nitrogen supply, thus mitigating the observed nutritional deficit (Saidou et al., 2018). The widespread magnesium deficiency in savanna soils, measured at (-73.6), is particularly

concerning. Magnesium is a key component of chlorophyll and plays a central role in photosynthesis and plant energy metabolism (Barkla & Pantoja, 1996). Such a marked deficiency can limit optimal crop development, causing visible symptoms such as leaf yellowing and reduced productivity. This deficiency is often linked to leaching caused by moderate rainfall and agricultural practices that progressively deplete the soils. Calcareous amendments or fertilizers containing magnesium are recommended to address this deficiency.

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Data Availability: All data are included in the content of the paper.

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