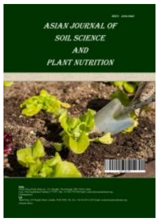

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Diagnosis and Recommendation Integrated System (DRIS) in Determining Mineral Status of Cotton in the Cotton Zones of Benin

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

This study aimed at developing parameters of the Diagnosis and Recommendation Integrated System (DRIS) model for the assessment nutrient status for cotton grown in Benin.. Soil physical and chemical characteristics, leaves nutrient content (N, P, K, Ca, Mg) and seed-cotton yield were assessed on samples gathered from 150 farmers' fields in 2018. Nutrient indices were computed using standard DRIS procedures. Results showed that phosphorus was in excess in the petiole and the whole leaves but in deficit in the limb. Potassium content was adequate according in the petiole and leaves but deficient in the limb. Ca content was limiting in the limb or the whole leaves and adequate in the petiole. Based on the diagnosis made in the petioles, Mg was deficient while adequate in the limbs and leaves. In the limb, the order of the macronutrients is as follows: K> P>

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N. On the other side, in the petiole and the whole leaves, the order of the macronutrients becomes: P> K> N. In the whole leaves and limb, the order of the secondary elements is as follows: Mg> Ca, whereas in the petiole the order of the secondary elements becomes: Ca> Mg.

Keywords: DRIS; nutrient balance; leaf organs; soil fertility; cotton; yield.

1. INTRODUCTION

In Benin and as many other countries of Africa, cotton constitutes an essential element of the economic activity. Its production in West and Central Africa reaches up to 1,100,000 tons and represents 5% of the world production and 12 to 13% of the cotton fiber on the world market. In Benin, cotton represents 40% of slogan entrances, 12 to 13% of the Gross Domestic Product (GDP) and income source for more than a third of the population [1]. Cotton is an important path for the socioeconomic development and, therefore, contributes to the struggle against poverty. However, stagnant or continuous poor yields has been observed due to the decrease in soil organic carbon content which has a negative impact on nutrient uptake [2,3,4]. On the sandy-loam soil of the Huanghuai-Hai Plain in China, Yang et al. [5] reported that the use of NPK fertilizer over a period of 14 years has maintained a good yield level of wheat and maize compared to manure, even though the soil had higher organic matter content than the normal. Other authors as Koulibaly et al. [6], Bationo et al. [7], Bado [8] and Fey et al. [9] reported that the continuous use of mineral fertilizer over a long period reduces soil organic matter content and leads to soil degradation. In this context, soil fertility diagnosis is needed for a rational fertilization. The Diagnosis and Recommendation Integrated System (DRIS) has been used to establish nutrient ratios that could be used to diagnose the cotton plant nutrition. This method uses a comparison of leaf tissue concentration ratios of pairs nutrient with the norms developed from high-yielding populations to diagnose nutrient status. DRIS has been reliable than any other method and successfully used to interpret the results of foliar analyses for a wide range of crops such as vegetables, potatoes, wheat [10,11]; rubber and sugarcane [12]; forage grass [13,14] mango [15]; pineapple [16,17,18], ananas [19], yam [20] and cotton [21]. The DRIS approach has been designed to provide a valid diagnosis irrespective of the age of the plant, organ harvested [22,23], cultivars, local conditions [24], or changes in tissue sampling method or sampling time [25]. However, Agbangba et al. [26] claimed that DRIS norms can vary according to pineapple varieties. In this work we hypothesize that the results of nutrient diagnosis based on petiole, limb or on the whole leaf gives the same result. This study aimed to develop parameters for cotton crop nutrition status using DRIS model in Benin.

2. MATERIALS AND METHODS

2.1 Site Location and Characteristics

The study was conducted in six (6) high cotton producing communes in Benin. They included : Banikoara (11°18′00″ N, 2°26′00″ E), Kandi (11°07′43″ N, 2°56′13″ E), Ouassa-Péhunco (10°13′42″ N, 2°00′07″ E), Sinendé (10°20′41″ N, 2°22′45″ E), Savalou (7°55′50″ N, 1°58′31″ E), Djidja (7°20′40″ N, 1°56′00″ E).

The communes of Banikoara, Kandi, Ouassa-Péhunco and Sinendé are characterized by a Sudano-Sahelian climate [27]. The rainfall pattern is unimodal characterized by the succession of a rainy season from April-May to October and a dry season from November to March with the harmattan. The average annual temperature is 27°C. The average annual rainfall is 900 mm.

The communes of Savalou and Djidja benefit of a subequatorial climate [27]. It is characterized by two rainy seasons (a long one from March-April to July then a short one from September to November) and two dry seasons (a short one that occurs July-August and a long one from December to March). The average annual temperature is 24°C. The average annual rainfall is 1000 mm.

2.2 Sampling Design and Chemical Analyses

The fully mature leaves on the main stem of youngest plants were sampled in a (5 x 4) m^2 plot at the first bloom as recommended by FAO [28]. The leaves petioles and limbs were obtained by hand from 150 producers. After air drying, material was further dried at 70°C for 72 hours to a constant weight, pre-ground by a

Brabender mill and stored in plastic bags. Soil samples, were also collected from 150 producers at 0-20 cm depth. Cotton fiber was harvested in a (5 x 4) m^2 area and repeated thrice per farmer's field.

Soil samples and leaves have been analyzed in the Soil Science, Waters and Environment Laboratory based in Agonkanmey in Benin. Soil texture (5 fractions) have been determined according to the international method modified by the use of ROBINSON pipette Tran and Boko (1978); the organic carbon by of Walkey and Black method, the total nitrogen by Kjeldahl method, the pH (1/2.5 ratio soil-water), the phosphorus according to Bray1 method, the exchangeable cations by the acetate of ammonium method (pH7). The potassium was measured with a Flame Photometer. The phosphorus has been determined in leaves by the spectrophotometer 1,100. Calcium and Magnesium was determined by Atomic Absorption Spectro-photometer.

2.3 Diagnosis and Recommendation Integrated System Methodology

The population was divided into high and low yielding subpopulations using the mean + interval of confidence as criteria for cut-off. The nutrient ratio was calculated for both of the high and low yielding populations so that each of the nutrients determined in the tissue appeared in the denominator and again in the numerator in the ratio with each of the other elements (for example N/P and P/N). For each form of expression, the variance for both high and low yielding populations was calculated. A variance ratio for each nutrient ratio was also determined by dividing the variance of the low yielding population by the variance of the high yielding population [29,30]. For each pair of nutrients, the form of expression, which gave the highest variance ratio, was selected as the parameter to be used for DRIS-evaluation. The mean of the selected parameters for the high yielding population became the foliar diagnostic norms were then used, along with the standard deviation, to calculate DRIS indices for diagnostic purposes.

Means and standard deviation (SD) of DRIS reference parameters in the high yielding subpopulation were then programmed for diagnostic purposes using the following general calibration formula [31,32].

X indices = $\left[f\left(\frac{X}{A}\right)+f\left(\frac{X}{B}\right)+\cdots-f\left(\frac{M}{X}\right)-f\left(\frac{N}{X}\right)-\cdots\right]$,

- where $f\left(\frac{X}{A}\right)=100\left[\left(\frac{X}{A}\right)/\left(\frac{x}{a}\right)-1\right]/CV$
- when $\frac{X}{A} > \frac{x}{a}+SD$
- and $f\left(\frac{X}{A}\right)=100\left(1-\left(\frac{x}{a}\right)/\left(\frac{X}{A}\right)\right)/CV$
- when $\frac{X}{A} < \frac{x}{a}-SD$, where:

$\frac{X}{A}$ is the ratio of concentration of nutrient X and A in the sample while $\frac{x}{a}$, CV, SD represent the mean, coefficient of variation, and standard deviation for the parameter $\frac{X}{A}$ in the high-yielding population, respectively. Similarly, other nutrient ratios $\frac{X}{B}$, $\frac{M}{x}$ and $\frac{N}{x}$ etc. are calibrated against the corresponding DRIS reference parameters, $\frac{x}{b}$, $\frac{m}{b}$ and $\frac{n}{x}$, etc. Nutrient indices calculated by this formula could range from negative to positive values depending on whether a nutrient is relatively insufficient or excessive with respect to all other nutrients considered. The more negative is the index value for a nutrient, the more limiting is that nutrient. According to Kelling and Shulte [33], a DRIS index from -15 to +15 indicates good nutrient balance in the plant; values from -25 to -15 indicate a possible deficiency and values lower than -25 show a likely nutrient deficiency of plant. Wadt (1996) proposed an interpretation method which has an advantage to detect excess of nutrients. This method compares nutrient index or its absolute value with the nutritional balance index (NBI). The nutritional balance index is the average of the distance to zero of all nutrient's indices. For N indices, NBI = (| Index A | + | IndexB | + ... + | Index N|)/N. According to Wadt (1996), these conclusions could be formulated for each nutrient (Nut) as,

- Deficiency = $I_{Nut.} < 0$ (and) $|I_{Nut.}| > NBI$
- Adequate = $|I_{Nut.}| < NBI$
- Excess = $I_{Nut.} > 0$ (and) $|I_{Nut.}| > NBI$

Descriptive statistics were performed for fiber yield, leaf nutrient concentration and nutrient ratio expression data using R statistical software.

They included, means, medians, minimum and maximum values, variances, CV's and skewness values, where a skewness value of zero indicates perfect symmetry, and values greater than 1.0 indicate marked asymmetry.

3. RESULTS

3.1 Soil Physico-chemical Characteristics

Three types of soils (Table 1) have been identified according to their texture: (i) soil with loamy sand texture; (ii) soil with a sandy clay loam texture and (iii) and sandy loam texture. The clay contents range from 4.74 to 24.15% and sand between 55.96 and 84.53% for all textures. Nitrogen content (0.056 and 0.06 g kg^{-1}) with pH ranging from 6.0 to 6.1 (medium to low acid) are average. The potassium, the sum of exchangeable cations and the cationic exchangeable capacity on sandy clay loam textured soils were globally low on other soil types. All soils have low potassium levels. The phosphorus content is low on soils with a sandy clay loam texture but high on the other soil types. So, soil used for this study presented more than three moderate limitations associated with one severe limitation.

3.2 Leaf Nutrients Concentration Variation

The cotton yield ranged from 562.5 kg ha^{-1} to 1690.0 kg ha^{-1} with an average of 1255.9 kg ha^{-1} in the full population. Sixty-seven (67) out of one hundred and fourteen (140) data points were assigned to the high-yielding subpopulation (≥1725.7 kg ha^{-1}). The mean values, range, coefficient of variation, skewness and kurtosis for the concentration of different nutrients in the different leaf organs are listed in Table 2. The concentration of N, P, K, Ca and Mg in the petiole samples of cotton grown by commune varied from 0.7 to 2.3, 0.2 to 2.5, 1.0 to 5.9, 0.5 to 2.1 and 0.1 to 1.4 g kg^{-1}, respectively. The concentration of N, P, K, Ca and Mg in the leaf limbs ranged from 2.3 to 4.7, 0.5 to 2.3, 0.7 to 3.6, 0.2 to 4.2, 0.2 to 1.4 g kg^{-1}, respectively. In the whole leaf, the concentration of N, P, K, Ca and Mg varied from 2.3 to 4.7, 0.5 to 2.1,1 to 5.9, 0.5 to 2.1, 0.1 to 1.4 g kg^{-1}, respectively. Considering the average concentration, the content of potassium was higher in Petiole (3.4 g kg^{-1}) and the whole leaf (3.4 g kg^{-1}) than in limb (1.7 g kg^{-1}). In contrast, limb presented higher content in N than petiole. The nutrients P and Mg had relatively similar contents in petiole and whole leaf. Calcium content was higher in limbs than in petiole and the whole leaf. Nitrogen content in all the leaf (petiole plus limb) was higher and similar to that in limb.

3.3 Binary Nutrients Ratio and Nutrient Diagnosis

The mean values, range, coefficient of variation, skewness, kurtosis and the variance ratios (Vlow/Vhigh) were presented in Tables 3, 4 and 5. The selected nutrient ratios had relatively large variance ratios (Vlow/Vhigh) and, therefore, these nutrient ratios got the maximum potential to differentiate between "healthy" and "unhealthy" plants (Walworth and Sumner, 1987) (Table 6). Equal number of ratios for each of the five elements (N, P, K, Ca and Mg) were selected in this study to meet an orthogonal requirement of the mathematical model. The mean values for these five nutrient ratios were taken as the reference value for calculation of DRIS indices for the different part of collected leaf samples. The comparison of the developed norms to the previous developed in Benin revealed difference even when the whole leaf was used as diagnosis material.

DRIS indices for each part of the cotton leaf and the whole leaf were computed using the DRIS norms established from the high yield population of nutrient indexing survey of cotton were presented in Fig. 1. The indices of nutrient N for petiole and the whole leaf were adequate ($|I_{Nut.}|$ < NBI) revealing normal nutrition in this element. The P is in excess nutrient as diagnosed based on petiole and the whole leaf and diagnosed as limiting based on limb. Potassium content was adequate according to petiole and leaf diagnosis but deficient based on limb. The Ca was limiting based on limb or whole leaf and adequate based on petiole diagnosis (Table 7). Deficiency symptoms were observed in most cases in accordance with the leaf chemical analyses. Based on petiole, Mg is deficient while adequate based on limb and leaf. The order of macro-element was K>P>N remained the same for diagnoses based on limb and P>K>N for petiole and for the whole leaf. The order of secondary element (Mg>Ca) were the same for both limb and the whole leaf and the order was Ca> Mg for petiole.

4. DISCUSSION

DRIS norms established in this study can prove useful diagnostic tool to predict deficiencies or imbalances in macro, secondary and

Table 1. Physico-chemical characteristics of the soils of the study area

Parameters	Clay	Loam	Sand	N	OM	V	C/N	pH_{eau}	pH_{KCl}	Ca	Mg	K	SC	CEC	Pass
					[%]							[Cmol kg^{-1}]			[$mgkg^{-1}$]
Soil with loamy sand texture [N=51]															
Mean	4.74	10.73	84.53	0.056	0.99	68.3	12.1	6.1	5.7	3.00	0.59	0.18	4.00	6.02	21
SD	1.54	2.33	2.83	0.024	0.35	17.2	6.2	0.4	0.5	1.26	0.26	0.09	1.53	2.53	13
Soil with sandy clay loam texture [N=12]															
Mean	24.15	19.89	55.96	0.060	1.04	61.9	10.3	6.0	5.4	4.89	1.39	0.17	6.67	10.35	8
SD	4.70	5.72	3.28	0.021	0.45	21.8	2.6	1.0	1.0	3.02	0.72	0.03	3.53	2.95	2
Soil with Sandy loam texture [N =87]															
Mean	11.86	16.53	71.61	0.061	1.14	62.8	12.1	6.1	5.5	3.50	0.82	0.19	4.77	7.28	14
SD	4.77	4.19	6.59	0.029	0.62	18.0	6.8	0.6	0.7	2.10	0.57	0.10	2.73	3.02	10

OM = organic matter; V = base saturation SC = sum of exchangeable cations; ECC = Exchangeable cations capacity; N = number of analyzed soil samples

Table 2. Summary statistics for Cotton yield and leaf nutrient concentration data for total (n=150) and high-yielding (n=68) sub-populations

Parameters	Low yielding sub population [n=82]						High yielding sub population [n=68]					
	Mean	CV	Min	Max	Skew	Kurt	Mean	CV	Min	Max	Skew	Kurt
Yield [kg^{-1}]	1255.9	22.6	562.5	1690.0	-0.4	-0.6	2054.4	16.7	1725.7	3187.5	1.6	2.7
Nutrients [g kg^{-1}]												
Petioles and limbes												
N	3.5	16.5	2.3	4.7	0.2	-0.5	3.5	18.3	1.7	4.6	-0.1	-0.5
P	0.8	32.5	0.5	2.1	2.2	7.5	0.9	77.4	0.5	6.3	7.0	54.0
K	3.4	27.3	1.0	5.9	-0.3	0.9	3.6	23.9	1.5	7.2	0.7	3.6
Ca	1.4	23.1	0.5	2.1	0.0	0.1	1.3	26.8	0.2	2.4	0.4	1.7
Mg	0.4	68.0	0.1	1.4	3.6	13.3	0.4	62.0	0.1	1.3	2.1	4.7
Limbes												
N	3.4	15.7	2.3	4.7	0.3	-0.1	3.5	17.9	1.7	4.6	-0.2	-0.5
P	0.8	36.7	0.5	2.3	2.5	8.9	0.9	76.9	0.5	6.3	7.0	53.9
K	1.7	32.7	0.7	3.6	1.1	2.1	2.1	40.5	1.0	4.3	1.0	-0.1
Ca	2.0	32.2	0.2	4.2	0.6	1.4	2.0	34.7	1.0	3.8	0.6	0.1
Mg	0.3	57.6	0.2	1.4	4.4	21.1	0.4	70.2	0.2	1.4	2.7	7.0
Petioles												
N	1.4	20.2	0.7	2.3	0.5	0.9	1.3	19.1	0.6	1.8	-0.4	-0.2
P	0.8	60.1	0.2	2.5	1.9	3.5	1.2	54.8	0.2	3.4	1.2	1.4

Parameters	Low yielding sub population [n=82]						High yielding sub population [n=68]					
	Mean	CV	Min	Max	Skew	Kurt	Mean	CV	Min	Max	Skew	Kurt
Yield [kg^{-1}]	1255.9	22.6	562.5	1690.0	-0.4	-0.6	2054.4	16.7	1725.7	3187.5	1.6	2.7
K	3.4	27.3	1.0	5.9	-0.3	0.9	3.6	22.6	1.5	5.4	-0.4	0.6
Ca	1.4	23.1	0.5	2.1	0.0	0.1	1.3	24.7	0.7	2.4	1.0	1.0
Mg	0.4	67.9	0.1	1.4	3.6	13.3	0.4	62.1	0.1	1.3	2.2	5.4

Max = maximum; Min = Minimum; Skew = Skewness; Kurt = Kurtosis

Table 3. Mean values of nutrient ratios for high and low-yielding sub-populations together with their respective coefficients of variance (CV's) and variances (low and high), skewness values for the high-yielding sub-population, and the variance ratios (Vlow/Vhigh) for petiole and limb

Parameters	Low yielding sub population [n=82]						High yielding sub population [n=68]						V
	Mean	CV	Min	Max	Skew	Kurt	Mean	CV	Min	Max	Skew	Kurt	low/high
N/P	4.4	25.0	1.3	6.7	-0.1	-0.3	4.5	33.7	0.5	7.6	0.2	-0.4	0.5
P/N	0.2	35.7	0.1	0.8	3.4	19.0	0.3	79.5	0.1	1.9	6.6	50.0	0.2
N/K	1.2	50.8	0.5	3.7	2.3	6.0	1.0	32.5	0.4	2.1	1.0	1.3	3.1
K/N	1.0	32.8	0.3	1.8	-0.2	-0.3	1.1	32.5	0.5	2.3	1.2	2.6	0.9
P/K	0.3	56.9	0.1	1.1	3.0	11.2	0.3	74.4	0.1	1.7	6.4	47.0	0.6
K/P	4.4	34.5	0.9	8.3	-0.1	-0.3	4.6	36.4	0.6	11.2	1.2	3.4	0.8
N/Ca	2.6	36.9	1.5	7.4	2.7	10.2	3.0	82.4	1.5	22.1	7.2	56.0	0.2
Ca/N	0.4	26.6	0.1	0.7	0.1	0.3	0.4	29.9	0.0	0.6	0.2	0.1	0.9
N/Mg	11.6	34.7	3.2	23.4	0.6	0.9	11.7	39.5	3.3	24.6	0.4	0.1	0.8
Mg/N	0.1	50.5	0.0	0.3	2.9	9.7	0.1	51.0	0.0	0.3	1.7	2.9	0.9
P/Ca	0.6	36.9	0.3	1.4	1.3	2.0	0.8	103.1	0.3	6.0	5.6	33.8	0.1
Ca/P	1.8	33.6	0.7	3.7	0.7	0.5	1.7	34.2	0.2	3.1	0.2	0.7	1.1
P/Mg	2.8	44.8	0.6	8.6	1.2	4.0	3.4	121.3	0.5	34.1	6.4	47.3	0.1
Mg/P	0.4	61.9	0.1	1.7	2.7	9.0	0.5	74.4	0.0	1.8	1.8	3.0	0.6
K/Ca	2.6	42.6	0.8	8.1	1.9	7.2	3.1	66.6	1.5	17.9	6.1	44.2	0.3
Ca/K	0.5	45.4	0.1	1.3	1.8	4.2	0.4	31.8	0.1	0.7	0.4	0.4	2.9
K/Mg	11.8	44.8	1.6	23.5	0.1	-0.6	12.8	49.1	1.9	35.3	0.7	1.3	0.7
Mg/K	0.1	92.8	0.0	0.6	3.1	10.1	0.1	73.5	0.0	0.5	2.8	11.0	2.0
Ca/Mg	4.7	33.3	1.1	10.5	0.1	2.3	4.5	42.1	0.3	10.2	0.2	0.5	0.7
Mg/Ca	0.3	65.7	0.1	1.0	2.9	8.3	0.3	145.1	0.1	3.9	6.6	49.2	0.1

Max = maximum; Min = Minimum; Skew = Skewness; Kurt = Kurtosis

Table 4. Mean values of nutrient ratios for high and low-yielding sub-populations together with their respective coefficients of variance (CV's) and variances (low and high), skewness values for the high-yielding sub-population, and the variance ratios (Vlow/Vhigh) for limb

Parameters	Low yielding sub population [n=82]						High yielding sub population [n=68]						V
	Mean	CV	Min	Max	Skew	Kurt	Mean	CV	Min	Max	Skew	Kurt	low/high
N/P	4.4	26.4	1.3	6.4	-0.2	-0.1	4.5	33.1	0.5	7.6	0.2	-0.4	0.6
P/N	0.3	41.0	0.2	0.8	3.3	14.8	0.3	79.8	0.1	1.9	6.7	50.8	0.2
N/K	2.2	34.2	1.0	5.7	1.7	5.3	1.8	35.5	0.7	4.2	1.1	2.2	1.3
K/N	0.5	30.5	0.2	1.0	0.7	1.0	0.6	37.4	0.2	1.4	1.3	1.8	0.5
N/Ca	2.1	110.4	0.9	21.9	8.1	70.1	2.0	44.8	1.0	4.2	1.3	0.7	6.5
Ca/N	0.6	30.9	0.0	1.1	0.1	0.8	0.6	34.5	0.2	1.0	-0.1	-0.8	0.8
N/Mg	11.4	25.6	3.2	18.7	-0.1	1.4	11.4	40.6	2.4	23.6	0.5	0.6	0.4
Mg/N	0.1	44.2	0.1	0.3	3.6	15.2	0.1	68.3	0.0	0.4	2.7	7.4	0.3
P/K	0.5	40.7	0.2	1.2	1.3	1.8	0.5	49.7	0.2	1.7	2.4	11.5	0.9
K/P	2.2	39.8	0.8	5.3	1.3	2.3	2.7	51.0	0.6	6.4	1.3	0.8	0.4
P/Ca	0.5	75.5	0.2	3.4	6.5	51.1	0.5	130.1	0.2	6.0	7.6	60.5	0.3
Ca/P	2.5	34.9	0.3	4.7	0.2	-0.3	2.5	39.5	0.2	5.0	0.7	0.4	0.8
P/Mg	2.8	39.3	0.6	7.7	1.2	4.4	3.2	124.9	0.5	34.1	7.0	54.3	0.1
Mg/P	0.4	57.8	0.1	1.6	2.9	10.1	0.5	86.6	0.0	2.1	2.3	4.9	0.3
K/Ca	1.2	169.0	0.3	17.9	8.1	70.1	1.3	73.9	0.4	3.6	1.4	0.3	4.0
Ca/K	1.3	43.8	0.1	3.3	0.8	1.8	1.1	50.2	0.3	2.7	0.4	0.4	1.0
K/Mg	5.7	39.9	1.6	13.3	0.8	0.9	7.1	64.2	1.7	20.2	1.6	1.9	0.3
Mg/K	0.2	47.1	0.1	0.6	1.9	4.9	0.2	60.0	0.0	0.6	1.7	3.4	0.7
Ca/Mg	6.8	39.8	0.3	16.3	0.7	2.0	6.3	43.5	1.1	14.8	0.4	1.3	0.9
Mg/Ca	0.2	192.2	0.1	3.9	7.8	65.7	0.2	92.3	0.1	1.0	2.6	5.4	4.4

Max = maximum; Min = Minimum; Skew = Skewness; Kurt = Kurtosis

Table 5. Mean values of nutrient ratios for high and low-yielding sub-populations together with their respective coefficients of variance (CV's) and variances (low and high), skewness values for the high-yielding sub-population, and the variance ratios (Vlow/Vhigh) for petiole

Parameters	Low yielding sub population [n=82]						High yielding sub population [n=68]						V
	Mean	CV	Min	Max	Skew	Kurt	Mean	CV	Min	Max	Skew	Kurt	low/high
N/P	2.3	58.7	0.5	6.8	1.5	2.3	1.5	68.6	0.4	6.3	2.4	7.5	1.7
P/N	0.6	63.9	0.1	1.9	1.7	2.9	0.9	50.5	0.2	2.4	0.8	0.6	0.7
N/K	0.5	54.1	0.2	1.5	2.4	6.7	0.4	38.8	0.2	1.0	1.5	3.6	2.7
K/N	2.6	37.2	0.7	5.9	0.6	1.5	2.8	35.6	1.0	6.4	0.9	1.3	0.9
N/Ca	1.1	36.1	0.6	2.9	2.1	6.6	1.0	23.9	0.4	1.5	0.0	-0.4	2.5
Ca/N	1.0	28.8	0.3	1.8	0.2	-0.1	1.0	28.9	0.7	2.2	1.7	4.5	1.0
N/Mg	4.7	38.2	0.9	10.5	0.7	1.6	4.5	39.4	1.1	9.1	0.3	-0.1	1.1
Mg/N	0.3	69.3	0.1	1.1	3.5	12.9	0.3	56.5	0.1	0.9	2.1	5.1	1.4
P/K	0.3	78.9	0.1	1.2	2.4	5.8	0.4	61.2	0.1	1.2	1.4	2.8	0.9
K/P	5.4	55.2	0.9	18.0	1.4	3.7	4.0	64.9	0.8	14.0	1.6	3.3	1.3
P/Ca	0.6	55.6	0.1	1.9	1.7	3.6	0.9	53.8	0.1	2.4	0.9	0.6	0.4
Ca/P	2.2	51.2	0.5	6.9	1.3	2.8	1.5	79.7	0.4	7.6	2.8	9.7	0.8
P/Mg	2.7	60.6	0.4	8.5	1.5	2.6	4.0	67.1	0.4	14.6	1.7	4.2	0.4
Mg/P	0.5	69.8	0.1	2.3	2.3	6.8	0.4	94.6	0.1	2.6	3.8	19.4	1.0
K/Ca	2.6	42.6	0.8	8.1	1.9	7.3	2.8	26.9	1.5	4.7	0.1	-0.5	2.2
Ca/K	0.5	45.3	0.1	1.3	1.8	4.2	0.4	29.9	0.2	0.7	0.9	-0.1	3.1
K/Mg	11.8	44.9	1.6	23.5	0.1	-0.6	12.8	50.2	1.9	35.3	0.7	1.2	0.7
Mg/K	0.1	92.7	0.0	0.6	3.1	10.1	0.1	84.0	0.0	0.5	2.9	10.0	1.4
Ca/Mg	4.7	33.3	1.1	10.5	0.1	2.3	4.6	40.5	1.1	10.2	0.3	0.5	0.7
Mg/Ca	0.3	65.7	0.1	1.0	2.9	8.3	0.3	64.7	0.1	0.9	2.1	3.4	0.9

Max = maximum; Min = Minimum; Skew = Skewness; Kurt = Kurtosis

micronutrient supply to cotton plants. The results suggested that DRIS norms developed in this study is different from those developed by Dagbenonbakin et al. [21]. In fact, in this work the yield of the reference population varies from 1725.7 to 3187.5 kg ha^{-1} while it ranged from 658.5 to 1240.9 kg ha^{-1} in the report of Dagbenonbakin et al. [21]. DRIS indices for specific leaf part and the whole leave were obtained. According to Kelling and Schulte [33] an index from -15 to +15 indicates good nutrient balance in the plants. Indices from -15 to -25 indicate possible deficiency and indices lower than -25 are likely to be deficient. The diagnosis result using DRIS approach depends on the leaf part used. The result of diagnosis is not consistent regardless the leaf organ used. Thus, calcium is the most limiting nutrient in the whole leave and in limb. Magnesium is the most limiting nutrient in the petiole. Most of the soils are loamy sand, while the CEC is texture-dependent due to low organic matter content. As a consequence, soils are poor in excheangeable cations (Ca, Mg, K). This is confirmed by the pH which was medium to low acid and the poor soil Ca and Mg content.

Table 6. DRIS norms, CV's and skewness values for the high-yielding sub-population, and variance ratios (Vlow/Vhigh) of nutrient ratio expressions selected for inclusion in the DRIS model for cotton and comparison to norms developed by Dagbenonbakin et al. [21]

Parameters	High yielding sub population [n=68]						V low/high	Norms developed from Dagbenonbakin et al. [21]
	Mean	CV	Min	Max	Skew	Kurt		
Petioles and limbes								
N/P	4.5	33.7	0.5	7.6	0.2	-0.4	0.5	9.65***
N/K	1.0	32.5	0.4	2.1	1.0	1.3	3.1	1.69***
K/P	4.6	36.4	0.6	11.2	1.2	3.4	0.8	5.26***
Ca/N	0.4	29.9	0.0	0.6	0.2	0.1	0.9	NA
Mg/N	0.1	51.0	0.0	0.3	1.7	2.9	0.9	0.09 ns
Ca/P	1.7	34.2	0.2	3.1	0.2	0.7	1.1	5.79***
Mg/P	0.5	74.4	0.0	1.8	1.8	3.0	0.6	0.96***
Ca/K	0.4	31.8	0.1	0.7	0.4	0.4	2.9	1.08***
Mg/K	0.1	73.5	0.0	0.5	2.8	11.0	2.0	0.18***
Ca/Mg	4.5	42.1	0.3	10.2	0.2	0.5	0.7	5.77***
Limbes								
N/P	4.5	33.1	0.5	7.6	0.2	-0.4	0.6	9.65***
N/K	1.8	35.5	0.7	4.2	1.1	2.2	1.3	1.69 ns
N/Ca	2.0	44.8	1.0	4.2	1.3	0.7	6.5	NA
N/Mg	11.4	40.6	2.4	23.6	0.5	0.6	0.4	10.55 ns
P/K	0.5	49.7	0.2	1.7	2.4	11.5	0.9	0.19 ns
Ca/P	2.5	39.5	0.2	5.0	0.7	0.4	0.8	5.79 ns
P/Mg	3.2	124.9	0.5	34.1	7.0	54.3	0.1	1.04***
Ca/K	1.1	50.2	0.3	2.7	0.4	0.4	1.0	1.08***
Mg/K	0.2	60.0	0.0	0.6	1.7	3.4	0.7	0.18***
Ca/Mg	6.3	43.5	1.1	14.8	0.4	1.3	0.9	5.77 ns
Petioles								
N/P	1.5	68.6	0.4	6.3	2.4	7.5	1.7	9.65***
N/K	0.4	38.8	0.2	1.0	1.5	3.6	2.7	1.69***
N/Ca	1.0	23.9	0.4	1.5	0.0	-0.4	2.5	NA
Mg/N	0.3	56.5	0.1	0.9	2.1	5.1	1.4	0.09***
K/P	4.0	64.9	0.8	14.0	1.6	3.3	1.3	5.26***
Ca/P	1.5	79.7	0.4	7.6	2.8	9.7	0.8	5.79***
Mg/P	0.4	94.6	0.1	2.6	3.8	19.4	1.0	0.96***
Ca/K	0.4	29.9	0.2	0.7	0.9	-0.1	3.1	1.08***
Mg/K	0.1	84.0	0.0	0.5	2.9	10.0	1.4	0.18***
Mg/Ca	0.3	64.7	0.1	0.9	2.1	3.4	0.9	0.17***

Max = maximum, Min = Minimum, Skew = Skewness, Kurt = Kurtosis, NA: not available

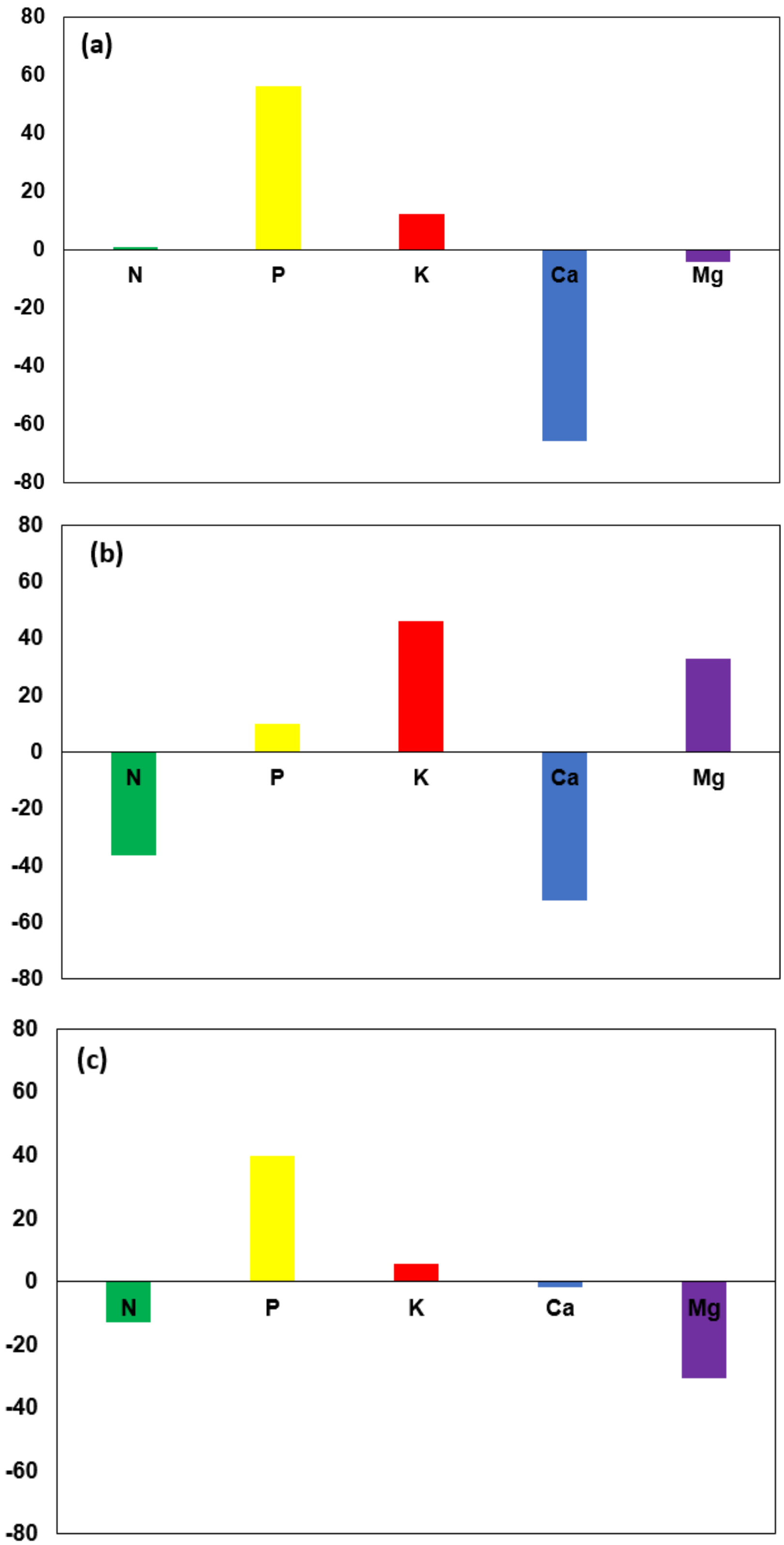

Fig. 1. Nutrient indices for petiole + limbe (a), limbe (b) and petiole (c)

Table 7. Nutrient diagnosis status

Leaf part	Nutrients					Nutrient Balance Index
	N	P	K	Ca	Mg	
Petiole	A	E	A	A	D	18.1
Limbe	D	A	E	D	A	35.5
Leaf	A	E	A	D	A	27.9

A = adequat; D = Deficient; E = excess

However, this is not consistent with some previous studies claiming that DRIS approach has been designed to provide a valid diagnosis irrespective of the plant age, harvested organ [22,10,13,34,22]. This is probably due to the fact that DRIS reference values were set using whole leaf, therefore there was no threshold for petiole and limb. According to diagnosis method of Braud [35], anions such as N, P, S, Cl and micronutrients are diagnosed in limbs whereas cations K, Ca and Mg are checked in petioles. This method of diagnosis is time consuming because it requires the separation of petiole and limbs.

The nutritional balance index (NBI) is a measure of balance among fields. It is calculated by adding the absolute values of indices generated for the sample [12]: the larger the value of the NBI, the greater the intensity of imbalances among nutrients at the time of sampling. Amongst the leaf organs, the NBI using limb is higher. Hence, the imbalance amongst the nutrients in cotton plants as diagnosed using limb is relatively higher than the others. Therefore, the DRIS methodology should be carried out either at limb, petiole or whole leaf level, depending on the objective of the study. The diagnosis of fertility has revealed a nutritional imbalance of the soil which necessitates the implementation of a balanced manure plan for the crop production.

5. CONCLUSION

The results showed a deficiency of magnesium, and especially calcium in cotton nutrition. In the whole leaf, nitrogen nutrition is hardly satisfied, whereas it is deficient in limb and petiole. However, the nutrition in potassium and especially in phosphorus was satisfied. This cannot facilitate proper mineral nutrition of the cotton plant. The improvement of the soil quality of the cotton zones through organic and / or mineral amendments, and the development of a balanced cotton fertilizer formula containing calcium and magnesium, is necessary to ensure the sustainable management of soils and optimum mineral nutrition of the cotton plant. Thus, the perspective of the study would be to look for optimal doses of calcium and magnesium in cotton growing in Benin.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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