Preliminary diagnosis of the nutrient status of cotton (*Gossypium hirsutum* L) in Benin (West Africa)

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Abstract

Critical leaf nutrient concentrations have often been used to diagnose the nutritional causes of crop under performance. The Diagnosis and Recommendation Integrated System (DRIS), however, provides a reliable means of linking leaf nutrient concentrations to the yield of cotton, and may be developed for this crop using existing experiment data. In the present study, carried out in the Upper Catchment of Benin, fiber yield and leaf nutrient concentration data from an organic and inorganic trials were used to establish Diagnosis and Recommendation Integrated System norms for nitrogen (N), phosphorus (P), potassium K, magnesium (Mg), calcium (Ca), sulphur (S) and zinc (Zn) and statistical parameters for cotton. The Diagnosis and Recommendation Integrated System norms provided by this study were as followings: N/P = 9.65; K/N = 0.59; N/Mg = 10.55; S/N = 0.08; P/K = 0.19; Ca/P = 5.79; Mg/P = 0.96; Zn/P = 0.01; Ca/K = 1.08; Mg/K = 0.18; Zn/K = 0.001; Ca/Mg = 5.77; S/Ca = 0.14; Mg/Zn = 143.84. Although the database was relatively small, the norms derived for nutrient ratios of key biological significance, i.e. N/S and K/N, were within the expected narrow ranges for higher plants, giving credibility to both the database and the Diagnosis and Recommendation Integrated System model. Data from future surveys and field experiments may subsequently be used to enlarge the database allowing the refinement of model parameters and hopefully an expansion of diagnostic scope to include other micro-nutrients. As it stands, this preliminary Diagnosis and Recommendation Integrated System model for cotton is a good diagnostic tool currently available for evaluating the N, P, K, Mg, Ca, S and Zn status for cotton crops in Benin.

Key words: Preliminary DRIS norms, fiber yield, cotton, Benin

Diagnostic préliminaire du statut nutritionnel de cotton (*Gossipium hirsutum L.*) au Bénin (Afrique de l'Ouest)

Résumé

La teneur critique des nutriments dans les feuilles est souvent utilisée pour diagnostiquer le statut nutritionnel des plantes et provoque généralement la contre performance des cultures. Cependant, le Système Intégré de Diagnostic et de Recommandation (SIDR) est un moyen d'établir un lien fiable entre la concentration foliaire des nutriments et le rendement en coton fibre et peut être développé pour cette culture en utilisant les données existantes d'expérimentation. Dans ce présent travail, réalisé dans le bassin versant de l'Ouémé Supérieur au Bénin, les données de rendement en coton fibre et des concentrations foliaires de nutriments sont utilisées pour établir les normes du Système Intégré de Diagnostic et de Recommandation de l'azote (N), du phosphore (P), du potassium (K), du magnésium (Mg), calcium (Ca) et du zinc (Zn). Les normes du Système Intégré de Diagnostic et de Recommandation fournies par ce travail ont été les suivantes : N/P = 9,65 ; K/N = 0,59 ; N/Mg = 10,55 ; S/N = 0,08 ; P/K = 0,19 ; Ca/P = 5,79 ; Mg/P = 0,96 ; Zn/P = 0,01 ; Ca/K = 1,08 ; Mg/K = 0,18 ; Zn/K = 0,001 ; Ca/Mg = 5,77 ; S/Ca = 0,14 ; Mg/Zn = 143,84. Bien que la base de données ait été relativement faible, les normes dérivant des nutriments ayant un rôle physiologique clé (ie N/S and K/N) étaient dans les gammes requises pour une meilleure production. Ce qui confère une fiabilité à la base de données utilisée et au modèle Système Intégré de Diagnostic et de Recommandation. Les résultats complémentaires d'autres essais permettront d'élargir cette base de données, de parfaire les paramètres du model et d'étendre le diagnostic à d'autres micro-éléments. Ce modèle préliminaire du Système Intégré de Diagnostic et de Recommandation pour le coton est un bon outil de diagnostic

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actuellement disponible pour évaluer le statut de N, P, K, Mg, Ca, S et Zn pour la culture du coton au Bénin.

Mots clés: Normes préliminaires SIDR, rendement fibre, coton, Bénin

INTRODUCTION

The use of chemical analysis of plant material for diagnostic purposes is based on the assumption that causal relationships exist between growth rate, yield and nutrient content in the shoot dry matter (Marschner, 1997). Critical leaf nutrient concentrations have frequently been used to diagnose nutritional status of plants (Tyner, 1946; Viets *et al.*, 1954; Beaufils et Sumner, 1977). The critical concentration approach is somewhat erroneous in that 'critical nutrient concentrations' are not independent diagnostics, but can vary in magnitude as the background concentrations of other nutrients increase or decrease in crop tissue (Walworth and Sumner, 1986; Bailey, 1989; Bailey, 1991; Bailey, 1993). These criteria have been evaluated for a wide range of crops (Katyal and Randhawa, 1985; Jones *et al.,* 1990; Westfall *et al.,* 1990; Kelling and Matocha, 1990) including cotton (Sabbe *et al.,* 1972; Dagbenonbakin, 2005). Walworth and Sumner (1987) underline that foliar analysis is helpful for assessing plant nutrient status only if adequate procedures are available for making diagnoses from analytical data. According to Beaufils (1973) and Walworth and Sumner (1987), an alternative approach to nutritional status evaluation is the Diagnosis and Recommendation Integrated System (DRIS). This method uses a comparison of leaf tissue concentration ratios of nutrient pairs with norms developed from high-yielding populations to diagnose nutrient status. DRIS has been used successfully to interpret the results of foliar analyses for a wide range of crops such as rubber and sugarcane (Elwali and Gascho, 1984), vegetables, potatoes, wheat (Amundson and Koehler, 1987; Meldal-Johnson and Sumner, 1980), forage grass (Bailey *et al.,* 1997a; Bailey *et al.*, 1997b; Bailey *et al.*, 2000) mango (Hundal and Dhanwinder Singh Brar, 2005) and even pineapple (Agbangba, 2008; Agbangba *et al.*, 2010; Dagbenonbakin *et al.*, 2010). As yet, it has not been applied to cotton probably because of the lack of suitable survey data to establish the DRIS model parameters.

As in Benin and many other countries of Africa, cotton is an essential element of the economic activity. The 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 assures an income for more than a third of the population. Cotton is an important path for the socioeconomic development and, therefore, contributes to the struggle against the poverty. The cotton production is therefore an essential motor for the farming economy in Benin.

The aim of the present study was to develop DRIS model parameters for cotton variety STAM18A using 68 fiber yields and leaf tissue nutrient concentrations data from the 2001 and 2002 organic and inorganic fertilizer survey in the Upper Catchment of Benin.

MATERIAL AND METHODS

Experimental site

The experiments were carried out in 2001 and 2002 at three sites as follows: Beterou (southern Borgou Department); Dogue (southern Donga Department); Wewe (border of southern Borgou and southern Donga Departments), at a distance of about 45, 87 and 80 km, respectively, from Parakou. The distribution of the plots at the different sites is shown in figures 1 and 2.

The table 1 presented the physical and chemical properties of soils at Beterou, Dogue and Wewe. Soil textures found in the top 20 cm were loamy sand with 3-10 % of clay and 76-86 % of sand, and sandy loam with 7-13 % of clay and 73-80 % of sand on all site. Soils in the three locations have low fertility.

The climate on the site is Soudanese-Guinean. The rainfall distribution is unimodal with two seasons; a rainy season from mid of April to mid of October, and the subsequent dry season. The average total annual rainfall is 1,167.6 mm. The average temperature is 25 °C. First rainfall begins in March, and becomes significant from May to September.

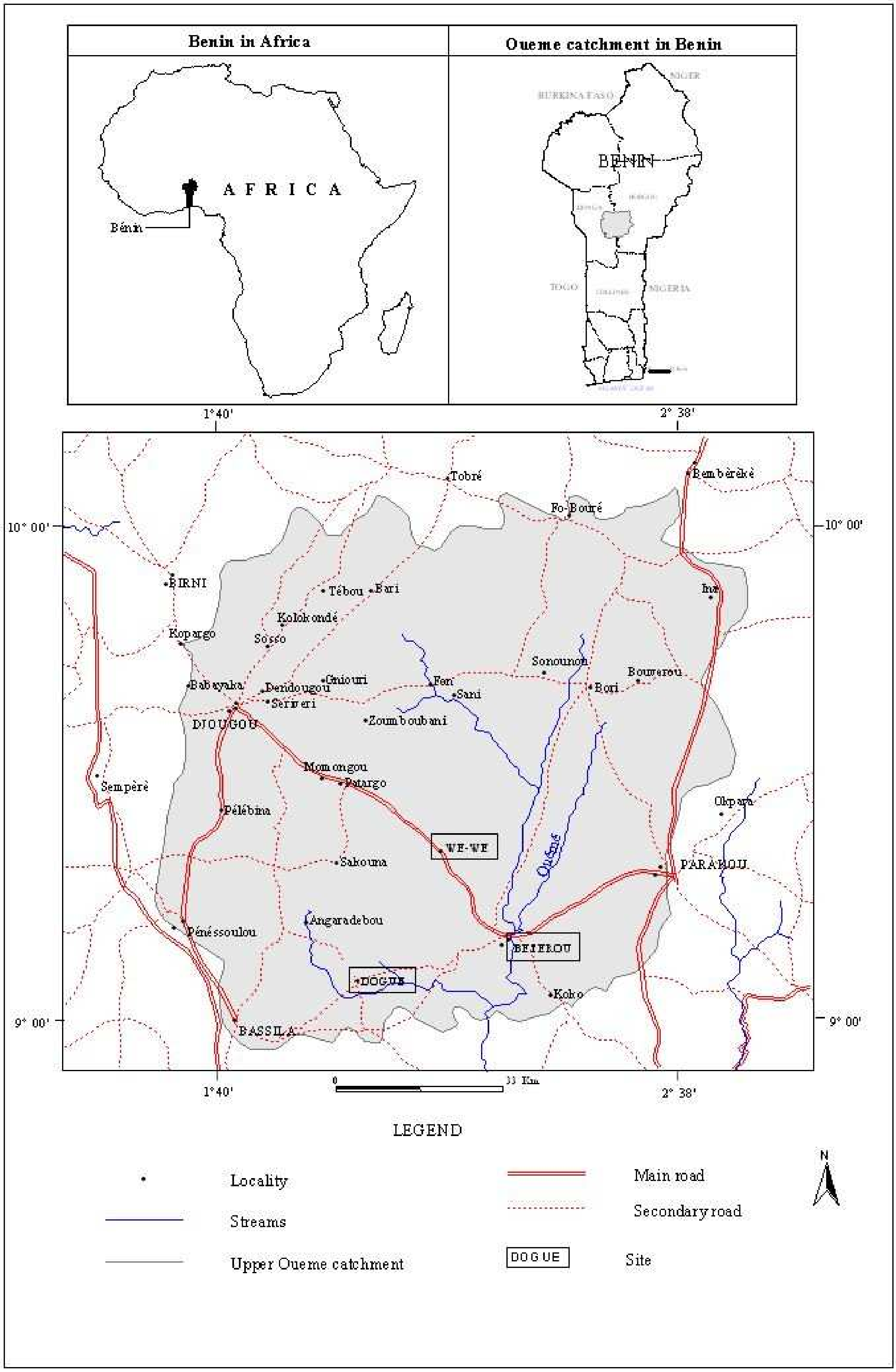

Figure 1. Location of the experiment area (Upper Ouémé Catchment)

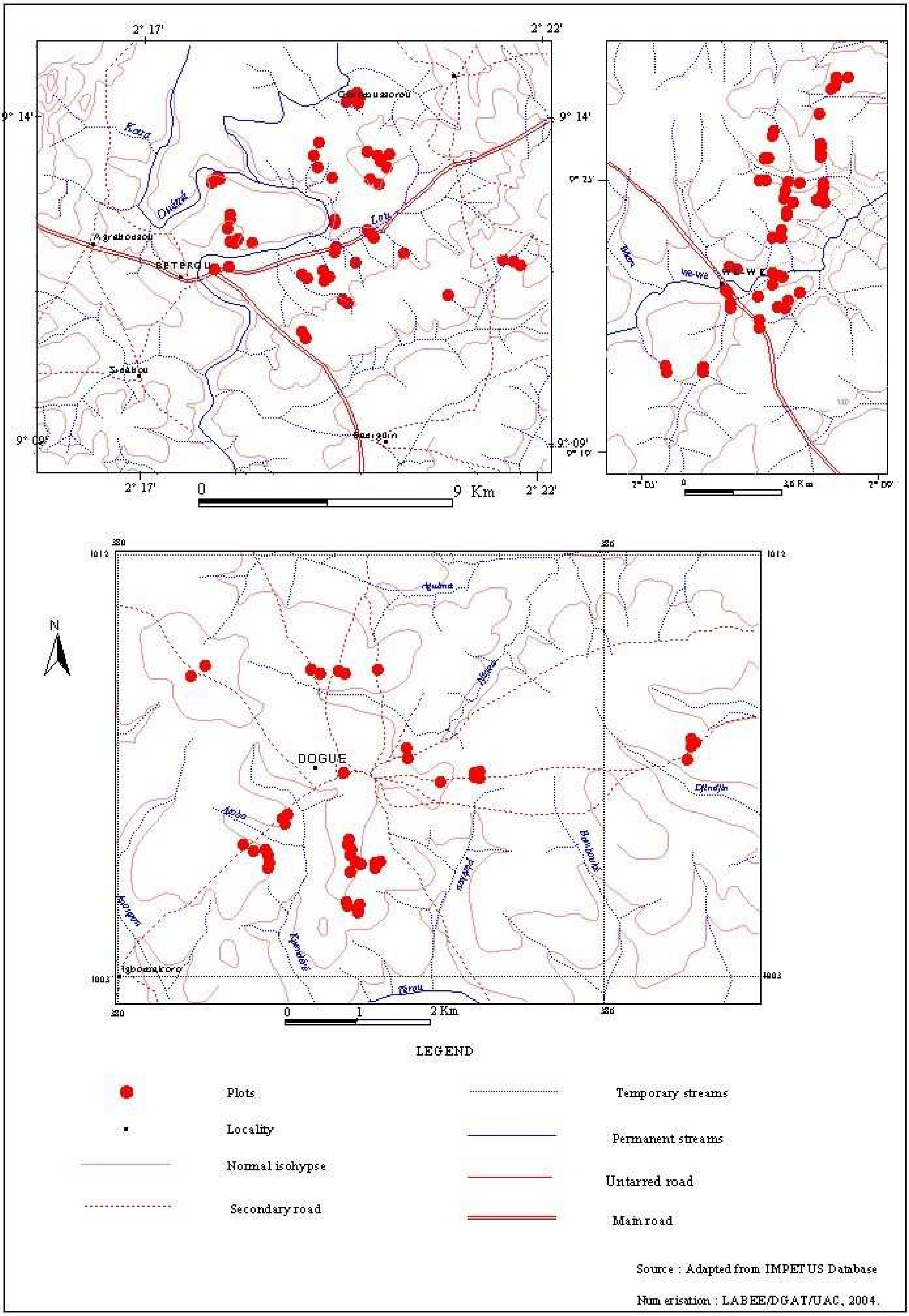

Figure 2. Map of the distribution of the field plots at the three sites

Table 1. Overview of soil characteristics (plough layer: 0 – 20 cm) at the beginning of the experiment (in parenthesis) Standard deviation

Sites	Clay	Silt	Sand	Texture	P	K	pH	N	OM	C/N
	Physical properties				Chemical properties					
	-------[%]------				Mg kg^{-1}	Cmolkg^{-1}		------[%]-----		
Lighter soils										
Beterou										
Mean	6.8	9.7	82.9	LS	11.1	0.25	6.7	0.064	1.53	14.1
	(1.1)	*(1.4)*	*(1.5)*		*(4.3)*	*(0.04)*	*(0.1)*	*(0.009)*	*(0.23)*	*(0.8)*
Dogue										
Mean	7.2	9.8	81.8	LS	4.0	0.12	6.4	0.058	1.26	12.76
	(0.8)	*(2.4)*	*(2.9)*		*(1.3)*	*(0.03)*	*(0.1)*	*(0.013)*	*(0.21)*	*(0.8)*
Wewe										
Mean	7.2	11.0	81.2	LS	6.3	0.14	6.6	0.058	1.26	16.7
	(0.9)	*(2.0)*	*(2.0)*		*(2.5)*	*(0.03)*	*(0.1)*	*(0.016)*	*(0.17)*	*(9.4)*
Heavier soils										
Beterou										
Mean	8.8	11.7	78.2	SL	17.6	0.31	6.7	0.061	1.66	15.5
	(1.5)	*(1.4)*	*(1.5)*		*(11.8)*	*(0.07)*	*(0.1)*	*(0.019)*	*(0.69)*	*(2.3)*
Dogue										
Mean	8.6	13.8	76.7	SL	5.2	0.15	6.4	0.064	1.42	13.1
	(0.7)	*(1.9)*	*(1.8)*		*(3.1)*	*(0.03)*	*(0.1)*	*(0.008)*	*(0.21)*	*(0.5)*
Wewe										
Mean	9.6	14.2	75.6	SL	8.1	0.20	6.8	0.068	1.47	13.3
	(1.8)	*(1.9)*	*(1.7)*		*(3.8)*	*(0.07)*	*(0.1)*	*(0.011)*	*(0.27)*	*(2.3)*

Sampling design and chemical analyses

Plants youngest fully mature leaves on the main stem were sampled at the first bloom as recommended by Jones and Steyn (1971). After air drying, material was further dried at 70 °C to a constant weight, pre-ground by a Brabender mill and stored dry. Soil samples, 0-20 cm depth, were collected at each farmer field before the experimental block was installed. The cotton fiber was harvested in a (2 x 2) m^2 area and repeated thrice per plot. Plant material was ground by a planetary mill (Retsch). The following analyses were carried: C, N and S determined by elemental analysis in the EuroEA 3000. Further elemental composition was determined after dry ashing in porcelain crucibles at 550°C in a muffle furnace, dissolving the ash in co ncentrated nitric acid, evaporation to dryness on a sand bath (to precipitate silicate), and taking up with concentrated nitric acid again, and transferred to volumetric flasks with several rinses of ultra pure water (MilliporeQ). P was determined using the molybdo-vanadate blue method, with a spectral photometer (model Eppendorf Digitalphotometer 6114) at wavelengths of 465 and 665 µm. K, Ca, Mg and micronutrients were determined on a Perkin-Elmer PE 1100 B atomic absorption spectrophotometer (flame).

The soil texture (five fractions) was done by Robinson pipette (Tran et Boko, 1978). The pH was determined in water (a soil/water ratio of 2:1) using a pH meter with glass combination electrode with a WTW pmx 2000; total N was determined using the macro Kjeldahl procedure described by Jackson (1958) with a Gerhardt Vapodest; organic C was determined using the method described by Walkley and Black (1934 in Tran et Boko, 1978) and the organic matter content calculated by multiplying organic C by 1.724; C, N, and S were determined by an automatic Elemental Analyser EuroEA 3000 according to the Dumas method; P was extracted with calcium-acetat-lactat-extraction (CAL) and determined by colour development in the extract with molybdenum blue and photometric measurement. Micronutrient levels were determined after extraction of soil samples with 01 N HCl, adjusted to volume, and filtered through Whatman No1. Analysis was done with a Perkin-Elmer flame atomic absorption spectrophotometer, Model 70PE 1100 B.

Development of the Diagnosis and Recommendation Integrated System (DRIS) model and data analysis

The fiber yield and leaf tissue nutrient concentration data DRIS norms and coefficients of variation (CVs) were derived according to the procedure by Walworth and Sumner (1987). Scatter diagrams of yield versus nutrient concentrations and all conceivable nutrients ratios were constructed and subdivided into high-yielding and low-yielding sub-populations with the cutoff point between the two subpopulations set at 652.5 kg ha^{-1} (mean ± margin error). The rational for this subdivision is that nutrient data for high-yielding plants are usually more symmetrical than those for low-yielding plants (Walworth and Sumner 1986; Walworth and Sumner 1986, 1987). The yield at which the division between the two sub-populations was set, was a compromise between maximizing the potential for data symmetry in the high-yielding sub-population (i.e. by excluding data for low-yielding) (Ramakrishna *et al.*, 2009), yet including as many data points as possible for statistical credibility (Walworth and Sumner, 1987).

Mean values or norms for each nutrient expression together with their associated CVs and variances were then calculated for the two sub-populations. The mean values in the high-yielding sub-population of fourteen nutrient expressions involving seven nutrients (N, P, K, Mg, Ca, Zn, and S) were ultimately chosen as the diagnostic norms for cotton. The selection was made along the following priorities. The first was to ensure that the leaf nutrient concentration data for the high-yielding sub-population were relatively symmetrical or unskewed, so that they provided realistic approximations of the likely range of interactive influences of different nutrients on crop productivity (Ramakrishna *et al.*, 2009). The second priority was to select nutrient ratio expressions that had relatively unskewed distributions in the high-yielding sub-population (skewness values <1.0), to try to ensure that calculated mean values or norms for these ratios would match well with the 'true' values at maximum crop yield. The third priority was to select nutrient expressions for which the variance ratios (Vlow/Vhigh) were relatively large (>1.0), thereby maximizing the potential for such expressions to differentiate between 'healthy' and 'unhealthy plants' (Walworth and Sumner 1987). As a final check, plots of yield versus nutrient ratios were prepared and fitted with boundary lines (the fitting being done by visual approximation) to ensure that the nutrient ratio values at the points of convergence of the boundary lines corresponded closely with the calculated mathematical means (norms).

Having evaluated the model parameters, DRIS indices may then be calculated for nutrients A to N using the following generalized equations (Bailey, 1997a; Bailey, 1997b; Hallmark, 1987):

X index = $\left[f\left(\frac{X}{A}\right) + f\left(\frac{X}{B}\right) + \cdots - f\left(\frac{M}{X}\right) - f\left(\frac{N}{X}\right) - \cdots \right]$, 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 $\frac{X}{A} < \frac{x}{a} - SD$.

$\frac{X}{A}$ is the ratio of concentrations of nutrients X and A in the sample while $\frac{x}{a}$, CV, SD are 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 $\frac{N}{x}$ are calibrated against the corresponding DRIS reference parameters, $\frac{x}{b}$, $\frac{m}{b}$ and $\frac{n}{x}$.

Nutrient indices calculated by this formula can 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.

Descriptive statistics were determined for tuber yield, leaf nutrient concentration and nutrient ratio expression data using Minitab statistical software version 14. Descriptive statistics 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.

RESULTS

Leaf nutrients concentration statistics

Summary statistics for the fiber yield and leaf nutrient concentration data available from the 2001, 2002 trial are given in Table 2. The fiber yield data ranged from 69.83 kg ha^{-1} to 646.02 kg ha^{-1} with a mean of 553.79 kg ha^{-1} in the full population. Twenty two (22) out of sixty eight (68) data points were assigned to the high-yielding subpopulation (≥ 652.5 kg ha^{-1}) fewer than would normally be used for the establishment of DRIS model parameters (Walworth et al. 1986). However, a preponderance of high-yielding data is not absolutely essential for the establishment of DRIS model parameters, provided sufficient such data are available to delineate maximum yield response surfaces to the nutrient variables plotted on the abscissa, and to enable optimal values for these variables to be determined at the points of convergence (apexes) of the yield response surfaces; and this indeed appeared to be the case. As regards the leaf nutrient concentrations, the data for all the nutrients N, P, K, Ca, Mg, Zn were relatively symmetrical, with all of them having skewness values less than 1.0 and hence were deemed suitable for DRIS model development.

Binary nutrients ratio statistics

Binary nutrient ratio combinations of all seven macro and micro nutrients were therefore calculated, and summary statistics evaluated for each of the resulting 42 nutrient ratio expressions (table 3). To determine which nutrient ratio expressions in table 3 should be included in the DRIS model, the selection priorities, previously outlined (above), were sequentially applied. Firstly, nutrient ratios were selected that had skewness values less than 1.0, thereby eliminating 16 nutrient ratio expressions. Secondly, on the basis of the variance ratios (Vlow/Vhigh), fourteen of the remaining nutrient ratio expressions (table 4) were selected which had ratios greater than 1.0 (excepted for S/N), i.e. N/P, K/N, N/Mg, S/N, P/K, Ca/P, Mg/P, Zn/P, Ca/K, Mg/K, Zn/K, Ca/Mg, S/Ca, Mg/Zn (table 3).

Table 2. Summary statistics for cotton fiber yield and leaf nutrient concentration data for total (n=68) and high-yielding (n=22) subpopulations

Parameters	Total yielding population (n = 68)						High yielding sub-population (n = 22)					
	Mean	CV (%)	Median	Minimum	Maximum	Skewness	Mean	CV (%)	Median	Minimum	Maximum	Skewness
Fiber (kg ha^{-1})	553.8	43.8	502.8	69.8	1240.9	0.5	836.7	17.9	809.0	658.5	1240.9	1.1
Nutrient (g kg^{-1})												
N	26.8	17.4	26.9	15.5	35.2	-0.3	27.2	17.2	26.8	15.5	34.2	-0.5
P	3.0	28.6	2.8	1.5	5.7	0.7	2.9	19.3	2.8	1.6	3.9	0.1
K	14.7	23.6	15.0	7.5	21.5	-0.3	15.9	19.3	15.9	7.5	21.1	-0.8
Ca	18.2	39.3	19.2	2.7	34.3	-0.5	16.3	41.2	19.9	3.4	23.3	-1.2
Mg	2.7	29.2	2.8	1.2	4.3	-0.3	2.8	28.9	2.9	1.3	4.3	-0.1
S	2.1	35.8	2.1	0.7	3.7	-0.1	2.2	42.5	2.4	0.7	3.7	-0.4
Nutrient (mg.kg^{-1})												
Zn	23.0	32.7	21.8	11.0	48.3	0.8	19.1	24.8	18.4	12.3	30.0	0.8

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

Nutrient Ratio	Low yielding sub-population						High yielding sub-population						Vlow/Vhigh
	Mean	CV	Median	Minimum	Maximum	Skewness	Mean	CV	Median	Minimum	Maximum	Skewness	
N/P	9.60	30.3	9.37	5.62	18.20	1.0	9.65	23.7	9.04	6.16	12.78	0.1	1.6
P/N	0.11	27.6	0.11	0.05	0.18	0.2	0.11	24.9	0.11	0.08	0.16	0.5	1.3
N/K	2.00	31.6	1.86	1.18	3.99	1.3	1.75	20.1	1.62	1.33	2.67	1.1	3.2
K/N	0.54	27.4	0.54	0.25	0.85	0.2	0.59	17.6	0.62	0.37	0.75	-0.5	2.0
N/Ca	1.93	101.3	1.33	0.84	9.70	3.1	2.47	91.9	1.58	1.05	7.97	1.8	0.7
Ca/N	0.71	32.0	0.75	0.10	1.19	-1.2	0.61	41.6	0.63	0.13	0.95	-0.9	0.8
N/Mg	10.88	31.5	10.07	6.37	22.09	1.4	10.55	29.1	10.24	5.55	17.17	0.7	1.2
Mg/N	0.10	26.2	0.10	0.05	0.16	0.0	0.10	30.5	0.10	0.06	0.18	1.0	0.7
N/S	14.66	37.2	13.56	8.16	33.77	1.8	15.85	63.7	11.94	6.96	39.90	1.6	0.3
S/N	0.08	28.8	0.07	0.03	0.12	0.0	0.08	41.6	0.08	0.03	0.14	-0.1	0.4
N/Zn	1157.55	30.0	1099.23	547.70	2302.73	1.3	1484.76	24.2	1600.00	824.22	2029.23	-0.5	0.9
Zn/N	0.0009	28.4	0.0009	0.0004	0.0018	1.0	0.0007	29.4	0.0006	0.0005	0.0012	1.1	2.2
P/K	0.21	21.1	0.21	0.12	0.33	0.8	0.19	20.7	0.18	0.12	0.26	0.2	1.4
K/P	4.90	21.0	4.87	3.00	8.35	0.8	5.57	21.6	5.60	3.84	8.12	0.7	0.7
P/Ca	0.21	90.7	0.15	0.06	0.88	2.8	0.27	100.6	0.14	0.13	0.97	1.9	0.5
Ca/P	6.78	46.4	6.59	1.14	17.41	0.9	5.79	41.1	7.13	1.03	7.80	-1.3	1.8
P/Mg	1.20	36.7	1.07	0.57	2.40	1.1	1.14	35.8	0.98	0.73	2.01	1.4	1.2
Mg/P	0.93	33.0	0.93	0.42	1.77	0.4	0.96	26.2	1.02	0.50	1.37	-0.8	1.5
P/S	1.61	40.6	1.48	0.79	4.17	1.6	1.74	71.9	1.17	0.84	4.97	1.7	0.3
S/P	0.70	34.0	0.67	0.24	1.27	0.3	0.77	40.5	0.86	0.20	1.19	-0.7	0.6
P/Zn	127.36	33.5	122.34	58.61	284.55	1.1	156.21	21.2	143.30	120.94	230.77	1.1	1.7
Zn/P	0.01	34.3	0.01	0.00	0.02	1.0	0.01	18.2	0.01	0.004	0.01	-0.6	6.0
K/Ca	1.10	119.9	0.77	0.27	6.48	3.1	1.55	105.1	0.77	0.62	5.52	1.8	0.7
Ca/K	1.45	48.0	1.29	0.15	3.67	0.8	1.08	42.8	1.30	0.18	1.62	-1.1	2.3
K/Mg	5.86	42.3	5.14	2.66	12.76	1.5	6.31	39.4	5.21	3.46	11.44	0.9	1.0

Nutrient Ratio	Low yielding sub-population						High yielding sub-population						Vlow/Vhigh
	Mean	CV	Median	Minimum	Maximum	Skewness	Mean	CV	Median	Minimum	Maximum	Skewness	
Mg/K	0.20	34.9	0.19	0.08	0.38	0.5	0.18	34.9	0.19	0.09	0.29	0.2	1.2
K/S	7.86	48.3	6.70	3.84	20.67	2.2	9.70	76.6	6.40	4.52	28.24	1.7	0.3
S/K	0.15	33.2	0.15	0.05	0.26	0.2	0.14	41.5	0.16	0.04	0.22	-0.7	0.7
K/Zn	625.51	41.3	565.31	277.34	1334.55	1.1	869.43	28.5	850.14	499.00	1289.23	0.3	1.1
Zn/K	0.00	37.5	0.0018	0.0007	0.0036	0.6	0.001	29.1	0.001	0.001	0.002	0.5	5.0
Ca/Mg	7.34	38.2	6.94	1.85	15.79	0.5	5.77	34.2	6.41	2.04	8.90	-0.8	2.0
Mg/Ca	0.17	60.7	0.14	0.06	0.54	2.6	0.21	57.8	0.16	0.11	0.49	1.7	0.7
Ca/S	9.62	35.5	9.20	2.64	19.59	0.6	7.53	34.8	6.94	4.60	16.36	1.9	1.7
S/Ca	0.12	50.3	0.11	0.05	0.38	2.6	0.14	27.3	0.14	0.06	0.22	-0.1	2.4
Ca/Zn	764.60	28.7	759.92	191.43	1078.91	-1.0	838.37	36.2	969.11	224.00	1191.27	-1.2	0.5
Zn/Ca	0.00	60.3	0.0013	0.0009	0.01	3.0	0.002	73.1	0.00	0.00	0.00	1.9	0.7
Mg/S	1.38	26.3	1.30	0.80	2.27	0.5	1.44	37.8	1.26	0.64	2.51	0.6	0.4
S/Mg	0.78	25.8	0.77	0.44	1.25	0.3	0.79	37.5	0.79	0.40	1.57	0.8	0.5
Mg/Zn	111.68	30.5	112.50	57.67	194.50	0.4	143.84	16.4	142.74	92.50	184.57	-0.3	2.1
Zn/Mg	0.01	32.3	0.01	0.01	0.02	0.7	0.01	18.5	0.01	0.01	0.01	1.2	5.6
S/Zn	83.78	32.0	75.02	44.89	158.50	1.1	113.71	37.2	118.49	45.33	185.00	-0.1	0.4
Zn/S	0.01	27.6	0.01	0.01	0.02	0.1	0.01	47.6	0.01	0.01	0.02	1.2	0.5

Table 4. DRIS norms, CV's and skeweness values for the high-yielding subpopulation, and variance ratios (Vlow/Vhigh) of nutrient ratio expressions selected for inclusion in the DRIS model for cotton

Nutrient Ratio	High yielding sub-population						Vlow/Vhigh
	Mean	CV (%)	Median	Minimum	Maximum	Skeweness	
N/P	9.65	23.7	9.04	6.16	12.78	0.1	1.6
K/N	0.59	17.6	0.62	0.37	0.75	-0.5	2.0
N/Mg	10.55	29.1	10.24	5.55	17.17	0.7	1.2
S/N	0.08	41.6	0.08	0.03	0.14	-0.1	0.4
P/K	0.19	20.7	0.18	0.12	0.26	0.2	1.4
Ca/P	5.79	41.1	7.13	1.03	7.80	-1.3	1.8
Mg/P	0.96	26.2	1.02	0.50	1.37	-0.8	1.5
Zn/P	0.01	18.2	0.01	0.004	0.01	-0.6	6.0
Ca/K	1.08	42.8	1.30	0.18	1.62	-1.1	2.3
Mg/K	0.18	34.9	0.19	0.09	0.29	0.2	1.2
Zn/K	0.001	29.1	0.001	0.001	0.002	0.5	5.0
Ca/Mg	5.77	34.2	6.41	2.04	8.90	-0.8	2.0
S/Ca	0.14	27.3	0.14	0.06	0.22	-0.1	2.4
Mg/Zn	143.84	16.4	142.74	92.50	184.57	-0.3	2.1

DISCUSSION

The DRIS model for cotton, developed in this study, is a diagnostic tool that may be used to predict if insufficiencies or imbalances in N, P, K, Mg S and Zn supplies are occurring in cotton crops in Benin and indeed elsewhere in the North of the country. Admittedly, the database used for model development was relatively small. However, the DRIS norms for the two nutrient ratios of known physiological and diagnostic importance, namely N/S (12.5) and K/N (0.59 ≈ 0.6), had norm values within the expected narrow ranges for higher plants, i.e. 11– 13 for N/S, 0.6–0.9 for K/N (Elwali and Gascho 1984; Meldal-Johnsen and Sumner 1980; Stevens and Watson 1986; Amundson and Koehler 1987; Jones *et al.* 1990; Kelling and Matocha 1990; Dampney 1992; Marschner 1995), thus giving credibility both to the database and to the DRIS model. Nitrogen and S are vital constituents of sulphur-containing amino acids and need to be present in quite specific proportions if the requisite proteins and protein containing structures are to be synthesized by plants (Marschner 1995). Equally, K is known to have a key role in N uptake and translocation (Minotti *et al.* 1968; Cushnahan *et al.* 1995), and therefore both N and K need to be present in quite specific proportions whether N accumulation and subsequent assimilation into proteins is to take place at optimal rates. There is perhaps less obvious physiological rationale for maintaining specific N/P, N/Mg, P/K, Ca/P, Mg/P, Zn/P, Ca/K, Mg/K, Zn/K, Ca/Mg, S/Ca, Mg/Zn ratios in leaf tissue, and this is probably why most of them had CV's greater than 30 % (Ramakrishna *et al.*, 2009). Nonetheless, the nutrients in question (N, P, K, Mg, Ca, Zn and S), being major yield-building components, probably do need to be kept in a state of relative balance within cotton tissue if fiber production is to be sustained and optimized.

CONCLUSION

Data from future field and surveys experiments may subsequently be used to enlarge the model database and allow the refinement of DRIS parameters and hopefully an expansion of diagnostic scope to include other micronutrients. As it stands, though, this preliminary DRIS model for cotton is one of the best diagnostic tools currently available for simultaneously evaluating the N, P, K, Ca, Mg, S and Zn statuses of cotton crops in Benin. Since cotton is the first export crop in Benin, the present DRIS model could be important as a tool for refining the nutrient needs of cotton crops in the region.

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