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RESEARCH ARTICLE

PRELIMINARY DRIS MODEL PARAMETERIZATION TO ACCESS GROUNDNUT (*ARACHIS HYPOGAEA L.)* NUTRIENT STATUS IN BENIN (WEST AFRICA)

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ABSTRACT

The use of critical concentration approach to diagnosis the nutrient status of plants 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. The Diagnosis and Recommendation Integrated System (DRIS), an alternative is sometimes less sensitive than the sufficiency range approach to differences caused by leaf position, tissues age, climate, soil conditions, and cultivar effect because it uses nutrient ratios. The DRIS provides a reliable means of linking leaf nutrient concentrations to the yield of groundnut, and may be developed for this crop using existing experimental data. The present study was carried out in the Upper Catchment of Benin in 2001 and 2002, and grain yield and leaf nutrient concentration data from organic and inorganic trials were used to establish DRIS norms for N, P, K, Mg, Ca, S and Zn and statistical parameters for groundnut. The DRIS norms from this study were K/Ca: 1.4, K/S: 15.8, K/N:0.7, Mg/Ca: 0.2, Mg/K: 0.2, Mg/P: 2.1, Mg/Zn: 159.8, N/Ca: 2, N/S: 23.9, Zn/N: 0.0008, P/K: 0.1, P/N: 0.1, P/S: 1.3, P/Ca: 0.1, P/Zn: 76.1, S/Ca: 0.1, and Zn/Ca: 0.002. 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 DRIS 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 the diagnostic scope such as to include other micro-nutrients. The nutrient status assessment using the selected DRIS norms shows a good nutrient level for N, P, K, Ca, S and Zn in the groundnut leaves for high yielding as their value was similar to those presented in the literature. As it stands, this preliminary DRIS model for groundnut offers a good diagnostic tool for evaluating the N, P, K, Ca, S and Zn status of groundnut crops in Benin.

INTRODUCTION

The use of chemical analysis of plant material for diagnostic purposes is based on the assumption that causal relationships exist between growth rate (and 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, 1991, 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). 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

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****Corresponding author:*** dagust63@yahoo.fr foliar analyses for a wide range of crops such as rubber and sugarcane (Elwali and Gascho 1984), potato (Meldal Johnson and Sumner, 1990; Mackay *et al*., 1987;), apple (Szü cs *et al*.,1990; Singh *et al*., 2000), peach (Awasthi *et al*., 2000), mango (Raj and Rao, 2006), sweetpotato (Ramakrishna *et al*., 2009), grassland swards (Bailey 1997), cauliflower (Hundal *et al*., 2003), rice (Singh and Agrawal, 2007), corn (Escano *et al*., 1981, Elwali *et al*., 1985, Soltanpour *et al*., 1995) , tomatoes (Hartz *et al*., 1998), pineapple (Angeles *et al*. 1990; Teixeira *et al*., 2009: Agbangba, 2008; Agbangba *et al*., 2010; Dagbenonbakin *et al*., 2010), cotton (Dagbenonbakin *et al*., 2009). The DRIS approach was designed to provide a valid diagnostic irrespective of plant age, tissue origin (Sumner, 1977a, Meldal-Johnsen and Sumner 1990, Bailey 1997, Jones, 1993 Sumner, 1977) cultivar, local conditions (Payne *et al*., 1990), or changes in the method of tissue sampling or the time of sampling (Moreno *et al*., 1996). The DRIS is sometimes less sensitive than the sufficiency range approach to differences caused by leaf position, tissues age, climate, soil conditions, and cultivar effect because it uses nutrient ratios (Sanchez *et al*., 1991). Once DRIS norms have been established and validated from a large population of randomly distributed observations, they should be universally applicable to that crop (Sumner 1977a, 1979) because of for a given species, there appear to be specific nutrient ratios for maximum crop performance that transcend local conditions, such soil, climate and cultivars (Snyder and Kretschmer, 1988, Snyder *et al*., 1989). As yet, DRIS has not been applied to groundnut.

China leads in production of groundnuts having a share of about 41.5% of overall world production (http://en.wikipedia.org/wiki/Peanut), followed by India (18.2%) and the United States of America (6.8%). Groundnut was found to be the first of important oilseed crops grown in West African countries followed by rapseed and mustard, sesame, linseed, safflower and castor. Groundnut is one of the main annual crops in Benin. The cultivated area of this crop occupies about 100,000 hectares (ha) in Benin. It still occupies an important place as in central Benin, for instance, groundnut seeds play an important role in traditional customs as people eat a fried paste made from its seed alone. Its importance as a cash crop in the economy of the region is highly documented (Bationo *et al*, 2007; Labitan, 2010). In the country, the groundnut oil is edible, used in cookery because it has a mild flavor and a relatively high smoke point and in the manufacture. Groundnut kernel is nutritionally rich, high protein content. Otherwise, whether crops consumption was found as a source of aflatoxin exposure, dietary exposure to aflatoxin from groundnut was less than from maize in young children from Benin and Togo (Egal *et al*., 2005). Due to its high monounsaturated content, it is considered healthier than saturated oils, and is resistant to rancidity. Collines Department is one of the main areas of production of this crop and the yield did not exceed 0.90 $t.ha^{-1}$ in Benin. Although groundnuts help countering malnutrition and childhood anemia, however, it importance in bridging the hunger gap in Benin is less well known in policy circles. It is known that the major problems of groundnut farmers in Benin are low crop productivity because this crop took up a larger proportion of the recovered 15N than the trees (Cattan 1993, Schilling 1997).

The aim of the present study was to develop DRIS model parameters for groundnut using grain yield and leaf tissue nutrient concentration data from the 2001 and 2002 through organic and inorganic fertilizer survey for assessing mineral nutrient of this crop in the Upper Catchment of Benin.

MATERIAL AND METHODS

Experimental site

Experiments were carried out in 2001 and 2002 at three sites: Beterou (southern Borgou Department), Dogue (southern Donga Department), and Wewe (border of southern Borgou and southern Donga Departments), at a distance of about 45, 87 and 80 km, respectively, from Parakou (Figure 1). The distribution of the plots at the different sites is shown in figure 2. Soil textures (table 1) at Beterou, Dogue and Wewe taken 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 Sudanese-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 1167.6 mm. The average temperature is 25°C. First rainfall begins in March, and becomes significant from May to September.

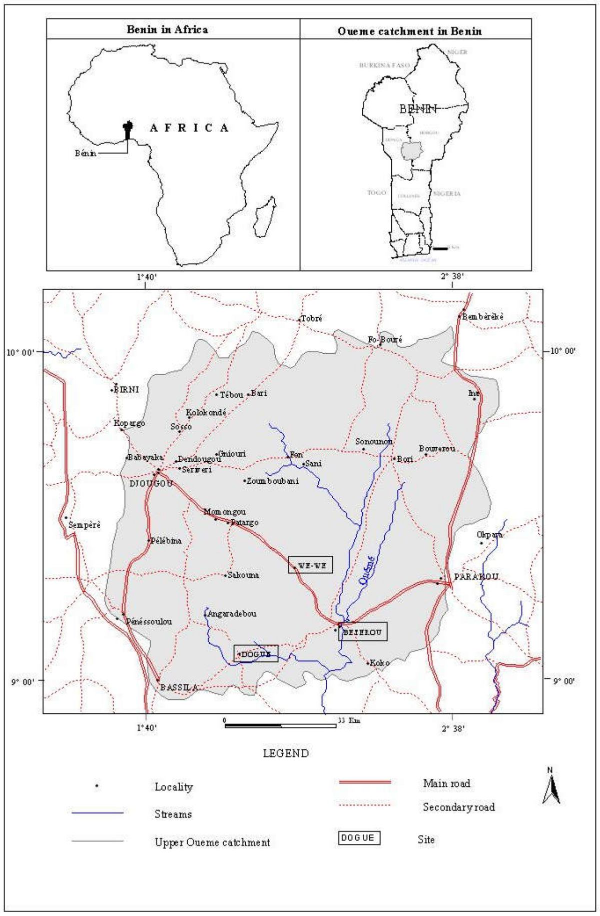
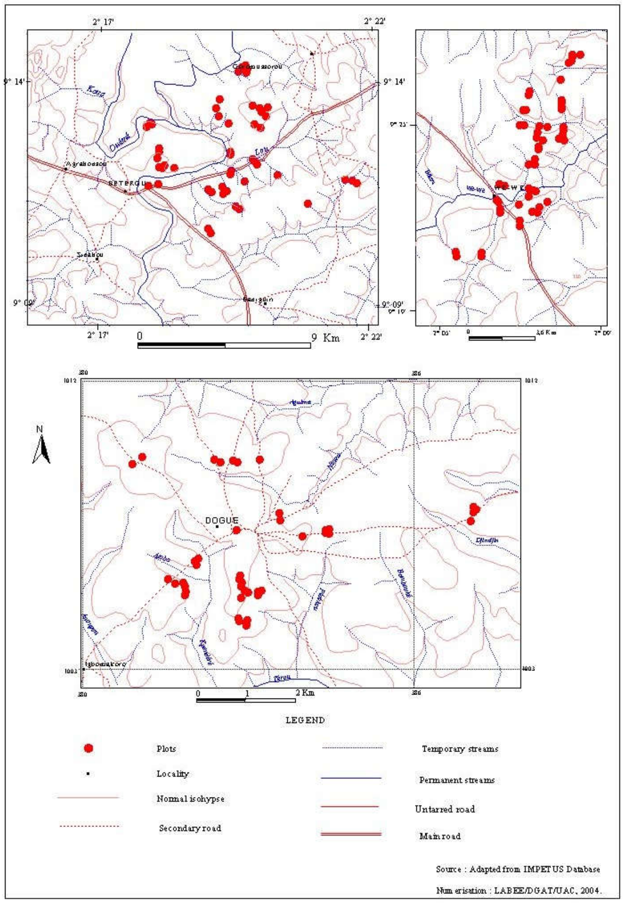


Figure 1. Location of the experiment area (Upper Oueme Catchment)



Source : Adapted from IMPETUS Database

Numérisation : LABEE/DGAT/UAC, 2004.

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

Sampling design and chemical analyses

Mature leaves from both the main stem and either cotyledon lateral branch were sampled at the blooming stage as recommended by FAO (2000) and Leo M *et al.* (1973). 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 groundnut grain 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 concentrated 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 al.*, 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) 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 DRIS model and data analysis

The grain yield and leaf tissue nutrient concentration data DRIS norms and coefficients of variation (CVs) were derived according to the procedure of 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 cut off point between the two subpopulations set at 1233,50 kg ha^{-1} (mean + interval of confidence). 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, 1987). The yield at which the separation 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 seventeen expressions involving seven nutrients (N, P, K, Ca, Mg, Zn, and S) were ultimately chosen as the diagnostic norms for groundnut. 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). The third priority was to select nutrient expressions for which the variance ratios (V low/V high) were relatively large (>1.0), thereby maximizing the potential for such expressions to differentiate between ‘healthy’ and ‘unhealthy plants’ (Walworth and Sumner 1987). Having evaluated the model parameters, DRIS indices may then be calculated for nutrients A to N using the following generalized equations (Bailey *et al.*, 1997a; Hallmark *et al.*, 1987):

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

Where $f\left(\frac{\mathrm{X}}{\mathrm{A}}\right)=100\left[\left(\frac{\mathrm{X}}{\mathrm{A}}\right)/\left(\frac{\mathrm{x}}{\mathrm{a}}\right)-1\right]/\mathrm{CV}$ when $\frac{\mathrm{X}}{\mathrm{A}} > \frac{x}{a}+\mathrm{SD}$

and $f\left(\frac{\mathrm{X}}{\mathrm{A}}\right)=100\left(1-\left(\frac{\mathrm{x}}{\mathrm{a}}\right)/\left(\frac{\mathrm{X}}{\mathrm{A}}\right)\right)/\mathrm{CV}$ when $\frac{X}{A} < \frac{x}{a}-\mathrm{SD}$.

$\frac{\mathrm{X}}{\mathrm{A}}$ 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 $\frac{\mathrm{X}}{\mathrm{A}}$ in the high-yielding population respectively. Similarly, other nutrient ratios $\frac{\mathrm{X}}{\mathrm{B}}$, $\frac{\mathrm{M}}{\mathrm{x}}$ and $\frac{\mathrm{N}}{\mathrm{x}}$ 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 grain yield, leaf nutrient concentration and nutrient ratio expression data using Minitab statistical software version 14. Descriptive 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 grain yield and leaf nutrient concentration data available from the 2001, 2002 trial are given in Table 2. The grain yield data ranged from 264.1 kg ha-1 to 2208.3 kg ha-1 with a mean of 1117.1 kg ha-1 in the full population. The difference between the low and the high sub-populations for yield was highly significant (p = 0.001). The average foliar N contents and K, Ca, and S concentrations were higher in the high-yielding sub-population than in the low-yielding sub-population, with the means being significantly higher (p < 0.01). So, higher nutrient contents were observed in the high- yielding sub-population. Only the Mg content was significantly higher in the low-yielding sub-population (p= 0.023). The Zn content is the same in the both subpopulation. Leaf N, K, Ca, Mg and Zn; P and S nutrient levels in the high yielding subpopulation in our experiments ranked between or are at the limit of the sufficiency ranges published by Mills *et al*., (1996) and Planck, (1989). Thirty five (36) out of eighty three (83) data points were assigned to the high-yielding subpopulation (≥1233.50 kg ha-1). As regards the leaf nutrient concentrations, the data for all the nutrients N, P, K, Ca, S and Zn were relatively symmetrical as well in the total population as in the reference one (high yielding population) with 5 of them having skewness values less than 1.0 and hence were deemed suitable for DRIS model development. The nutrient Mg was highly skewed in the total population but was relatively symmetrical in the reference population. As a result, the data sets for all the nutrient N, K, Ca ,P, Mg and Zn; and S is relevant to parameterize DRIS model.

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

	Physical properties				Chemical properties					
Sites	Clay	Silt	Sand	Texture	P	K	pH	N	OM	C/N
	-------[%]------				Mg kg^{-1}	Cmolkg^{-1}		------[%]-----		
Lighter soils										
Beterou										
Mean	6.8	9.7	82.9		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		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		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		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)*

Binary nutrients ratio statistics

Binary nutrient ratio combinations of all seven 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 4 nutrient ratio expressions.

Table 2. Summary statistics for groundnut yield and leaf nutrient concentration data for total (n=83) and high-yielding (n=36) sub-populations

	Totalyieding population (n=83)			Low yieldingsub-population (n = 47)			High yielding sub-population (n = 36)			Sufficiency ranges (Campwell, 2000)
Parameters	**Mean**	**CV**	**Skew**	**Mean**	**CV**	**Skew**	**Mean**	**CV**	**Skew**	
Grain (kg ha-1) ***	1114.6	48.3	0.24	695.4	33.5	0.2	1661.9	15.2	-0.1	
Nutrients (%)										
N***	3.3	15.0	-0,1	3.1	17.5	-0.5	3.6	7.2	0.2	3.5 - 4.5
P**	0.2	19.3	1.6	0.2	22.1	1.2	0.2	11.4	-0.0	0.2 - 0.5
K***	2.2	24.4	0.2	2.0	23.9	0.0	2.5	22.5	0.3	1.7 - 3.0
Ca***	1.5	36.8	-1.5	1.3	49.24	-0.9	1.8	10.7	-0.4	0.5 - 2.0
Mg**	0.5	73.2	2.8	0.6	80.91	1.9	0.4	17.8	0.8	0.3 - 0.8
S***	1.2	24.1	-1.7	0.1	28.6	-1.8	0.2	12.6	1.2	0.2 - 0.35
Nutrient (ppm)										
ZnNs	27.5	31.5	0.3	27.3	33.5	0.1	27.7	29.3	0.6	20 - 60

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)

Ratios	Low yielding sub-population						High yielding sub-population						V (low /high)
	Mean	CV(%)	Median	Mini	Max	Skew	Mean	CV(%)	Median	Mini	Max	Skew	
N/P	15.0	27.0	14.5	7.0	23.6	-0.1	18.4	13.5	18.5	13.3	24.0	0.1	2.7
N/K	1.6	24.3	1.6	1.0	2.5	0.5	1.6	26.6	1.6	1.0	2.4	0.4	0.8
N/Ca	4.1	90.6	2.3	1.6	16.3	1.7	2.0	12.5	2.0	1.6	2.7	0.9	217.9
N/Mg	7.5	46.9	7.6	1.2	15.2	-0.1	8.9	16.9	8.9	5.2	12.1	-0.1	5.5
N/S	27.2	47.7	25.4	16.6	106.6	5.4	23.9	12.3	23.5	17.4	28.6	-0.2	19.3
N/Zn	1241.1	33.2	1194.2	684.3	3136.7	2.2	1402.6	31.0	1361.8	660.3	2218.1	0.2	0.9
P/N	0.1	33.8	0.1	0.0	0.1	1.5	0.1	13.9	0.1	0.0	0.1	0.6	10.1
P/K	0.1	38.5	0.1	0.1	0.2	1.3	0.1	25.1	0.1	0.1	0.1	0.6	4.1
P/Ca	0.4	120.0	0.2	0.1	1.6	1.6	0.1	15.4	0.1	0.1	0.2	0.6	646.1
P/Mg	0.6	83.4	0.4	0.1	2.1	2.3	0.5	17.0	0.5	0.3	0.7	0.4	32.2
P/S	2.1	94.1	1.6	1.0	14.3	5.7	1.3	15.1	1.3	1.0	1.9	0.8	96.1
P/Zn	93.1	56.7	83.0	35.5	256.8	1.7	76.1	27.7	71.5	43.6	123.3	0.4	6.3
K/N	0.7	23.8	0.6	0.4	1.0	0.3	0.7	26.2	0.6	0.4	1.0	0.2	1.0
K/P	9.8	33.4	9.9	4.1	18.2	0.5	12.2	24.0	12.2	7.5	19.0	0.2	1.3
K/Ca	2.8	96.9	1.5	0.8	11.9	1.8	1.4	28.7	1.2	0.8	2.3	0.5	47.1
K/Mg	4.8	46.6	4.7	0.8	9.3	-0.2	6.0	33.9	5.5	2.6	10.7	0.7	1.2
K/S	18.0	52.3	15.8	8.8	69.5	4.0	15.8	20.0	15.7	9.5	21.6	0.1	8.9
K/Zn	792.2	25.9	818.1	386.8	1310.5	0.1	894.5	23.4	880.2	481.7	1298.2	0.0	1.0
Ca/N	0.4	45.6	0.4	0.1	0.6	-0.8	0.5	11.8	0.5	0.4	0.6	-0.1	9.0
Ca/P	6.3	55.8	6.6	0.6	11.1	-0.5	9.2	14.9	9.2	6.4	12.5	0.1	6.7
Ca/K	0.6	51.7	0.7	0.1	1.2	-0.3	0.8	28.1	0.8	0.4	1.3	0.4	2.1
Ca/Mg	3.1	51.5	3.6	0.1	5.9	-0.8	4.4	18.3	4.3	2.9	6.4	0.7	3.8
Ca/S	9.7	43.6	10.9	1.3	16.5	-0.8	12.0	17.2	11.6	7.6	15.4	-0.2	4.2
Ca/Zn	463.5	56.2	474.5	78.0	1488.9	1.2	701.2	32.5	717.7	350.4	1265.8	0.5	1.3
Mg/N	0.2	99.4	0.1	0.1	0.8	1.8	0.1	19.0	0.1	0.1	0.2	1.4	94.3
Mg/P	2.9	77.5	2.2	0.5	8.5	1.6	2.1	17.4	2.1	1.4	3.2	0.7	37.8
Mg/K	0.3	92.9	0.2	0.1	1.2	1.9	0.2	34.1	0.2	0.1	0.4	0.9	22.6
Mg/Ca	1.5	195.3	0.3	0.2	13.4	2.5	0.2	17.7	0.2	0.2	0.3	0.3	5116.7
Mg/S	6.2	117.2	3.2	1.1	29.3	2.1	2.8	23.2	2.8	2.0	4.5	1.0	125.7
Mg/Zn	263.6	105.5	138.7	89.8	1042.7	2.0	159.8	29.5	154.7	81.4	264.6	0.3	34.9
S/N	0.0	20.7	0.0	0.0	0.1	-1.0	0.0	12.9	0.0	0.0	0.1	0.7	2.3
S/P	0.6	31.1	0.6	0.1	1.0	-0.5	0.8	14.2	0.8	0.5	1.0	-0.1	2.8
S/K	0.1	30.4	0.1	0.0	0.1	0.1	0.1	21.3	0.1	0.0	0.1	0.8	1.9
S/Ca	0.2	97.2	0.1	0.1	0.8	2.2	0.1	18.9	0.1	0.1	0.1	0.9	93.5
S/Mg	0.3	56.3	0.3	0.0	0.9	0.9	0.4	21.0	0.4	0.2	0.5	0.0	4.8
S/Zn	49.9	43.5	47.6	13.0	142.2	2.0	58.7	28.9	55.5	28.1	93.6	0.3	1.6
Zn/N	0.0	27.5	0.0	0.0	0.0	0.3	0.0	33.7	0.0	0.0	0.0	0.8	1.0
Zn/P	0.0	43.0	0.0	0.0	0.0	0.5	0.0	28.3	0.0	0.0	0.0	0.6	2.1
Zn/K	0.0	30.1	0.0	0.0	0.0	1.2	0.0	26.0	0.0	0.0	0.0	1.0	2.0
Zn/Ca	0.0	84.0	0.0	0.0	0.0	1.8	0.002	33.9	0.0	0.0	0.0	0.7	26.3
Zn/Mg	0.0	45.0	0.0	0.0	0.0	-0.7	0.0	30.5	0.0	0.0	0.0	0.6	1.9
Zn/S	0.0	47.0	0.0	0.0	0.1	2.6	0.0	32.1	0.0	0.0	0.0	1.2	3.5

CV: Coefficient of variation; Mini: Minimum; Maxi: Maximum; Skew: Skewness

Table 4. 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 groundnut.

Nutrient Ratios	Norms (mean)	CV (%)	Skew	V(low/high)
K/Ca	1.4	28.7	0.5	47.1
K/N	0.7	26.2	0.2	1 .0
K/S	15.8	20.0	0.1	8.9
Mg/Ca	0.2	17.7	0.3	5116.7
Mg/K	0.2	34.1	0.9	22.6
Mg/P	2.1	17.4	0.7	37.8
Mg/Zn	159.8	29.5	0.3	34.9
N/Ca	2.0	12.5	0.9	217.9
N/S	23.9	12.3	-0.2	19.3
Zn/N	0.0OO8	33.7	0.8	1.0
P/Ca	0.1	15.4	0.6	646.1
P/K	0.1	25.1	0.6	4.1
P/N	0.1	13.9	0.6	10.1
P/S	1.3	15.1	0.8	96.1
P/Zn	76.1	27.7	0.4	6.3
S/Ca	0.1	18.9	0.9	93.5
Zn/Ca	0.002	33.9	0.7	26.3

CV: Coefficient of variation; Skew: Skewness

Secondly, on the basis of the variance ratios (Vlow/Vhigh), which had ratios greater than 1.0, 17 of the thirty eight remaining nutrient ratio expressions were ultimately chosen as DRIS norms for groundnut. There are K/Ca: 1.4, K/S: 15.8, K/N:0.7, Mg/Ca: 0.2, Mg/K: 0.2, Mg/P: 2.1, Mg/Zn: 159.8, N/Ca: 2, N/S: 23.9, Zn/N: 0.0008, P/K: 0.1, P/N: 0.1, P/S: 1.3, P/Ca: 0.1, P/Zn: 76.1, S/Ca: 0.1, and Zn/Ca: 0.002.

DISCUSSION

Admittedly, the database used for the DRIS model development was relatively small. However, most of the nutrient content and yields of high and low-subpopulations were significantly different. This variation is a consequence of the source of data. All the data were gathered from fertilization experiments, were soil nutrient availability changed due to fertilization treatments. The means and variance of selected nutrient ratios from the subpopulations were also different. According to Reis and Monnerat (2003), those differences between nutritional status of high and low-yielding subpopulations are indicative of reliability of DRIS norms that will be developed. Moreover, most of the selected ratio (14 out of 17) has a low coefficient of variation less than 30%. That means probably the nutrients needed to be kept in such balance within groundnut tissue if grain production is to be sustained and optimized (Ramakrishna *et al*., 2009). The lower coefficient of variation were associated with a great ratio of variance ratio between the low- and high- yielding group (Vlow/Vhigh> 1). As pointed out by Bailey *et al.* (1997), DRIS norms (nutrient ratios) with large ratio of variance and small coefficient of variation imply that the balance between these specific pairs of nutrients could be of critical importance for crop production. Therefore, nutrient ratios with a large ratio of variance with a small coefficient of variation indicate that a high yield should be associated with a small variation around the average nutrient ratio. The DRIS norms for K/N (0.7) a nutrient ratios of known physiological and diagnostic importance had norm values within the expected narrow ranges for higher plants, i.e. 0.6–0.9 (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 another proof of credibility both to the database and to the DRIS model. Potassium 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. Furthermore, Ca and Zn are in a good balance (Ca/Zn = 500, derived from Zn/Ca = 0.002) as reported that Ca/Zn ratio less than 45-50 indicated zinc toxicity which is a significant problem and occurs when Zn concentration approaches 200 ppm (Campwell, 2000). The DRIS model for groundnut, developed in this study, is then a diagnostic tool that may be used to predict if insufficiencies or imbalances in N, P, K, Ca, Mg, S and Zn supplies are occurring in groundnut crops in Benin. 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 groundnut is one of the best diagnostic tools currently available for simultaneously evaluating the N, P, K, Ca, Mg, S and Zn status of groundnut crops in Benin.

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