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# Diagnosis and recommendation integrated system (DRIS) model establishment for diagnosing Sorghum (*Sorghum bicolor*) nutrient status in Benin (West Africa)

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**The Diagnosis and Recommendation Integrated System (DRIS) is a potential method for interpreting plant foliar nutrient composition. It provides a reliable means of linking leaf nutrient concentrations to the yield of sorghum, and has been developed for this crop using experimental data from organic and inorganic trials carried out in the Upper Catchment of Benin. Grain yield and leaf nutrient concentration were used to establish DRIS norms for N, P, K, Mg, Ca, S and Zn and statistical parameters for sorghum. The DRIS norms provided by this study were N/P: 6.5, K/N: 0.7, N/Ca: 4.6, S/N: 0.1, N/Zn: 712.2, K/P: 4.7, P/Ca: 0.7, S/P: 0.4, Zn/P: 0.01, K/Ca: 3.3, S/K: 0.1, K/Zn: 510.1, S/Zn: 39.0, Ca/Zn: 164.0, and S/Ca: 0.3. Although the database was relatively small, the norms derived for nutrient ratios of key biological significance, that is, 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. As it stands, this preliminary DRIS model for sorghum offers a good diagnostic tool for evaluating the N, P, K, Ca, S and Zn status of sorghum crops in Benin.**

**Key words:** DRIS norms, grain yield, sorghum, Benin.

## INTRODUCTION

Sorghum is quantitatively the world's fifth largest most important cereal grain after wheat, rice, maize and barley (Barnaud, 2007). Africa provides more than the middle of the total world sorghum production (55%) and uses more than 95% in human food and the remainder in cattle feeding (Dehaynin, 2007). Diagnostic research carried out in the different parts of Benin has indicated that sustainable agricultural development is being seriously compromised by declining soil fertility (Koudokpon, 1992, cited by Wennink et al., 2000; Van der pool et al., 1993; Dagbenonbakin, 2005). In the north of Benin, sorghum is the important traditional food crops due to their drought tolerance, diseases and notorious striga weeds. Despite the popularity of sorghum grown annually in northern

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Benin, there is a lack of information concerning the requirements for different nutrients. Very little consideration has been given to the requirement of sorghum for nutrients as farmers do not use to apply mineral fertilizer to sorghum. However, Dagbenonbakin (2005) found that mineral fertilizer and mulch increased grain, panicle and total biomass of sorghum. Therefore, there is a need for information that could be used to make better fertilizer for sorghum which would allow growers to maximize returns from their fertilizer inputs.

The Diagnosis and Recommendation Integrated System (DRIS) has been used to establish nutrients ratios that could be used to diagnose the nutritional status of sorghum. 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 sorghum (Arogun, 1978), corn (Escano et al., 1981; Elwali et al., 1985; Soltanpour et al., 1995), rubber and sugarcane (Elwali and Gascho 1984); potato (Meldal-Johnson and Sumner, 1980; Mackay et al., 1987), apple (Szü cs et al.,1990; Singh et al., 2000), pineapple (Angeles et al., 1993; Teixeira et al., 2009; Agbangba et al., 2010; Dagbenonbakin et al., 2010), grassland swards (Bailey 1997a, b), tomatoes (Hartz et al., 1998), peach (Awasthi et al., 2000), cauliflower (Hundal et al., 2003), mango (Raj and Rao, 2006), rice (Singh and Agrawal, 2007), sweet potato (Ramakrishna et al., 2009), cotton (Dagbenonbakin et al., 2009), and yam (Dagbenonbakin et al., 2011). The DRIS approach was designed to provide a valid diagnostic irrespective of plant age, tissue origin (Sumner, 1977a; Meldal-Johnsen and Sumner, 1980; Bailey, 1997a; 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). 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 a given species, there appear to be specific nutrient ratios for maximum crop performance that transcend local conditions, such as soil, climate and cultivars (Snyder and Kretschmer, 1988). However, Elwali and Gascho (1984) using a small data base concluded that local calibration is necessary to improve the accuracy of DRIS diagnosis, at least when based only on a small data set. In a review paper on DRIS, Bangroo et al. (2010) concluded that DRIS norms should be developed for specific conditions, in which all other factors to be correlated with yield or quality (or any other variable) be known and isolated: cultivar, climate, soil and crop management, productivity etc., attaining the specific objectives. The aim of the present study was to develop local DRIS model parameters for sorghum using grain yield and leaf tissue nutrient concentration data from the 2001 and 2002 obtained in organic and inorganic fertilizer survey of this crop in the Upper Catchment of Benin.

## MATERIALS AND METHODS

### Site location and characteristics

The field trials were established in Upper Ouémé Catchment in the Republic of Benin, West Africa from 2001 and 2002 at three sites: Beterou, Dogue and Wewe that are located at 9°23 N 66 and 2°07 E, 9°06 N and 1° 56 E and 9°12 N and 2° 16 E respectively. The climate on the three sites is Sudano-Guinean. The rainfall distribution is unimodal with two seasons: a rainy season from mid April to mid October, and the subsequent dry season. Averaged over the last 30 years, total annual rainfall was 1018.4 mm for Beterou, 1167.6 mm for Dogue and 1023.5 mm for Wewe. The maximum temperature is 40°C in the dry season, the minimum is 10°C and the average is 25°C. An average rainfall shows a peak in August. First rains begin in March, and are significant from May to September - the period of intensive farming activities. Rainfall ceases in November or December at all three sites. Harmattan (cold and dry wind) and the monsoon (warm and humid wind) are two wind systems in the north of Benin, with harmattan as the dominating system. The natural vegetation in the region is a tree/shrub savannah with the dominating species: *Pterocarpus erinaceus, Anogeissus lleiocarpa, Vitellaria paradoxa, Parkia biglobosa, Burkea africana, Nauklea latifolia, Daniella oliveri*, and *Phoenix reclinata*. Plantations with perennials comprise *Anacardium occidentale*, *Tectona grandis*, and *Mangifera indica*. The occurrence of weeds is also not neglected. These are: *Panicum maximum, Pennisetum pedicellatum, Imperata cylindrica, Andropogon* spp, etc.

Soils of the sites were Plinthosols and Ferric-Profondic Luvisols in Beterou, Plinthosols and Lixisols in Dogue and Acrisols or Plinthic-Lixisols in Wewe. Soil textures in the top 20 cm were loamy sand with 3 to 10% of clay and 76 to 86% of sand, and sandy loam with 7 to 13% of clay and 73 to 80% of sand on all site. Organic matter (OM) and total nitrogen contents in the experimental soils varied from low (1.5 and 3% respectively), to intermediate (0.25 and 0.3%, respectively). On most plots, organic matter contents were low to intermediate, and higher levels (OM >2.5%) were only found in exceptional cases. All sites showed weakly acid (6.1< pH < 6.5) to neutral (6.6 < pH < 7.3) soils. C/N ratios ranged between 10 and 18, indicating largely uninhibited mineralization, the higher values found on sites which were cleared recently and /or which may still contain carbon from slash and burn. The highest C/N ratios were found on plots in the forest of Wewe. The potassium content ranged from low (< 0.15 cmol $kg^{-1}$) in Dogue to intermediate (0.15 < K < 0.30 cmol $kg^{-1}$) supply in Beterou and Wewe and in some plots of Dogue. Other individual plots that presented high levels of available K were sites following fallow and those on which cotton crop were produced. The Cation Exchange Capacity (CEC) (<15 cmol $kg^{-1}$) was low in all the three sites. In summary, soils in all the three locations had low soil fertility.

### Experimental design

The experimental design was a randomized complete block with four replications. Altogether, there were eight plots divided into two groups consisting of four plots each. In year 2001, the first plot was treated with manure, second plot with mineral fertilizer, third plot with combination of manure and mineral fertilizer, whereas the fourth plot was left as control (no application of fertilizer). In years 2002 and 2003, the same combinations were made taking crop residues from external sources as a source of organic matter at the place of manure. Organic matter was either farmyard manure provided by the farmers or crop residues.

## Field management

Organic matter was either farmyard manure provided by individual farmers or crop residues (groundnut, maize, yam, cotton, sorghum, or fallow) at the rate of 10 t $ha^{-1}$, applied only in 2001. In 2002, the residual effect of the manure was compared with the mulching at the same amount because no farmyard manure was applied. Notice that, plots on which manure was applied in 2001 were not cleared from crop residues. Mineral fertilizer applications were 23 kg N $ha^{-1}$ and 46 kg P $ha^{-1}$ as urea and triple super phosphate respectively in 2001 whereas it was 28 kg N $ha^{-1}$, 46 kg P $ha^{-1}$ and 28 kg K $ha^{-1}$ as urea and NPKSB (14-23-14-5-1) in 2002. The N content in the manure ranged from 1.4 to 1.75%, P between 0.18 and 0.31%. K contents were more variable and amounted from 0.70 to 5.50%, whereas Ca ranged between 0.66 and 1.46%, and Mg between 0.24 and 0.66%. Plots were laid out at a size of 8 m × 8 m. Sakarabougourou with long vegetation period provided by farmers is the sorghum variety used during the two years of the experiment.

It was sown as one pinch and later thinned to two plants per spot, resulting in a plant density of 62500 plants $ha^{-1}$, spaced at 80 cm between and 40 cm within rows.

## Sampling design and chemical analysis

Plants youngest fully mature leaves on the main stem were sampled at first bloom as recommended by FAO (2000) and Jones et al. (1990). 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 to 20 cm depth, were collected at each farmer field before the experimental block was installed. The sorghum grain was harvested in a (2 × 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. Potassium, 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 and Boko, 1978); the pH was determined in water (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) cited by Tran and Boko (1978) with a Gerhardt Vapodest; organic C was determined using the method described by Walkley and Black (1934) cited by Tran and 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 0.1 N HCl, adjusted to volume, and filtered through Whatman No. 1. Analysis was done with a Perkin-Elmer flame atomic absorption spectrophotometer, Model 70PE 1100 B.

## DRIS model development 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 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 using the cut off point between the two subpopulations set at 1234.58 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 division between the two sub-populations was set was a compromise between maximizing the potential for data symmetry in the high-yielding sub-population (that is, 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 fifteen nutrient expressions involving six nutrients (N, P, K, Ca, Zn, and S) were ultimately chosen as the diagnostic norms for sorghum. 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 (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) and the fourth priority was to select equal numbers of nutrient expressions for each of the nutrients, since this was an absolute orthogonal requirement of the mathematical model (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., 1997; 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 $f\left(\frac{X}{A}\right) = 100\left[\left(\frac{X}{A}\right) / \left(\frac{x}{a}\right) - 1\right] / CV$ 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

**Table 1.** Summary statistics for sorghum yield and leaf nutrient concentration data for total (n=90) and high-yielding (n=42) sub-populations.

| Parameters | Total yielding population (n = 90) | | | | | | High yielding sub-population (n = 42) | | | | | | V (low/high) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | Var | Median | Mini | Maxi | Skew | Mean | Var | Median | Mini | Maxi | Skews | |
| Grain (kg ha$^{-1}$) | 1095.2 | 454975.0 | 1057.5 | 33.0 | 3310.8 | 0.6 | 1688.7 | 202509.0 | 1628.5 | 1121.6 | 3310.8 | 1.4 | 2.2 |
| Nutrient (g kg$^{-1}$) | | | | | | | | | | | | | |
| N | 16.9 | 8.0 | 17.4 | 10.2 | 22.4 | -0.4 | 16.9 | 7.3 | 17.3 | 10.9 | 21.7 | -0.6 | 1.1 |
| P | 2.6 | 0.4 | 2.7 | 1.6 | 5.3 | 1.4 | 2.7 | 0.3 | 2.7 | 1.7 | 5.0 | 1.3 | 1.1 |
| K | 12.6 | 5.9 | 12.7 | 7.1 | 17.1 | -0.3 | 12.2 | 5.2 | 12.1 | 8.1 | 16.7 | 0.1 | 1.1 |
| Ca | 4.0 | 0.9 | 3.8 | 2.0 | 7.5 | 0.6 | 3.9 | 0.6 | 3.8 | 2.6 | 5.5 | 0.4 | 1.6 |
| Mg | 2.7 | 0.3 | 2.5 | 1.6 | 4.5 | 0.8 | 2.6 | 0.3 | 2.5 | 1.6 | 3.7 | 0.7 | 1.2 |
| S | 0.9 | 0.1 | 0.9 | 0.3 | 1.6 | 0.0 | 0.9 | 0.1 | 1.0 | 0.3 | 1.4 | -0.4 | 0.9 |
| Nutrient (mg kg$^{-1}$) | | | | | | | | | | | | | |
| Zn | 23.6 | 13.4 | 23.5 | 16.4 | 32.8 | 0.3 | 23.9 | 12.2 | 23.6 | 18.0 | 32.0 | 0.4 | 1.1 |

Mini: Minimum, Maxi: Maximum, Skew: Skewness , Var: Variance.

$\frac{N}{x}$ 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 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 1. The grain yield data ranged from 33 to 3310.8 kg ha$^{-1}$ with a mean of 1095.2 kg ha$^{-1}$ in the full population. Twenty-two (n=42) out of sixty-eight (n=90) data points were assigned to the high-yielding subpopulation (≥1234.58 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, S and Zn were relatively symmetrical, with six (6) 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 nutrients were therefore calculated, and summary statistics evaluated for each of the resulting 42 nutrient ratio expressions (Table 2). To determine which nutrient ratio expressions in Table 2 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), which had ratios greater than 1.0, six (6) of the twenty-six remaining nutrient ratio expressions were given up. The scatter plot check (Figure 1) allowed then selecting 15 ratios (out of 20) which have a Gaussian distribution as DRIS norms. There are: N/P: 6.5, K/N: 0.7, N/Ca: 4.6, S/N: 0.1, N/Zn: 712.2, K/P: 4.7, P/Ca: 0.7, S/P: 0.4, Zn/P: 0.01, K/Ca: 3.3, S/K: 0.1, K/Zn: 510.1, S/Zn: 39.0, Ca/Zn: 164.0, and S/Ca: 0.3 (Table 3). The comparison of the norms to the published norms (Table 4) showed that the norms of N/P, K/N, N/Ca and K/P were significantly different whereas K/Ca and P/Ca were similar to the proposed norms by Arogun (1978).

## DISCUSSION

The DRIS model developed for sorghum in this study is a diagnostic tool that may be used to predict if insufficiencies or imbalances in N, P, K, Ca, Mg, S and Zn supplies are

**Table 2.** 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).

| Parameters | Low yielding subpopulation | | | | | | High yielding subpopulation | | | | | | | V (low |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ratios | Mean | CV(%) | Median | Mini | Maxi | Skew | Mean | Var | CV(%) | Median | Mini | Maxi | Skew | /high) |
| N/P | 6.9 | 25.2 | 6.5 | 2.4 | 11.9 | 0.7 | 6.5 | 1.9 | 21.0 | 6.5 | 2.4 | 10.6 | 0.001 | 1.6 |
| P/N | 0.2 | 31.9 | 0.2 | 0.1 | 0.4 | 3.2 | 0.2 | 0.002 | 30.0 | 0.2 | 0.1 | 0.4 | 3.4 | 1.0 |
| N/K | 1.3 | 22.5 | 1.3 | 0.8 | 2.4 | 2.0 | 1.4 | 0.1 | 21.1 | 1.4 | 1.0 | 2.3 | 1.2 | 1.0 |
| K/N | 0.8 | 18.7 | 0.8 | 0.4 | 1.2 | 0.1 | 0.7 | 0.02 | 18.7 | 0.7 | 0.4 | 1.0 | -0.2 | 1.1 |
| N/Ca | 4.6 | 39.3 | 4.1 | 1.6 | 9.3 | 0.5 | 4.6 | 1.8 | 29.4 | 4.6 | 2.2 | 7.5 | 0.4 | 1.7 |
| Ca/N | 0.3 | 42.9 | 0.2 | 0.1 | 0.6 | 1.2 | 0.2 | 0.01 | 32.4 | 0.2 | 0.1 | 0.4 | 1.1 | 2.1 |
| N/Mg | 6.7 | 32.2 | 6.8 | 2.6 | 11.0 | 0.2 | 6.8 | 3.1 | 26.2 | 6.5 | 3.1 | 11.4 | 0.5 | 1.5 |
| Mg/N | 0.2 | 36.5 | 0.1 | 0.1 | 0.4 | 1.2 | 0.2 | 0.002 | 29.4 | 0.2 | 0.1 | 0.3 | 1.5 | 1.7 |
| N/S | 19.6 | 27.9 | 17.5 | 10.4 | 39.0 | 1.3 | 19.6 | 36.6 | 30.9 | 17.4 | 13.4 | 39.5 | 1.6 | 0.8 |
| S/N | 0.1 | 24.7 | 0.1 | 0.0 | 0.1 | 0.3 | 0.1 | 0.0002 | 23.5 | 0.1 | 0.03 | 0.1 | -0.7 | 1.1 |
| N/Zn | 740.7 | 19.7 | 750.4 | 381.6 | 1130.7 | -0.2 | 712.2 | 14440.3 | 16.9 | 712.0 | 438.8 | 1085.0 | 0.4 | 1.5 |
| Zn/N | 0.001 | 24.0 | 0.001 | 0.001 | 0.003 | 1.7 | 0.001 | 0.00000010 | 17.7 | 0.001 | 0.001 | 0.002 | 1.0 | 1.0 |
| P/K | 0.2 | 35.2 | 0.2 | 0.1 | 0.6 | 3.1 | 0.2 | 0.004 | 27.4 | 0.2 | 0.1 | 0.5 | 1.4 | 1.4 |
| K/P | 5.2 | 26.5 | 5.0 | 1.7 | 9.3 | 0.5 | 4.7 | 1.3 | 24.1 | 4.6 | 2.2 | 7.1 | 0.1 | 1.5 |
| P/Ca | 0.7 | 41.9 | 0.6 | 0.2 | 1.5 | 0.7 | 0.7 | 0.04 | 28.9 | 0.7 | 0.3 | 1.2 | 0.3 | 1.9 |
| Ca/P | 1.7 | 46.3 | 1.6 | 0.7 | 4.4 | 1.2 | 1.5 | 0.3 | 34.5 | 1.4 | 0.8 | 3.2 | 1.5 | 2.3 |
| P/Mg | 1.0 | 32.6 | 1.0 | 0.4 | 1.7 | 0.04 | 1.1 | 0.1 | 21.9 | 1.1 | 0.5 | 1.7 | 0.2 | 2.0 |
| Mg/P | 1.1 | 41.1 | 1.0 | 0.6 | 2.6 | 1.5 | 1.0 | 0.1 | 25.5 | 1.0 | 0.6 | 2.1 | 1.9 | 3.3 |
| P/S | 3.0 | 41.3 | 2.8 | 1.6 | 8.5 | 2.4 | 3.2 | 2.3 | 47.2 | 2.8 | 1.8 | 8.8 | 2.5 | 0.7 |
| S/P | 0.4 | 30.4 | 0.4 | 0.1 | 0.6 | 0.1 | 0.4 | 0.01 | 28.2 | 0.4 | 0.1 | 0.6 | -0.6 | 1.3 |
| P/Zn | 114.5 | 34.4 | 112.8 | 50.7 | 309.4 | 2.5 | 113.2 | 741.7 | 24.1 | 107.5 | 69.2 | 208.8 | 1.2 | 2.1 |
| Zn/P | 0.01 | 31.8 | 0.01 | 0.003 | 0.02 | 1.3 | 0.01 | 0.00000430 | 22.2 | 0.01 | 0.005 | 0.01 | 0.3 | 2.2 |
| K/Ca | 3.5 | 39.7 | 3.5 | 1.5 | 6.5 | 0.3 | 3.3 | 1.1 | 30.8 | 3.3 | 1.5 | 6.0 | 0.4 | 1.8 |
| Ca/K | 0.3 | 42.3 | 0.3 | 0.2 | 0.7 | 0.6 | 0.3 | 0.01 | 33.6 | 0.3 | 0.2 | 0.7 | 1.0 | 1.7 |
| K/Mg | 5.0 | 33.0 | 5.0 | 2.6 | 8.5 | 0.4 | 4.8 | 1.4 | 24.2 | 4.8 | 3.1 | 7.6 | 0.5 | 2.0 |
| Mg/K | 0.2 | 33.5 | 0.2 | 0.1 | 0.4 | 0.5 | 0.2 | 0.003 | 23.9 | 0.2 | 0.1 | 0.3 | 0.3 | 2.0 |
| K/S | 15.0 | 29.8 | 14.8 | 6.7 | 26.2 | 0.4 | 14.3 | 23.8 | 34.2 | 13.1 | 7.3 | 26.6 | 1.1 | 0.8 |
| S/K | 0.1 | 33.5 | 0.1 | 0.0 | 0.1 | 1.3 | 0.1 | 0.001 | 30.2 | 0.1 | 0.04 | 0.1 | 0.3 | 1.1 |
| K/Zn | 558.9 | 18.0 | 559.3 | 344.1 | 798.0 | -0.01 | 510.1 | 5841.8 | 15.0 | 508.6 | 333.7 | 700.0 | 0.4 | 1.7 |
| Zn/K | 0.00 | 19.8 | 0.002 | 0.001 | 0.003 | 1.1 | 0.00 | 0.00000010 | 15.2 | 0.002 | 0.001 | 0.00 | 0.7 | 1.0 |
| Ca/Mg | 1.5 | 21.7 | 1.6 | 0.8 | 2.4 | -0.2 | 1.5 | 0.1 | 23.8 | 1.5 | 1.0 | 2.5 | 0.9 | 0.9 |
| Mg/Ca | 0.7 | 25.5 | 0.6 | 0.4 | 1.2 | 1.2 | 0.7 | 0.02 | 22.3 | 0.7 | 0.4 | 1.0 | 0.2 | 1.3 |
| Ca/S | 4.9 | 43.7 | 4.5 | 1.5 | 12.0 | 1.4 | 4.7 | 5.4 | 49.0 | 4.1 | 2.0 | 11.1 | 1.2 | 0.8 |
| S/Ca | 0.2 | 45.7 | 0.2 | 0.1 | 0.6 | 1.7 | 0.3 | 0.01 | 42.1 | 0.2 | 0.1 | 0.5 | 0.5 | 1.1 |
| Ca/Zn | 180.6 | 32.0 | 162.8 | 90.9 | 301.2 | 0.4 | 164.0 | 1711.5 | 25.2 | 162.9 | 98.5 | 290.8 | 0.7 | 1.9 |
| Zn/Ca | 0.01 | 31.9 | 0.01 | 0.003 | 0.01 | 0.5 | 0.01 | 0.00000260 | 25.0 | 0.01 | 0.003 | 0.01 | 0.5 | 1.5 |
| Mg/S | 3.2 | 36.2 | 2.9 | 1.7 | 7.1 | 1.6 | 3.1 | 1.7 | 41.8 | 2.8 | 1.3 | 7.0 | 1.2 | 0.8 |
| S/Mg | 0.3 | 30.0 | 0.3 | 0.1 | 0.6 | 0.2 | 0.4 | 0.02 | 36.2 | 0.4 | 0.1 | 0.7 | 0.5 | 0.6 |
| Mg/Zn | 118.7 | 25.5 | 113.9 | 69.0 | 190.0 | 0.6 | 110.1 | 568.7 | 21.7 | 105.2 | 65.4 | 176.2 | 0.7 | 1.6 |
| Zn/Mg | 0.01 | 24.9 | 0.01 | 0.01 | 0.01 | 0.4 | 0.01 | 0.00000400 | 21.0 | 0.01 | 0.01 | 0.02 | 0.5 | 1.3 |
| S/Zn | 40.3 | 32.4 | 38.2 | 17.0 | 90.2 | 1.3 | 39.0 | 133.8 | 29.7 | 39.4 | 16.0 | 71.0 | 0.3 | 1.3 |
| Zn/S | 0.03 | 32.7 | 0.03 | 0.01 | 0.1 | 1.3 | 0.03 | 0.00009760 | 34.9 | 0.03 | 0.01 | 0.1 | 1.4 | 0.8 |

Mini: Minimum, Maxi: Maximum, skew: skewness.

occurring in sorghum 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 (10.0) and K/N (0.7), had norm values within the expected narrow ranges for higher plants, that is, 11 to 13 for N/S, 0.6 to 0.9 for K/N (Elwali and Gascho, 1984;

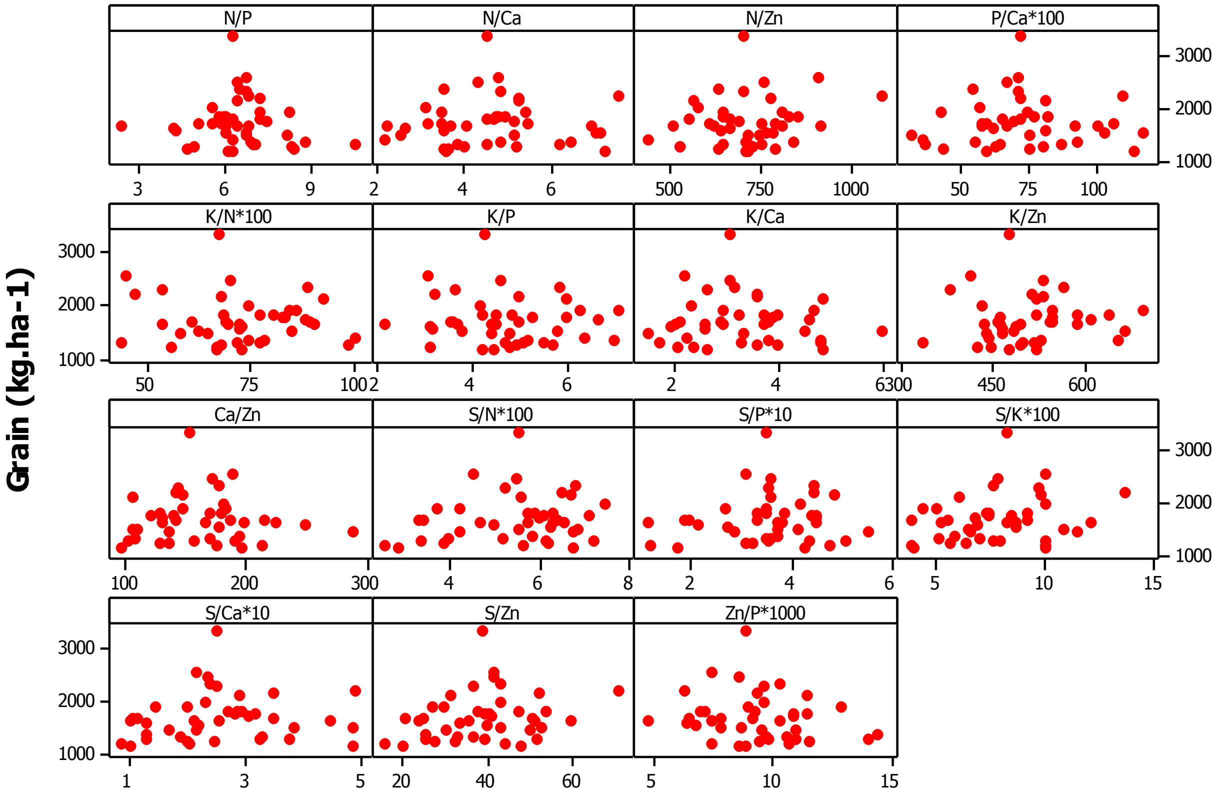


**Figure 1.** Plots of grain yield versus nutrient ratios showing the Gaussian distribution for the 15 DRIS norms selected.

**Table 3.** 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 sorghum.

| Parameter | High yielding subpopulation | | | | | | V (low/high) |
|---|---|---|---|---|---|---|---|
| | Mean | CV(%) | Median | Mini | Maxi | Skew | |
| N/P | 6.5 | 21.0 | 6.5 | 2.4 | 10.6 | 0.001 | 1.6 |
| K/N | 0.7 | 18.7 | 0.7 | 0.4 | 1.0 | -0.2 | 1.1 |
| N/Ca | 4.6 | 29.4 | 4.6 | 2.2 | 7.5 | 0.4 | 1.7 |
| S/N | 0.1 | 23.5 | 0.1 | 0.03 | 0.1 | -0.7 | 1.1 |
| N/Zn | 712.2 | 16.9 | 712.0 | 438.8 | 1085.0 | 0.4 | 1.5 |
| K/P | 4.7 | 24.1 | 4.6 | 2.2 | 7.1 | 0.1 | 1.5 |
| P/Ca | 0.7 | 28.9 | 0.7 | 0.3 | 1.2 | 0.3 | 1.9 |
| S/P | 0.4 | 28.2 | 0.4 | 0.1 | 0.6 | -0.6 | 1.3 |
| Zn/P | 0.01 | 22.2 | 0.01 | 0.005 | 0.01 | 0.3 | 2.2 |
| K/Ca | 3.3 | 30.8 | 3.3 | 1.5 | 6.0 | 0.4 | 1.8 |
| S/K | 0.1 | 30.2 | 0.1 | 0.04 | 0.1 | 0.3 | 1.1 |
| K/Zn | 510.1 | 15.0 | 508.6 | 333.7 | 700.0 | 0.4 | 1.7 |
| S/Ca | 0.3 | 42.1 | 0.2 | 0.1 | 0.5 | 0.5 | 1.1 |
| Ca/Zn | 164.0 | 25.2 | 162.9 | 98.5 | 290.8 | 0.7 | 1.9 |
| S/Zn | 39.0 | 29.7 | 39.4 | 16.0 | 71.0 | 0.3 | 1.3 |

Mini: Minimum, Maxi: maximum, Skew: skewness.

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 Sulphur are vital constituents of sulphur-containing amino acids

**Table 4.** DRIS norms selected and comparison to the norms proposed by Arogun (1978).

| Proposed DRIS norms | | DRIS norms proposed by Arogun (1978) | |
|---|---|---|---|
| **Parameter** | **Mean** | **Parameter** | **Mean** |
| N/P** | 6.5 | N/P [(i)] | 8.929 |
| K/N*** | 0.7 | K/N[(i)] | 0.425 |
| N/Ca*** | 4.6 | N/Ca | 7.200 |
| K/Ca[ns] | 3.3 | K/Ca | 3.080 |
| K/P** | 4.7 | K/P[(i)] | 3.861 |
| P/Ca[ns] | 0.7 | P/Ca | 0.759 |
| S/N | 0.1 | - | - |
| N/Zn | 712.2 | - | - |
| S/P | 0.4 | - | - |
| Zn/P | 0.01 | - | - |
| S/K | 0.1 | - | - |
| K/Zn | 510.1 | - | - |
| S/Ca | 0.3 | - | - |
| Ca/Zn | 164.0 | - | - |
| S/Zn | 39.0 | - | - |
| - | - | Mg/Ca | 0.553 |
| - | - | P/Mg | 1.518 |
| - | - | Mg/K | 0.183 |
| - | - | Mn/N | 0.079 |

***, **: Significant at 1 and 5%, respectively; [(i)] inverse relation in the original norm.

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, 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/Ca, N/Zn, K/P, P/Ca, S/P, Zn/P, K/Ca, S/K, K/Zn, S/Zn, and S/Ca ratios in leaf tissue (Ramakrishna et al., 2009), and this is probably why most of them had CV's greater than 24%. Nonetheless, the nutrients in question (N, P, K, Ca, Zn and S), being major yield-building components, probably do need to be kept in a state of relative balance within sorghum tissue if grain production is to be sustained and optimized. The fact that some norms are significantly different from the literature ones proves that local calibration of DRIS norms is important (Elwali and Gascho, 1984).

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 sorghum is one of the best diagnostic tools currently available for simultaneously evaluating the N, P, K, Ca, S and Zn statuses of sorghum crops in Benin.

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