Revista Brasileira de Ciência do Solo

Division – Soil Use and Management | Commission – Soil Fertility and Plant Nutrition

The Use of DRIS for Nutritional Diagnosis in Oil Palm in the State of Pará

Gilson Sergio Bastos de Matos[(1)*], **Antonio Rodrigues Fernandes**[(1)], **Paulo Guilherme Salvador Wadt**[(2)], **Antônio José de Abreu Pina**[(3)], **Vinícius Ide Franzini**[(4)] and **Helen Monique Nascimento Ramos**[(5)]

[(1)] Universidade Federal Rural da Amazônia, Instituto de Ciências Agrárias, Belém, Pará, Brasil.
[(2)] Empresa Brasileira de Pesquisa Agropecuária, Embrapa Acre, Rio Branco, Acre, Brasil.
[(3)] Marborges Agroindústria S.A., Gerência Agrícola, Moju, Pará, Brasil.
[(4)] Empresa Brasileira de Pesquisa Agropecuária, Embrapa Amazônia Oriental, Belém, Pará, Brasil.
[(5)] Universidade Federal Rural da Amazônia, Programa de Pós-Graduação em Agronomia, Belém, Pará, Brasil.

* Corresponding author:
E-mail: gilsonsbm@yahoo.com.br

ABSTRACT: The oil palm crop has expanded significantly in the state of Pará, which has not been followed in a proportional manner by studies aiming at increasing yield through plant nutrition. The objective of this study was to evaluate general and specific norms of the Diagnosis and Recommendation Integrated System (DRIS) for genetic materials of oil palm (African and interspecific hybrid) at two ages (young and adult plants) and evaluate possible deficiencies in fertilization and soil correction practices. The DRIS norms were composed of means, standard deviations, and coefficients of variation of bivariate, specific, and general relationships among nutrients of 144 leaf samples. The DRIS norms specific for genetic material did not differ from the general norms; however, a large number of differences were found between specific bivariate relationships for age groups, among themselves, and in relation to the general norms. The regression analysis between the nutritional balance index and yield were better explained when age groups were discriminated. In the young plants, the number of cases of stands with deficiencies followed the order Ca > Fe > B > S > Mn > K > Mg = Cu > Zn > N > P; and for adults, this order was Ca > Mn > Zn > Fe > S = B > N = Cu > K > Mg > P. The DRIS norms can be utilized in diagnostics regardless of genetic material; however, they must be specified for the age of the plant. Most of the stands showed deficiency in Ca and micronutrients, coinciding with the least used nutrients in oil palm crops in the state of Pará, as well as emphasizing the need for soil liming.

Keywords: *Elaeis guineensis* Jacq., *E. oleifera* × *E. guineensis*, eastern Amazonia, plant nutrition.

INTRODUCTION

African oil palm (*Elaeis guineensis* Jacq.) is the most productive oleaginous plant, occupying an estimated area of 16.4 million hectares worldwide (Potts et al., 2014). Expansion in cultivation of this palm, combined with management practices aiming at achieving high yields, could completely satisfy the vegetable oil market for food and even satisfactorily meet the demands of the biofuel market (Fairhurst and Härdter, 2003). However, the demand for mineral fertilizers by this crop can reach 60 % of the production cost variable, leading researchers to concur in the importance of studies on fertilization and plant nutrition (Viégas and Müller, 2000; Rodrigues et al., 2006; Franzini et al., 2012), which are scarce in Brazil.

The use of leaf nutritional assessment based on the Diagnosis and Recommendation Integrated System (DRIS), in addition to the traditional methods such as the levels or critical ranges, is an important tool because it mitigates the distortions of diagnoses caused by the effect of dilution, concentration, age, or plant organ (Mourão Filho, 2004). For the calculation of DRIS, all ratios between nutrients are considered. They are then compared to the ratios of a reference population or standards, allowing calculation of indices that point to nutritional balance of the plant on a dimensionless scale (Beaufils, 1973).

The DRIS theory was developed with a universal character to make accurate diagnoses, regardless of the growing region, plant part, or phenological stage of the plant (Jones Jr, 1993) and cultivar (Reis Jr and Monerat, 2002), but the studies have diverged from these premises (Silva et al., 2005; Carvalho et al, 2011;. Martín et al, 2013). The need for studies to validate the scope of DRIS norms is now clear; therefore, the specific effect of the genetic material and plant age should be taken into account (Mourão Filho, 2004).

The most common sources of oil palm genetic material are the Tenera type African cultivar, which have been drastically affected by the anomaly of lethal yellowing (LY) that has no identified etiologic agent. As a result, such species have been replaced in areas of higher rainfall by interspecific hybrids (*E. guineensis* × *E. oleifera*), ISH, which are not affected by LY (Cunha et al., 2012).

Nutritional diagnoses for oil palm have been widely interpreted for African species and the ISH based on sufficiency ranges (Viégas and Müller, 2000). However, in addition to non-susceptibility to LY, ISH have distinct characteristics when compared to African palms, such as one third the speed of vertical stalk growth (0.20 m yr^{-1}), tolerance to insect pests, and greater content of unsaturated oil (Lopes et al., 2012). Moreover, they have tolerance to waterlogged soils and water stress (Gomes Junior et al., 2014), a low rate of natural pollination (Lopes et al., 2012), and apparently higher nutritional requirements, especially for magnesium (Franzini et al., 2012) and boron.

Differences in performance among palm cultivars in the field should be considered in nutritional assessment in order to enhance the accuracy of leaf diagnostics and to contribute to proper fertilization management. It should also be noted that the natural increase in yield according to the age of the plant will be reflected in different nutritional requirements. Oil palms younger than six years old have higher leaf nutrient content than older palms (Fairhurst and Härdter, 2003), showing different nutrient relocation patterns. In addition, more accurate nutritional diagnostics can be used for calibrating fertilization of the crop, as well as for giving direction to the need for soil correction through liming, which is not a common practice for oil palm and it is questioned by producers (Franzini et al., 2012).

Variations in nutritional patterns diagnosed through DRIS were observed for different genetic materials and ages of *Eucalyptus* spp. (Wadt et al., 1999; Silva et al., 2005), suggesting the use of specific DRIS. However, for some cotton cultivars (*Gossypium hirsutum*) (Singh et al., 2012) and for two age groups of cupuaçu trees *Theobroma*

grandiflorum (Dias et al., 2010), the general DRIS, regardless of the genetic material or age, was successful for nutritional diagnosis of these species.

In this context, the hypothesis was that Specific DRIS norms are more suitable for diagnosis than general ones and are able (through the DRIS indices) to highlight the major nutritional limitations of the oil palm. The objective of this study was to evaluate the use of preliminary norms of DRIS as a tool to carry out nutritional diagnoses in oil palm according to the genetic material and plant age, and to identify possible deficiencies in soil correction practices and fertilization adopted for this crop in the state of Pará, Brazil.

MATERIALS AND METHODS

We monitored 33 commercial stands of African oil palms (*Elaeis guineensis* Jaqc.) and their interspecific hybrid (*E. oleifera* × *E. guineensis*) - ISH, distributed in the municipalities of Moju and Tomé-Açu, in the northeast of the state of Pará (Figure 1). In this region, the average annual temperatures were 26 °C, with average annual rainfall of 2,500 mm in Moju and 2,300 mm in Tomé-Açu, with less rain in the months of July and August.

In the routine commercial collections, performed over a maximum of 30 days in the least rainy period of the year (November/2011; December/2012; September/2013; November/2015), the eight central leaflets of leaf number 17 were considered from about 24 to 30 plant from rows located from ¼ to ¾ of the east-west extension of the stand (Rodrigues et al., 2006). Leaf number 17 corresponds to the index leaf for nutritional diagnosis considering that oil palm phyllotaxis is arranged in spirals where counting begins at the apex after the arrow-leaf and ends at the leaf nearest the soil. A total
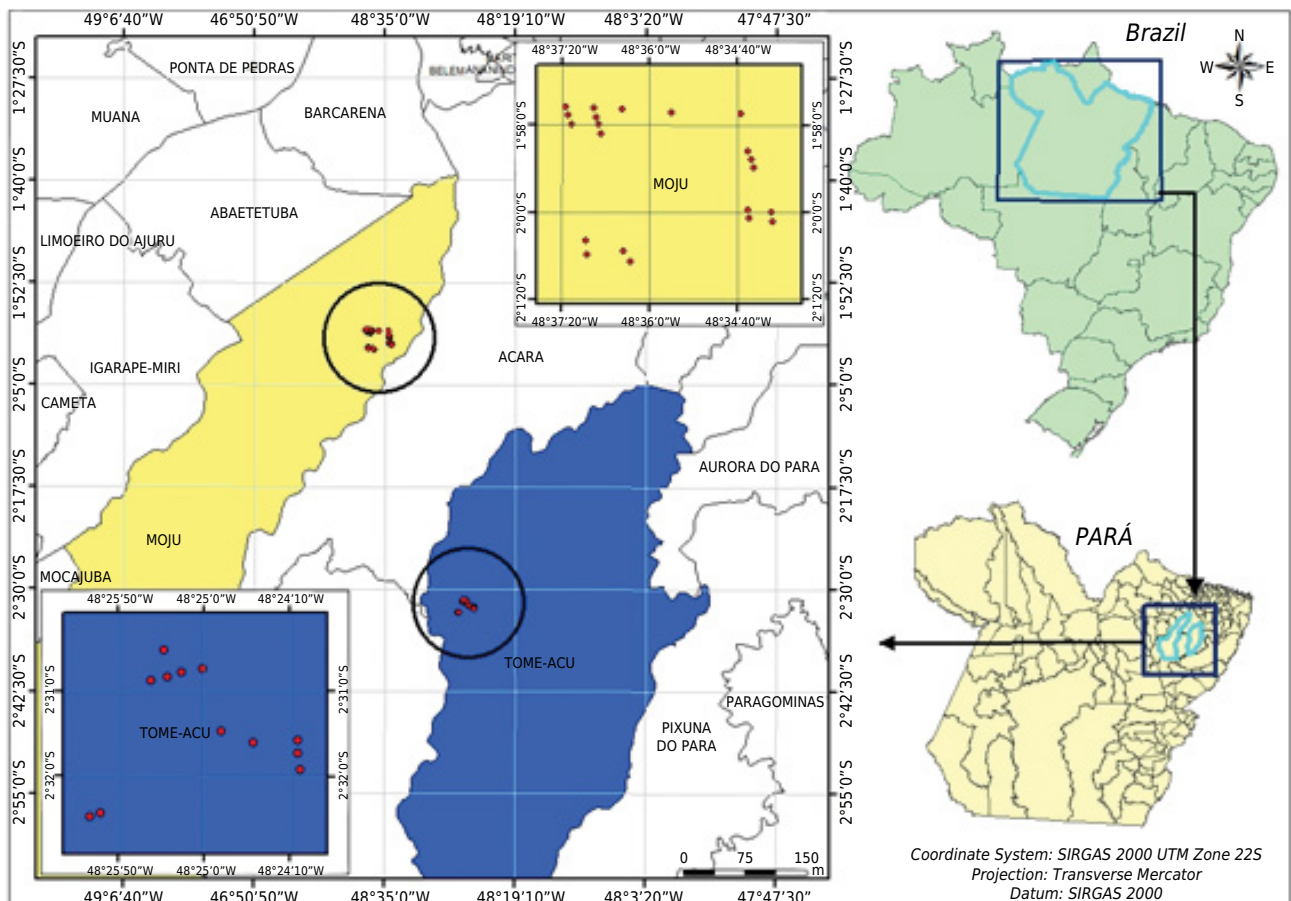
Figure 1. Location of commercial oil palm stands in the municipalities of Moju and Tomé-Açu in northeastern Pará, Eastern Amazon, Brazil.

of 144 collected samples were washed in distilled water; the leaflets were dried in a forced-air circulation oven at 65 °C and subsequently passed through a 20-mesh sieve. After that, the samples were subjected to chemical analysis of the total content of N, P, K, Ca, Mg, S, B, Cu, Fe, Mn, and Zn, according to the method described in Malavolta et al. (1997). Composite soil samples were formed from 25 individual samples in 35 stands containing both African palm and ISH (at different ages) for chemical and particle size (0.00-0.20 m) characterization. These samples were collected from under the canopy projection between the rows of plants whose leaves were sampled. Soil analysis was performed according to Donagema et al. (2011) (Table 1).

Using the results of leaf analysis and yield data from fresh fruit bunches in Mg ha^{-1} accumulated each year, the means and standard deviations of nutritional relationships (bivariate) of the reference populations were calculated. The general population (not discriminating genetic material and age) consisted of African oil palm, interspecific hybrid oil palm (ISH), young oil palm (≤6 years of age), and adult oil palm (>6 years of age).

Following common practice in the areas evaluated, soil correction through liming was not performed and palm tree seedlings were planted in holes spaced in an equilateral triangle (9 × 9 × 9 m) along with 300 g of natural reactive phosphate (10 % of P_2O_5 soluble in citric acid).

In young crops, maintenance mineral fertilization was performed with NPK+Mg+S formulations according to recommendations made on the basis on leaf analysis. The use of natural phosphate in topdressing was common in all areas in the first five years after planting, on average. Organic waste from agricultural industry was applied on young

Table 1. Chemical properties and particle size of soil samples (0.00-0.20 m)

Property	Mean	Median
pH($CaCl_2$)	4.29	4.20
P (mg dm^{-3})	5.5	2.0
K$^+$ (cmol$_c$ dm^{-3})	0.09	0.07
Ca^{2+} (cmol$_c$ dm^{-3})	0.96	0.90
Mg^{2+} (cmol$_c$ dm^{-3})	0.25	0.20
Na$^+$ (cmol$_c$ dm^{-3})	0.04	0.03
Al^{3+} (cmol$_c$ dm^{-3})	0.36	0.30
H+Al (cmol$_c$ dm^{-3})	3.97	4.00
CEC pH 7.0 (cmol$_c$ dm^{-3})	5.28	5.36
SB (cmol$_c$ dm^{-3})	1.34	1.27
V (%)	25.70	25.88
m (%)	22.04	19.11
S (mg dm^{-3})	20.1	21.0
B (mg dm^{-3})	0.5	0.5
Cu (mg dm^{-3})	0.4	0.3
Fe (mg dm^{-3})	232	195
Mn (mg dm^{-3})	7.0	5.0
Zn (mg dm^{-3})	2.1	1.7
Sand (g kg^{-1})	594	590
Silt (g kg^{-1})	130	150
Clay (g kg^{-1})	277	270
OM (%)	2.0	2.0

Methods of extraction and determination in according with Donagema et al. (2011). pH($CaCl_2$): pH in $CaCl_2$ solution; H+Al: potential acidity; CEC: cation exchange capacity; SB: sum of bases; V: bases saturation; m: aluminum saturation; OM: organic matter.

plants as follows: 6 Mg ha^{-1} of empty fruit or stems (containing 9.8 kg of N, 1.1 kg of P, 16.4 kg of K, 8.4 kg of Ca, 2.6 kg of Mg, 1.1 kg of S, 15.2 g of B, 15.1 g of Cu, 28 g of Zn, 41.9 g of Mn, and 430.8 g of Fe for each Mg of dry weight), 2 Mg ha^{-1} of mesocarp fiber (containing 12.1 kg of N, 1.9 kg of P, 4.7 kg of K, 7.6 kg of Ca, 1.8 kg of Mg, 1.1 kg of S, 16.6 g of B, 23 g of Cu, 19.7 g of Zn, 25.3 g of Mn, and 415 g of Fe per Mg of dry matter), and 65 Mg ha^{-1} of effluent (with 28 g m^{-3} of N; 13.5 g m^{-3} of P; 1,157 g m^{-3} of K; 365 g m^{-3} of Ca; 335 g m^{-3} of Mg; and 166 g m^{-3} of S).

In crops where productive maturity started at 6 to 7 years, 91 kg N, 22 kg of P_2O_5, 175 kg K_2O, 28 kg of MgO, 25 kg of CaO, and 12 kg of S were applied per hectare for a yield of 25 Mg ha^{-1} of fresh fruit bunches. These older plantations receive the micronutrients Cu, Mn, and Zn along with NPK formulations seasonally. Additionally, about 100 g per plant of Ulexite or Borax has been applied as a source of B. In both young and adult plants, the Mg source is magnesium oxide and especially kieserite. Fungicides based on Cu were not applied on the crops, a factor that could influence its content in the plant.

In the database containing the content of each nutrient and the yield of reference subpopulations (satisfactory yield), the Lilliefors test (p<0.05) was applied according to Barbosa et al. (2006), for verification of normality. From that, the following stands were selected:

(a) The general population consisted of 19 stands that showed high yield, over 24 Mg ha^{-1}, which is a reference value for mature palms considered as having satisfactory yield (PalmElit, 2014). In bivariate relationships, for the specific reference population of African oil palms and ISH, the areas selected were those with yield higher than 19 Mg ha^{-1}, which represented 23 and 21 samples, respectively; and

(b) The reference population for the age groups were composed of stands with yields above 9 Mg ha^{-1} in young plants (31 samples) and 19 Mg ha^{-1} for the adult plants (37 samples). The separation value of population set for young plants was the mean yield of all stands, which, in turn, is regarded as very high for crops at this age in the region.

Yield values established to separate specific reference populations were similar to those used in irrigated plantations of oil palm in India (Behera et al., 2015). In this study, stands with yield higher than 20 Mg ha^{-1} were characterized as high yielding for generation of DRIS norms.

The reference populations above had a low number of samples in their composition, which is due to the low yield of most stands according to the standards published for oil palm (PalmElit, 2014). However, the number of samples used as a reference in this study, around 20 or more, is considered sufficient for DRIS diagnosis according to Partelli et al. (2006) and Dias et al. (2010). The low yield of the plots evaluated is mainly due to fertilizer application rates that were not consistent with the nutritional requirements of the species. In this respect, a key factor was the low value of Ca in the soil (Table 1) as a result of not using liming in this crop.

The bivariate relationship groups resulting from the general and specific reference population from plots with African palm or with ISH were compared to each other (in a paired manner), in which the number of samples that formed the norms corresponded to the number of replications for each population. Similarly, the bivariate relationships of the general control and specific populations with young and adult palms were also compared.

Comparisons were performed by means of their variances using the F test, and their means, using the Student t test, both at 5 % probability. According to Dias et al. (2010), use of the t test complementing this type of comparison was necessary since the lack of a significant F test only indicates that the relationships were obtained in relatively homogeneous environments, but this did not avoid the occurrence of different averages, considering that the resulting variances of the DRIS method come from a variety of uncontrolled factors, not only from the availability of nutrients.

When a large number of significant differences was found among the reference populations through their relationships, they were used to calculate the DRIS indices and nutritional balance index (NBI). The paired ratios of the most important nutrients (norms) were chosen according to the criterion of the highest variance ratio (Letzsch, 1985), and DRIS indices were calculated according to Beaufils (1973). From the DRIS indices, the NBI was calculated according to the expression NBI = | N Index | + | P index | + ... + | Index Zn |, as well as its mean value, which corresponds to the value of NBI divided by the number of nutrients of analysis (NBIm). The DRIS and NBI indices make up the dimensionless values.

The indices calculated for all samples (reference and non-reference subpopulation) were interpreted in two manners. First, regressions were adjusted between NBI and yield in the general and specific populations. Then, the potential response to fertilization (PRF) was calculated, in which three nutritional classes were established: poor, adequate, or excessive (Wadt et al., 1999). The nutrient was considered appropriate when the nutritional content, in module, was lower than the NBIm; poor, when the negative nutritional content, in module, was also higher than NBIm; and excessive, when the positive nutritional content was, in module, greater than the NBIm. The PRF was presented graphically according to the nutritional status of the DRIS indices (deficient, adequate, or excessive).

The nutritional evaluation methods and F and t statistical tests were calculated using electronic spreadsheets.

RESULTS AND DISCUSSION

The values of the means, standard deviations, and coefficients of variation of the paired ratios of nutrient factors in the stands with satisfactory production of the general or specific population of palm oil for age and genetic material (Tables 2 and 3) may be diagnostic parameters of this crop. Regarding oil palm, the ratios between N and P, N and K, K and Mg, and K and B are considered the most important ones in the field (Fairhurst and Härdter, 2003). The N/P ratio is a well-known index for this crop; and it should be around 16 to characterize balanced P and N nutrition (Rodrigues et al., 2006). Thus, all the N/P ratios found in this study are balanced.

Such nutritional ratios also provide support for obtaining DRIS norms, which can be calculated by the F method (Letzsch, 1985) or by the R method of Nick (1997), which selects only the orders of the most important ratios (half of the ratios). The DRIS norms can also be composed of all ratios (direct or inverse), as was done for the 'Pera' orange (*Citrus sinensis*) crop (Dias et al., 2013).

For oil palm crops, locally or regionally developed DRIS norms may provide greater accuracy in the diagnosis of nutritional imbalances (Wadt et al., 2012). For this crop, DRIS norms were established recently, but under the conditions of Colombia (Herrera Peña, 2015) and India (Behera et al., 2015), where cultivars or ages were not distinguished.

Regardless of the reference population, the highest coefficients of variations are around 30 % and appear more frequently in the ratios containing Cu and Zn. The ratios with higher coefficients of variations have less influence on obtaining DRIS indices since the reduced functions are weighted by this variable (Santana et al., 2008). These values can also indicate higher nutritional imbalances for these nutrients.

For genetic materials, only the ratios N/Ca, N/Mn, K/Ca, Ca/Mg, Ca/N, Ca/K, S/Mn, S/N, S/ K, S/Mg, and Mn/S, out of the total of 110, showed significant differences (Table 4). Such relationships correspond to 10 % of the total, when the general reference population was compared to the ISH reference population. Most of these discrepant relationships involve Ca and S. By comparing the reference population of African palm with that of ISH, only the ratios N/Ca, Ca/Zn, Ca/N, Mg/Fe, S/Mn, B/Mn, Mn/Zn, and Mn/S were different ($p<0.05$).

RBCS

Matos et al.   The Use of DRIS for Nutritional Diagnosis in Oil Palm...

Table 2. Average (x), standard deviation (s), and coefficient of variation (CV) of the macro (g kg⁻¹) and micronutrients (g kg⁻¹) contents and nutritional relationships for a general control population (indiscriminately for genetic material and age) and for specific reference populations with African type oil palm and interspecific hybrids (IHE)

	General		CV	African		CV	IHE		CV		General		CV	African		CV	IHE		CV
	x	s		x	s		x	s			x	s		x	s		x	s	
			%			%			%				%			%			%
N	27.9	2.5	9	27.3	2.6	10	26.5	2.4	9	B	24.4	5.1	21	24.4	5.16	21	24.3	5.1	21
N/P	17.68	2.51	14	16.98	2.36	14	16.54	3.14	19	B/Cu	4.45	1.5	33	4.39	1.49	34	4.9	1.51	31
N/K	3.95	0.95	24	4.05	0.85	21	3.95	0.66	17	B/Fe	0.29	0.1	29	0.27	0.07	26	0.3	0.06	21
N/Ca	3.98	0.83	21	3.78	0.80	21	3.30	0.69	21	B/Mn	0.10	0.0	23	0.09	0.02	21	0.1	0.04	36
N/Mg	13.67	2.57	19	13.22	2.05	15	13.12	2.45	19	B/Zn	1.51	0.3	21	1.47	0.33	22	1.6	0.45	27
N/S	23.84	5.76	24	22.72	6.09	27	21.16	6.86	32	B/N	8.41	1.4	16	8.37	1.49	18	9.2	1.95	21
N/B	0.12	0.02	17	0.12	0.02	19	0.11	0.02	19	B/P	148	30.8	21	142	31.01	22	152	35.16	23
N/Cu	0.53	0.13	25	0.52	0.15	28	0.53	0.15	28	B/K	33.49	10.7	32	33.9	9.45	28	36.4	8.42	23
N/Fe	0.03	0.01	24	0.03	0.01	21	0.03	0.01	25	B/Ca	33.15	7.5	23	31.3	7.41	24	30.2	7.58	25
N/Mn	0.01	0.00	18	0.01	0.00	18	0.01	0.00	22	B/Mg	115	29.2	25	109.9	21.76	20	120.5	29.65	25
N/Zn	0.18	0.04	23	0.18	0.04	23	0.18	0.03	20	B/S	202	60.7	30	191.1	65.18	34	195.2	77.11	40
P	1.70	0.03	2	1.80	0.29	16	1.70	0.20	12	Cu	5.87	1.3	22	5.97	1.30	22	5.7	1.31	23
P/K	0.23	0.06	28	0.24	0.05	22	0.24	0.05	20	Cu/Fe	0.07	0.0	35	0.07	0.02	34	0.1	0.03	38
P/Ca	0.23	0.05	20	0.22	0.05	21	0.20	0.04	20	Cu/Mn	0.03	0.0	35	0.02	0.01	36	0.0	0.01	32
P/Mg	0.78	0.16	21	0.79	0.14	17	0.81	0.14	17	Cu/Zn	0.37	0.1	31	0.36	0.11	30	0.3	0.10	28
P/S	1.37	0.35	26	1.37	0.40	29	1.31	0.43	33	Cu/N	2.02	0.5	25	2.05	0.51	25	2.0	0.47	23
P/B	0.01	0.00	21	0.01	0.00	23	0.01	0.00	26	Cu/P	35.63	9.4	26	34.86	9.47	27	33.7	10.83	32
P/Cu	0.03	0.01	32	0.03	0.01	37	0.03	0.01	41	Cu/K	7.90	2.3	29	8.30	2.50	30	8.0	2.51	31
P/Fe	0.00	0.00	23	0.00	0.00	21	0.00	0.00	20	Cu/Ca	8.19	3.0	37	7.92	2.98	38	6.8	2.61	38
P/Mn	0.00	0.00	20	0.00	0.00	21	0.00	0.00	27	Cu/Mg	27.63	9.1	33	27.2	8.72	32	26.4	7.40	28
P/Zn	0.01	0.00	29	0.01	0.00	29	0.01	0.00	26	Cu/S	48.1	16.8	35	46.4	17.37	37	43.0	19.3	45
P/N	0.06	0.01	15	0.06	0.01	14	0.06	0.01	18	Cu/B	0,25	0.1	32	0.3	0.09	34	0.2	0.08	35
K	7.70	1.50	19	7.80	1.49	19	7.50	1.60	21	Fe	90.00	21.8	24	89.0	23.51	26	91.4	19.50	21
K/Ca	1.04	0.25	24	0.96	0.20	21	0.86	0.27	31	Fe/Mn	0.38	0.1	29	0.4	0.10	28	0.4	0.12	35
K/Mg	3.61	0.94	26	3.39	0.85	25	3.37	0.61	18	Fe/Zn	5.73	2.1	36	5.8	1.90	33	5.7	1.48	26
K/S	6.38	2.27	36	5.88	2.01	34	5.60	2.35	42	Fe/N	30.9	7.2	23	32.2	6.58	20	32.6	8.16	25
K/B	0.03	0.01	32	0.03	0.01	30	0.03	0.01	28	Fe/P	543	144	26	544.4	136	25	524	106.8	20
K/Cu	0.14	0.06	42	0.14	0.06	46	0.14	0.05	36	Fe/K	122	38.4	32	128.9	32	25	128	35.05	27
K/Fe	0.01	0.00	36	0.01	0.00	31	0.01	0.00	29	Fe/Ca	121	30.0	25	120.6	30	25	105	25.25	24
K/Mn	0.00	0.00	30	0.00	0.00	29	0.00	0.00	32	Fe/Mg	414	82.1	20	416.8	68	16	418.7	93.59	22
K/Zn	0.05	0.02	38	0.05	0.02	36	0.05	0.01	32	Fe/S	733	233	32	731.0	237	32	675	242	36
K/N	0.27	0.07	27	0.26	0.06	25	0.26	0.05	18	Fe/B	3.78	1.1	29	3.9	1.01	26	3.6	0.73	21
K/P	4.70	1.20	25	4.34	0.91	21	4.28	1.01	24	Fe/Cu	16.19	5.2	32	16.8	5.78	34	17.5	7.28	42
Ca	7.70	1.70	22	7.70	1.85	24	7.80	1.60	21	Mn	258	74.2	29	260.00	76.00	29	255	72.00	28
Ca/Mg	3.53	0.76	21	3.60	0.71	20	4.10	0.90	22	Mn/Zn	15.13	3.3	22	15.9	3.09	19	17.1	4.79	28
Ca/S	6.14	1.64	27	6.11	1.65	27	6.61	2.40	36	Mn/N	84.16	16.2	19	91.0	16.44	18	97	20.03	21
Ca/B	0.03	0.01	22	0.03	0.01	22	0.03	0.01	22	Mn/P	1477	304	21	1540	328	21	1597	437	27
Ca/Cu	0.14	0.06	43	0.15	0.07	46	0.17	0.08	46	Mn/K	331	94.9	29	367	96	26	384	105	27
Ca/Fe	0.01	0.002	27	0.01	0.00	28	0.01	0.00	23	Mn/Ca	330	72.7	22	338	68	20	314	73.4	23
Ca/Mn	0.00	0.001	20	0.00	0.00	20	0.00	0.00	21	Mn/Mg	1136	248	22	1194	249	21	1256	288	23
Ca/Zn	0.05	0.01	30	0.05	0.01	29	0.06	0.02	32	Mn/S	1969	449	23	2024	506	25	2064	798	39
Ca/N	0.26	0.06	21	0.28	0.06	20	0.32	0.06	20	Mn/B	10.22	2.3	23	11.1	2.37	21	11.0	3.21	29
Ca/P	4.57	0.90	20	4.63	0.96	21	5.12	1.02	20	Mn/Cu	44.81	16.2	36	47.7	16.53	35	51.7	20.0	39
Ca/K	1.01	0.23	22	1.09	0.23	21	1.24	0.31	25	Mn/Fe	2.87	0.9	31	2.9	0.81	27	3.1	0.92	29
Mg	2.44	0.5	20	2.50	0.52	21	2.40	0.50	21	Zn	17.12	4.6	27	17.1	4.20	25	17.2	5.2	30
Mg/S	1.80	0.53	30	1.76	0.55	31	1.69	0.66	39	Zn/N	5.75	1.3	23	5.9	1.27	22	5.9	1.33	23
Mg/B	0.01	0.00	23	0.01	0.00	21	0.01	0.00	24	Zn/P	103	32.4	32	101.1	31.48	31	98.2	31.06	32
Mg/Cu	0.04	0.01	30	0.04	0.01	32	0.04	0.02	37	Zn/K	23.2	9.3	40	24.3	9.05	37	23.7	7.66	32
Mg/Fe	0.00	0.001	23	0.00	0.00	15	0.00	0.00	25	Zn/Ca	23.2	9.5	41	22.5	8.43	38	19.8	6.89	35
Mg/Mn	0.00	0.000	19	0.00	0.00	20	0.00	0.00	23	Zn/Mg	79	22.8	29	77.9	21.06	27	77.8	23.22	30
Mg/Zn	0.01	0.004	29	0.01	0.00	28	0.01	0.00	27	Zn/S	136	48.8	36	132.1	47.21	36	121.1	36.57	30
Mg/N	0.08	0.013	17	0.08	0.01	15	0.08	0.01	16	Zn/B	0.69	0.2	24	0.71	0.16	23	0.7	0.20	29
Mg/P	1.33	0.27	20	1.31	0.22	17	1.28	0.22	17	Zn/Cu	3.02	1.1	35	3.04	1.00	33	3.1	0.81	27
Mg/K	0.29	0.07	24	0.31	0.06	21	0.31	0.06	19	Zn/Fe	0.20	0.1	39	0.19	0.07	34	0.2	0.06	32
Mg/Ca	0.30	0.07	24	0.29	0.06	22	0.26	0.07	26	Zn/Mn	0.07	0.0	26	0.07	0.02	24	0.1	0.02	31
S	1.3	0.050	4	1.4	0.54	39	1.3	0.5	38										
S/B	0.01	0.002	38	0.01	0.00	38	0.01	0.00	42										
S/Cu	0.02	0.009	37	0.02	0.01	39	0.03	0.01	48										
S/Fe	0.00	0.001	36	0.00	0.00	45	0.00	0.00	45										
S/Mn	0.00	0.000	30	0.00	0.00	32	0.00	0.00	55										
S/Zn	0.01	0.003	31	0.01	0.00	31	0.01	0.00	40										
S/N	0.04	0.013	30	0.048	0.016	34	0.054	0.02	44										
S/P	0.80	0.286	36	0.826	0.35	42	0.883	0.38	43										
S/K	0.18	0.062	35	0.196	0.085	44	0.217	0.11	50										
S/Ca	0.18	0.052	30	0.177	0.053	30	0.176	0.07	42										
S/Mg	0.61	0.219	36	0.640	0.257	40	0.725	0.38	52										

Table 3. Average (x), standard deviation (s), and coefficient of variation (CV) of the macro (g kg⁻¹) and micronutrients (g kg⁻¹) contents and nutritional relationships of reference populations with young (≤6 years after planting) and adult (>6 years after planting) palms

	≤6 years		CV	>6 years		CV		≤6 years		CV	>6 years		CV
	x	s	%	x	s	%		x	s	%	x	s	%
N	26.9	2.33	9	26.9	2.66	10	B	24.7	5.68	23	24.2	4.6	19
N/P	15.91	2.46	15	16.74	2.85	17	B/Cu	4.69	0.96	21	4.61	1.59	34
N/K	3.82	1.11	29	4.06	0.74	18	B/Fe	0.27	0.07	25	0.27	0.07	26
N/Ca	3.18	0.50	16	3.60	0.82	23	B/Mn	0.09	0.03	38	0.09	0.02	26
N/Mg	11.68	2.50	21	13.21	2.35	18	B/Zn	1.51	0.59	39	1.49	0.35	23
N/S	20.45	7.29	36	21.92	6.34	29	B/N	0.89	0.24	27	0.86	0.15	17
N/B	1.19	0.27	23	1.20	0.22	18	B/P	13.94	3.14	23	14.27	3.16	22
N/Cu	5.44	1.20	22	5.35	1.57	29	B/K	3.33	0.98	29	3.49	0.91	26
N/Fe	0.31	0.07	22	0.32	0.07	23	B/Ca	2.82	0.83	30	3.04	0.70	23
N/Mn	0.10	0.03	26	0.11	0.02	20	B/Mg	10.23	2.61	26	11.27	2.66	24
N/Zn	1.66	0.36	22	1.76	0.39	22	B/S	18.52	8.28	45	18.67	6.30	34
P	1.77	0.27	15	1.73	0.25	14	Cu	5.71	1.17	20	5.98	1.41	24
P/K	0.24	0.06	23	0.25	0.05	21	Cu/Fe	0.06	0.02	29	0.07	0.02	38
P/Ca	0.20	0.03	14	0.22	0.05	22	Cu/Mn	0.02	0.01	34	0.02	0.01	35
P/Mg	0.74	0.13	18	0.80	0.14	18	Cu/Zn	0.32	0.10	32	0.35	0.11	30
P/S	1.32	0.49	37	1.34	0.41	30	Cu/N	0.19	0.04	22	0.20	0.05	26
P/B	0.08	0.02	22	0.07	0.02	24	Cu/P	3.04	0.70	23	3.39	1.06	31
P/Cu	0.35	0.08	24	0.33	0.14	41	Cu/K	0.72	0.21	29	0.82	0.26	31
P/Fe	0.02	0.01	26	0.02	0.004	20	Cu/Ca	0.61	0.17	28	0.75	0.30	40
P/Mn	0.01	0.00	26	0.01	0.002	24	Cu/Mg	2.25	0.70	31	2.67	0.87	32
P/Zn	0.11	0.03	30	0.11	0.03	28	Cu/S	3.91	1.61	41	4.44	1.86	42
P/N	0.06	0.01	14	0.06	0.01	17	Cu/B	0.22	0.05	21	0.25	0.09	36
K	8.14	1.45	18	7.37	1.49	20	Fe	88	24.28	28	91.5	19.8	22
K/Ca	0.88	0.25	28	0.91	0.21	24	Fe/Mn	0.34	0.11	32	0.36	0.11	29
K/Mg	3.15	0.62	20	3.34	0.75	23	Fe/Zn	5.62	1.60	29	5.72	1.70	30
K/S	5.84	2.59	44	5.57	1.86	33	Fe/N	3.42	0.80	23	3.25	0.71	22
K/B	0.33	0.10	30	0.31	0.09	29	Fe/P	54.66	18.22	33	53.61	12.46	23
K/Cu	1.50	0.44	29	1.39	0.61	44	Fe/K	13.20	5.87	44	13.10	3.42	26
K/Fe	0.09	0.03	31	0.08	0.03	30	Fe/Ca	10.99	3.72	34	11.48	2.83	25
K/Mn	0.03	0.01	31	0.03	0.01	27	Fe/Mg	39.92	12.39	31	42.10	8.29	20
K/Zn	0.48	0.18	37	0.46	0.15	33	Fe/S	68.66	24.83	36	69.99	22.07	32
K/N	0.28	0.06	23	0.26	0.05	21	Fe/B	3.99	1.19	30	3.87	0.93	24
K/P	4.37	1.01	23	4.22	0.86	20	Fe/Cu	18.62	6.59	35	17.54	6.83	39
Ca	8	1.82	23	7.53	1.67	22	Mn	275	80	29	24.5	67	273
Ca/Mg	3.71	0.74	20	3.80	0.86	23	Mn/Zn	17.66	5.98	34	16.34	4.03	25
Ca/S	6.64	2.57	39	6.27	2.03	32	Mn/N	10.48	2.37	23	9.36	1.82	19
Ca/B	0.38	0.10	27	0.35	0.07	22	Mn/P	165.8	41.8	25	156.1	38.98	25
Ca/Cu	1.76	0.50	28	1.62	0.79	49	Mn/K	39.50	12.90	33	37.79	9.48	25
Ca/Fe	0.10	0.03	31	0.09	0.02	25	Mn/Ca	32,97	8.02	24	33.07	7.54	23
Ca/Mn	0.03	0.01	25	0.03	0.01	22	Mn/Mg	119,9	29.02	24	122.01	25.61	21
Ca/Zn	0.54	0.18	33	0.52	0.17	33	Mn/S	212,5	78.74	37	203.67	63.72	31
Ca/N	0.32	0.05	16	0.29	0.07	22	Mn/B	12,54	4.30	34	11.21	2.66	24
Ca/P	5.06	0.67	13	4.81	1.06	22	Mn/Cu	57,62	20.13	35	50.37	18.95	38
Ca/K	1.22	0.31	26	1.16	0.27	23	Mn/Fe	3,23	1.06	33	3.00	0,82	27
Mg	2.64	0.51	19	2.29	0.43	19	Zn	16,6	4.4	27	17.5	4,7	27
Mg/S	1.87	0.76	41	1.72	0.59	34	Zn/N	0.64	0.16	26	0.59	0.13	23
Mg/B	0.11	0.03	30	0.09	0.02	23	Zn/P	10.31	3.70	36	10.03	3.23	32
Mg/Cu	0.49	0.15	32	0.42	0.15	36	Zn/K	2.56	1.37	54	2.44	0.83	34
Mg/Fe	0.03	0.01	33	0.02	0.01	21	Zn/Ca	2.06	0.72	35	2.17	0.83	38
Mg/Mn	0.01	0.002	24	0.01	0.00	20	Zn/Mg	7.71	3.51	46	7.86	2.25	29
Mg/Zn	0.15	0.05	36	0.14	0.04	28	Zn/S	12.72	6.13	48	12.81	4.47	35
Mg/N	0.09	0.02	21	0.08	0.01	16	Zn/B	0.78	0.32	42	0.71	0.17	25
Mg/P	1.40	0.25	18	1.29	0.23	18	Zn/Cu	3.50	1.33	38	3.12	0.95	31
Mg/K	0.33	0.07	21	0.31	0.06	20	Zn/Fe	0.20	0.07	34	0.19	0.06	33
Mg/Ca	0.28	0.06	20	0.28	0.07	25	Zn/Mn	0.07	0.03	49	0.07	0.02	29
S	1.34	0.55	41	1.34	0.54	40							
S/B	0.07	0.03	51	0.06	0.02	37							
S/Cu	0.30	0.12	39	0.27	0.12	45							
S/Fe	0.02	0.01	44	0.02	0.01	41							
S/Mn	0.01	0.003	51	0.01	0.003	47							
S/Zn	0.09	0.03	30	0.09	0.03	38							
S/N	0.06	0.02	37	0.05	0.02	39							
S/P	0.90	0.42	47	0.85	0.35	41							
S/K	0.22	0.12	55	0.21	0.09	43							
S/Ca	0.18	0.08	44	0.18	0.06	35							
S/Mg	0.67	0.37	55	0.68	0.32	46							

Table 4. Probability values (p-value) obtained from the F and Student's t test for comparison of relationships calculated in a general reference population (indiscriminately for genetic material and ages) and for specific reference populations with African type oil palm and interspecific hybrids (ISH)

Relationship	General × African		General × ISH		African × ISH		Relationship	General × African		General × ISH		African × ISH	
	F	t	F	t	F	t		F	t	F	t	F	t
N/P	0.78	0.36	0.34	0.21	0.20	0.61	S/N	0.39	0.49	0.02*	0.13	0.10	0.33
N/K	0.64	0.74	0.13	0.98	0.26	0.66	S/P	0.39	0.76	0.23	0.42	0.69	0.61
N/Ca	0.85	0.43	0.42	0.01*	0.52	0.04*	S/K	0.18	0.40	0.02*	0.15	0.28	0.48
N/Mg	0.31	0.54	0.83	0.49	0.41	0.89	S/Ca	0.95	0.94	0.15	0.99	0.14	0.96
N/S	0.82	0.54	0.46	0.19	0.59	0.43	S/Mg	0.49	0.74	0.03*	0.26	0.09	0.39
N/B	0.69	0.87	0.93	0.15	0.75	0.11	B/Cu	0.92	0.89	0.89	0.37	0.96	0.29
N/Cu	0.62	0.94	0.62	0.93	0.99	0.88	B/Fe	0.51	0.51	0.22	0.78	0.53	0.26
N/Fe	0.44	0.48	0.95	0.58	0.39	0.93	B/Mn	0.44	0.21	0.09	0.84	0.01*	0.45
N/Mn	0.72	0.18	0.89	0.04*	0.60	0.41	B/Zn	0.91	0.65	0.16	0.36	0.17	0.19
N/Zn	0.78	0.70	0.35	0.61	0.49	0.89	B/N	0.75	0.93	0.15	0.12	0.23	0.11
P/K	0.48	0.46	0.32	0.33	0.75	0.79	B/P	0.98	0.51	0.57	0.76	0.56	0.35
P/Ca	0.90	0.88	0.56	0.08	0.46	0.10	B/K	0.59	0.89	0.31	0.36	0.61	0.37
P/Mg	0.46	0.94	0.46	0.65	0.99	0.67	B/Ca	0.95	0.43	0.97	0.22	0.91	0.61
P/S	0.61	0.97	0.39	0.59	0.70	0.62	B/Mg	0.19	0.54	0.95	0.55	0.16	0.19
P/B	0.62	0.47	0.47	0.92	0.80	0.44	B/S	0.76	0.59	0.31	0.77	0.44	0.85
P/Cu	0.44	0.73	0.14	0.39	0.44	0.59	Cu/Fe	0.77	0.77	0.90	0.78	0.66	0.99
P/Fe	0.77	0.92	0.66	0.78	0.87	0.68	Cu/Mn	0.79	0.54	0.29	0.20	0.40	0.47
P/Mn	0.93	0.57	0.31	0.53	0.32	0.89	Cu/Zn	0.75	0.85	0.46	0.61	0.66	0.72
P/Zn	0.99	0.88	0.84	0.66	0.82	0.77	Cu/N	0.91	0.84	0.76	0.95	0.66	0.78
P/N	0.94	0.39	0.23	0.14	0.17	0.42	Cu/P	0.97	0.79	0.54	0.54	0.54	0.70
K/Ca	0.31	0.23	0.75	0.03*	0.17	0.20	Cu/K	0.77	0.60	0.76	0.91	0.98	0.69
K/Mg	0.63	0.43	0.07	0.36	0.15	0.94	Cu/Ca	0.95	0.77	0.53	0.14	0.56	0.21
K/S	0.59	0.47	0.89	0.29	0.48	0.67	Cu/Mg	0.86	0.87	0.38	0.64	0.46	0.74
K/B	0.60	0.74	0.25	0.23	0.50	0.32	Cu/S	0.90	0.76	0.56	0.38	0.63	0.54
K/Cu	0.83	0.82	0.48	0.90	0.34	0.91	Cu/B	0.74	0.81	0.94	0.41	0.68	0.28
K/Fe	0.31	0.39	0.22	0.45	0.80	0.89	Fe/Mn	0.79	0.67	0.64	0.44	0.45	0.68
K/Mn	0.52	0.23	0.69	0.14	0.81	0.70	Fe/Zn	0.72	0.94	0.16	0.90	0.26	0.82
K/Zn	0.59	0.60	0.28	0.56	0.56	0.97	Fe/N	0.70	0.57	0.58	0.50	0.33	0.86
K/N	0.56	0.66	0.05	0.68	0.16	0.94	Fe/P	0.80	0.98	0.20	0.64	0.28	0.59
K/P	0.22	0.29	0.46	0.24	0.64	0.82	Fe/K	0.44	0.53	0.69	0.62	0.71	0.90
Ca/Mg	0.78	0.78	0.45	0.04*	0.28	0.05	Fe/Ca	0.98	0.95	0.45	0.08	0.41	0.07
Ca/S	0.98	0.95	0.11	0.48	0.09	0.44	Fe/Mg	0.39	0.90	0.58	0.86	0.14	0.94
Ca/B	0.88	0.40	0.65	0.16	0.74	0.53	Fe/S	0.94	0.97	0.88	0.44	0.93	0.44
Ca/Cu	0.64	0.73	0.25	0.16	0.46	0.27	Fe/B	0.68	0.62	0.08	0.46	0.15	0.15
Ca/Fe	0.79	0.91	0.91	0.09	0.70	0.11	Fe/Cu	0.65	0.73	0.16	0.51	0.29	0.72
Ca/Mn	0.83	0.64	0.72	0.42	0.54	0.19	Mn/Zn	0.78	0.45	0.11	0.14	0.05*	0.35
Ca/Zn	0.94	0.83	0.37	0.12	0.30	0.15	Mn/N	0.95	0.19	0.37	0.03*	0.37	0.30
Ca/N	0.95	0.44	0.64	0.01*	0.58	0.03*	Mn/P	0.76	0.53	0.13	0.32	0.19	0.63
Ca/P	0.81	0.83	0.60	0.08	0.76	0.11	Mn/K	0.96	0.23	0.67	0.10	0.69	0.58
Ca/K	0.95	0.26	0.19	0.01*	0.18	0.07	Mn/Ca	0.76	0.70	0.97	0.50	0.73	0.27
Mg/S	0.93	0.83	0.36	0.55	0.38	0.67	Mn/Mg	1.00	0.46	0.52	0.17	0.50	0.45
Mg/B	0.76	0.66	0.93	0.53	0.83	0.26	Mn/S	0.61	0.71	0.02*	0.64	0.04*	0.84
Mg/Cu	0.66	0.83	0.27	0.61	0.46	0.75	Mn/B	0.96	0.23	0.18	0.41	0.17	0.87
Mg/Fe	0.06	0.69	0.79	0.97	0.03*	0.72	Mn/Cu	0.95	0.57	0.37	0.23	0.38	0.47
Mg/Mn	0.99	0.42	0.62	0.18	0.60	0.54	Mn/Fe	0.64	0.76	0.90	0.35	0.55	0.47
Mg/Zn	0.77	0.99	0.69	0.95	0.91	0.94	Zn/N	0.88	0.73	0.94	0.69	0.82	0.94
Mg/N	0.66	0.61	0.86	0.47	0.79	0.79	Zn/P	0.88	0.88	0.85	0.66	0.96	0.76
Mg/P	0.40	0.79	0.42	0.53	0.99	0.67	Zn/K	0.89	0.70	0.40	0.85	0.46	0.81
Mg/K	0.73	0.44	0.47	0.54	0.69	0.85	Zn/Ca	0.60	0.78	0.17	0.20	0.37	0.25
Mg/Ca	0.61	0.72	0.75	0.08	0.84	0.11	Zn/Mg	0.71	0.92	0.95	0.92	0.65	0.99
S/B	0.71	0.55	0.40	0.51	0.62	0.91	Zn/S	0.87	0.78	0.21	0.28	0.26	0.39
S/Cu	0.66	0.64	0.06	0.16	0.12	0.30	Zn/B	0.90	0.66	0.48	0.62	0.38	0.35
S/Fe	0.26	0.79	0.16	0.33	0.74	0.50	Zn/Cu	0.80	0.94	0.27	0.87	0.37	0.92
S/Mn	0.81	0.88	0.00*	0.52	0.01*	0.45	Zn/Fe	0.44	0.78	0.26	0.70	0.68	0.91
S/Zn	0.91	0.74	0.10	0.26	0.10	0.37	Zn/Mn	0.63	0.47	0.63	0.33	0.32	0.71

*: significant (p<0.05) by the F test or by Student's t test.

The small number of differences indicates that the general reference population may represent both African oil palm and ISH. This means that some features of ISH, such as their distinct patterns of environmental resistance and vegetative growth (Gomes Junior et al., 2014), at least initially, they were not remarkable enough to express different nutritional relationships from African species, a fact that facilitates the application of DRIS in areas with these cultivars. Similarly, it was found, in cotton (*Gossipium hirsutum*) crops, that DRIS can be applied regardless of the cultivar used (Singh et al., 2012). These results are in agreement with the proposed DRIS calculation, which, in theory, transcends the effect of the cultivar when nutrient norms are set in maximum performance populations (Reis Jr and Monerat, 2002).

There were a large number of significant differences among the bivariate relationships of the evaluated reference populations as a function of age groups (general reference population, young and adult plants) (Table 5). This indicates that the DRIS norms should be applied distinctly (specifically) for the phases of the productive life of this crop in order to increase the accuracy of diagnoses made by this method. These results disagree with the premises of DRIS, which were created as supporting diagnostics by means of nutritional relationships regardless of the part or age of the sampled plant (Jones Jr, 1993). According to Mourão Filho (2004), the use of general DRIS norms, to the detriment of specific ones, has relevance only when they are derived from databases with as much variability as possible (different locations, ages, genetic material, and soil fertilities, among other factors), which was not the case for the data used in this study. However, to oil palm, more results of analysis and yield should be inserted in the preliminary set norms to increase the number of samples within control populations for greater accuracy of DRIS calculations.

The differences detected by the nutritional relationships of age ranges are due to the fact that nutrients are largely located for leaf dry matter production in the young palms; however, in adult palms, a constant reallocation of nutrients occurs to the bunch (Fairhurst and Härdter, 2003), generating different leaf patterns.

For *cupuaçu* (*Theobroma grandiflorum*) crops in the Amazon, DRIS norms were not differentiated between the two age ranges tested (Dias et al., 2010). In contrast, higher accuracy with the use of specific norms considering different ages or plant stages was observed for crops such as eucalypt (*Eucalyptus* spp.) (Wadt et al., 1999) and passion fruit (*Passiflora edulis*) (Carvalho et al., 2011). Diverging results in the literature reinforce the need to evaluate DRIS norms according to plant development stages before applying these standard relationships to commercial diagnostics.

In relating the nutrient balance index (NBI) with the yield of the general populations of young and adult palms, the correlation coefficient was significant in all cases (Figure 2). The coefficient of the general population, which was significantly lower, indicates that there are other factors besides plant nutrition that strongly affect yield (Hernandes et al., 2014); that is, when considering other sources of variation, such as the age of the plant, the models will be accurate.

According to the potential response to fertilization, the diagnosis of N, P, K, and Mg, the nutrients considered most important for oil palm, most often were balanced (Figure 3). Regarding the number of cases of nutritional deficiency in stands of young crops, the decreasing order was Ca > Fe > B > Mn > S > K = Mg > Cu > Zn > N > P; and in the adult plants, the order was Ca > Mn = Zn > Fe > S = B > N = Cu > K > Mg > P. In both age groups, micronutrient deficiencies were more expressive than those of primary macronutrients; however, Ca and P were the nutrients with highest and lowest occurrences of deficiencies, respectively. For frequencies of nutritional excess, Cu and B stand out in young plants (20 cases each) and Cu in adult plants (32 cases).

Table 5. Probability values (p-value) obtained in F test and Student's t test for comparison of relationships calculated in a general reference population (indiscriminately for genetic material and ages) and for specific reference populations with young (≤6 years after planting) and adult (>6 years after planting) palms
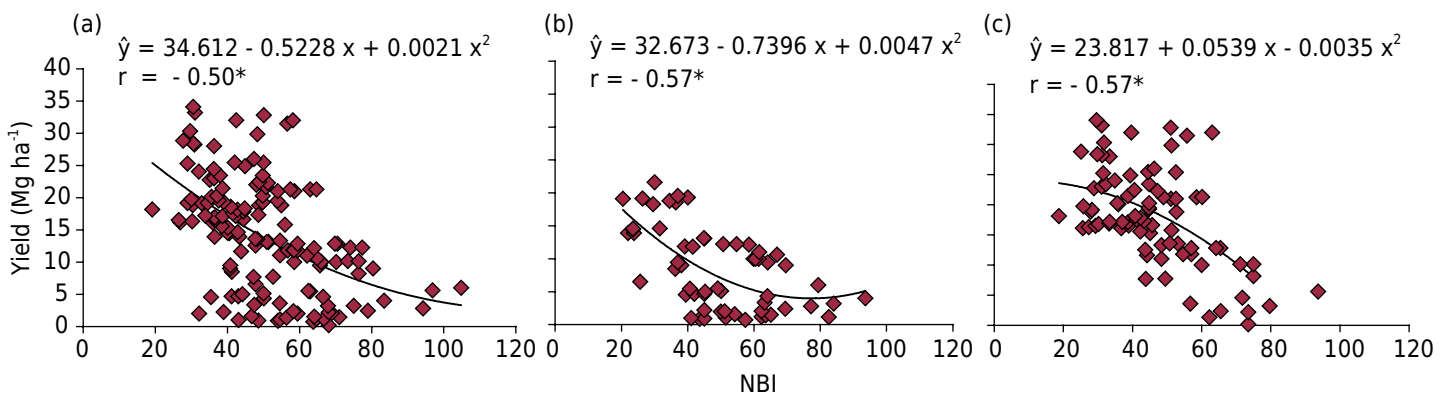
	General vs ≤6 years		General vs > 6 years		≤6 years vs >6 years			General vs ≤6 years		General vs >6 years		≤6 years vs >6 years	
	F	t	F	t	F	t		F	t	F	t	F	t
N/P	0.02*	0.89	0.20	0.21	0.41	0.20	S/N	0.03*	0.06	0.37	0.18	0.87	0.37
N/K	0.65	0.49	0.32	0.69	0.02*	0.32	S/P	0.31	0.09	0.60	0.56	0.28	0.60
N/Ca	0.00*	0.01*	0.01*	0.11	0.01*	0.01*	S/K	0.10	0.00*	0.61	0.15	0.08	0.61
N/Mg	0.01*	0.86	0.01*	0.52	0.73	0.01*	S/Ca	0.88	0.07	0.99	0.86	0.20	0.99
N/S	0.07	0.30	0.38	0.26	0.42	0.38	S/Mg	0.48	0.02*	0.94	0.37	0.37	0.94
N/B	0.00*	0.00*	0.81	0.00*	0.21	0.81	B/Cu	0.53	0.04*	0.78	0.72	0.01*	0.78
N/Cu	0.00*	0.00*	0.78	0.00*	0.14	0.78	B/Fe	0.43	0.33	0.75	0.58	0.86	0.75
N/Fe	0.00*	0.00*	0.39	0.00*	0.71	0.39	B/Mn	0.14	0.10	0.57	0.24	0.05	0.57
N/Mn	0.00*	0.00*	0.09	0.00*	0.41	0.09	B/Zn	0.98	0.01*	0.89	0.83	0.00*	0.89
N/Zn	0.00*	0.00*	0.25	0.00*	0.71	0.25	B/N	0.00*	0.00*	0.46	0.00*	0.01*	0.46
P/K	0.43	0.56	0.65	0.24	0.64	0.65	B/P	0.00*	0.00*	0.67	0.00*	0.97	0.67
P/Ca	0.04*	0.02*	0.08	0.49	0.01*	0.08	B/K	0.00*	0.00*	0.52	0.00*	0.67	0.52
P/Mg	0.29	0.26	0.05	0.70	0.58	0.05	B/Ca	0.00*	0.00*	0.26	0.00*	0.33	0.26
P/S	0.66	0.16	0.88	0.73	0.31	0.88	B/Mg	0.00*	0.00*	0.11	0.00*	0.93	0.11
P/B	0.00*	0.00*	0.73	0.00*	0.73	0.73	B/S	0.00*	0.00*	0.93	0.00*	0.12	0.93
P/Cu	0.00*	0.00*	0.62	0.00*	0.01*	0.62	Cu/Fe	0.14	0.08	0.19	0.67	0.04*	0.19
P/Fe	0.00*	0.00*	0.83	0.00*	0.16	0.83	Cu/Mn	0.03*	0.17	0.10	0.29	0.34	0.10
P/Mn	0.00*	0.00*	0.37	0.00*	0.91	0.37	Cu/Zn	0.16	0.62	0.26	0.60	0.91	0.26
P/Zn	0.00*	0.00*	0.90	0.00*	0.73	0.90	Cu/N	0.00*	0.00*	0.44	0.00*	0.22	0.44
P/N	0.02*	0.84	0.25	0.16	0.43	0.25	Cu/P	0.00*	0.00*	0.10	0.00*	0.03*	0.10
K/Ca	0.03*	0.97	0.68	0.05	0.37	0.68	Cu/K	0.00*	0.00*	0.08	0.00*	0.22	0.08
K/Mg	0.07	0.04*	0.26	0.28	0.26	0.26	Cu/Ca	0.00*	0.00*	0.03*	0.00*	0.00*	0.03*
K/S	0.45	0.57	0.63	0.19	0.06	0.63	Cu/Mg	0.00*	0.00*	0.03*	0.00*	0.23	0.03*
K/B	0.00*	0.00*	0.43	0.00*	0.54	0.43	Cu/S	0.00*	0.00*	0.22	0.00*	0.42	0.22
K/Cu	0.00*	0.00*	0.39	0.00*	0.07	0.39	Cu/B	0.21	0.01*	0.17	0.90	0.00*	0.17
K/Fe	0.00*	0.00*	0.55	0.00*	0.66	0.55	Fe/Mn	0.25	0.96	0.53	0.51	0.86	0.53
K/Mn	0.00*	0.00*	0.82	0.00*	0.46	0.82	Fe/Zn	0.84	0.23	0.81	0.97	0.75	0.81
K/Zn	0.00*	0.00*	0.60	0.00*	0.35	0.60	Fe/N	0.00*	0.00*	0.37	0.00*	0.51	0.37
K/N	0.62	0.50	0.11	0.49	0.34	0.11	Fe/P	0.00*	0.00*	0.79	0.00*	0.03*	0.79
K/P	0.33	0.41	0.52	0.13	0.34	0.52	Fe/K	0.00*	0.00*	0.94	0.00*	0.00*	0.94
Ca/Mg	0.42	0.90	0.64	0.23	0.42	0.64	Fe/Ca	0.00*	0.00*	0.55	0.00*	0.12	0.55
Ca/S	0.41	0.05	0.52	0.81	0.17	0.52	Fe/Mg	0.00*	0.00*	0.41	0.00*	0.02*	0.41
Ca/B	0.00*	0.00*	0.10	0.00*	0.08	0.10	Fe/S	0.00*	0.00*	0.82	0.00*	0.50	0.82
Ca/Cu	0.00*	0.00*	0.38	0.00*	0.01*	0.38	Fe/B	0.52	0.77	0.64	0.76	0.16	0.64
Ca/Fe	0.00*	0.00*	0.25	0.00*	0.09	0.25	Fe/Cu	0.16	0.29	0.51	0.42	0.85	0.51
Ca/Mn	0.00*	0.00*	0.83	0.00*	0.41	0.83	Mn/Zn	0.06	0.01*	0.30	0.23	0.02*	0.30
Ca/Zn	0.00*	0.00*	0.55	0.00*	0.73	0.55	Mn/N	0.00*	0.00*	0.03*	0.00*	0.13	0.03*
Ca/N	0.00*	0.70	0.03*	0.08	0.21	0.03*	Mn/P	0.00*	0.00*	0.33	0.00*	0.68	0.33
Ca/P	0.05	0.15	0.24	0.39	0.01*	0.24	Mn/K	0.00*	0.00*	0.54	0.00*	0.08	0.54
Ca/K	0.01*	0.14	0.46	0.03*	0.38	0.46	Mn/Ca	0.00*	0.00*	0.96	0.00*	0.08	0.07
Mg/S	0.72	0.11	0.38	0.61	0.15	0.38	Mn/Mg	0.00*	0.00*	0.75	0.00*	0.72	0.96
Mg/B	0.00*	0.00*	0.08	0.00*	0.02*	0.08	Mn/S	0.00*	0.00*	0.62	0.00*	0.47	0.75
Mg/Cu	0.00*	0.00*	0.07	0.00*	0.88	0.07	Mn/B	0.02*	0.01*	0.14	0.16	0.22	0.62
Mg/Fe	0.00*	0.00*	0.12	0.00*	0.00*	0.12	Mn/Cu	0.02*	0.34	0.13	0.26	0.01*	0.14
Mg/Mn	0.00*	0.00*	0.54	0.00*	0.19	0.54	Mn/Fe	0.21	0.45	0.35	0.58	0.72	0.13
Mg/Zn	0.00*	0.00*	0.22	0.00*	0.05	0.22	Zn/N	0.00*	0.00*	0.25	0.00*	0.13	0.35
Mg/N	0.00*	0.12	0.00*	0.51	0.03*	0.00*	Zn/P	0.00*	0.00*	0.74	0.00*	0.24	0.25
Mg/P	0.34	0.79	0.06	0.59	0.57	0.06	Zn/K	0.00*	0.00*	0.69	0.00*	0.43	0.74
Mg/K	0.08	0.92	0.30	0.32	0.64	0.30	Zn/Ca	0.00*	0.00*	0.56	0.00*	0.00*	0.69
Mg/Ca	0.39	0.28	0.86	0.33	0.32	0.86	Zn/Mg	0.00*	0.00*	0.84	0.00*	0.43	0.56
S/B	0.00*	0.00*	0.33	0.00*	0.02*	0.33	Zn/S	0.00*	0.00*	0.95	0.00*	0.01*	0.84
S/Cu	0.00*	0.00*	0.34	0.00*	0.82	0.34	Zn/B	0.23	0.00*	0.30	0.74	0.07	0.95
S/Fe	0.00*	0.00*	0.65	0.00*	0.51	0.65	Zn/Cu	0.16	0.30	0.19	0.71	0.00*	0.30
S/Mn	0.00*	0.00*	0.96	0.00*	0.65	0.96	Zn/Fe	0.86	0.39	0.83	0.73	0.06	0.19
S/Zn	0.00*	0.00*	0.95	0.00*	0.17	0.95	Zn/Mn	0.64	0.01*	0.91	0.42	0.77	0.83

*: significant ($p < 0.05$) by the F test or by Student's t test.

The occurrence of samples with N, and particularly K, predominantly in nutritional status of adequate is not common in evaluations of oil palm crops. When evaluated for sufficiency ranges, the appearance of more cases of deficiency is normal since these nutrients are the most exported via bunches (Viégas and Müller, 2000). In irrigated oil palm in India, Behera et al. (2015) observed K as having the most and N as the second most occurrences of deficiencies in palm stands by means of evaluation by DRIS indices. In contrast, similar to the results of this study, K and N indices rates, with few cases of deficiency were also observed in DRIS diagnosis of oil palm in Colombia; this was attributed to a regular supply of these nutrients (Herreira Peña, 2015).

Deficiency of Ca and the micronutrients B, Fe, Mn, and Zn is due to scant attention given to these elements in nutritional management of oil palm in the state of Pará. In this crops, soil is not corrected by liming, due to the low response of this species in other countries (Fairhurst and Härdter, 2003), which explains the low Ca content in the soils of the stands studied (Table 1). Values lower than 1.5 cmol$_c$ dm^{-3} for the state of Pará are considered low, according to Brasil and Cravo (2010). Nevertheless, the absence of liming has been questioned for oil palm crops in the Amazon; therefore, further local studies should be carried out (Franzini et al., 2012). It is important to highlight that Ca deficiency has been reported as a possible cause of the disorder known as lethal yellowing in oil palm (Laing, 2012), a problem that has decimated several commercial crops in the state.

In general, fertilization in this region is carried out by replacing the nutrients N, P, and K. Secondary macronutrients (Ca, Mg, and S) are rarely included in the formulations of commercial fertilizers, and micronutrients are seldom applied, except for B. In addition, when soil correction is not carried out, micronutrient availability is restricted (Franzini et al., 2012).

(a) $\hat{y} = 34.612 - 0.5228\,x + 0.0021\,x^2$ $r = -0.50*$

(b) $\hat{y} = 32.673 - 0.7396\,x + 0.0047\,x^2$ $r = -0.57*$

(c) $\hat{y} = 23.817 + 0.0539\,x - 0.0035\,x^2$ $r = -0.57*$

Figure 2. Relationship between nutritional balance indices (NBI) and yields of oil palm stands considering DRIS norms composed by oil palms of all ages (a), young palms (≤6 years) (b), and adult palms (>6 years) (c) in the state of Pará, Brazil. *: significant (p<0.05) by Student's t test.
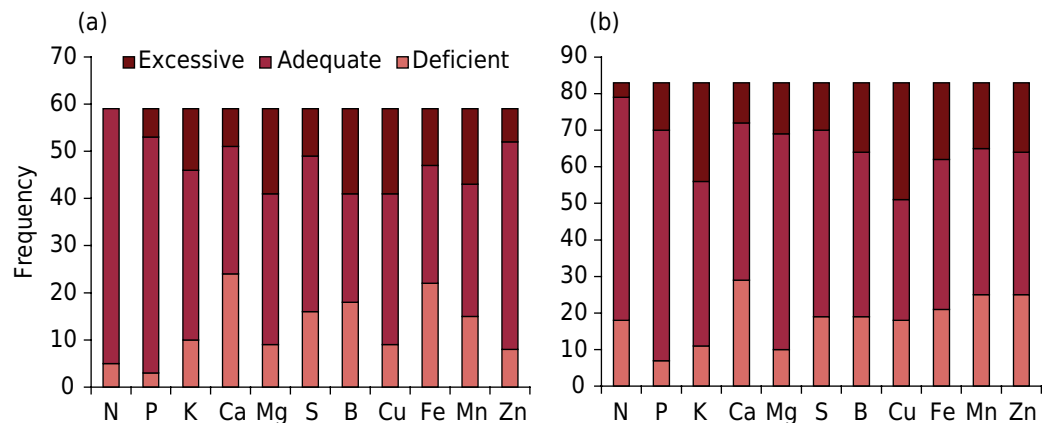
Figure 3. Response potential to fertilization in stands with young (≤6 years) (a) and adult (>6 years) (b) oil palm plants in the northeast of the state of Pará, Brazil.

Deficiency of B has been identified as the most common deficiency in oil palm crops around the world. This is due to the low clay content in the soil commonly used for growing this palm, excessive rainfall in the production regions, and correlation of B with high yielding genetic materials when they are well supplied with N, P, and K (Gutiérrez-Soto and Torres-Acuña, 2013). This last situation is not applicable to the crops studied here since the optimal levels of N fertilization and especially potassium fertilization have not been achieved in practice.

Leaf diagnostics for Fe showed several cases of deficiency even in the soils of the stands studied that had Fe content higher than 45 mg dm^{-3} (Table 1), which is a value considered adequate for the state of Pará (Brasil and Cravo, 2010). This Fe deficiency can be related to Ca in soil and plant deficiency that affect negatively the plasmalem integrity decreasing another cation and the anion uptake (Silva e Trevisan, 2015).

The high incidence of cases of deficiency and excess of B and Cu indicate that those nutrients are in greatest imbalance in the crops evaluated. For B, this is because the boundary between its deficiency and excess is very narrow (Silva et al., 2015). However, the excess of Cu in the leaves, which was more representative in adult plants, may be related to deficiencies of Ca. This macronutrient has the role of regulating Cu uptake by the plant, regardless of its concentration in the soil, which is due to ionic antagonism (Silva and Trevizan, 2015).

In oil palm crops in Colombia, Fe and Zn were the most and second most deficient nutrients, respectively, according to DRIS indices, surpassing the primary macronutrients (Herrera Peña, 2015), as in this study. In commercial areas evaluated by those authors, it was reported that Fe and Zn negatively influenced production since the other elements were relatively well supplied.

CONCLUSIONS

Regardless of genetic material, general DRIS norms have an effect similar to that of specific norms considering the type of African oil palms and their interspecific hybrids for nutritional diagnosis.

Evaluation of the nutritional status of oil palm using DRIS should consider the age of the plants, separating the young (≤6 years) from the adult (>6 years) plants for greater accuracy of diagnoses.

Oil palm stands, regardless of age, showed high numbers of deficiency of Ca, Fe, and Mn. In addition, B and Zn were limiting in the young and adult plants, respectively.

Absence of liming on oil palm should be reviewed, and fertilization in the state of Pará should be stricter in providing Ca and micronutrients to increase yield.

REFERENCES

Barbosa DHSG, Vieira HD, Partelli FL, Souza RM. Estabelecimento de normas DRIS e diagnóstico nutricional do cafeeiro arábica na região noroeste do Estado do Rio de Janeiro. Cienc Rural. 2006;36:1717-22. https://doi.org/10.1590/S0103-84782006000600008

Beaufils ER. Diagnosis and recommendation integrated system (DRIS). Soil Sci Bull Univ Natal (Sudafrica). 1973;1:1-132.

Behera SK, Rao BN, Suresh K, Manoja K. Soil nutrient status and leaf nutrient norms in oil palm (*Elaeis guineensis* Jacq.) plantations grown on southern plateau of India. Proc Natl Acad Sci India Sect B Biol Sci. 2015;85:1-7. https://doi.org/10.1007/s40011-015-0508-y

Brasil EC, Cravo MS. Interpretação de análise de solos. In: Cravo MS, Viégas IJM, Brasil EC, editores. Recomendações de adubação e calagem para o estado do Pará. Belém: Embrapa Amazônia Oriental; 2010. p.153-5.

Carvalho AJC, Fontes PSF, Freitas MSM, Monnerat PH, Fontes AG. Yellow passion fruit plant nutritional diagnosis at different phenological stages by the diagnosis and recommendation integrated system method. J Plant Nutr. 2011;34:614-26. https://doi.org/ 10.1080/01904167.2011.538558

Cunha RNV, Lopes R, Rocha RNC, Lima WAA, Teixeira PC, Barcelos E, Rodrigues MRL, Rios SA. Domestication and breeding of the American oil palm. In: Borém A, Lopes MTG, Clement CR, Noda H, editors. Domestication and breeding: Amazon species. Viçosa, MG: Suprema; 2012. p.275-96.

Dias JRM, Wadt PGS, Sampaio FAR, Pittelkow FK, Miotti AA, Rosa MR. Estabelecimento de normas DRIS para cupuaçuzeiro na região amazônica. Rev Caatinga. 2010;23:121-8.

Dias JRM, Wadt PGS, Tucci CAF, Santos JZL, Silva SV. Normas DRIS multivariadas para avaliação do estado nutricional de laranjeira 'Pera' no Estado do Amazonas. Rev Cienc Agron. 2013;44:2519.

Donagema GK, Campos DVB, Calderano SB, Teixeira WG, Viana JHM, organizadores. Manual de métodos de análise do solo. 2a ed. rev. Rio de Janeiro: Embrapa Solos; 2011.

Fairhurst T, Härdter R. Oil palm - Management for large and sustainable yields. Singapore: Potash & Phosphate Institute (PPI), Potash & Phosphate Institute of Canada (PPIC), and International Potash Institute (IPI, Basel); 2003.

Franzini VI, Silva ARB, Gomes Junior RA. Acidez do solo e sua correção em palma de óleo. Belém: Embrapa Amazônia Oriental; 2012. (Embrapa Amazônia Oriental, Documentos, 386).

Gomes Junior RA, Gurgel FL, Peixoto LA, Bhering LL, Cunha RNV, Ricardo L, Pina AJA, Veiga AS. Evaluation of interspecific hybrids of palm oil reveals great genetic variability and potential selection gain. Ind Crops Prod. 2014;52:512-8. https://doi.org/10.1016/j.indcrop.2013.10.036

Gutiérrez-Soto MV, Torres-Acuña J. Síntomas asociados a la deficiencia de boro en la palma aceitera (*Elaeis guineensis* Jacq.) en Costa Rica. Agron Mesoam. 2013;24:441-9.

Hernandes A, Souza HA, Amorim DA, Natale W, Lavres Junior J, Boaretto AE, Camacho MA. DRIS norms for pêra orange. Commun Soil Sci Plant Anal. 2014;45:2853-67. https://doi.org/10.1080/00103624.2014.956933

Herrera Peña GE. Obtención del sistema integrado de diagnóstico y recomendación integral (DRIS) en el cultivo de palma de aceite (*Elaeis guineensis* Jacq.) [dissertação]. Bogotá: Universidad Nacional de Colombia; 2015.

Jones Jr JB. Modern interpretation systems for soil and plant analysis in the USA. Aust J Exp Agric. 1993;33:1039-43. https://doi.org/10.1071/EA9931039

Laing D. Deficiência temporária de cálcio como causa primária do amarelecimento fatal do dendezeiro. Piracicaba: IPNI; 2012. (Informações agronômicas, 137).

Letzsch WS. Computer program for selection of norms for use in the diagnosis and recommendation integrated system (DRIS). Commun Soil Sci Plant Anal. 1985;16:339-47. https://doi.org/10.1080/00103628509367609

Lopes R, Cunha RNV, Resende MDV. Produção de cachos e parâmetros genéticos de híbridos de caiaué com dendezeiro. Pesq Agropec Bras. 2012;47:1496-503. https://doi.org/10.1590/S0100-204X2012001000012

Malavolta E, Vitti GC, Oliveira SA. Avaliação do estado nutricional de plantas: princípios e aplicações. São Paulo: Potafos; 1997.

Martín I, Benito A, Romero I, Domínguez N, García-Escudero E. Preliminary diagnosis and recommendation integrated system norms for leaf nutrient diagnosis of tempranillo grapevine in the rioja appellation. Commun Soil Sci Plant Anal. 2013;44:655-67. https://doi.org/10.1080/00103624.2013.745388

Mourão Filho FAA. DRIS: Concepts and applications on nutritional diagnosis in fruit crops. Sci Agric. 2004;61:550-60. https://doi.org/10.1590/S0103-90162004000500015

Nick JA. DRIS para cafeeiros podados [dissertação]. Piracicaba: Universidade de São Paulo, Escola Superior de Agricultura "Luiz de Queiroz"; 1998.

PalmElit. Plant material solutions for the tropics. [Accessed: 10 Dec. 2014]. Available at: http://www.palmelit.com/en/literature.

Partelli FL, Vieira HD, Monnerat PH, Viana AP. Estabelecimento de normas DRIS em cafeeiro conilon orgânico e convencional no Estado do Espírito Santo. Rev Bras Cienc Solo. 2006;30:443-51. https://doi.org/10.1590/S0100-06832006000300006

Potts J, Lynch M, Wilkings A, Huppé G, Cunningham M, Voora V. The state of sustainability initiatives review 2014. State of Sustainability Initiatives. [Accessed: 20 Jan 2014]. Available at: https://www.iisd.org/pdf/2014/ssi_2014.pdf.

Reis Jr RA, Monnerat PH. Sugarcane nutritional diagnosis with DRIS norms established in Brazil, South Africa and United States. J Plant Nutr. 2002;30:2831-51. https://doi.org/10.1081/PLN-120015542

Rodrigues MRL, Amblard P, Barcelos E, Macedo JLV, Cunha RNV, Tavares AM. Avaliação do estado nutricional do dendezeiro: análise foliar (Reformulada). Manaus: Embrapa Amazônia Oriental; 2006. (Circular técnica, 26).

Santana JG, Leandro WM, Naves RV, Cunha PP. Normas DRIS para interpretação de análises de folha e solo, em laranjeira pêra, na região central de Goiás. Pesq Agropec Trop. 2008;38:109-17.

Silva GGC, Neves JCL, Alvarez V VH, Leite FP. Avaliação da universalidade das normas DRIS, M-DRIS e CND. Rev Bras Cienc Solo. 2005;29:755-61. https://doi.org/10.1590/S0100-06832005000500011

Silva MLS, Trevisan AR. Interações iônicas e seus efeitos na nutrição de plantas. Piracicaba: IPNI; 2015. (Informações agronômicas, 49).

Silva MR, Assmann TS, Martin TN, Caldas TS. Adubação bórica na produção de forragem e componentes radiculares de trevo branco. Biosci J. 2015;31:65-72. https://doi.org/10.14393/BJ-v31n1a2015-18142

Singh D, Singh K, Hundal HS, Sekhon KS. Diagnosis and recommendation integrated system (DRIS) for evaluating nutrient status of cotton (*Gossipium hirsutum*). J Plant Nutr. 2012;35:192-202. https://doi.org/10.1080/01904167.2012.636122

Viégas IJM, Müller AA. A cultura do dendezeiro na Amazônia brasileira. Belém: Embrapa Amazônia Oriental; 2000.

Wadt PGS, Novais RF, Alvarez V VH, Barros NF, Dias LE. Variações no estado nutricional de eucaliptos por influência do material genético e da idade da árvore. Pesq Agropec Bras. 1999;34:1797-803. https://doi.org/10.1590/S0100-204X1999001000005

Wadt PGS, Dias JRM. Normas DRIS regionais e inter-regionais na avaliação nutricional de café Conilon. Pesq Agropec Bras. 2012;47:822-30. https://doi.org/10.1590/S0100-204X2012000600013