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Universality of Kenworthy and DRIS norms for prata and cavendish bananas grown in two environments

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ABSTRACT: Tissue analysis results are interpreted by comparing them with nutrient standards; however, using universal standards may lead to a misleading nutritional diagnosis. This study aimed to evaluate the degree of universality of Kenworthy and DRIS norms for irrigated 'Prata-Anã' (AAB) and 'Grande Naine' (AAA) banana plants grown in two environments. The study was carried out using a database containing leaf nutrient contents and yield data of two farms located in Ponto Novo, Bahia State, and Missão Velha, Ceará State, Brazil. A reference population was that with yields above the average yield plus 0.5 standard deviation. Using a reference population, the mean, standard deviation, and coefficient of variation of nutrient content and dual nutrient ratios were calculated for each site × cultivar combination. To verify the homogeneity of variance among populations, F-test was used ($p \leq 0.05$). Means were compared using t-test ($p \leq 0.05$). Differences in climate and soil at each farm explain the high frequency of significant differences found between norms for each site. Kenworthy norms established for interpreting leaf nutrient contents of P, K, Ca, Mg, S, Cu, Fe, Mn, and Zn for 'Prata-Anã' grown in Ceará were higher than those in Bahia, while for N and B contents, the norms were higher in Bahia. This is due to differences in soil fertility and alkalinity affecting nutrient availability as well as non-nutritional factors. Kenworthy and DRIS norms for 'Prata-Anã' and 'Grande Naine' bananas grown in Ceará have higher variability and are greater than for those grown in Bahia. Norms are less convergent for 'Prata-Anã' than 'Grande Naine'. Site- and cultivar-specific norms are recommended over universal ones for assessing the nutritional status of 'Prata-Anã' and 'Grande Naine' banana plants cultivated in different environments.

Keywords: *Musa* spp. AAB and AAA, nutrition, site-specific conditions, diagnosis.

INTRODUCTION

Plant tissue analysis results should be compared with nutrient standards for interpretative purposes. This can be accomplished by employing several methods such as sufficiency range (Cantarutti et al., 2007), which has been traditionally used (Silva and Carvalho, 2006), mainly due to its simplicity; however, it has been criticized for not taking account the interaction between nutrients and its difficulty in accounting for changes in dry matter nutrient content as the plant ages.

Balance indices of Kenworthy (BIKW) allow the assessment of the nutritional status of plants based on the percentage deviation of a given nutrient from the norm — i.e., coefficients of variation of each leaf nutrient content in a population from which the norms were derived from (Kenworthy, 1961; Cantarutti et al., 2007). However, using methods that take only the supposedly right amount of a nutrient into consideration, such as sufficiency ranges and BIKM, may lead to misleading diagnosis because nutrient balance is not taken into account; having adequate nutrient levels does not prevent plants from having nutritional imbalances.

Therefore, Beaufils (1973) developed the Diagnosis Recommendation Integrated System (DRIS) to interpret leaf analysis results. This approach compares ratios between nutrient contents of a sampled population with norms derived from a high-yielding population by using a standard formula to calculate an index for each nutrient (Reis Junior and Monnerat, 2002). High-yielding populations are used to calculate the norms based on the assumption that, in such population, the mean of a ratio between two nutrients is similar to the optimum value (Silva and Carvalho, 2006).

Diagnosis Recommendation Integrated System has been developed to provide a valid nutritional diagnosis irrespective of plant age or sampled plant organ, thereby permitting universal applicability (Sumner, 1977; Walworth and Sumner, 1987; Jones Junior, 1993; Bailey et al., 1997); however, this universality has been questioned (Hallmark and Beverly, 1991).

In a study on ‘Prata-Anã’ banana, Pereira et al. (2015) concluded that site-specific norms were different from universal norms, as well as their respective nutritional diagnoses. Reis Junior and Monnerat (2002) evaluated the use of universal DRIS norms for sugarcane and reported that regionally established norms are preferable to universal ones. In assessing the nutritional status of corn, Dara et al. (1992) reported that DRIS indices derived from norms found in the literature were less precise than indices derived from site-specific norms. Other studies have evaluated universal norms against site-specific norms, such as Silva et al. (2005) for eucalyptus, Modesto et al. (2014) for corn, and Santos and Rozane (2017) for atemoya.

Several studies have also reported DRIS norms for banana plants. Silva and Carvalho (2006) established DRIS norms for ‘Prata-Anã’ bananas; Angeles et al. (1993) and Teixeira et al. (2007) for ‘Grande Naine’ bananas. Although studies on the determination of DRIS and BIKW norms for ‘Prata-Anã’ and ‘Grande Naine’ bananas are found in the literature, further research is needed to develop, evaluate, and discuss the universality of these norms, because the generalized use of norms for different environments and cultivars may lead to misleading assessments of nutritional status of banana plants. This study aimed to determine Kenworthy and DRIS norms for irrigated ‘Prata-Anã’ and ‘Grande Naine’ banana plants grown in two environments and to verify the universality of the norms.

MATERIALS AND METHODS

Studies were carried out using data collected from two commercial farms belonging to the company Sítio Barreiras. The first farm is located in Missão Velha, Ceará State, Brazil

(7° 35’ 90” S, 39° 21’ 17” W, and altitude of 442 m a.s.l.). The climate is Aw — tropical climate with dry winters and rains concentrated in the summer (Köppen-Geiger). Mean annual precipitation and mean annual temperature is 942 mm and 25.8 °C, respectively. Table 1 shows climate data recorded during data collection. The soil at the farm was, predominately, a *Latossolo Vermelho-Amarelo* (Santos et al., 2018), which corresponds to a Ferralsol (IUSS Working Group WRB, 2015) or an Oxisol (Soil Survey Staff, 2014).

At the farm, there were 57 plots with ‘Prata-Anã’ and 11 plots with ‘Grande Naine’ bananas. Average plot area was 3.26 ha and all plants were fertigated. The results of soil tests are summarized in table 2.

The second farm is located in Ponto Novo, Bahia, Brazil (10° 51’ 46” S, 40° 08’ 01” W, 362 m a.s.l.). The climate is Aw (Köppen-Geiger classification) with mean annual precipitation of 696 mm and mean annual temperature of 24.1 °C. Climate data recorded during data collection are in table 1. The predominant soil was classified as a *Latossolo Amarelo* (Santos et al., 2018), which corresponds to a Ferralsol (IUSS Working Group WRB, 2015) or an Oxisol (Soil Survey Staff, 2014). At this farm, there were 117 plots, each one with an average area of 4.53 ha — 100 plots for ‘Prata-Anã’

Table 1. Climate data recorded on automatic weather stations installed at the farms in Missão Velha, Ceará, and Ponto Novo, Bahia, in 2016

Month	Mean Temp.	Max Temp.	Min Temp.	Precipitation	RH	VPD	Max. wind speed
	°C			mm	%	kPa	m s^{-1}
			Missão Velha – CE				
January	26.91	31.96	21.86	231.10	74.22	0.76	1.60
February	26.95	33.17	20.73	60.90	77.61	0.67	1.60
March	27.79	33.38	22.21	198.50	78.13	0.68	1.54
April	27.05	32.84	21.26	33.50	74.05	0.78	3.09
May	27.14	33.40	20.88	30.00	66.65	1.01	3.09
June	26.23	32.64	19.82	17.60	64.00	1.05	7.72
July	26.39	33.22	19.57	0.00	50.60	1.46	5.14
August	27.00	34.68	19.32	0.00	45.92	1.67	5.14
September	28.29	35.58	21.01	3.10	45.66	1.78	4.63
October	29.26	36.72	21.81	0.00	44.07	1.93	3.60
November	29.67	36.32	23.03	0.00	43.41	1.97	3.09
December	29.04	35.61	22.47	69.10	52.98	1.58	3.09
			Ponto Novo – BA				
January	25.19	29.84	22.37	190.83	82.92	0.48	5.18
February	25.83	31.86	21.08	20.80	74.06	0.75	5.98
March	26.90	32.95	21.85	0.00	69.02	0.94	6.58
April	26.51	32.63	21.37	14.45	64.73	1.05	5.58
May	24.48	29.58	20.45	49.25	76.05	0.64	6.21
June	23.12	27.93	19.47	31.55	78.08	0.54	5.68
July	22.60	28.29	18.16	8.85	75.48	0.60	6.11
August	23.33	29.25	18.57	11.75	71.71	0.72	6.50
September	24.48	30.63	19.66	1.80	69.65	0.82	6.75
October	25.99	32.57	20.86	5.95	66.99	0.98	7.10
November	24.53	25.23	23.82	184.00	70.79	0.74	1.34
December	25.2	25.98	24.42	44.20	69.49	0.80	1.32

Max Temp.: maximum temperature; Min Temp.: minimum temperature; RH: relative humidity; VPD: vapor pressure deficit. CE: Ceará State; BA: Bahia State.

Table 2. Chemical properties of the soils cultivated with 'Prata-Anã' and 'Grande Naine' bananas in Missão Velha, CE, and Ponto Novo, BA, at 0.00-0.20 and 0.20-0.40 m layers

Site	Cultivar	Layer	pH(H_2O)	OM	P	K^+	Ca^{2+}	Mg^{2+}	CEC	V	P-Rem
		m		g dm^{-3}	mg dm^{-3}		mmol$_c$ dm^{-3}			%	mg L^{-1}
Ceará	Prata-Anã	0.00-0.20	7.3	29.2	164.4	8.4	79.7	17.9	114.7	91.1	53.4
		0.20-0.40	8.0	29.0	140.0	9.0	132.0	25.0	175.1	94.8	49.8
	Grande Naine	0.00-0.20	7.4	32.0	140.0	9.3	113.0	27.0	156.0	95.0	54.1
		0.20-0.40	7.9	18.0	79.0	4.9	91.0	21.0	124.0	94.0	47.9
Bahia	Prata-Anã	0.00-0.20	6.5	20.0	106.0	3.0	28.0	11.0	52.0	81.0	45.1
		0.20-0.40	6.4	12.0	21.0	2.1	11.0	5.0	38.0	58.0	44.6
	Grande Naine	0.00-0.20	6.5	18.0	81.0	3.8	27.0	10.0	52.0	80.0	44.7
		0.20-0.40	6.1	12.0	28.0	2.4	14.0	5.0	32.0	62.0	43.5

pH in water in a 1:2.5 ratio; OM: soil organic matter content obtained by organic carbon × 1.724 (Walkley-Black); P and K^+: Mehlich-1 extraction; Ca^{2+} and Mg^{2+} extracted with KCl 1 mol L^{-1}; CEC: cation exchange capacity at pH 7; V: base saturation; P-rem: P-remaining.

and 17 plots for 'Grande Naine' banana. All plants were fertigated and soil chemical properties are presented in table 2.

For each cultivar × site combination, fertigation was performed weekly using urea or ammonium sulfate (N), potassium chloride (K), zinc sulfate (Zn), boric acid (B), and manganese sulfate (Mn). Fertilizer rates were determined based on soil test results from each area and recommendations for the crop (Silva, 2015), and varied up to 180 kg ha^{-1} yr^{-1} of N, 450 kg ha^{-1} yr^{-1} of K_2O, 15 kg ha^{-1} yr^{-1} of Zn, 10 kg ha^{-1} yr^{-1} of B, and 3 kg ha^{-1} yr^{-1} of Mn. Irrigation scheduling was based on crop evapotranspiration (ETc), which is the product of daily reference evapotranspiration (ETo) and crop coefficient (Kc) for each cultivar, Prata-Anã (Borges et al., 2011) and Grande Naine (Allen et al., 1998). Daily ETo was estimated based on data from automatic weather stations installed at each site. This daily irrigation management started when the weather stations were installed, in 2016. In previous years, irrigation was managed similarly; however, it was based on regional historical averages for monthly periods (Inmet, 2018). Regarding supplemental irrigation, average net and gross annual irrigation depths were, respectively, 1,739.4 and 1,459.5 mm for 'Prata-Anã' and 1,524.1 and 1,265.7 mm for 'Grande Naine', both grown in Ceará. In Bahia, net and gross irrigation depths were, respectively, 1,738.4 and 1,489.4 mm for 'Prata-Anã' and 1,546.9 and 1,317.0 mm for 'Grande Naine'. Potential application efficiency was set at 90 % for a micro-sprinkler irrigation system.

Results of leaf tissue analysis and annual yield data of each plot were used. Leaf tissue sampling was performed once a semester and followed the recommendations of Martin-Prével (1987). The mid-portion of the third leaf lamina, counting from the plant apex, was collected from plants transitioning to the flowering stage, until the inflorescence had two or three open clusters of male flowers (Rodrigues et al., 2010). The samples were processed and analyzed as leaf macro- (N, P, K, Ca, Mg, and S) and micronutrient (B, Cu, Fe, Mn, and Zn) contents (Bataglia et al., 1983). Yields (Mg ha^{-1} yr^{-1}) were estimated by weighing hands at harvest.

The database was divided into four datasets as a function of site and cultivar. Two datasets were from the farm located in Missão Velha, CE, and contained tissue analysis results from samples collected twice a year and annual yields estimated between 2010 and 2017 for 'Prata-Anã' (AAB) and 'Grande Naine' (AAA) plantations. For 'Prata-Anã', the initial sample containing 850 recordings, mean±standard deviation of 35.91 ± 7.8 Mg $ha^{-1}yr^{-1}$, was subdivided into low- and high-yielding populations. High-yielding populations were considered as reference populations and had yields greater than the average yield plus 0.5 standard deviation, which corresponded to 39.81 Mg ha^{-1} yr^{-1} or 72.72 % of the maximum recorded yield (n = 253). For 'Grande Naine', the initial sample containing 150 recordings, mean ± standard deviation of 52.35 ± 12.98 Mg ha^{-1} yr^{-1}, was subdivided into low- and high-yielding populations. The reference population was that with yields above the average plus 0.5 standard deviation, which corresponded to 58.84 Mg ha^{-1} yr^{-1} or 72.24 % of the maximum recorded yield (n = 46).

The other two datasets, one for ‘Prata-Anã’ and the other for ‘Grande Naine’, were from the farm located in Ponto Novo, BA, and contained tissue analysis results from samples collected twice a year and annual yields recorded between 2014 and 2016. For ‘Prata-Anã’, the initial sample consisting of 481 recordings, mean ± standard deviation of 34.89 ± 13.59 Mg ha^{-1} yr^{-1}, was also subdivided into low- and high-yielding populations. The reference population (high-yielding population) was that with a yield greater than average plus 0.5 standard deviation, which corresponded to 41.69 Mg ha^{-1} yr^{-1} or 57 % of the maximum recorded yield (n =147). For ‘Grande Naine’, the initial sample composed of 64 recordings, mean ± standard deviation of 65.15 ± 21.94 Mg ha^{-1} yr^{-1}, was subdivided into low- and high-yielding populations. The reference population was that with a yield greater than average plus 0.5 standard deviation, which corresponded to 76.12 Mg ha^{-1} yr^{-1} or 75.80 % of the maximum recorded yield (n =19).

From reference populations of each site × cultivar combination, mean, standard deviation, and coefficient of variation of leaf nutrient contents were calculated to compose the norms for calculating balance indices of Kenworthy. To compose DRIS norms, mean, standard deviation, and coefficient of variation of dual ratios between nutrient contents was calculated.

The universality of DRIS and Kenworthy norms established for each site and cultivar was evaluated by comparing, based on means and variances, one cultivar with the other for the same site, and one site with the other for the same cultivar. The homogeneity of variances was tested using F-test (p≤0.05). The means were compared using t-test (p≤0.05). Additionally, we calculated the relative frequency (%) at which the means and standard deviations of DRIS and Kenworthy norms was not significantly different.

To compose the norms for determining Balance indices of Kenworthy (BIKW), mean, standard deviation, coefficient of variation, and variance of leaf nutrient contents from the reference populations of each site × cultivar combination were calculated. To compose DRIS norms from reference populations of each site × cultivar combination, the mean, standard deviation, coefficient of variation, and variances of all bivariate relationships between nutrients were calculated, considering the direct (A/B) and reverse (B/A) relationships. These bivariate relationships were used for all nutrient contents composing the database.

The universality of Kenworthy norms established for each cultivar × site combination was evaluated by comparing, based on means and variances of leaf nutrient contents, one cultivar with the other for the same site, and one site with the other for the same cultivar. The universality of DRIS norms established for each site and cultivar was evaluated by comparing, based on means and variances of all bivariate relationships between nutrients, one cultivar with the other for the same site, and one site with the other for the same cultivar.

The homogeneity of variances was tested using F-test (p≤0.05). Means were compared using t-test (p≤0.05). Additionally, we calculated the relative frequency (%) at which the means and standard deviations of DRIS and Kenworthy norms were not significantly different.

RESULTS

Kenworthy norms (means and variances) for site (Ceará and Bahia) and cultivar (‘Prata-Anã’ and ‘Grande Naine’) were compared and statistical differences between means occurred

Table 3. Norms derived from leaf nutrient contents in 'Prata-Anã' (P.A. – AAB) and 'Grande Naine' (G.N. – AAA) and their dual ratios established by Kenworthy and DRIS methods for Missão Velha, CE, and Ponto Novo, BA, and comparison between means and variances of the site- and cultivar- specific norms

Normas	Ceará						Bahia						CE		BA		PA		GN	
	P.A.			G.N.			P.A.			G.N.			P.A. × G.N.		P.A. × G.N.		CE × BA		CE × BA	
	Ŷ	s	CV	Ŷ	S	CV	Ŷ	s	CV	Ŷ	s	CV	Ŷ	s	Ŷ	s	Ŷ	s	Ŷ	s
N	21.91	1.58	7.22	21.77	1.84	8.46	23.00	2.94	12.79	22.02	1.85	8.40	ns	ns	ns	*	*	*	ns	ns
P	1.68	0.25	14.87	1.64	0.23	13.89	1.61	0.13	8.16	1.56	0.11	7.14	*	ns	*	ns	*	*	*	*
K	33.99	6.35	18.68	36.19	6.33	17.48	31.36	7.15	22.81	32.64	7.75	23.73	ns	ns	ns	ns	*	ns	ns	ns
Ca	6.49	1.25	19.31	7.88	1.90	24.14	5.62	0.57	10.11	6.97	0.86	12.36	*	*	*	*	*	*	*	*
Mg	2.38	0.37	15.52	2.59	0.39	15.22	2.70	0.43	16.10	2.85	0.13	4.43	*	ns	*	*	*	*	*	*
S	1.55	0.27	17.32	1.54	0.22	14.44	1.47	0.15	10.38	1.49	0.12	7.88	*	ns	*	ns	*	*	*	*
Cu	6.18	2.36	38.16	5.91	2.63	44.49	5.30	0.84	15.89	6.49	0.59	9.12	ns	ns	*	*	*	*	ns	*
Fe	67.40	12.79	18.97	68.71	10.91	15.88	57.34	15.21	26.52	59.02	9.11	15.43	ns	ns	ns	*	*	*	ns	ns
Zn	16.49	2.99	18.10	15.79	2.89	18.29	14.83	1.56	10.49	15.39	1.33	8.65	ns	ns	*	ns	*	*	ns	*
Mn	179.40	92.53	51.58	168.88	121.88	72.17	84.68	32.16	37.98	73.55	16.88	22.96	ns	*	ns	*	ns	*	ns	*
B	11.06	4.56	41.20	9.64	3.05	31.68	14.74	2.72	18.46	13.41	2.14	15.99	ns	*	ns	ns	*	*	*	ns
N/P	13.34	2.05	15.40	13.54	2.22	16.37	14.39	2.27	15.80	14.18	1.79	12.61	ns	ns	ns	ns	*	ns	ns	ns
N/K	0.67	0.14	20.94	0.62	0.11	17.36	0.80	0.30	37.90	0.73	0.28	38.29	*	*	*	ns	*	*	*	*
N/Ca	3.51	0.74	21.10	3.19	2.77	87.00	4.14	0.70	16.88	3.22	0.57	17.73	*	*	*	ns	*	ns	ns	*
N/Mg	9.42	1.52	16.13	8.53	1.15	13.50	8.73	1.77	20.30	7.74	0.76	9.86	*	*	*	*	*	*	*	*
N/S	14.37	1.94	13.51	14.34	2.17	15.16	15.80	2.52	15.93	14.79	1.44	9.72	ns	ns	ns	*	*	*	ns	*
N/Cu	3.89	1.09	27.91	4.07	1.10	27.03	4.44	0.83	18.72	3.40	0.29	8.42	*	ns	*	*	*	*	*	*
N/Fe	0.33	0.06	17.39	0.32	0.06	17.16	0.48	0.44	93.21	0.38	0.07	17.74	*	ns	*	*	*	*	*	ns
N/Zn	1.37	0.26	18.74	1.42	0.25	17.37	1.57	0.25	16.06	1.44	0.17	12.04	*	ns	*	*	*	ns	*	ns
N/Mn	0.19	0.16	88.60	0.24	0.22	91.58	0.31	0.11	36.41	0.32	0.08	25.88	*	*	*	ns	*	*	*	*
N/B	2.37	1.20	50.47	2.55	1.04	40.58	1.60	0.29	17.94	1.67	0.24	14.52	*	ns	*	ns	*	*	*	*
P/N	0.08	0.01	16.51	0.08	0.01	14.68	0.07	0.01	15.45	0.07	0.01	12.71	*	ns	*	ns	*	*	*	ns
P/K	0.05	0.01	21.10	0.05	0.01	20.04	0.05	0.02	27.71	0.05	0.02	36.22	*	ns	*	ns	*	*	*	*
P/Ca	0.27	0.06	23.47	0.24	0.24	98.40	0.29	0.04	12.65	0.23	0.03	13.52	*	*	*	ns	*	*	*	*
P/Mg	0.71	0.11	15.43	0.64	0.07	11.58	0.61	0.12	19.27	0.55	0.04	7.96	*	*	*	*	*	ns	*	*
P/S	1.09	0.13	11.51	1.07	0.10	9.17	1.10	0.10	8.81	1.05	0.08	7.97	*	*	*	ns	*	*	*	ns
P/Cu	0.29	0.07	24.01	0.30	0.08	26.33	0.31	0.05	17.07	0.24	0.03	14.30	*	ns	*	*	*	*	*	*
P/Fe	0.03	0.00	16.93	0.02	0.00	16.12	0.03	0.03	94.29	0.03	0.01	19.12	*	ns	*	*	*	*	*	ns
P/Zn	0.10	0.02	15.18	0.11	0.02	16.82	0.11	0.01	12.85	0.10	0.02	14.90	*	ns	*	ns	*	ns	*	ns
P/Mn	0.01	0.01	80.58	0.02	0.02	86.11	0.02	0.01	34.88	0.02	0.01	28.00	*	*	*	ns	*	*	*	*
P/B	0.18	0.10	53.98	0.19	0.08	43.45	0.11	0.02	19.86	0.12	0.02	18.73	*	ns	*	ns	*	*	*	*
K/N	1.56	0.29	18.62	1.66	0.26	15.90	1.40	0.41	29.16	1.49	0.37	25.04	*	ns	*	ns	*	*	*	*
K/P	20.54	4.04	19.65	22.43	4.57	20.39	19.47	4.28	22.00	20.92	4.85	23.17	*	ns	ns	ns	*	ns	ns	ns
K/Ca	5.41	1.34	24.84	5.35	5.06	94.53	5.61	1.35	24.11	4.69	1.06	22.65	ns	*	*	ns	*	ns	ns	*
K/Mg	14.53	3.09	21.26	14.16	2.70	19.05	11.80	3.06	25.94	11.46	2.76	24.10	ns	ns	ns	ns	*	ns	*	ns
K/S	22.18	4.19	18.89	23.78	4.70	19.79	21.42	5.21	24.34	21.67	4.29	19.82	ns	ns	ns	ns	ns	*	ns	ns
K/Cu	6.00	1.80	29.94	6.71	1.97	29.30	6.10	1.81	29.68	5.07	1.33	26.34	*	ns	*	ns	ns	ns	*	*
K/Fe	0.52	0.11	21.08	0.54	0.13	23.42	0.65	0.64	97.88	0.58	0.18	31.12	*	ns	ns	*	*	*	*	*
K/Zn	2.12	0.48	22.78	2.36	0.53	22.44	2.14	0.58	26.91	2.15	0.60	27.90	*	ns	ns	ns	*	*	*	ns
K/Mn	0.28	0.24	85.84	0.40	0.37	91.24	0.42	0.18	41.77	0.47	0.17	35.58	*	*	*	ns	*	*	*	*
K/B	3.61	1.76	48.79	4.17	1.63	38.96	2.22	0.67	30.08	2.56	0.85	33.24	*	ns	*	ns	*	*	*	*
Ca/N	0.30	0.06	21.40	0.36	0.08	22.55	0.25	0.05	19.66	0.32	0.05	16.60	*	*	*	ns	*	*	*	*
Ca/P	3.94	0.90	22.79	4.88	1.22	25.02	3.51	0.47	13.24	4.47	0.52	11.63	*	*	*	ns	*	*	*	*
Ca/K	0.20	0.05	26.51	0.22	0.06	28.91	0.19	0.05	28.19	0.23	0.07	30.72	*	*	*	*	*	ns	*	ns

continue

continuation

Normas	Ceará						Bahia						CE		BA		PA		GN	
	P.A.			G.N.			P.A.			G.N.			P.A. × G.N.		P.A. × G.N.		CE × BA		CE × BA	
	Ȳ	s	CV	Ȳ	s	CV	Ȳ	s	CV	Ȳ	s	CV	Ȳ	s	Ȳ	s	Ȳ	s	Ȳ	s
Ca/Mg	2.76	0.51	18.34	3.06	0.59	19.09	2.12	0.33	15.37	2.44	0.27	10.86	*	ns	*	ns	*	*	*	*
Ca/S	4.24	0.89	21.05	5.15	1.17	22.80	3.85	0.49	12.63	4.69	0.65	13.82	*	*	*	*	*	*	*	*
Ca/Cu	1.16	0.41	35.15	1.48	0.56	37.59	1.09	0.20	18.64	1.09	0.19	17.31	*	*	ns	ns	*	*	*	*
Ca/Fe	0.10	0.02	20.10	0.12	0.03	24.94	0.12	0.10	89.49	0.12	0.03	27.22	*	*	*	*	*	*	*	ns
Ca/Zn	0.40	0.09	22.47	0.51	0.14	27.28	0.38	0.05	13.68	0.46	0.09	20.57	*	*	*	*	*	*	*	*
Ca/Mn	0.05	0.05	85.77	0.09	0.08	88.89	0.07	0.02	32.44	0.10	0.04	34.88	*	*	*	*	*	*	*	*
Ca/B	0.70	0.35	50.35	0.93	0.43	46.19	0.39	0.07	17.36	0.54	0.13	23.60	*	*	*	*	*	*	*	*
Mg/N	0.11	0.02	16.42	0.12	0.02	13.91	0.12	0.02	19.33	0.13	0.01	9.96	*	ns	*	*	*	*	*	ns
Mg/P	1.43	0.23	15.77	1.59	0.19	12.11	1.69	0.30	17.75	1.83	0.14	7.59	*	ns	*	*	*	*	*	ns
Mg/K	0.07	0.02	22.22	0.07	0.02	21.12	0.09	0.03	28.24	0.09	0.03	36.14	*	ns	*	*	*	*	*	*
Mg/Ca	0.38	0.08	20.32	0.39	0.47	118.43	0.48	0.07	14.16	0.41	0.04	10.75	*	*	*	*	*	ns	ns	*
Mg/S	1.55	0.24	15.74	1.69	0.21	12.16	1.84	0.22	11.96	1.92	0.18	9.15	*	ns	*	ns	*	ns	*	ns
Mg/Cu	0.42	0.12	29.25	0.48	0.14	28.21	0.52	0.08	15.88	0.44	0.05	10.59	*	ns	*	*	*	*	*	*
Mg/Fe	0.04	0.01	16.71	0.04	0.01	17.97	0.06	0.05	96.41	0.05	0.01	18.55	*	ns	*	*	*	*	*	ns
Mg/Zn	0.15	0.02	16.88	0.17	0.03	15.63	0.18	0.03	14.02	0.19	0.02	10.75	*	ns	*	ns	*	ns	*	ns
Mg/Mn	0.02	0.02	84.34	0.03	0.03	94.98	0.04	0.01	36.31	0.04	0.01	25.18	*	*	*	ns	*	*	*	*
Mg/B	0.26	0.14	53.66	0.31	0.14	46.38	0.19	0.04	21.58	0.22	0.03	15.80	*	ns	*	ns	*	*	*	*
S/N	0.07	0.01	17.72	0.07	0.01	14.19	0.06	0.01	15.28	0.07	0.01	10.26	*	*	*	*	*	*	*	*
S/P	0.93	0.14	14.60	0.95	0.11	11.50	0.91	0.08	9.21	0.96	0.08	8.06	*	*	*	ns	*	*	*	ns
S/K	0.05	0.01	26.69	0.04	0.01	21.23	0.05	0.01	27.16	0.05	0.01	30.06	*	*	*	ns	*	ns	*	*
S/Ca	0.25	0.06	22.57	0.23	0.21	92.23	0.26	0.03	11.36	0.22	0.03	14.40	*	*	*	ns	*	*	ns	*
S/Mg	0.66	0.13	19.76	0.60	0.08	13.15	0.55	0.08	15.00	0.52	0.05	8.74	*	*	*	*	*	*	*	*
S/Cu	0.27	0.06	23.37	0.28	0.07	24.22	0.28	0.04	14.13	0.23	0.03	12.37	*	ns	*	ns	*	*	*	*
S/Fe	0.02	0.00	20.34	0.02	0.00	16.67	0.03	0.03	97.37	0.03	0.00	18.08	*	*	*	*	*	*	*	ns
S/Zn	0.10	0.02	19.88	0.10	0.02	21.24	0.10	0.01	10.93	0.10	0.01	13.57	*	ns	*	ns	*	*	*	*
S/Mn	0.01	0.01	83.85	0.02	0.02	87.79	0.02	0.01	34.18	0.02	0.01	25.70	*	*	*	ns	*	*	*	*
S/B	0.17	0.09	55.43	0.18	0.08	44.53	0.10	0.02	19.38	0.11	0.02	20.71	*	ns	*	ns	*	*	*	*
Cu/N	0.28	0.11	37.95	0.27	0.12	45.08	0.23	0.04	18.52	0.30	0.03	8.96	*	ns	*	*	*	*	*	*
Cu/P	3.71	1.39	37.51	3.63	1.48	40.85	3.31	0.58	17.57	4.19	0.60	14.28	ns	ns	*	ns	*	*	*	*
Cu/K	0.19	0.09	46.79	0.17	0.07	41.58	0.18	0.07	39.72	0.22	0.08	35.50	*	*	*	ns	*	*	*	ns
Cu/Ca	0.99	0.40	40.84	0.87	0.86	99.16	0.95	0.18	19.19	0.95	0.16	17.35	*	*	ns	ns	*	*	ns	*
Cu/Mg	2.64	1.00	38.07	2.30	0.97	42.26	1.99	0.39	19.48	2.28	0.24	10.71	*	ns	*	*	*	*	ns	*
Cu/S	3.96	1.25	31.68	3.82	1.48	38.84	3.62	0.57	15.75	4.37	0.51	11.74	ns	ns	*	ns	*	*	*	*
Cu/Fe	0.09	0.04	37.98	0.09	0.04	44.27	0.11	0.10	88.83	0.11	0.02	17.60	*	ns	*	*	*	*	*	*
Cu/Zn	0.38	0.13	33.83	0.39	0.21	53.87	0.36	0.05	13.45	0.42	0.04	9.51	*	*	*	ns	*	*	*	*
Cu/Mn	0.05	0.05	88.76	0.06	0.06	97.38	0.07	0.03	36.08	0.09	0.02	25.46	*	*	*	ns	*	*	*	*
Cu/B	0.66	0.41	62.25	0.70	0.42	60.41	0.37	0.08	21.64	0.49	0.08	15.36	*	ns	*	ns	*	*	*	*
Fe/N	3.09	0.64	20.65	3.18	0.55	17.33	2.54	0.79	31.12	2.70	0.46	17.02	*	ns	*	*	*	*	*	ns
Fe/P	40.69	8.04	19.76	42.54	8.01	18.84	35.74	9.07	25.38	38.02	6.84	17.99	ns	ns	ns	ns	*	*	ns	ns
Fe/K	2.04	0.52	25.54	1.96	0.51	26.15	1.96	0.79	40.38	2.02	1.02	50.37	*	ns	ns	ns	*	*	ns	*
Fe/Ca	10.65	2.34	21.99	10.05	8.58	85.36	10.27	2.78	27.08	8.70	2.27	26.03	ns	*	ns	ns	*	*	ns	*
Fe/Mg	28.71	5.56	19.37	26.99	5.74	21.26	21.87	8.18	37.39	20.76	3.46	16.68	ns	ns	ns	*	*	*	ns	*
Fe/S	43.97	8.80	20.01	45.11	8.28	18.37	39.19	9.91	25.29	39.79	7.49	18.83	ns	ns	ns	ns	*	*	ns	ns
Fe/Cu	11.84	3.46	29.17	12.78	3.58	28.02	10.95	2.85	26.03	9.15	1.59	17.40	ns	ns	ns	*	*	*	*	*
Fe/Zn	4.16	0.81	19.39	4.47	1.04	23.26	3.85	0.84	21.87	3.83	0.42	10.92	*	*	ns	*	*	ns	*	*

continue

continuation

Normas	Ceará						Bahia						CE		BA		PA		GN	
	P.A.			G.N.			P.A.			G.N.			P.A. × G.N.		P.A. × G.N.		CE × BA		CE × BA	
	Ȳ	s	CV	Ȳ	s	CV	Ȳ	s	CV	Ȳ	s	CV	Ȳ	s	Ȳ	s	Ȳ	s	Ȳ	s
Fe/Mn	0.58	0.59	101.29	0.73	0.60	82.24	0.76	0.33	43.03	0.83	0.16	19.75	*	ns	*	*	*	*	*	*
Fe/B	7.20	3.57	49.53	8.13	3.69	45.32	4.01	1.36	33.90	4.48	0.86	19.12	ns	ns	*	*	*	*	*	*
Zn/N	0.76	0.14	18.95	0.73	0.13	17.64	0.65	0.11	16.28	0.70	0.09	12.41	*	ns	*	ns	*	*	*	*
Zn/P	9.90	1.54	15.51	9.73	1.70	17.50	9.26	1.12	12.12	9.93	1.39	13.99	ns	ns	*	ns	*	*	ns	ns
Zn/K	0.50	0.13	26.14	0.45	0.11	25.49	0.51	0.16	31.31	0.51	0.20	38.67	*	ns	*	ns	*	*	*	*
Zn/Ca	2.61	0.59	22.75	2.35	2.38	101.35	2.66	0.33	12.57	2.25	0.41	18.37	*	*	*	ns	*	*	ns	*
Zn/Mg	7.00	1.20	17.08	6.13	0.96	15.65	5.60	0.93	16.57	5.41	0.55	10.21	*	*	ns	*	*	*	*	*
Zn/S	10.71	1.74	16.27	10.35	1.93	18.61	10.15	1.11	10.93	10.37	1.34	12.93	*	ns	ns	ns	*	*	ns	*
Zn/Cu	2.86	0.69	23.98	2.94	0.85	29.00	2.84	0.34	11.97	2.38	0.24	9.97	*	*	*	*	*	*	*	*
Zn/Fe	0.25	0.05	18.61	0.23	0.05	20.12	0.30	0.30	99.64	0.26	0.03	10.78	*	ns	*	*	*	*	*	*
Zn/Mn	0.14	0.12	84.69	0.17	0.16	89.46	0.20	0.07	34.74	0.22	0.04	19.74	*	*	*	*	*	*	*	*
Zn/B	1.80	1.03	57.31	1.87	0.91	48.38	1.04	0.22	21.34	1.17	0.19	16.57	ns	ns	*	ns	*	*	*	*
Mn/N	8.26	4.36	52.70	7.88	5.69	72.31	3.77	1.58	42.04	3.35	0.77	23.00	ns	*	ns	*	*	*	ns	*
Mn/P	108.92	58.65	53.85	106.52	80.76	75.82	53.23	21.88	41.11	47.39	11.64	24.55	ns	*	ns	*	ns	*	ns	*
Mn/K	5.44	2.98	54.86	4.78	3.38	70.83	2.96	1.71	57.53	2.47	1.19	48.13	ns	ns	ns	*	*	*	ns	*
Mn/Ca	28.14	14.59	51.84	23.20	17.80	76.72	15.14	5.85	38.66	10.78	2.94	27.27	ns	*	ns	*	*	*	ns	*
Mn/Mg	76.46	39.29	51.39	68.71	52.30	76.11	32.04	12.51	39.07	25.77	5.70	22.12	ns	*	ns	*	*	*	ns	*
Mn/S	117.38	61.72	52.58	112.55	82.06	72.91	58.25	22.72	39.01	49.42	11.79	23.86	ns	*	ns	*	ns	*	ns	*
Mn/Cu	31.52	18.58	58.95	30.65	21.15	69.01	16.37	6.58	40.20	11.39	2.76	24.20	ns	ns	ns	*	*	*	ns	*
Mn/Fe	2.74	1.45	53.07	2.46	1.77	72.16	1.79	2.25	125.47	1.25	0.28	22.01	*	*	ns	*	*	*	*	*
Mn/Zn	11.19	6.20	55.36	10.96	8.22	74.98	5.74	2.13	37.06	4.77	1.02	21.32	ns	*	ns	*	*	*	ns	*
Mn/B	19.77	16.48	83.36	19.94	17.37	87.11	5.80	2.04	35.23	5.59	1.44	25.71	ns	ns	ns	*	*	*	ns	*
B/N	0.51	0.21	42.34	0.44	0.14	32.24	0.65	0.14	21.70	0.61	0.10	15.74	*	*	*	*	*	*	*	*
B/P	6.69	2.72	40.74	5.97	2.02	33.87	9.24	2.03	21.95	8.63	1.57	18.17	*	*	ns	ns	*	*	*	ns
B/K	0.33	0.13	39.66	0.27	0.08	31.27	0.52	0.23	44.91	0.47	0.26	55.38	*	*	*	ns	*	*	*	*
B/Ca	1.76	0.81	46.01	1.41	1.23	87.27	2.64	0.53	19.91	1.97	0.50	25.26	*	*	*	ns	*	*	*	*
B/Mg	4.77	2.09	43.75	3.81	1.40	36.65	5.59	1.34	23.99	4.71	0.77	16.42	*	*	*	*	*	*	*	*
B/S	7.25	3.05	42.07	6.33	2.14	33.77	10.15	2.28	22.44	9.09	2.02	22.24	*	*	ns	ns	*	*	*	ns
B/Cu	1.95	0.91	46.65	1.82	0.82	45.08	2.84	0.61	21.34	2.07	0.35	16.83	*	ns	*	*	*	*	*	*
B/Fe	0.17	0.07	43.83	0.14	0.06	38.45	0.30	0.25	84.52	0.23	0.04	19.21	*	*	*	*	*	*	*	ns
B/Zn	0.69	0.30	43.54	0.63	0.24	37.93	1.01	0.22	21.50	0.88	0.14	16.33	*	*	*	*	*	*	*	*
B/Mn	0.09	0.10	110.65	0.11	0.10	93.86	0.19	0.06	32.36	0.19	0.05	27.87	*	ns	*	ns	*	*	*	*

Norms: contents and dual ratios of a reference population (≥ average yield + 0.5 standard deviation). Leaf concentrations of N, P, K, Ca, Mg, and S are expressed as g kg^{-1} and Cu, Fe, Zn, Mn, and B as mg kg^{-1}; ȳ: mean leaf concentration and mean dual ratio; s: standard deviation; CV: coefficient of variation (%); PA: Prata-Anã; GN: Grande Naine; ns: non-significant; *: significant ($p \leq 0.05$) using t-test for the means and F-test for the variances; data collected from high-yielding populations or reference population.

at the same frequency as between variances (Table 3). For DRIS norms, however, statistical differences between means were more frequent than between variances (Table 3). Of 11 comparisons made between specific norms for ‘Prata-Anã’ and ‘Grande Naine’ bananas grown in Ceará, four differences between means (36.40 %) and three between variances (27.30 %) were observed. When comparing specific norms for cultivars grown in Bahia, six significant differences were found for both means and variances (54.50 %). When comparing norms established for ‘Prata-Anã’ bananas grown at each site, ten significant differences (90.90 %) were verified for both means and variances. For ‘Grande Naine’, five significant differences between means (45.50 %) and seven significant differences between variances (63.60 %) were observed when comparing one site with the other.

Of 110 comparisons made between DRIS norms established for 'Prata-Anã' and 'Grande Naine' banana plants grown in Ceará, 86 (78.20 %) differences between means and 52 (47.30 %) between variances were observed.

When comparing norms established between sites, Ceará and Bahia, for each cultivar, for 'Prata-Anã' were verified 106 (96.40 %) significant differences between means and 95 (86.40 %) between variances. For `Grande Naine' were detected significant differences between sites, with a frequency of 83 (75.50 %) for means and 82 (74.50 %) for variances. These results show the greatest variability between locations for the cultivar Prata-Anã.

Kenworthy and DRIS norms are established using the mean and variance of leaf nutrient contents and dual nutrient ratios (Urano et al., 2007). Thus, the high frequency of statistical differences between norms, as reported herein, limits extrapolations. This suggests a need for establishing site- and cultivar-specific norms rather than universal norms. When comparing Kenworthy norms established in Ceará with those established in Bahia for 'Prata-Anã', the means differed for all nutrients except Mn. Kenworthy norms established for 'Prata-Anã' grown in Ceará were higher than those established in Bahia for P, K, Ca, Mg, S, Cu, Fe, Mn, and Zn, and lower for N and B.

DISCUSSION

Soil organic matter, Ca and Mg contents in Ceará are within the optimum range and soil K and P contents are above the optimum range for 'Prata-Anã' banana plants (Silva, 2015). Specific norms allow a more precise diagnosis of nutritional status of plants (Pereira et al., 2015). Conversely, misleading diagnoses may arise when using universal norms because of mistaken extrapolations, which are a result of poor knowledge transfer (Resende et al., 2002, 2017). This has been shown when comparing DRIS norms established for corn grown in different parts of the world (Modesto et al., 2014). Plant material also influences norms because each cultivar has its nutrient demand (Soares et al., 2008), even when belonging to the same banana subgroup, either at the seedling stage (Silva et al., 2014; Souza et al., 2016) or under field conditions (Hoffmann et al., 2010a,b).

Differences in soil and climate mainly explain the high frequency of significantly different norms when comparing Ceará with Bahia (Tables 1 and 2). In general, the soil in Ceará is significantly more fertile than in Bahia. When comparing with the soil in Bahia, the soil in Ceará, at a layer of 0.00-0.20 m, higher soil organic matter, P, K, Ca, Mg contents, and cation exchange capacity are observed, suggesting differences in soil fertility.

The highest values for Kenworth norms established in Ceará compared to Bahia for P, K, Ca, Mg, S, Cu, Fe, Mn, and Zn, and lower for N and B were expected due to the greater soil fertility in Ceará; however, as the soil is more alkaline, with pH above 7.0, the availability of micronutrients in Ceará, particularly metallic cations such as Cu, Fe, Mn, Zn, and B, might have been negatively affected.

When comparing Kenworthy norms established for 'Grande Naine', the means in Ceará were statistically higher for P, Ca, Mg, S, and B than in Bahia. Despite the differences between the two sites, average banana yields of 'Prata-Anã' were similar, 35.91 Mg ha^{-1} yr^{-1} in Ceará and 34.89 Mg ha^{-1} yr^{-1} in Bahia. The average yield of 'Grande Naine' grown in Ceará, 52.35 Mg ha^{-1} yr^{-1}, was lower than that of 'Grande Naine' grown in Bahia, 65.15 Mg ha^{-1} yr^{-1}, though the variability in 'Grande Naine' banana yields was substantially greater in Bahia. Thus, non-nutritional factors might have played a major role in limiting 'Grande Naine' yields in Ceará. These factors include monthly maximum temperatures over 34 °C from August to December, relative humidity close to 50 % and high vapor pressure deficit. Although these data refer to the year 2016, they are consistent with climatological cumin of weather stations located in Barbalha, Ceará, and Senhor do Bonfim, Bahia (Inmet, 2018); these stations are closest to Missão Velha and Ponto Novo, respectively. Such weather conditions might have led to decreased photosynthetic rates and, consequently, losses in yield (Arantes et al., 2016, 2018; Ramos et al., 2018).

Norms established for 'Grande Naine' were more convergent, that is, they had less variability than those for 'Prata-Anã' because 'Grande Naine' has been around for a longer time; hence, the cultivar has higher trait heritability. Studies on breeding export bananas, such as those belonging to the AAA Cavendish subgroup (*Musa acuminata*), have been carried out to improve precocity and flowering uniformity, increasing productivity, decreasing plant height, obtaining cylindrical bunches with uniform fruits for simpler packing and transporting (Silva et al., 2013), and making these traits more heritable.

Furthermore, several 'Grande Naine' clones have emerged from positive selection done by growers and companies with the main objective of increasing harvest index. This practice highly contributed to the narrowing of the cultivar's genetic base, and a narrower genetic base may in turn enhance heritability. Cultivars within a subgroup tend to share more uniform phenotypic traits, especially when the cultivar has a single genome such as AAA. 'Prata-Anã', however, belongs to the triploid AAB genome subgroup, which is the result of a cross between *Musa balbisiana* and *Musa acuminata*.

Therefore, specific norms and fertilization suggestion model are more reliable and thus recommended (Urano, 2007; Serra et al., 2010; Deus et al., 2018b) because these norms are developed regionally, with lower variability in soil, climate conditions, and yield potential. Accordingly, our results may be safely extrapolated as a tool for assessing the nutritional status of 'Prata-Anã' and 'Grande Naine' banana plants grown in site-specific. This is particularly important for 'Prata Anã' due to the greater variability of standards between locations. Thus, it reinforces the need to develop standards and solutions for assessing bananas' nutritional status while considering site- and cultivar-specific conditions.

The high coefficients of variation are more associated with micronutrients compared to macronutrients for both for Kenworth standards, expressed by leaf nutrient contents, and for DRIS standards, expressed by bivariate relationships between nutrients, at any combination of cultivar and environment. Micronutrient contents generally have high CV values (Deus et al., 2018a) even in dual relationships, as evidenced for Mn (Silva and Carvalho, 2006; Teixeira et al., 2019). This is associated with greater interference from factors in how it moves through the soil-plant system and the high variability of micronutrient analysis results. It worth noting that micronutrient availability in the soil is affected by pH, organic matter content, clay content, parent material, and, specifically for Fe and Mn, by the indirect effect of reduction potential; these factors may interfere with ion-root contact (Abreu et al., 2007), thereby affecting leaf micronutrient contents in banana plants. The availability of Fe and Mn may also be affected temporally due to anoxia (Resende et al., 2017), common in soils having poor drainage under heavy rain.

Moreover, this discussion suggests that proposing precise interpretive diagnosis and crop management must take account of interactions between nutrients and soil and weather conditions affecting how nutrients flow within the soil-plant system, as well as the notion of the soil as an *in situ* natural body interacting with plant genotype and atmosphere, so that nutrient availability to plant may be predicted, which is not possible by soil and leaf analysis alone (Resende et al., 2002), even when norms are well established; in summary, different environments, different managements (Resende et al., 2017).

CONCLUSIONS

DRIS and Kenworthy norms are different for each site and cultivar.

DRIS and Kenworthy norms for 'Prata-Anã' and 'Grande Naine' have higher variability and are greater in Ceará than in Bahia.

Site- and cultivar-specific DRIS and Kenworthy norms are recommended for assessing the nutritional status of 'Prata-Anã' and 'Grande Naine' banana plants grown under different environmental conditions.

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