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Model for determining nutritional and non-nutritional limitations of Grande Naine banana in the Brazilian semiarid region[1]

Modelo para determinação de limitações nutricionais e não nutricionais para bananeira 'Grande Naine' no Semiárido brasileiro

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HIGHLIGHTS:
Nutrition and other factors limit the yield of Grande Naine banana.
Nutritional and non-nutritional limitations maintain magnitudes between environments of Grande Naine banana.
Non-nutritional factors further limit the yield of the Grande Naine banana.

ABSTRACT: Plant nutrition is essential in attaining higher yields; however, non-nutritional factors play a major role in limiting crop yield. This study aimed to model and determined nutritional and non-nutritional limitations of Grande Naine banana grown in Ceará and Bahia states, Brazil, based on nutritional balance and equilibrium. The data used in this study were collected between 2010 and 2017 from two farms, located in Missão Velha, Ceará (7° 35' 90" S and 39° 21' 17" W, and 442 m of altitude), and Ponto Novo, Bahia (10° 51' 46" S and 40° 08' 01" W, and 342 m of altitude). Plots with yields greater than the average plus 0.5 standard deviations were defined as high-yielding populations (HYP) and used as a reference population to establish the norms. Plots with yields below this limit, low-yielding populations (LYP), were used for nutritional diagnosis. The database was divided into four. The first and second databases, from the area located in Missão Velha, contained 46 samples from a reference population with a yield greater than 58.84 t ha^{-1} per year, and 104 samples from an LYP, respectively. The third and four databases, from the area located in Ponto Novo, contained 19 samples from a reference population with a yield greater than 76.12 t ha^{-1} per year, and 46 samples from an LYP, respectively. Nutritional factors limited Grande Naine banana yield in Ceará and Bahia by 11.17 and 14.79%, while non-nutritional factors limited by 30.11 and 29.41%, respectively. In Grande Naine banana, non-nutritional factors are more yield-limiting than nutritional factors.

Key words: *Musa* spp., diagnostic methods, plant nutrition

RESUMO: A nutrição de plantas é essencial para se atingir produtividades elevadas, porém fatores não nutricionais podem limitar bastante o rendimento das culturas. Objetivou-se com o presente estudo ajustar o modelo e quantificar as limitações de ordem nutricional e não nutricional com base no grau de balanço e equilíbrio em bananeiras 'Grande Naine' cultivadas nos estados da Bahia e Ceará. Utilizou-se banco de dados de teores de nutrientes nas folhas e de produtividade coletados entre 2010 e 2017 em duas fazendas, localizadas em Missão Velha, Ceará (7° 35' 90" S e 39° 21' 17" W, e altitude de 442 m), e Ponto Novo, Bahia (10° 51' 46" S, 40° 08' 01" W, e altitude de 342 m). Os talhões com produtividade acima da média mais 0,5 desvio-padrão, definidos como de alta produtividade (PAP), foram considerados população de referência e utilizados para geração das normas, enquanto os talhões com produtividade abaixo desse limite, população de baixa produtividade (PBP), foram utilizados para diagnóstico nutricional. O banco de dados foi subdividido em quatro. O primeiro e o segundo, respectivamente, com 46 amostras e população de referência com produtividade maior que 58,84 t ha^{-1} ano^{-1}, 104 amostras para a PBP, área de Missão Velha. O terceiro e quarto, respectivamente, com 19 amostras e população de referência acima de 76,12 t ha^{-1} ano^{-1}, 46 amostras para a PBP, área de Ponto Novo. Fatores nutricionais limitaram a produtividade de bananais 'Grande Naine' em 11,17 e 14,79%, e não nutricionais, em 30,11 e 29,41%, respectivamente, para o Ceará e a Bahia. Fatores não nutricionais limitam mais a produtividade da bananeira 'Grande Naine' comparados aos nutricionais.

Palavras-chave: *Musa* spp., métodos de diagnóstico, nutrição de plantas

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Introduction

Knowing nutrient demands and responses to fertilizers of plants is relevant in formulating fertilizer recommendations for crops, such as cupuaçu (Dias et al., 2010; Wadt et al., 2012), coffee (Wadt & Dias, 2012), sugarcane (Santos et al., 2013), eucalyptus (Pulito et al., 2015), pitaya (Almeida et al., 2016), coconut (Ribeiro et al., 2016), and banana (Silva et al., 2014; Souza et al., 2016; Deus et al., 2018).

The nutritional status of banana plants can be assessed using foliar analysis, which is often achieved by interpreting Sufficiency Ranges (SR). This method is easy to interpret, and typical values are available in the literature (Fontes, 2016); however, non-nutritional factors, such as cultivar, light, temperature, and water supply (Jarrel & Beverly, 1981). Balance indexes of Kenworthy (Kenworthy, 1961) and Diagnosis and Recommendation Integrated System (DRIS) (Beaufils, 1973) are also used for plant nutritional diagnosis.

By employing DRIS for assessing the nutritional status of 'Prata-Anã' banana plants, Silva & Carvalho (2005) reported that Cu and Mn concentrations were mostly classified as deficient while Ca, Mg, and Mn concentrations were predominately excessive. Angeles et al. (1993) reported that DRIS is more efficient in assessing the banana nutritional status as to N, P, and K than using Critical Levels.

This study aimed to model and determined nutritional and non-nutritional limitations of Grande Naine banana grown in Ceará and Bahia states, Brazil, based on nutritional balance and equilibrium.

Material and Methods

The data used in this study were collected between 2010 and 2017 from two farms belonging to the Sítio Barreiras company. The first farm is located in Missão Velha, state of Ceará (CE), Brazil (7° 35' 90" S, 39° 21' 17" W, and 442 m altitude). The region climate is Aw-type, tropical savanna climate with dry winters and rainy summers (Köppen-Geiger) (Alvares et al., 2013). Mean annual rainfall and temperature are 942 mm and 25.8 °C, respectively. Table 1 shows the meteorological data collected throughout the experiment. The soil at the farm was predominately Oxisol, whose fertility had been enhanced by consecutive fertilizer applications (Table 2). On this farm, the company had 11 plots, each measuring 3.26 ha on average, where fertigated Grande Naine bananas were grown.

The second farm is located in Ponto Novo, state of Bahia (BA), Brazil, (10° 51' 46" S, 40° 08' 01" W, and 342 m of altitude). The climate is also Aw, according to the Köppen-Geiger classification (Alvares et al., 2013). Mean annual rainfall and temperature are 697 mm and 24.1 °C, respectively. The soil is classified as Oxisol. The company had 17 plots on this farm, each measuring 4.53 ha on average, where fertigated Grande Naine bananas were cultivated.

Plants were spaced at 2.6 x 2.6 m (1,479 plants ha^{-1}). 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 doses were determined based on soil test results from each area and crop recommendations (Silva, 2015) and ranged up to 180, 450, 15, 10, and 3 kg ha^{-1} per year of N, K_2O, Zn, B, and Mn, respectively. Irrigation scheduling

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

Month	Mean Temp	Max Temp	Min Temp	Precipitation (mm)	RH (%)	VPD (kPa)	Max. wind speed ($m\ s^{-1}$)
		(°C)					
			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	25.20	25.98	24.42	44.20	69.49	0.80	1.32

Max Temp - Maximum temperature; Min Temp - Minimum temperature; RH - Air relative humidity; VPD - Vapor pressure deficit; Source - Obtained by the authors from meteorological data recorded by automatic weather stations installed at the respective farms located in Missão Velha, CE, and Ponto Novo, BA, Brazil

Table 2. Soil chemical properties of the areas cultivated with Grande Naine banana in Missão Velha, CE, and Ponto Novo, BA, Brazil, at 0-0.20 and 0.20-0.40 m layers

Area	Layer (m)	pH (H_2O)	OM (g dm^{-3})	P (mg dm^{-3})	K^+	Ca^{2+}	Mg^{2+}	CEC	V (%)	P-Rem (mg L^{-1})
					(mmol$_c$ dm^{-3})					
Missão Velha	0-0.20	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
Ponto Novo	0-0.20	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 (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+} - KCl 1 mol L^{-1}; CEC - Cation exchange capacity at pH 7; V - Base saturation; P-rem - P-remaining; Remaining phosphorus, the concentration of P in the equilibrium solution after stirring the air-dried fine earth (TFSA) for one hour with 10 mmol L^{-1} $CaCl_2$ solution, containing 60 mg L^{-1} of P, in 1:10 ratio; Source - Elaborated by authors from Soil Fertility Database of Farms located in Missão Velha, CE, and Ponto Novo, BA, Brazil

was based on crop evapotranspiration (ETc), which is the product of daily reference evapotranspiration (ETo) by crop coefficient (Kc) for Grand Nain cultivar (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, 1,524.1 and 1,265.7 mm for Grande Naine grown in Ceará. In Bahia, net and gross irrigation depths were, respectively, 1,546.9 and 1,317.0 mm for Grande Naine. Potential application efficiency was set at 90% for a micro-sprinkler irrigation system. Yield data and foliar tissue analysis results recorded between 2010 and 2017 in a database belonging to the Sítio Barreiras company were used in this study. Yields (t ha^{-1} per year) were measured in each plot by weighing harvested hands. Leaf tissue sampling was carried out once a semester and followed the recommendations (Rodrigues et al., 2010). Leaf tissue sample results were processed and analyzed for leaf macro- (N, P, K, Ca, Mg, and S) and micronutrient (B, Cu, Fe, Mn, and Zn) concentrations (Bataglia et al., 1983).

The database was divided into two site-specific databases. One of them was from the farm located in Missão Velha, CE. It contained leaf tissue analysis results and annual yield data recorded between 2010 and 2017 from Grande Naine (AAA) plantations. The initial sample containing 150 recordings, mean ± standard deviation of 52.35 ± 12.98 t ha^{-1} per year, was subdivided into low-yielding populations (LYP) and high-yielding populations (HYP). HYP were considered as reference populations. They were those with a yield greater than mean + 0.5 standard deviations. This corresponded to 58.84 t ha^{-1} per year (72.24% of the highest yield) for a sample size of 46. The remainders, 104 samples, were LYP.

The other database was from the farm located in Ponto Novo, BA. It contained leaf tissue analysis results of Grande Naine banana from samples collected twice a year and annual yields recorded between 2014 and 2016. The initial sample consisting of 65 recordings, mean ± standard deviation of 65.15 ± 21.94 t ha^{-1} per year, was subdivided into LYP and HYP; the latter, reference populations, were those with a yield greater than mean + 0.5 standard deviations, which corresponded to 76.12 t ha^{-1} per year (75.80% of the highest yield), and had 19 samples. As for LYP, there were 46 samples.

The reference populations, or HYP, were used for setting Balance indexes of Kenworthy and DRIS indexes, while LYP was used for nutritional diagnosis (Deus et al., 2018).

From reference populations, the mean and variability within leaf nutrient concentrations, as well as pairwise nutrient ratios, were obtained. Then, the Balance indexes of Kenworthy and the DRIS indexes were calculated (Rodrigues Filho, 2018).

Balance indexes of Kenworthy and the DRIS indexes of each nutrient were replaced in potential nutrient-response curves created using the Boundary Line approach (Rodrigues Filho, 2018), thereby relating estimated relative yield (ERY) values to indexes calculated for each nutrient.

The lowest ERY associated with the most limiting nutrient was selected (the Law of the Minimum). After identifying the most limiting nutrient, the following equation was used:

$$NL = 100\% - ERY \quad (1)$$

where:

NL - nutritional limitation (%);

ERY - estimated relative yield obtained using the potential nutrient-response curve (%); and,

100% - hypothetical reference value if plant nutrient concentration were within ideal levels. Therefore, yield loss due to nutritional factors were estimated.

Yield loss due to non-nutritional factors was estimated using the following equation:

$$NNL = ERY - ARY \quad (2)$$

where:

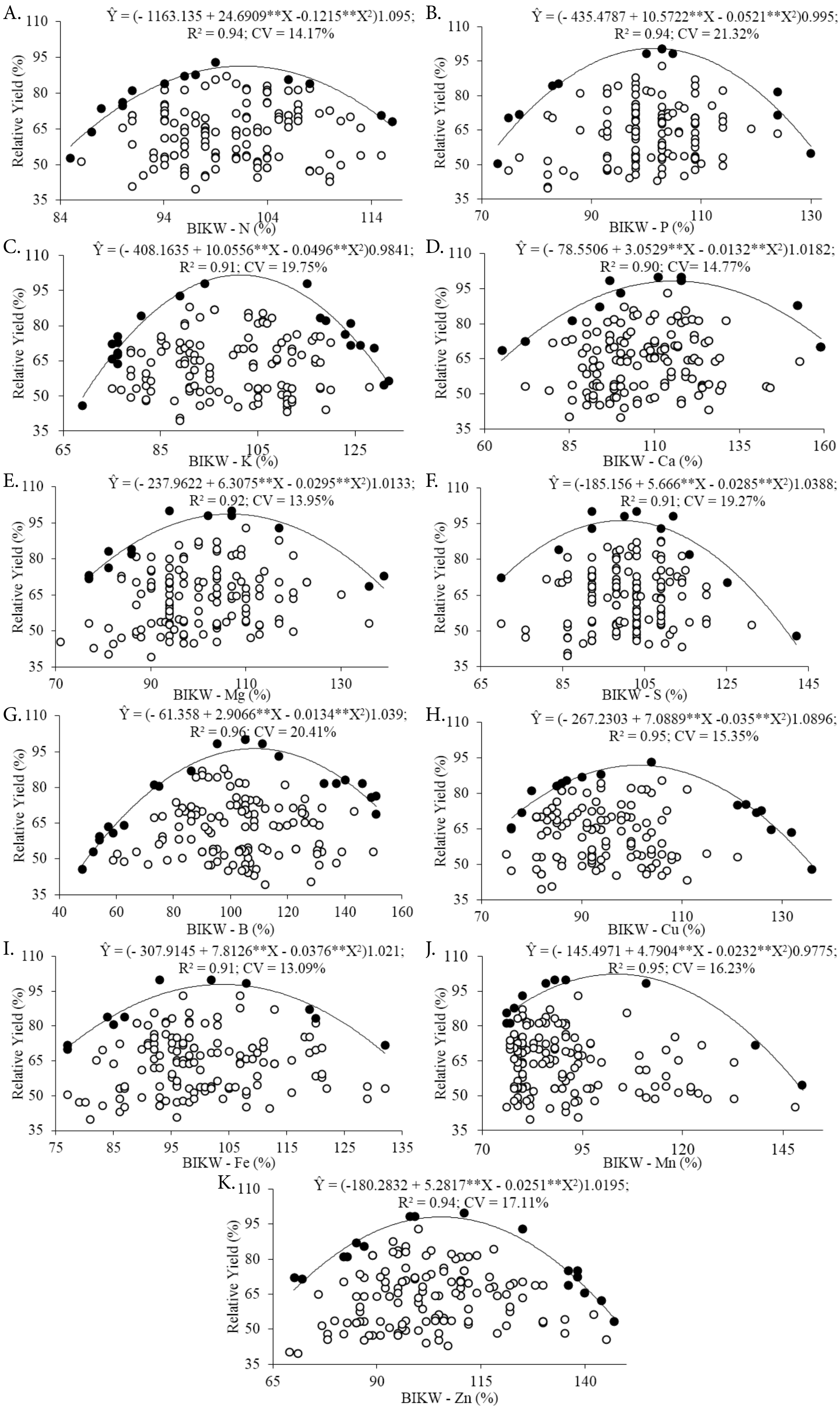
NNL - non-nutritional limitation (%); and,

ARY - actual relative yield, calculated based on the highest yield (%).

Results and Discussion

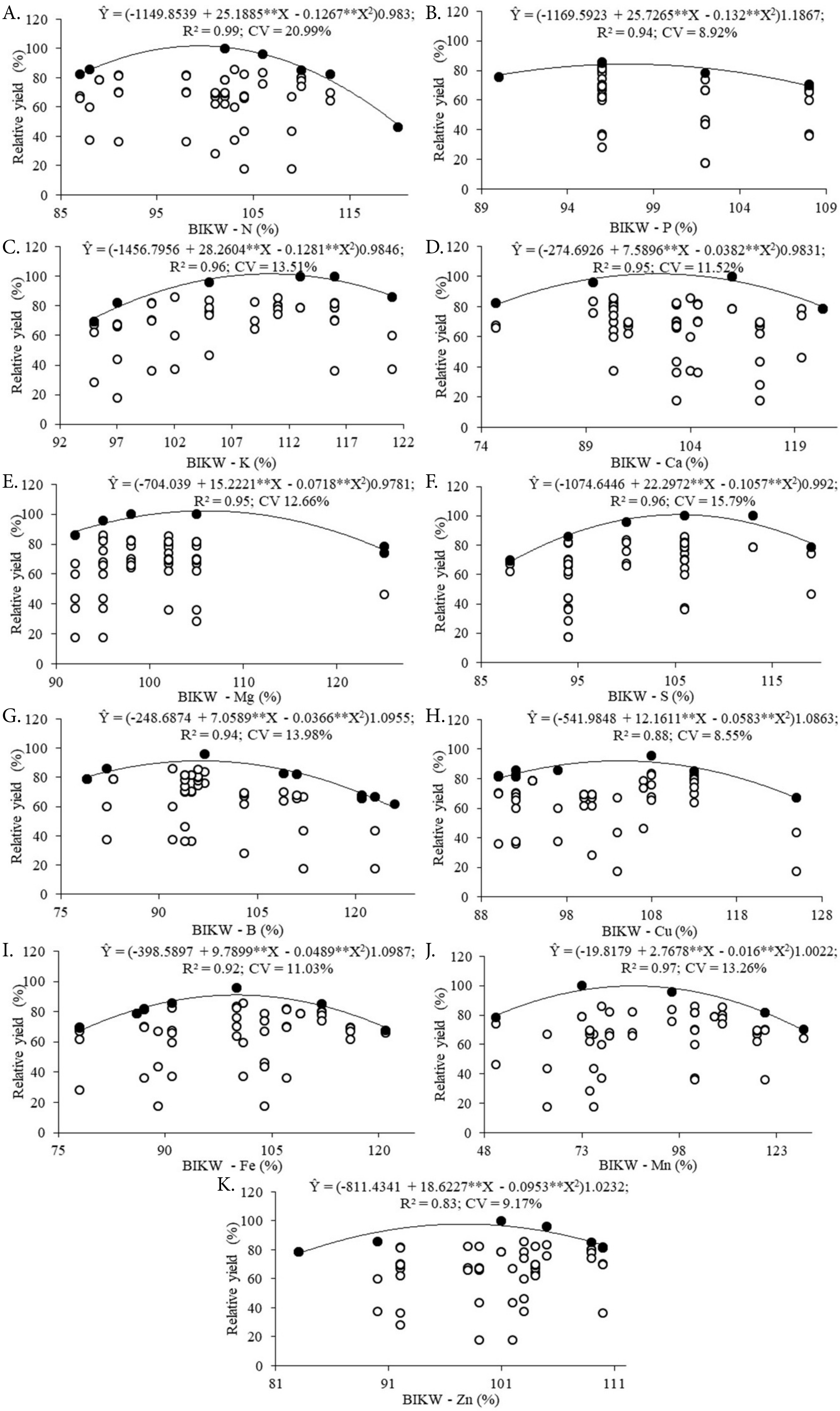
Results were based on the Law of the Minimum and potential nutrient-response curves estimated by the Boundary Line approach, using the indexes of Kenworthy (Figures 1 and 2) and DRIS indexes (Figures 3 and 4) adjusted according to Rodrigues Filho (2018). The extent to which each nutrient and non-nutritional factor limited the yield was determined (Table 3) using Eqs. 1 and 2.

Based on the Balance indexes of Kenworthy, K was the most limiting macronutrient in plants grown in Ceará with ERY of 88.83%, while Cu was the most limiting micronutrient with ERY of 83.22% (Table 3). Bases on the DRIS indexes, the most limiting macronutrient was also K with an ERY of 91.77%, while Mn was the most limiting micronutrient with an ERY



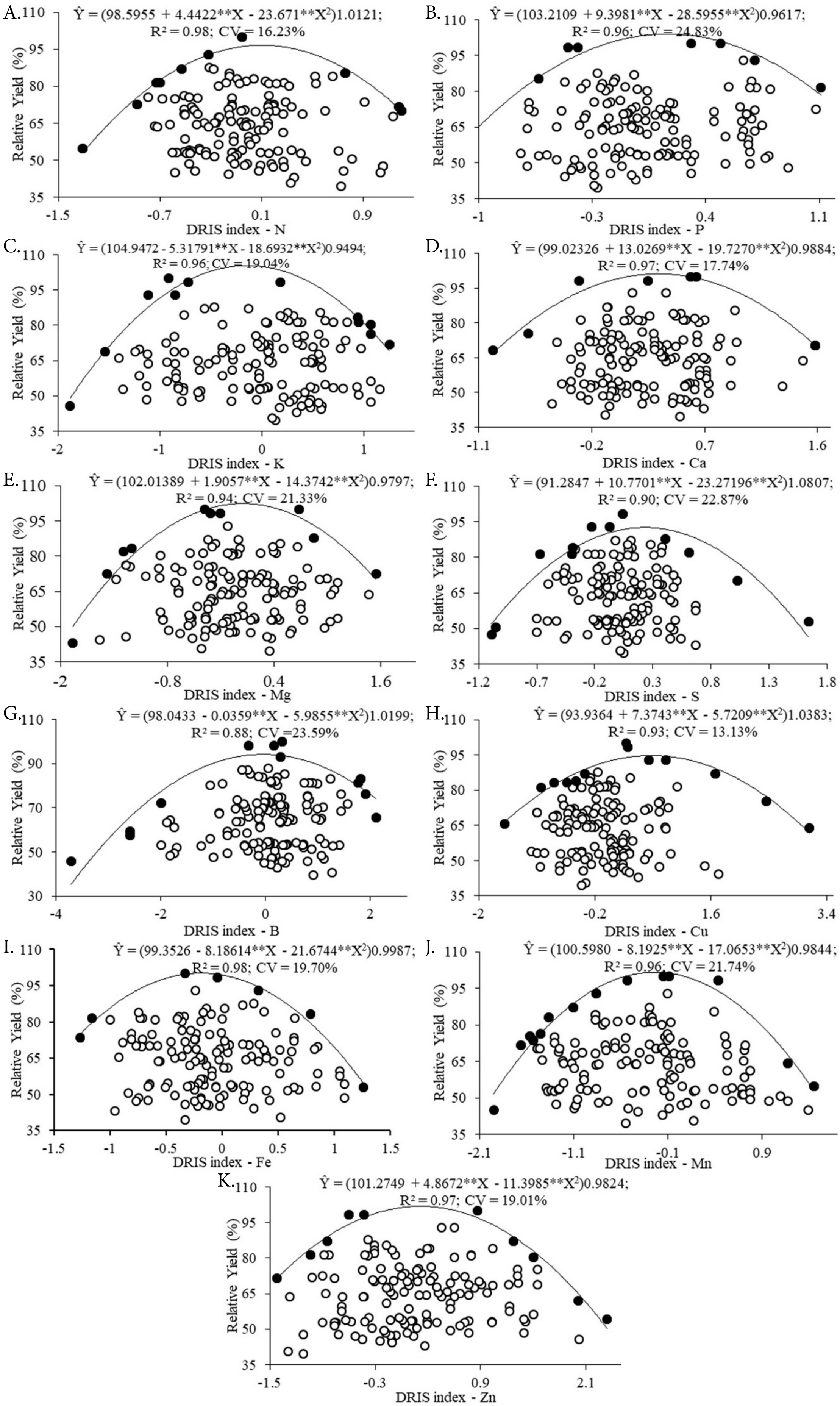
** - Significant at $p \leq 0.01$ by the t-test; The multipliers 1.095; 0.995; etc. found in the equations correspond to an adjustment factor for the equation to assume the value of 100% Relative Yield

Figure 1. Boundary line fitted according to the relationship between relative yield (%) and balance indexes of Kenworthy (BIKW) for leaf N (A), P (B), K (C), Ca (D), Mg (E), S (F), B (G), Cu (H), Fe (I), Mn (J), and Zn (K) concentrations in Grande Naine banana grown in Missão Velha, CE, Brazil



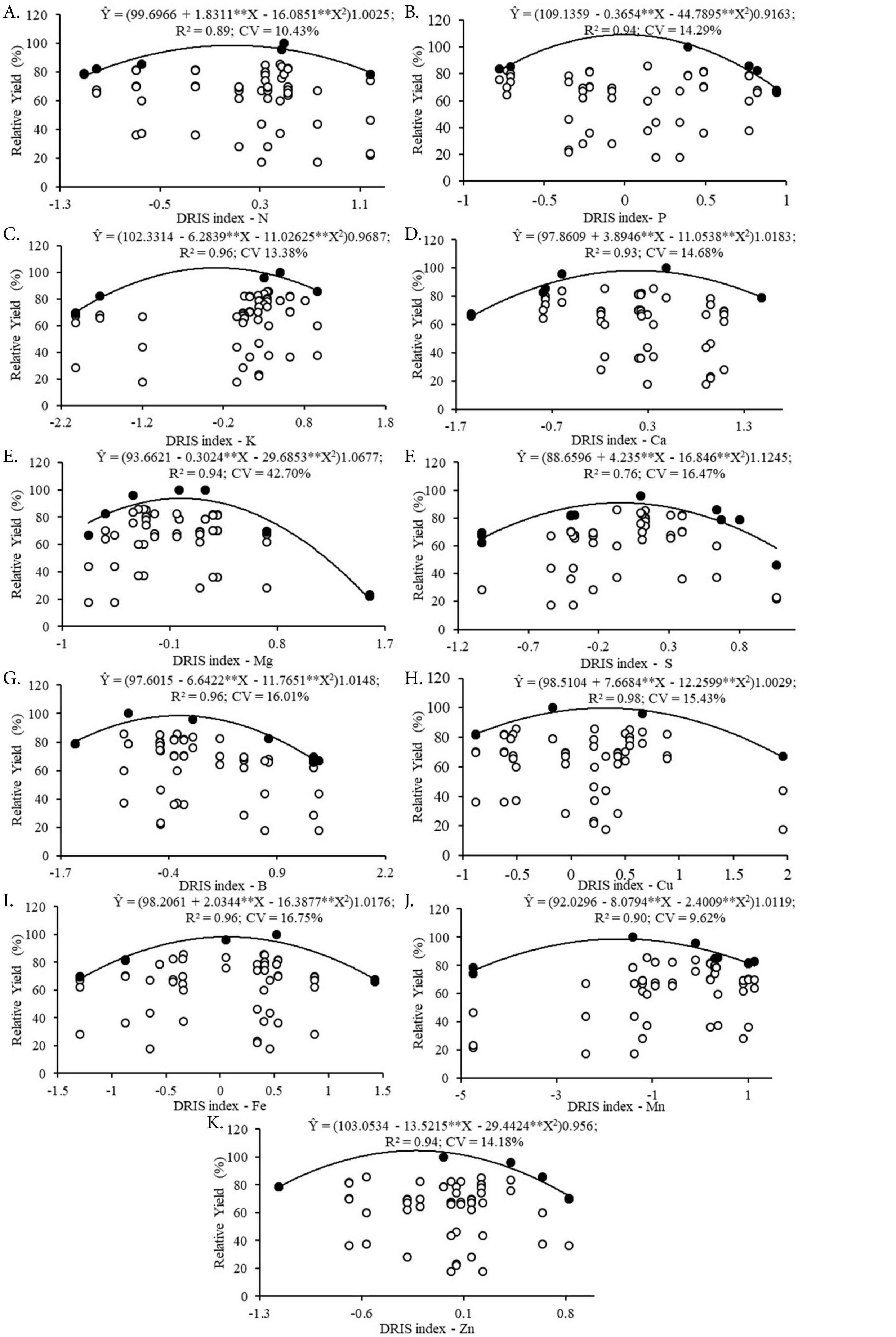
** - Significant at $p \leq 0.01$ by the t-test; The multipliers 0.983; 1.1867; etc. found in the equations correspond to an adjustment factor for the equation to assume the value of 100% Relative Yield

Figure 2. Boundary line fitted according to the relationship between relative yield (%) and Balance indexes of Kenworthy (BIKW) for leaf N (A), P (B), K (C), Ca (D), Mg (E), S (F), B (G), Cu (H), Fe (I), Mn (J), and Zn (K) concentrations in Grande Naine banana



** - Significant at $p \leq 0.01$ by the t-test; The multipliers 1.0121; 0.9617; etc. found in the equations correspond to an adjustment factor for the equation to assume the value of 100% Relative Yield

Figure 3. Boundary line fitted according to the relationship between relative yield (%) and DRIS indexes for leaf N (A), P (B), K (C), Ca (D), Mg (E), S (F), B (G), Cu (H), Fe (I), Mn (J), and Zn (K) concentrations in Grande Naine banana



** - Significant at p ≤ 0.01 by the t-test; The multipliers 1.0025; 0.9163; etc. found in the equations correspond to an adjustment factor for the equation to assume the value of 100% Relative Yield

Figure 4. Boundary line fitted according to the relationship between relative yield (%) and DRIS indexes for leaf N (A), P (B), K (C), Ca (D), Mg (E), S (F), B (G), Cu (H), Fe (I), Mn (J), and Zn (K) concentrations in Grande Naine banana

Table 3. Actual relative yield (ARY) and estimated relative yield (ERY) of low-yielding populations (LYP) based on balance indexes of Kenworthy (BIKW) and DRIS indexes for Grande Naine banana

ARY	ERY										
	N	P	K	Ca	Mg	S	B	Cu	Fe	Mn	Zn
	(%)										
Ceará											
Balance indexes of Kenworthy											
58.72	93.15	94.02	88.83	94.45	94.37	96.37	89.87	83.22	93.40	91.01	89.09
DRIS indexes											
58.72	95.14	93.59	91.77	92.28	94.76	94.22	94.16	92.94	93.39	89.20	92.29
Bahia											
Balance indexes of Kenworthy											
55.08	88.47	94.75	86.22	94.86	93.05	86.76	89.20	94.02	91.02	90.62	96.10
DRIS indexes											
55.08	94.05	91.01	90.89	94.59	85.21	92.25	88.02	93.55	89.44	90.92	93.87

of 89.20% (Table 3). In bananas, K is the most absorbed and exported nutrient (Moreira & Fageria, 2009; Hoffman et al., 2010) and the most recycled and dynamic element in the soil where bananas are grown (Donato et al., 2016). Therefore, K was considered the most limiting nutrient, associated with a relative yield of 88.83% compared to optimum nutritional conditions (100%). Accordingly, it is assumed that the banana plantation had yield losses of 11.17% attributable to inadequate nutrition.

The ARY was 58.72%; thus, if only nutritional constraints had been considered, the yield would have been higher, around 88.83% when considering K as the most limiting element or 83.22% when Cu is the most limiting element. As the actual yield was lower than the estimated yield, it is suggested that 30.11% of the attainable yield was lost due to non-nutritional factors, e.g., weather conditions, since maximum temperatures recorded between August and December were above 34 °C while the mean air relative humidity remained below 50% (except for December) (Table 1). Under these conditions, banana plants might have undergone considerable thermal stress, thereby hindering photosynthesis rates and lowering yield (Arantes et al., 2016; Arantes et al., 2018; Ramos et al., 2018).

In Bahia, using the Kenworthy approach, the most limiting macronutrient was K (ERY of 86.22%), while the most limiting micronutrient was B (ERY of 89.20%) (Table 3). When using DRIS indexes, however, Mg was the most limiting macronutrient (ERY of 85.21%), while the most limiting micronutrient was B (ERY of 88.02%) (Table 3). Likewise, the highest expected yield was 85.21%, limited by Mg. If under optimal nutritional conditions, Grande Naine bananas would have 100% of their yield potential; then, it can be inferred that inadequate nutrition resulted in a 14.79% loss in yield.

The banana plantation located in Bahia had an ARY of 55.08%; therefore, had only nutritional constraints been considered, the actual yield would be up to 85.21% greater than the estimated yield. As the actual yield was lower than the estimated yield, it is suggested that non-nutritional factors led to an additional 29.41% loss in yield.

Although weather conditions over the year were generally milder in Bahia than in Ceará (Table 1), the maximum wind speed was above 5 m s^{-1} for most of the year, which could have damaged the leaf blade, reducing the overall photosynthetic rate (Robinson & Galán Saúco, 2012; Donato et al., 2016).

It is essential to consider sunlight, water, temperature, and soil aeration, which all influence nutrient flow within the soil-plant system; therefore, crops can be better managed, and their nutrient status is more precisely diagnosed. Understanding the soil as an in situ natural body and its relationship with crops and the atmosphere is of utmost importance in gaining insight into nutrient availability to plants. This is not possible only using soil and leaf tissue analyses (Resende et al., 2002).

Furthermore, regardless of how advanced diagnosing tools are, assessing plant nutritional status demands from the diagnostician logical thinking and experience to understand and properly apply the data provided by studies such as the present study (Fontes, 2016).

Conclusion

Nutritional factors limited the yield by 11.17 and 14.79%, while non-nutritional factors are more yield-limiting by 30.11 and 29.41%, in Grande Naine bananas cultivated in Ceará and Bahia, respectively.

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