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Nutrient parameters limiting banana plant development in Vale do Ribeira, São Paulo State, Brazil

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ABSTRACT: Vale do Ribeira is one of the largest banana producing regions in Brazil. However, information on soil fertility and nutrient status that could limit fruit production remains scarce. Thus, the present study diagnosed the most limiting nutrient parameters for the Nanica and Prata banana cultivars, in Vale do Ribeira, São Paulo State, based on soil and leaf chemical analyses. The data assessed included samples from commercial plantations in the municipalities of Eldorado, Cajati, Jacupiranga, Pariquera-açú, Registro and Sete Barras, between 2012 and 2020. The results of soil (pH, V, P, K, Ca, Mg, S, B, Cu, Fe, Mn and Zn) and leaf chemical analyses (N, P, K, Ca, Mg, S, B, Cu, Fe, Mn and Zn) were interpreted according to literature values and their maximums, minimums, means, coefficients of variation (CV), and confidence intervals (CI) were calculated at $P < 0.05$. Parameter classes were assessed according to their frequency distribution. A large part of the samples exhibited pH and V values similar to those recommended for banana plants. Although, average soil nutrient concentrations were considered high, soil K, Mg and S levels did not provide adequate banana plant nutrition, since these nutrients were deficient in the plants.
Key words: *Musa spp.*, soil fertility, soil analysis, leaf analysis.

Parâmetros nutricionais limitantes ao desenvolvimento de bananeiras no Vale do Ribeira – SP

RESUMO: O Vale do Ribeira é uma das maiores regiões produtoras de banana do Brasil. Contudo, ainda são escassas informações sobre a fertilidade do solo e o estado nutricional das plantas que possam limitar a produção da fruta na região. Deste modo, o presente trabalho objetivou diagnosticar os parâmetros nutricionais mais limitantes para as cultivares de bananeira, Nanica e Prata, no Vale do Ribeira – SP, a partir de laudos de análises químicas de solo e folha. Os dados avaliados compreenderam amostragens realizadas em pomares comerciais, nos municípios de Eldorado, Cajati, Jacupiranga, Pariquera-açú, Registro e Sete Barras entre os anos 2012 e 2020. Os resultados das análises químicas de solo (pH, V, P, K, Ca, Mg, S, B, Cu, Fe, Mn e Zn) e folha (N, P, K, Ca, Mg, S, B, Cu, Fe, Mn e Zn) foram interpretados de acordo com valores disponíveis na literatura e calculados seus valores máximos, mínimos, médias, coeficientes de variação (CV) e intervalos de confiança (IC) a $P < 0.05$. As classes de interpretação dos parâmetros foram avaliadas de acordo com sua distribuição de frequência. Grande parte das amostras apresentaram valores de pH e V próximos aos indicados para a bananeira. As concentrações de nutrientes no solo, em média, foram consideradas altas, no entanto, para K, Mg e S, a concentração no solo não refletiu em adequada nutrição da bananeira, estando esses nutrientes deficientes na planta.
Palavras-chave: *Musa spp.*, fertilidade do solo, análise de solo, análise de folha.

INTRODUCTION

The rapid-growing banana plant (*Musa spp.*) requires substantial amounts of nutrients, mainly potassium (K) and nitrogen (N), for adequate development (DEUS et al., 2020; NYOMBI, 2020). These nutrients are directly related to plant development, and fruit production and quality, with the amount extracted differing as a function of cultivar, phenological status and plant age (COSTA et al., 2019; OLIVEIRA et al., 2022).

Although, the nutrients banana plants need are partially provided by the soil and soil-plant cycling, these sources are insufficient for the crop to achieve economically feasible production, requiring the supply of acidity correctors and fertilizers. Thus, it is important to identify the nutrient parameters that limit crop growth, development and production in order to supplying adequate amounts and proportions of nutrients (DEUS et al., 2018a; LIMA NETO et al., 2020; LIMA NETO et al., 2022).

In general, determining the need for acidity correctors for banana plants is based almost exclusively on soil chemical analysis (DEUS et al., 2018a). However, the concentrations indicated in these analyses do not represent what is necessarily absorbed and metabolized by the plant, due to the interference of biotic and abiotic factors involved in nutrient absorption, which are not considered in fertilization tables (ROZANE et al., 2016; DEUS et

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al., 2018b). Thus, it is important to use plant tissue chemical analysis in conjunction with soil analysis, primarily for fruit species, since, in addition to exploring the deepest arable layer, this group of plants also acquires certain stability with physiological maturity (MARSCHNER, 1995).

Leaves are the principal organ used in plant tissue chemical analysis because this is where the highest photoassimilate production occurs and greatest flow of nutrients absorbed by the plant occurs, better reflecting nutrient status (ROZANE et al., 2016; PRADO & ROZANE, 2020).

Determining soil fertility and the nutrient status of banana plants in commercial plantations, via soil and leaf chemical analyses, and comparing them with literature values will make it possible to ascertain which parameters may limit crop yield in the region under current production standards. Identifying deficient or excess nutrients in soil and leaf tissue will enable more accurate nutrient recommendations in banana crops, thereby ensuring greater yield and more efficient fertilizer use (GUIMARÃES & DEUS, 2021). As such, this study identified the most limiting nutrient parameters for banana plants (Nanica and Prata cultivars) in commercial plantations located in Vale do Ribeira, São Paulo State, the largest producing area of the fruit in Brazil.

MATERIALS AND METHODS

The soil fertility and nutrient status of Nanica and Prata banana cultivars was determined based on soil and leaf chemical analyses of commercial plantations, located in the municipalities of Cajati, Eldorado, Jacupiranga, Pariquera-açú, Registro and Sete Barras, in the Vale do Ribeira region of São Paulo state. The climate in the region is Af (tropical wet with no dry season), according to the Köppen classification system (ALVARES et al., 2013), with average annual rainfall of 1,500 mm.

The database consisted of 2549 and 2519 soil and leaf chemical analyses, respectively, conducted between 2012 and 2020 by commercial laboratories with quality control certifications awarded by São Paulo state (RAIJ et al., 2001).

Soil samples were collected in the fertilization region of the banana plants, from a 1-meter-wide area in front of the youngest lateral shoot, approximately 0.4 m from the pseudostem, in the 0.0-20 cm layer (NATALE & ROZANE, 2018; GUIMARÃES et al., 2020). The following were analyzed: pH, base saturation (V), phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), boron (B), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn). Extractions and determinations followed the methodology proposed by RAIJ et al. (2001): pH in calcium chloride; P, K, Ca and Mg in ion-exchange resin; S extracted by calcium phosphate turbidimetry; B via hot water; and Cu, Fe, Mn and Zn in DTPA at pH 7.3.

Leaf samples followed the International Sampling Method of Reference (MARTIN-PRÉVEL, 1984), where the third leaf (l3) from the apex was collected when all the female flowers had no bracts and there were two or three open male flowers. A 0.1 m-wide central strip was removed and the central vein and peripheral halves discarded. The following leaf contents were determined: nitrogen (N), phosphorous (P), potassium (K), calcium (Ca), magnesium (Mg), sulfur (S), boron (B), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn). N was analyzed applying the micro-Kjeldahl method and P, K, Ca, Mg, S, B, Cu, Fe, Mn and Zn were quantified using a spectrophotometer, after acid digestion, according to the methodology described by BATAGLIA et al. (1983).

The results of soil chemical analyses were interpreted according to the classes (Table 1) proposed in the Bulletin 100: Fertilization and Liming Recommendation for São Paulo state (Boletim 100: Recomendações de Adubação e Calagem para o Estado de São Paulo; CANTARELLA et al., 2022) and the Fertilization and Liming Manual for Paraná State (Manual de Adubação e Calagem para o Estado do Paraná; PAULETTI & MOTTA, 2019). For Ca concentrations in São Paulo, interpretation was based on RAIJ et al. (1997). P (extracted by resin in São Paulo) and Fe were interpreted only for São Paulo, since P in Paraná is extracted by Mehlich-1 and for Fe there is no indication of interpretation classes.

'Nanica' and 'Prata' banana leaf nutrient contents were interpreted based on the sufficiency ranges established for the crop in São Paulo (CANTARELLA et al., 2022) and Paraná (PAULETTI & MOTTA, 2019). For São Paulo, S was interpreted based on the sufficiency range indicated in RAIJ et al. (1997). Nutrient content within the sufficiency range was classified as adequate and those below or above this range as deficient and excessive, respectively (Table 2). Because interpretations of leaf analyses indicated for São Paulo and Paraná are not specific to banana cultivars, we decided to study data with no distinction for cultivar.

Soil and leaf chemical analysis data were submitted to the Shapiro-Wilk test for normality ($P > 0.05$), which indicated that all the variables met

Table 1 - Soil chemical attribute classes for São Paulo and Paraná.

Interpretation	------pH-----	------V------	-----P-----	------K^+------	---------Ca^{+2}--------	--------Mg^{+2}--------
classes	$CaCl_2$	%	mg dm^{-3}	------ $mmol_c$ dm^{-3} ------		mg dm^{-3}
------------São Paulo------------						
Very low	< 4.4	< 25	< 5.0	-	-	-
Low	4.4-5.0	25-50	5.0-15.0	<1.6	< 3.0	< 5.0
Medium	5.1-5.5	50-70	16.0-40.0	1.6-3.0	4.0-7.0	5.0-8.0
High	5.6-6.0	70-90	41.0-60.0	3.1-6.0	> 7.0	> 8.0
Very high	> 6.0	> 90	> 60.0	> 6.0	-	-
------------$cmol_c$ dm^{-3}------------						
				Paraná²		
Very low	< 4.0	< 20	-	< 0.06	< 0.5	< 0.2
Low	4.0-4.4	21-35	-	0.06-0.12	0.5-1.0	0.2-0.4
Medium	4.5-4.9	36-50	-	0.13-0.21	1.1-2.0	0.5-1.0
High	5.0-5.5	51-70	-	0.22-0.45	2.1-6.0	1.1-2.0
Very high	> 5.5	> 70	-	> 0.45	> 6.0	> 2.0
	$S\text{-}SO_4^{-2}$	B	Cu	Fe	Mn	Zn
------------mg dm^{-3}------------						
------------São Paulo¹------------						
Very low	-	-	-	-	-	-
Low	< 5.0	< 0.60	< 2.0	< 5.0	< 5.0	< 5.0
Medium	5.0-10.0	0.60-1.0	2.0-5.0	5.0-12.0	5.0-10.0	5.0-10.0
High	> 10.0	> 1.0	> 5.0	> 12.0	> 10.0	> 10.0
Very low	-	-	-	-	-	-
------------Paraná²------------						
Very low	< 1.0	< 0.10	< 0.2	-	< 5.0	< 0.4
Low	1.0-2.0	0.11-0.20	0.2-0.5	-	5.0-15.0	0.4-0.8
Medium	2.1-3.0	0.21-0.30	0.6-0.8	-	16.0-30.0	0.9-1.2
High	3.1-0.60	0.31-0.60	0.9-3.0	-	31.0-100.0	1.3-10.0
Very high	> 6.0	> 0.60	> 3.0	-	> 100.0	> 10.0

[1]RAIJ et al. (1997), CANTARELLA et al. (2022); [2]PAULETTI & MOTTA (2019).

the assumption. Maximums, minimums, coefficients of variation (CV) and confidence intervals (CI) of the parameters studied were calculated (P < 0.05). The results of the interpretations were presented as relative frequency (%), using vertical bar graphs.

RESULTS AND DISCUSSION

Soil fertility diagnosis in commercial banana plantations

pH exhibited the lowest variation (11.8%) between the soil chemical attributes assessed in banana plantations, with an amplitude of 3.7 and mean of 5.1 (Table 3). At a 95% confidence level, it can be inferred that in Vale do Ribeira, the pH of a soil sample from the banana crop will be between 5.08 and 5.13. According to NYOMBI (2020), banana plants exhibit good vegetative development, with pH varying between 5.5 and 8.0. At low pH (4.5), yield declines by 50% due to the scarce availability of nutrients such as phosphorus, especially in tropical soils. These pH values (5.5 to 8.0) correspond to the medium-to-very high classes for São Paulo (CANTARELLA et al., 2022) and high-to-very high for Paraná (PAULETTI & MOTTA, 2019). Thus, in 53.7% of the samples, pH values were classified between medium and very high for São Paulo and 59.4% between high and very high for Paraná (Figures 1a and 1b).

Soil base saturation (V) varied from 2.3 to 92.6%, with an average of 67.2%, and 95% CI between 66.6 and 67.9% (Table 3). According to the interpretation classes for Paraná (PAULETTI & MOTTA, 2019), 55.6% of the samples obtained very high values (Figure 1b). In the interpretations indicated for São Paulo (CANTARELLA et al., 2022), 55% of the samples exhibited high V values (Figure 1a). The larger percentage of very high and high samples for Paraná (PAULETTI & MOTTA, 2019) and São Paulo

Table 2 - Reference ranges for interpretation of banana plant leaf nutrient content for São Paulo and Paraná States.

	-------N--------	--------P--------	-------K--------	-------Ca-------	------Mg-------	-------S-------
	---g kg^{-1}---					
São Paulo[1]	25.0-30.0	1.7-2.1	30.0-40.0	2.0-5.0	6.0-1.0	2.5-8.0
Paraná[2]	17.0-36.0	1.6-3.2	24.0-56.0	4.9-12.0	1.3-6.0	1.6-3.7
	B	Cu	Fe	Mn	Zn	
	---mg kg^{-1}---					
São Paulo[1]	10.0-25.0	7.0-20.0	80.0-200.0	220.0-1000.0	15.0-30.0	
Paraná[2]	9.0-75.0	6.0-30.0	45.0-360.0	88.0-180.0	12.0-50.0	

[1]RAIJ et al. (1997). CANTARELLA et al. (2022); [2]PAULETTI & MOTTA (2019).

(CANTARELLA et al., 2022), respectively, correspond to a V above 70%, deemed adequate for the banana crop by the same authors.

Average soil P concentration and variation were 114.6 mg dm^{-3} and 88.2%, respectively (Table 3). A random sample from a banana plot in Vale do Ribeira has a 95% likelihood of P concentration between 110.7 and 118.6 mg dm^{-3} (Table 3). Based on the recommended interpretation classes for the nutrient in São Paulo (CANTARELLA et al., 2022), 62.2% of soil samples obtained very high values (>60 mg dm^{-3}) (Figure 1c). These results indicate excess phosphate fertilization, also observed in Cavendish banana plantations in Santa Catarina state, where P was classified as very high in 85% of the plantations (GUIMARÃES & DEUS, 2021).

Average K soil concentration was 4.1 $mmol_c$ dm^{-3}, with a 95% CI. A soil sample from a commercial banana plantation in Vale do Ribeira will likely have a concentration between 3.9 and 4.2 $mmol_c$ dm^{-3} (Table 3). Most of the soil samples showed high K concentrations, considering the classification proposed by PAULETTI & MOTTA (2019) for Paraná (34%) and CANTARELLA et al. (2022) for São Paulo (32.1%) (Figures 1c and 1d).

Soil Ca and Mg concentrations obtained a CV of 41.2 and 47.0%, respectively, with average Ca and Mg of 57.1 and 18.5 $mmol_c$ dm^{-3}, respectively (Table 3). According to interpretation classes indicated for São Paulo state (RAIJ et al., 1997; CANTARELLA et al., 2022), Ca and Mg exhibited the largest percentage of samples with high soil concentrations, at 98.7 and 100%, respectively) (Figure 1c). For interpretations proposed by PAULETTI & MOTTA (2019), which provide a larger number of classes to classify soil Ca and Mg concentrations, 47.9 and 47.2% of soil samples were classified as high for Ca and Mg, respectively (Figure 1d).

Table 3 - Minimum, maximum, mean, coefficient of variation (CV) and confidence interval (CI) values of the soil chemical parameters of 2549 samples collected in commercial Nanica and Prata banana plantations in Vale do Ribeira – SP.

	------Minimum-----	-----Maximum-----	--------Mean--------	-------CV (%)------	----------CI*---------
pH $CaCl_2$	3.4	7.1	5.1	11.8	5.08-5.13
Ca ($mmol_c$ dm^{-3})	1.0	199.0	57.1	41.2	56.2-58.1
Mg ($mmol_c$ dm^{-3})	1.0	75.0	18.5	47.0	18.1-18.8
K ($mmol_c$ dm^{-3})	0.1	27.2	4.1	86.6	3.9-4.2
P (mg dm^{-3})	3.0	832.7	114.6	88.2	110.7-118.6
V (%)	2.3	92.6	67.2	25.3	66.6-67.9
S (mg dm^{-3})	0.3	242.0	21.1	131.7	20.0-22.2
B (mg dm^{-3})	0.1	7.1	0.5	111.8	0.5-0.6
Fe (mg dm^{-3})	0.8	980.0	140.9	74.6	136.8-144.9
Mn (mg dm^{-3})	0.4	147.0	24.1	94.2	23.2-24.9
Cu (mg dm^{-3})	0.1	13.3	2.5	82.1	2.4-2.6
Zn (mg dm^{-3})	0.1	65.0	6.6	104.90	6.4-6.9

*significant at $P < 0.05$.

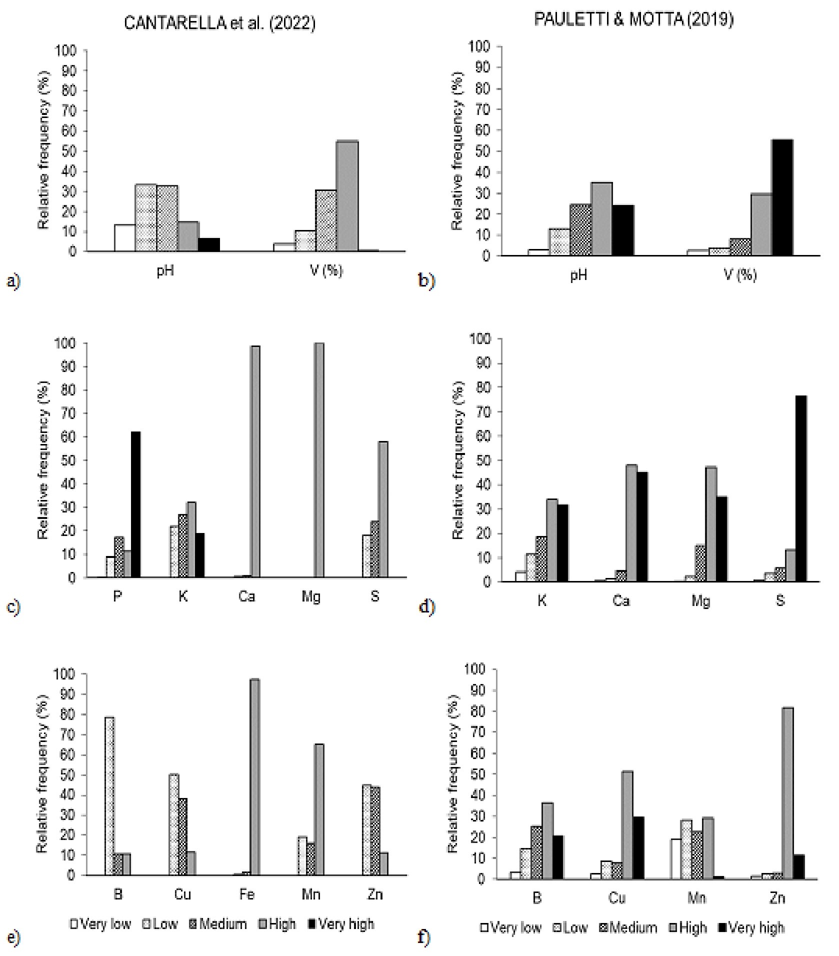

Figure 1 - Relative frequency (%) of commercial Nanica and Prata banana plantations with soil chemical parameters interpreted as very low, low, medium, high and very high in Vale do Ribeira – SP.

S obtained the highest CV among the soil chemical attributes (131.7%), an average concentration of 21.1 mg dm^{-3} and 95% CI between 20.0 and 22,2 mg dm^{-3} (Table 3). According to the interpretation classes suggested by PAULETTI & MOTTA (2019) for Paraná and CANTARELLA et al. (2022) for São Paulo, 76.5% of the samples showed soil S concentrations classified as very high and 58% high, respectively (Figures 1c and 1d).

Soil micronutrient concentrations varied considerably, with B exhibiting the highest variation (111.8%), followed by Zn (104.9%,) Mn (94.2%), Cu (82.1%) and Fe (74.6%) (Table 3).

Based on recommended soil fertility classes for São Paulo State (CANTARELLA et al., 2022), more than 55% of the areas assessed showed high Ca, Mg, S, Fe and Mn concentrations (Figures 1c and 1e), differing from the interpretations for Paraná (PAULETTI & MOTTA, 2019), with a larger percentage of samples containing high B, Cu and Zn concentrations (Figure 1f). This difference is due to the lower number of interpretation classes for Ca, Mg, S, B, Cu, Fe, Mn and Zn attributed by CANTARELLA et al. (2022), only low, medium and high classes for these nutrients (Table 1). This increases the amplitude of the classes, making it possible to classify a larger number of samples as high.

Diagnosis of banana nutrient status

Average Leaf N content was 26.7 g kg^{-1}, with a 17.0% variation and CI between 26.6 and 26.9 g kg^{-1} (Table 4). Based on the reference range indicated by PAULETTI & MOTTA (2019) for Paraná, 98.3% of the samples were considered to have adequate N content

Table 4 - Minimum, maximum, mean, coefficient of variation (CV) and confidence interval (CI) values of the leaf nutrient content of 2519 samples collected from Nanica and Prata banana plants in Vale do Ribeira – SP.

	------Minimum-----	------Maximum-----	--------Mean--------	-------CV (%)-------	----------CI*---------
N ($g\ kg^{-1}$)	18.2	74.6	26.7	17.0	26.6-26.9
P ($g\ kg^{-1}$)	0.9	4.5	2.1	14.6	2.0-2.1
K ($g\ kg^{-1}$)	5.1	67.5	29.0	28.8	28.7-29.4
Ca ($g\ kg^{-1}$)	1.0	20.0	7.0	27.7	6.9-7.0
Mg ($g\ kg^{-1}$)	1.0	9.6	3.0	25.2	3.0-3.1
S ($g\ kg^{-1}$)	0.3	4.9	2.0	23.7	1.96-2.0
B ($mg\ kg^{-1}$)	1.6	85.3	11.5	49.3	11.3-11.8
Cu ($mg\ kg^{-1}$)	1.1	21.0	8.4	36.9	8.3-8.5
Fe ($mg\ kg^{-1}$)	10.0	598.0	115.7	46.1	113.6-117.8
Mn ($mg\ kg^{-1}$)	20.0	1850.0	354.3	67.8	344.9-363.7
Zn ($mg\ kg^{-1}$)	9.0	48.0	20.1	23.3	20.0-20.3

*significant at $P < 0.05$.

(Figure 2b). According to the recommendations of CANTARELLA et al. (2022) for São Paulo, only 54.3% of the samples were within the range considered adequate for banana plants (Figure 2a). NYOMBI (2020) that N is primarily responsible for vegetative growth and very important in leaf area formation.

Leaf P content exhibited less variation (14.6%) among nutrients, with a range between minimum and maximum content of 3.6 $g\ kg^{-1}$ (Table 4). As observed for N, most of the samples (96.0%) were within the range deemed adequate for banana plants in Paraná (PAULETTI & MOTTA, 2019) (Figure 2b). Based on the range indicated for the crop

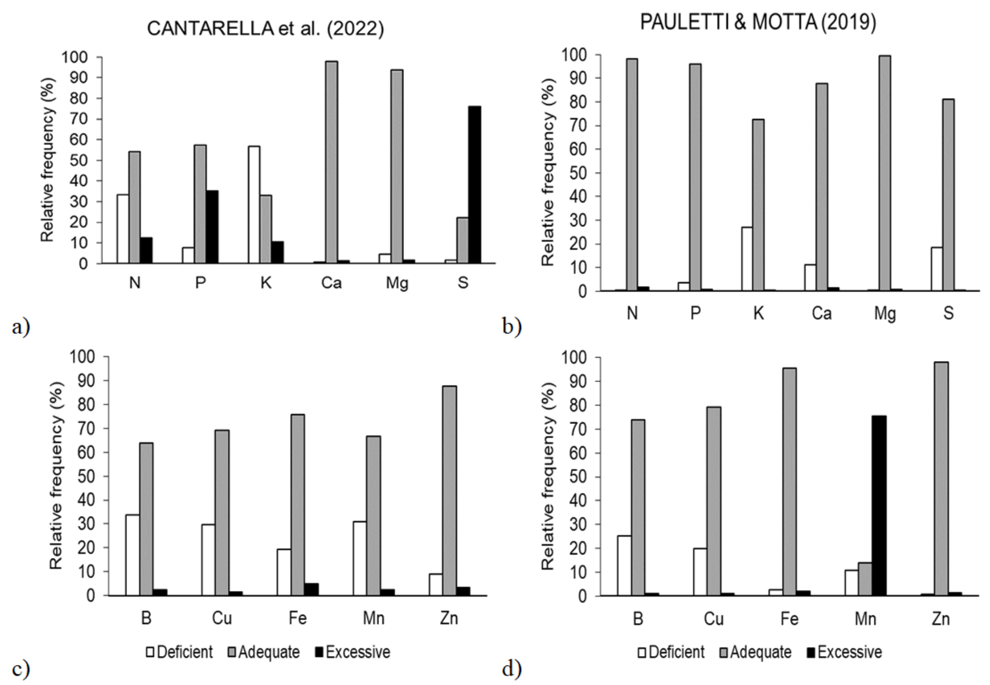

Figure 2 - Relative frequency (%) of commercial Nanica and Prata banana plantations with leaf nutrient content considered deficient, adequate and excessive in Vale do Ribeira – SP.

in São Paulo (CANTARELLA et al., 2022), 57.4% of the samples were adequate (Figure 2a). SILVA & RODRIGUES (2001) reported results similar to those observed in the present study, when they conducted a nutrient survey of 'Prata-anã' banana plants in Minas Gerais state, recording a 15% variation and 2.4 g kg^{-1} amplitude among samples.

The lower variation and higher frequency of leaf samples with adequate P content may be related to the large percentage of soil samples with high and very high P content (73.5%) (Figure 1c). Low soil P mobility means that adding NPK fertilizers to established banana plantations allows this nutrient to accumulate in the surface layer. Over time, adsorption sites become saturated and the added P is stabilized in intermediately labile forms, thereby retaining this nutrient, which may later be made available to plants (SANTOS et al., 2008). This is the likely reason for the large percentage of samples with adequate P content.

K obtained the highest variation among the macronutrients (28.8%), with an average of 29.0 g kg^{-1} and CI between 28.7 and 29.4 g kg^{-1} (Table 4). Considering the recommended reference range for banana plants in Paraná (PAULETTI & MOTTA, 2019), 72.7% of the samples were deemed to have adequate K content (Figure 2b). However, most of the samples (56.6%) exhibit K content below the range recommended for the crop by CANTARELLA et al. (2022) for São Paulo, and are classified as deficient (Figure 2a). Given that soil Ca and Mg concentrations in the plots are predominantly high, this K deficiency in banana leaves may have occurred due to competition between these cations for the same absorption site (NATALE & ROZANE, 2018).

Ca obtained an average leaf content of 7.0 g kg^{-1}, CV of 27.7% and CI between 6.9 and 7.0 g kg^{-1} (Table 4), with recommendations for Paraná (PAULETTI & MOTTA, 2019) and São Paulo (CANTARELLA et al., 2022) indicating that 87.7% of samples were adequate and 85.4% had a higher-than-recommended content, respectively (Figures 2a and 2b). The results obtained with the ranges indicated for Paraná are similar to those reported by SILVA & RODRIGUES (2001) and GODOY et al. (2011), who found that 98.0 and 86.0% of leaf samples, respectively, exhibited adequate Ca content, in a nutrient survey of Prata-anã, Prata and Cavendish banana plants.

The high percentage of leaf samples with adequate Ca content is partially explained by the high soil concentrations of this nutrient, similarly to that observed by GODOY et al. (2011), who associated the high percentage of adequate leaf content with high soil Ca concentrations, due to the periodic liming in banana plantations in Vale do Ribeira.

The average Mg content observed in leaf samples was 3.0 g kg^{-1}, CV of 25.2% and 95% CI between 3.0 and 3.1 g kg^{-1} (Table 4). Leaf Mg content was considered adequate in 99.4% of the samples, according to reference values indicated by PAULETTI & MOTTA (2019) for Paraná (Figure 2b). The opposite was observed for the ranges established by CANTARELLA et al. (2022) in São Paulo, where 99.4% of the samples obtained deficient leaf Mg content (Figure 2a).

Unlike that observed for Ca, in which high soil concentrations reflected in adequate plant levels, the opposite was observed for K and Mg, since, despite exhibiting higher percentages of soil samples classified as high, large percentages of leaf samples with content below the adequate nutrient range were found. Interactions between cations changed the cationic balance, whereby high soil Ca concentrations may inhibit K and Mg plant absorption and lead to lower leaf content of these nutrients in most of the samples (GUIMARÃES & DEUS, 2021).

Average leaf S content was 2.0 g kg^{-1}, with a 23.7% variation and 95% CI between 1.96 and 2.0 g kg^{-1} (Table 4). As observed for Mg, S obtained a larger number of samples (81.3%) with content within the reference range (1.6 – 3.7 g kg^{-1}) established by PAULETTI & MOTTA (2019) for Paraná (Figure 2d). A comparison between the data with those recommended by RAIJ et al. (1997) for São Paulo, revealed that 86.5% of the samples displayed values below the indicated range (2.5 – 8.0 g kg^{-1}), and were classified as deficient (Figure 2c).

The high percentage of S-deficient samples is related to the use of S-deficient fertilizers and leaching of this nutrient in the soil profile. Liming increases pH in the surface layer, thereby raising negative soil charges and, due to repulsion by the negatively-charged colloids, S-SO_4^{2-} leaches from the soil with water flow and its concentration declines in the profile (CAIRES et al., 2003).

Average leaf B, Fe and Cu content was 11.5, 8.4 and 115.7 mg kg^{-1}, respectively (Table 4), all within the reference ranges indicated for banana plants in Paraná (PAULETTI & MOTTA, 2019) and São Paulo (CANTARELLA et al., 2022) (Table 2). In regard to leaf content for Paraná, most of the samples were adequate for B (73.7%), Cu (79.1%) and Fe (95.6%) (Figure 2d). Based on ranges recommended for São Paulo, 63.8, 69.1 and 75.8% of the samples exhibited adequate B, Cu and Fe content, respectively (Figure 2c).

Leaf Mn content obtained the highest variation (67.8%) among the nutrients, with an average of 354.3 mg kg^{-1} (Table 4). The results corroborated those reported by GODOY et al. (2011), who conducted a similar study in Prata and Cavendish banana plants in Ribeira, observing a CV of 88.7 and 140.5%, respectively. However, the amplitude was higher in the present study (20.0 – 1850.0 mg kg^{-1}) and, according to VILLASEÑOR et al. (2020), high leaf Mn content in banana plants may reduce fruit yield, due to nutrient imbalance (DEUS et al., 2018b; LIMA NETO et al., 2022).

In 75.3% of the samples leaf Mn content was higher than that of the reference range for banana plants in Paraná (Figure 2d). Considering recommendations for São Paulo, the content of 66.7 % of the samples was within the adequate range for the crop (Figure 2c). The high frequency of samples with adequate or excessive Mn content according to indications for São Paulo and Paraná is likely related to the large percentage of samples with high soil concentrations of this nutrient (Figures 1e and 1f), as well as applications of plant protection products containing Mn, used to control fungal diseases such as Yellow and Black Sigatoka.

Zn exhibited the lowest CV (23.3%) among the micronutrients assessed, with an average of 20.1 mg kg^{-1} and CI between 20.0 and 20.3 mg kg^{-1} (Table 4). Leaf Zn content was considered adequate in 97.9 and 87.9% of the samples, according to sufficiency ranges established for the crop in Paraná and São Paulo, respectively (Figures 2c and 2d).

A comparison between the data and reference values for banana plants in Paraná showed the following percentages of samples with leaf content (in descending order) outside the adequate range: Mn (86.0%) > K (27.3%) > B (26.3%) > Cu (20.9%) > S (18.7%) > Ca (12.3 %) > Fe (4.4%) > P (4.0%) > Zn (2.1%) > N (1.7%) > Mg (0.7 %) (Figure 2d). However, for the ranges indicated for São Paulo, a higher percentage of samples with higher-than-recommended content was observed in the following order: Mg (99.5%) > S (86.6%) > Ca (85.6%) > K (67.0%) > N (45.7%) > P (42.6%) > B (36.2%) > Mn (33.3%) > Cu (30.9%) > Fe (24.2%) > Zn (12.2%) (Figure 2c).

Based on the sufficiency ranges for São Paulo, an average of 48.7% of the samples exhibited adequate nutrient content for banana plants (Figure 2c), and an average of 81.4% for Paraná (Figure 2d). The high percentage of samples with content within the recommended nutrient ranges are due to the larger amplitudes and lower values of the ranges of PAULETTI &MOTTA (2019) when compared to those of CANTARELLA et al. (2022) (Table 2).

Interpretations of soil and leaf tissue chemical analyses differed in classification between the standards indicated for São Paulo and Paraná, demonstrating the importance of establishing and using specific values for each region to ensure more accurate result interpretation (CARVALHO JÚNIOR et al., 2019).

Although, the soil nutrient concentrations were considered high on average, in some cases this did not reflect in adequate nutrition for the banana plant, leading to the deficiency of some nutrients, such as K, which is most exported by the trusses (TEIXEIRA et al., 2008; OLIVEIRA et al., 2022). The results demonstrated the need to improve the nutritional management of banana plantations in Vale do Ribeira, through periodic soil and leaf chemical analyses in order to comply with the recommended doses of acidity correctors and fertilizers and achieve the pH indicated for the banana plant without compromising nutrient availability and absorption by the crop.

CONCLUSION

More than 80% of the samples exhibited higher-then-recommended pH for banana plants, and over 55% obtained higher V values, albeit not restricting plant growth and development in the commercial plantations of Vale do Ribeira. The nutrients K, Ca, Mg, Fe and Mn obtained the largest number of samples with high soil concentrations in banana plantations in the region.

In general, there is a higher percentage of samples with N, P, B, Cu, Fe and Zn content considered adequate for banana plants in Paraná and São Paulo. However, the former state showed a higher percentage of samples with excess Mn and São Paulo had the highest percentage of samples with deficient K, Mg and S and excess Ca.

Although, there was a greater percentage of soil samples with high K, Ca, Mg, S, Fe and Mn concentrations, this did not occur in the leaves, where K, S and Mg were more limiting.

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DECLARATION OF CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

AUTHORS' CONTRIBUTIONS

The authors contributed equally to the manuscript.

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