Nutritional status and production of 'Prata-Anã' (AAB) and 'BRS Platina' (AAAB) banana plants with organic fertilization

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ABSTRACT: The objective of this research was to evaluate the nutritional status and yield of 'Prata' bananas fertilized with different sources for organic management applied to soils with improved fertility. Two cultivars ('Prata-Anã' and 'BRS Platina'), five annual potassium rates (0, 200, 400, 600, and 800 kg ha-1 of K_2O) supplied by bovine manure and rock powder, and six evaluation periods (210, 390, 570, 750, 930, and 1.110 days after transplanting – DAT) were laid out in a randomized block design, in a 2 x 5 x 6 factorial arrangement with three replicates. The yield was determined over three cycles. The levels of K and S in leaves increased with increasing rates of K_2O interacting with the evaluation periods. The levels of N, P, and Cu increased with increasing rates of K_2O. High soil fertility and manure and rock powder applications were not enough to maintain appropriate levels of leaf Mn in 'Prata-Anã'. The levels of leaf K, S, Cu, and Zn in the cultivar Prata-Anã differed from those of the 'BRS Platina'. Applying manure and rock powder as organic fertilizers did not increase the yield of 'Prata-Anã' and 'BRS Platina' banana plants grown on soils with improved fertility during four production cycles.
Keywords: *Musa* spp.; leaf tissue analysis; yield.

Estado nutricional e produção de bananeiras 'Prata-anã' (AAB) e 'BRS Platina' (AAAB) com fertilização orgânica

RESUMO: Objetivou-se com esta pesquisa avaliar o estado nutricional e o rendimento de bananeiras 'Prata' com diferentes fontes de fertilização para manejo orgânico em solos com fertilidade melhorada. Duas cultivares ('Prata-Anã' e 'BRS Platina'), cinco doses anuais de potássio (0, 200, 400, 600 e 800 kg ha-1 de K_2O) fornecidas por meio de esterco bovino e pó de rocha, e seis períodos (210, 390, 570, 750, 930 e 1.110 dias após o transplantio), distribuídos em delineamento de blocos ao acaso, em esquema fatorial 2 x 5 x 6 com três repetições. O rendimento foi determinado por três ciclos. Os teores de K e S nas folhas aumentaram com aumento das taxas de K_2O em interação com os períodos de avaliação. Os níveis de N, P e Cu aumentaram com o aumento das doses de K_2O. A alta fertilidade do solo e as aplicações de esterco e pó de rocha não são suficientes para manter os níveis adequados de Mn em 'Prata-Anã'. Os teores de K, S, Cu e Zn na cultivar Prata-Anã diferem de 'BRS Platina'. O esterco e o pó de rocha como fertilizantes orgânicos não aumentam o rendimento das bananeiras 'Prata' cultivadas em solos com fertilidade melhorada durante quatro ciclos de produção.
Palavras-chave: *Musa* spp.; análise de tecido foliar; rendimento.

1. INTRODUCTION

Bananas require large amounts of nutrients that should be supplied according to the current crop's nutritional demands (DONATO et al., 2010). The use of organic fertilizers may be a feasible and environmentally sustainable alternative. Thus, it is essential to know the nutrient and yield responses of banana plants grown on atypical soil conditions to different fertilizer sources - mineral, organic, or organomineral. There are several methods for assessing the nutritional status of plants using data from tissue analysis. These methods include the sufficiency range technique which is univariate and considers only one nutrient, methods that consider bivariate relationships between two nutrients such

as diagnosis and recommendation of an integrated system (DRIS), and the compositional nutrient diagnosis (CND) that is a multivariate method that considers relationships between all nutrients. Other methods are also used such as Kenworthy balanced indices (KWBI) and the mathematical chance (ChM).

Recently, for the assessment of nutritional status has been employed machine learning, and compositional data analysis (CoDa) methods that measure the effects of featured combinations on banana yield and rank nutrients in the order of their limitation (LIMA NETO et al., 2020), and nutrient assessments in real time (ARANTES et al., 2016). Despite its great simplicity, the sufficiency range technique is the most

used to assess the nutritional status of 'Prata' banana (Musa AAB) plantations (SILVA, 2015) with accurate results. Leaf tissue analysis is important for assessing the nutritional status of crops. This analysis, in combination with soil chemical analysis and visual diagnosis, reflects the dynamic of nutrients in the soil-plant system (ARANTES et al., 2016).

Several studies on the application of organic fertilizers for bananas show that the use of these materials is feasible (DAMATTO JUNIOR et al., 2011a,b; RIBEIRO et al., 2013; SANTOS et al., 2014). The application of these kinds of fertilizers to soils increases diversity and biological activity and aids the suppression of pathogens (GEENSE et al., 2015). Rock powder is a low-cost fertilizer containing many nutrients such as potassium, phosphorus, calcium, magnesium, iron, manganese, silicon, copper, and molybdenum. It is used to recover, renew, or fertilize poor and unbalanced soils (HARLEY; GILKES, 2000). Valentini et al. (2016) emphasize that these minerals are more efficiently taken up by plants when used in combination with manure.

However, there is a demand for studies in conditions soils of high or improved fertility, where nutrient contents and base saturation were changed from a dystrophy condition to eutrophy by anthropic actions (addition of organic material of animal and vegetable origin from the crop itself in previous years) over time. In this sense, it is important to estimate how many cycles a nutrient-demanding crop such as banana can be grown without reducing its productivity in the absence of fertilizer application, inputs currently with prohibitive prices, particularly potassium. Fertilization systems, together with varieties of great national importance such as 'Prata-Anã' and its hybrid 'BRS Platina' resistant to fusariosis, based on bovine manure and rock powder, are complementary to supply nutrients to plants, improve physical quality and biological properties of the soil and make it possible to reduce the input of external inputs to the property, currently with very high costs.

Therefore, these fertilizers may ensure greater long-term sustainability and recovery in banana plantations. The objective of this study was to evaluate the nutritional status and yield of 'Prata-Anã' and 'BRS Platina' bananas fertilized with bovine manure and rock powder and grown on soils with improved fertility.

2. MATERIALS AND METHODS

The experiment was carried out at the Baiano Federal Institute, Guanambi campus, located in the state of Bahia, Brazil (14°17'27" S, 42°46'53" W, 537 m a.s.l.). The soil was classified originally as a typical dystrophic medium-textured Latossolo Vermelho-Amarelo corresponding to an Oxisol (SANTOS et al., 2018). However, after 20 years of successive soil amendment and fertilizer applications, the soil assumed enhanced fertility (MARQUES et al., 2018), where nutrient contents and base saturation were changed from a dystrophy condition to eutrophy. Mean annual rainfall and temperature were 680 mm and 26°C, respectively.

Tissue-cultured plantlets were transplanted on August 21, 2012, at a spacing of 2.5 m x 2.0 m. Cultural practices followed the recommendations of Rodrigues et al. (2015). The area was subsoiled, plowed, harrowed, and furrowed. Fertilizers were mixed in the soil removed when digging the planting hole according to the rate corresponding to the treatment.

Plants were irrigated using pressure compensating micro-sprinklers (Netafim Israel, Kibutz, Hatzerim, Israel), with a flow rate of 130 L h^{-1}. Irrigations were performed based on the crop evapotranspiration (ETc), that is the product of reference evapotranspiration (ETo), calculated using the modified Penman-Monteith method and the crop coefficient (Kc). The crop coefficient varied with the growth stage in the first cycle when it assumed a constant value of 1.4 from flowering onward (COELHO et al., 2012). The Penman-Monteith method was used because it integrates the largest number of meteorological variables (wind, vapor pressure deficit, relative humidity, and solar radiation) involved in the process of obtaining evapotranspiration, and because it is the standard method of FAO.

The treatments consisted of two banana cultivars ('Prata-Anã', AAB and 'BRS Platina', AAAB), five annual potassium rates composed of bovine manure and rock powder (0.00-0.00, 40.00-3.25, 80.00-6.50, 120.00-9.75, and 160.00-13.00 t ha^{-1} for manure and rock powder) that were determined based on the annual rates of 0, 200, 400, 600 and 800 kg ha^{-1} of K$_2$O, and six evaluation periods (210, 390, 570, 750, 930 and 1.110 days after transplanting – DAT). The treatments were arranged in a randomized block design, in a 2 x 5 x 6 factorial arrangement with three replicates. The experimental plots consisted of 20 plants of which the six located at the center were used for measurements (measurement plants). Before transplanting, soil samples were collected at each plot for testing.

The soil test analysis shows that the soil was highly fertile (Table 1) as a result of fertilizer applications over the years. On a dry basis (65°C), the bovine manure had on average 16.72% moisture content, 637.3 g kg^{-1} of organic matter, and the following macronutrient levels (g kg^{-1}): Ca = 1.7, Mg = 0.2, K = 2.5, N = 5.2, S = 2.3 (EPA 3051/APHA 3120B) and P = 4.7 (APHA 4500-PC). Micronutrient levels (mg kg^{-1}) were as follow: B = 2.1, Cu = 45.2, Zn = 200.5, Mn = 391.8 and Fe = 1 932.4 (EPA 3051/APHA 3120B). Manure density and pH were 0.38 g cm-3 and 7.42 (official method – MA), respectively. Rock powder, marketed by the mining company Terra Produtiva under the brand Naturalplus® (natural fertilizer), contains 30.0 g kg^{-1} of K$_2$O, 10.0 g kg^{-1} of P$_2$O$_5$, 52.0 g of kg^{-1} CaO, 30.0 g of kg^{-1} MgO, 63.0 g of kg^{-1} Fe$_2$O$_3$, 1.5 g of kg^{-1} MnO, 630 g of kg^{-1} SiO$_2$, 69 mg of kg^{-1} Zn (ICP95A – lithium metaborate fusion – ICP OES), 127 mg kg^{-1} of Cu, and 5 mg kg^{-1} of organic matter (IMS95A – lithium metaborate fusion – ICP MS).

For setting the potassium rates, the highest annual N rates found in the literature were used (SOUTO et al., 1997), 700 kg N ha^{-1}, since N is slowly released from organic fertilizers compared to mineral fertilizers. With this N rate, five annual N rates were determined: 700, 525, 350, 175, and 0 kg ha^{-1}. For K$_2$O, the rates were 800, 600, 400, 200 and 0 kg ha^{-1}. The ratio of N to K$_2$O was 1.7 to 1; therefore, based on the manure N content, the manure rate was set at 160 Mg ha^{-1} per year to meet the N demand of 700 kg ha^{-1}. At this manure rate, 405 kg ha^{-1} of K$_2$O annually were supplied. Finally, based on the K$_2$O level in the rock powder, the rock powder rate was set at 13 Mg ha^{-1} annually to supply the remaining 395 kg ha^{-1} of K$_2$O, for a total of 800 kg ha^{-1} of K$_2$O (the highest rate).

The same procedures were carried out to determine the remaining nutrient rates per year (kg ha^{-1}) for P$_2$O$_5$-Ca-Mg-S: 0.00-0.00-0.00-0.00; 401-228-105-77; 801-456-211-155; 1,202-685-316-232, and 1,603-913-421-310, respectively. The

fertilizer rates were split into six applications, every 60 d, for 2.000 plants ha⁻¹. Forty g of boric acid, 60 g of zinc sulfate, and 80 g of urea were applied at the vegetative stage in the first cycle, using a mechanical backpack sprayer. Ten g of zinc sulfate and 10 g of boric acid were applied to each banana plant in the rhizome of removed suckers. In the second cycle, 3 g of copper sulfate (split into three applications) and 30 g

of magnesium sulfate were applied to each plant in the rhizome of removed suckers (NOMURA et al., 2011). The application of micronutrients in the first cycle was due to the already high pH in the soil and the likely increase in pH from the application of manure that may restrict the availability of micronutrients (PADILHA JUNIOR et al., 2020).

Table 1. Chemical soil properties in blocks (B1, B2, and B3) before transplant, at depths of 0.0-0.2 and 0.2-0.4 m.
Tabela 1. Propriedades químicas do solo em blocos (B1, B2 e B3) antes do transplante, nas profundidades de 0,0-0,2 e 0,2-0,4 m.

Depth of soil layer	pH[1]	OM[2]	P[3]	K[3]	Na[3]	Ca[4]	Mg[4]	Al[4]	H+Al[5]	SB	t	T
m		g kg⁻¹	mg dm⁻³			................cmol_c dm⁻³................						
B1 0.0-0.2	7.2	12.0	463.7	439	0.1	4.3	1.8	0.0	0.8	7.4	7.4	8.1
B2 0.0-0.2	7.6	15.0	502.6	520	0.1	5.1	1.6	0.0	0.8	8.1	8.1	8.9
B3 0.0-0.2	7.5	10.0	438.7	520	0.1	4.3	1.6	0.0	0.8	7.4	7.4	8.1
B1 0.2-0.4	7.2	2.0	233.4	359	0.1	3.3	1.3	0.0	0.8	5.6	5.6	6.4
B2 0.2-0.4	7.4	2.0	294.3	439	0.1	3.9	1.0	0.0	0.8	6.2	6.2	6.9
B3 0.2-0.4	7.4	1.0	159.5	318	0.1	3.4	1.1	0.0	0.7	5.4	5.4	6.1
Depth of soil layer	V	m	B[6]	Cu[3]	Fe[3]	Mn[3]	Zn[3]	Prem[7]	EC	-	-	-
m		%	.............mg dm⁻³............................					mg L⁻¹	ds m⁻¹	-	-	-
B1 0.2-0.4	91	0	0.7	2.1	19.4	47.7	42.4	44.7	1.3	-	-	-
B2 0.2-0.4	91	0	1.2	2.0	18.0	46.7	51.8	43.3	1.5	-	-	-
B3 0.2-0.4	91	0	0.9	2.6	29.4	45.1	28.3	42.8	1.6	-	-	-
B1 0.2-0.4	88	0	1.0	1.1	25.6	28.3	9.5	43.8	1.1	-	-	-
B2 0.2-0.4	89	0	0.9	1.3	19.9	26.5	10.7	43.6	1.4	-	-	-
B3 0.2-0.4	89	0	1.1	1.2	35.0	28.4	6.0	39.3	1.3	-	-	-

[1]pH in water; [2]colorimetry; [3]Mehlich-1 extraction; [4]KCl 1 mol L⁻¹; [5]pH SMP (Shoemaker-McLean-Pratt method); [6]BaCl₂ extractor; [7]equilibrium solution of P; OM - organic matter; SB - sum-of-bases; t - effective cation exchange capacity; T - cation exchange capacity at pH 7; V - base saturation; m - Aluminum saturation; Prem - remaining phosphorus; EC - electrical conductivity; mg dm⁻¹ = ppm; cmol_c dm⁻³ = meq 100cm⁻³.

Leaves were sampled according to Rodrigues et al. (2010) at 210, 390, 570, 750, 930, and 1,110 DAT that corresponded to the flowering in the first cycle (225 DAT), harvest in the first cycle (397 DAT), flowering in the second cycle (478 DAT), harvest in the second cycle (630 DAT), flowering in the third cycle (770 DAT), harvest in the third cycle (912 DAT), and flowering in the fourth cycle (1,020 DAT), respectively. Leaf samples were collected from the measurement plants of each treatment replicate to represent each experimental plot.

Levels of N, P, K, Ca, Mg, S (g kg⁻¹), B, Cu, Fe, Mn and Zn (mg kg⁻¹) in leaves were determined as follows: N by sulfuric acid digestion (Kjeldahl method); P, K, S, Ca, Mg, Cu, Fe, Mn, and Zn by nitric-perchloric acid digestion, and B by dry digestion. Nutrient levels were interpreted for determining the crop's nutritional status using the sufficiency range technique (SILVA, 2015) for 'Prata-Anã' banana. Weights of bunches and hands were determined over three production cycles. In obtaining the mean yield was adjusted to the actual yield by multiplying the effectively harvested population (76%) by the initial planting density (2.000 plants ha-1), as there were plant losses due to strong winds and other treatment-unrelated factors.

Data were subjected to an analysis of variance. Significant interactions were studied. For measurement periods, means were grouped using the Scott-Knott criterion. For cultivars, means were compared using the F-test. Interactions between evaluation periods and potassium rates were subjected to regression analysis and the interactions between evaluation times and potassium doses in the respective cultivars were analyzed by a response surface models. Main effects were

studied by testing the means and regression analysis. For regressions, the goodness of fit was considered adequate, based on the coefficients of determination and significant regression parameters (t-test).

3. RESULTS

Interactions (P≤0.05) were observed between K₂O rates (kg ha⁻¹ per year) (bovine manure and rock powder) and evaluation periods for potassium (K) and sulfur (S) levels in leaves of 'Prata-Anã' and 'BRS Platina' banana (Figure 1). Interactions between K₂O rate and cultivar were significant for manganese (Mn) (Figure 2). Interactions between cultivars and evaluation periods were also significant for K, S, copper (Cu), zinc (Zn) and iron (Fe) levels (Table 2). The annual rates of K₂O (kg ha⁻¹) had an independent effect (P≤0.05) on nitrogen (N), phosphorus (P), calcium (Ca), and Cu (Figure 3). Evaluation periods had an independent effect (P≤0.05) on N, P, Ca, magnesium (Mg), boron (B), and manganese (Mn) levels (Table 3). The yield weights of bunches and hands fluctuated independently with evaluation periods and K₂O rates.

4. DISCUSSION

Using the response surface method, leaf K levels (Figure 1A) were fitted to K₂O rates (kg ha⁻¹ per year) and evaluation periods (DAT). The levels of K increased with increasing K₂O rates and decreased with increasing DAT. Mean leaf K levels ranged from 32.5 to 33.9 g kg⁻¹, which is within the sufficiency range for K (SILVA, 2015). For evaluation periods, the highest mean was recorded at 390 DAT, which was above 35.0 g kg⁻¹.
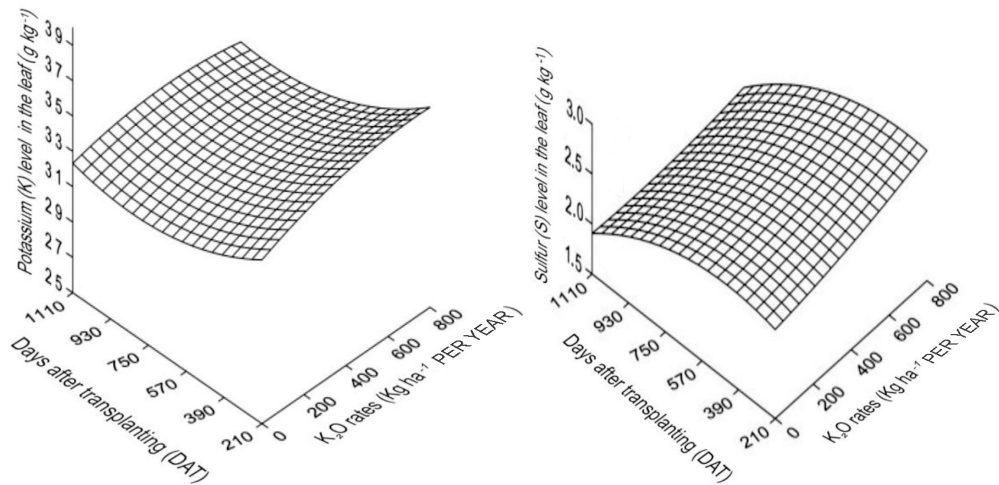
$$K(\widehat{Leaf}) = 36.229 - 0.01070(K) + 0.0000006472(K)^2 + 0.006240(DAT) - 0.0000002455(K_2O) - 0.00000039484(DAT)^2$$
$$S(\widehat{Leaf}) = 2.2179 + 0.001078(S) - 0.000000122(S)^2 + 0.00003695(DAT) - 0.0000000457(K_2O) - 0.00000002976(DAT)^2$$

Figure 1. Response surface models for mean leaf A) potassium and B) sulfur (g kg⁻¹) levels in 'Prata-Anã' and 'BRS Platina' banana plants as a function of K₂O rates (kg ha⁻¹ per year) supplied by bovine manure and rock powder and evaluation periods (DAT).
Figura 1. Modelos de superfície de resposta para níveis médios de folha A) de potássio e B) de enxofre (g kg⁻¹) em bananeiras 'Prata-Anã' e 'BRS Platina' em função das doses de K₂O (kg ha⁻¹ por ano) fornecido por esterco bovino e pó de rocha e períodos de avaliação (DAT).

$$(\hat{Y} - 'Prata - An\tilde{a}') = 80.11930 - 0.0875589^{**}(K_2O) + 0.000111088^{**}(K_2O)^2, r^2 = 0.75$$
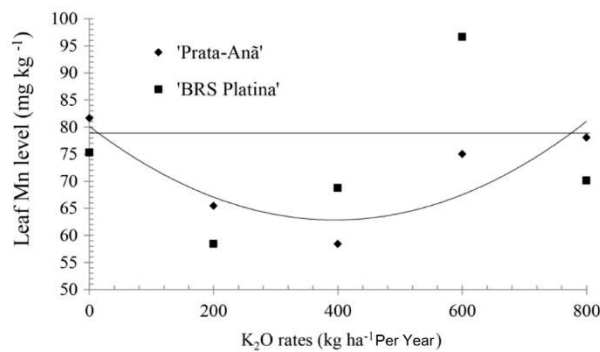$$(\bar{Y} - 'BRS\ Platina') = 78.88$$

Figure 2. Leaf Manganese levels (mg kg⁻¹) in 'Prata-Anã' and 'BRS Platina' banana plants as a function of K₂O rates (kg ha⁻¹ per year) supplied by bovine manure and rock powder. Significant at 5% and ** significant at 1% according to the t-test.
Figura 2. Níveis foliares de manganês (mg kg⁻¹) em bananeiras 'Prata-Anã' e 'BRS Platina' em função das doses de K₂O (kg ha⁻¹ por ano) fornecidas por esterco bovino e pó de rocha. Significativo a 5% e ** significativo a 1% de acordo com o teste t.

Table 2. Mean leaf levels of potassium (K), sulfur (S), copper (Cu), zinc (Zn), and iron (Fe) in 'Prata-Anã' and 'BRS Platina' banana plants as a function of K₂O rates (kg ha⁻¹ per year) supplied by bovine manure and rock powder at different evaluation periods (DAT).
Tabela 2. Teores foliares médios de potássio (K), enxofre (S), cobre (Cu), zinco (Zn) e ferro (Fe) em bananeiras 'Prata-Anã' e 'BRS Platina' em função do K₂O doses (kg ha⁻¹ por ano) fornecidas por esterco bovino e pó de rocha nas diferentes épocas de avaliação (DAT).

Period	K (g kg⁻¹)		S (g kg⁻¹)		Cu (mg kg⁻¹)		Zn (mg kg⁻¹)		Fe (mg kg⁻¹)	
	'Prata-Anã'	'BRS Platina'	'Prata-Anã'	'BRS Platina'	'Prata-Anã'	'BRS Platina'	'Prata-Anã'	'BRS Platina'	'Prata-Anã'	'BRS Platina'
210	32.8Ab	37.0Aa	2.2Cb	2.4Ca	10.59Aa	10.13Ba	20.18Ba	22.88Ba	70.20Aa	86.44Ba
390	34.1Ab	37.1Aa	2.8Ab	3.0Aa	10.03Ab	11.10Aa	25.18Ab	30.36Aa	135.58Aa	159.31Ba
570	33.3Aa	31.7Cb	2.6Ba	2.7Ba	8.10Ba	6.47Db	18.10Ba	16.13Da	87.12Aa	91.11Ba
750	30.7Bb	33.7Ba	2.1Ca	2.2Ca	6.04Ca	6.37Da	19.23Ba	18.61Ca	148.98Aa	166.55Ba
930	31.8Ba	33.2Ba	1.7Db	2.1Da	5.88Ca	4.95Eb	15.86Ca	14.52Da	64.52Aa	82.05Ba
1110	32.5Aa	33.3Ba	2.1Ca	2.0Da	7.40Ba	7.98Ca	20.12Bb	23.51Ba	81.97Ab	278.80Aa
CV (%)	5.81		10.03		16.23		20.51		112.48	

DAT = days after transplant. Means followed by the same letters, lowercase in the lines for cultivars do not differ from one another according to the F test, and uppercase in the columns for evaluation periods belong to the same grouping according to the Scott-Knott criterion at 5% probability. CV – coefficient of variation.

$\hat{y}$ (N in Leaf) = 29.24549 – 0.0028357**(K₂O), r² = 0.76

A

B

$\hat{y}$ (P in Leaf) = 2.09667 – 0.0002875**(K₂O), r² = 0.93

$\hat{y}$ (Ca in Leaf) = 7.11552 – 0.00554018*(K₂O) +
0,000018944**(K₂O)² – 0.00000001640*(K₂O)³, r² = 0.73

C

D

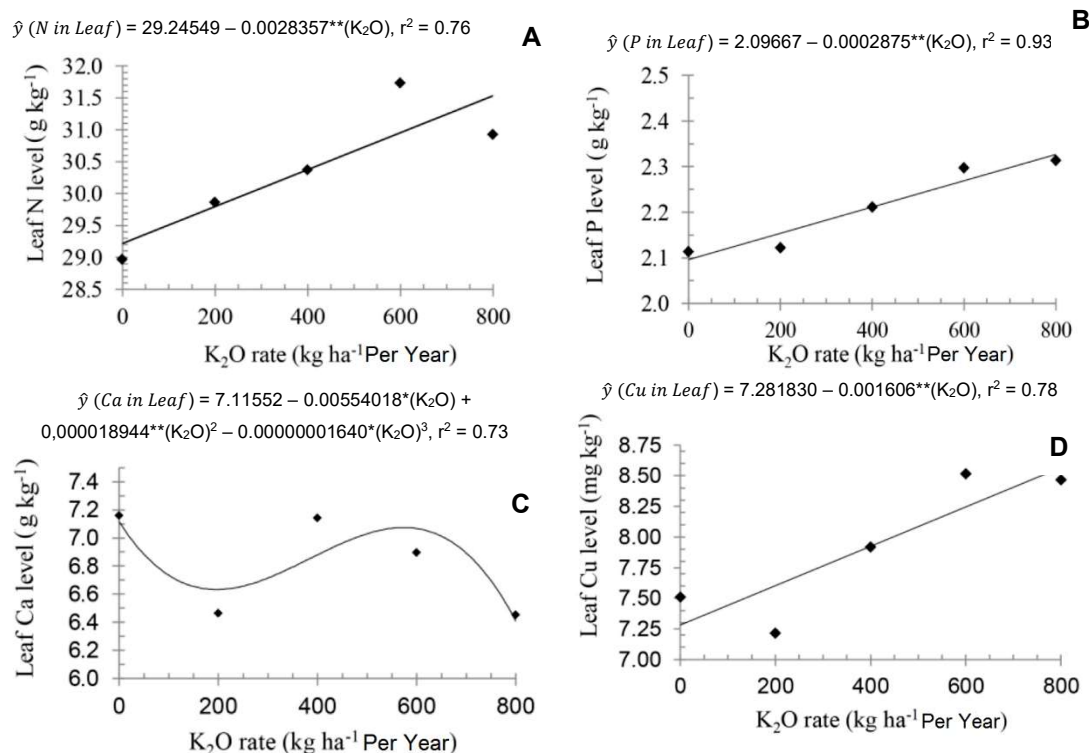$\hat{y}$ (Cu in Leaf) = 7.281830 – 0.001606**(K₂O), r² = 0.78

Figure 3. Mean leaf levels of A) nitrogen, B) phosphorus, and C) calcium (g kg⁻¹), and D) copper (mg kg⁻¹) in 'Prata-Anã' and 'BRS Platina' banana plants as a function of K₂O rates (kg ha⁻¹ per year) supplied by bovine manure and rock powder. *Significant at 5% and ** Significant at 1% according to the t-test.
Figura 3. Níveis médios foliares de A) nitrogênio, B) fósforo e C) cálcio (g kg⁻¹) e D) cobre (mg kg⁻¹) em bananeiras 'Prata-Anã' e 'BRS Platina' como em função das doses de K₂O (kg ha⁻¹ por ano) fornecidas por esterco bovino e pó de rocha. * Significativo a 5% e ** Significativo a 1% de acordo com o teste t.

Table 3. Mean leaf levels of nitrogen, phosphorus, calcium, magnesium (g kg⁻¹), boron and manganese (mg kg⁻¹) in 'Prata-Anã' and 'BRS Platina' banana plants as a function of K₂O rates (kg ha⁻¹ per year) supplied by bovine manure and rock powder at different evaluation periods (DAT).
Tabela 3. Níveis médios foliares de nitrogênio, fósforo, cálcio, magnésio (g kg⁻¹), boro e manganês (mg kg⁻¹) nas bananeiras 'Prata-Anã' e 'BRS Platina' em função das doses de K₂O (kg ha⁻¹ por ano) fornecido por esterco bovino e pó de rocha em diferentes épocas de avaliação (DAT).

Leaves levels		Evaluation periods – days after transplant (DAT)						CV (%)
		210	390	570	750	930	1 110	
N		31.8 B	36.0 A	29.5 C	27.4 D	27.4 D	29.9 C	6.21
P	g kg⁻¹	2.2 B	2.5 A	2.2 B	2.0 C	1.9 C	2.2 B	8.65
Ca		5.1 D	9.5 A	5.8 C	6.3 C	5.8 C	8.1 B	17.92
Mg		3.5 C	6.7 A	4.4B	4.2B	3.9C	4.8B	24.10
B		13.73 D	22.58 C	28.12B	34.25A	23.03C	30.12B	27.77
Mn	mg kg⁻¹	64.07 C	100.30A	61.59 C	83.18 B	48.45 D	79.16 B	28.09

Means followed by the same letters belong to the same grouping according to the Scott-Knott criterion, at 5% probability. CV – coefficient of variation.

In the present study 50.68% (405 kg ha⁻¹ per year) of K₂O was supplied by manure. Despite the low concentration of K in animal-sourced organic fertilizers, the whole content of this macronutrient is mineralized, thus it was released into the soil as fast as mineral K fertilizer, while rock-based fertilizers slowly release K into the soil. Using mineral fertilizers, Silva et al. (2011), Silva et al. (2013), and Silva and Simão (2015) report linear increases in leaf K level in 'Prata-Anã' banana as a function of K₂O rates over four cycles. However, Damatto Junior et al. (2011a) report no effects of organic fertilizer rates as high as 630.4 kg ha⁻¹ per year on the leaf nutrient content of 'Prata-Anã' banana over five production cycles. The K level in leaves decreases from 210 to 750 DAT. Then, it increases again up to 1,110 DAT. This is influenced by the

application of fertilizers, by the supply of K from the decomposition of banana waste since 60 to 86% of the K absorbs returns to the soil (HOFFMANN et al., 2010b), favoring nutritional economy, plant water status regulation, osmotic adjustment, and stress protection (MARSCHNER, 2012).

Leaf S levels were fitted to a quadratic surface response model as a function of rates of K₂O (kg ha⁻¹ per year) and DAT (Figure 1B). The levels increased with increasing rates of K₂O up to 570 DAT, followed by a decrease. Mean values ranged from 2.2 to 2.3 and from 1.9 to 2.9 g kg⁻¹ as a function of K₂O rates and DAT. For both responses, means were above the sufficiency range for S (SILVA, 2015). The increase in leaf S levels observed in this study is related to the

presence of S in manure. Each K_2O rate provided 0, 77, 155, 232, and 310 kg ha^{-1} per year of S. Nutrient recycling is a contributing factor as 85% of the S taken up by 'Prata-Anã' returns to the soil (HOFFMANN et al., 2010b).

Leaf Mn levels in 'Prata-Anã' banana were fitted to a quadratic model as a function of K_2O rates (kg ha^{-1} per year) supplied by bovine manure and rock powder (Figure 2). The model estimated a minimum leaf Mn level of 62.83 mg kg^{-1} at a rate of 394.81 kg ha^{-1} per year of K_2O, and the maximum leaf Mn level of 82.50 mg kg^{-1} at the K_2O rates of 0 and 800 kg ha^{-1} per year. This shows an initial decrease followed by an increase returning to the initial level. For 'BRS Platina', the leaf Mn level response was not fitted to any model, averaging 78.88 mg kg^{-1}. For both cultivars, Mn levels were deficient (SILVA, 2015), but banana plants expressed no deficiency symptoms.

Damatto Junior et al. (2011a) report no effect of organic compost on leaf Mn levels of 'Prata-Anã'. However, the levels are within an adequate range and, for some rates, toxicity symptoms are expressed by plants grown on a soil with pH of 5.9. In this study, the decrease in Mn level might have been due to the initial soil pH (Table 1), averaging 7.4 in the 0-20 cm layer. The soil pH is one of the main factors affecting the availability of Mn^{++}. Metallic cations such as Mn, Zn, and Cu are more adsorbed to increased negative charges on soil particles due to carboxylic and phenolic compounds released from the breakdown of humic substances contained in manure and banana trash (PADILHA JÚNIOR et al., 2020). Nonetheless, the levels of Mn increased from the rate of 394.81 kg ha^{-1} per year of K_2O since manure and rock powder are Mn sources.

Additionally, Mn is the most accumulated micronutrient by bananas, although 90% of this nutrient is returned to the soil by most banana cultivars (HOFFMANN et al., 2010a). Table 3 shows that leaf Mn levels were higher at 390, 750, and 1,110 DAT, corresponding to periods after the harvest of the first, second, and third cycles, respectively, when there was already a nutrient contribution from the breakdown of banana litter. Regarding the constant supply of Mn via fertilization and recycling, the Mn level was in a deficient range, as pH increases with increasing manure rates and irrigation water. These factors are considered to limit nutrient absorption.

There were interactions between cultivars and evaluation periods for K and S level in leaves of 'Prata-Anã' and 'BRS Platina' banana plants. We observed two and four groupings for 'Prata-Anã' and three and four groupings for 'BRS Platina', respectively, according to the Scott-Knott criterion (P≤0.05) (Table 2). The highest leaf K levels recorded in 'Prata-Anã' ranged between 32.5 and 34.1 g kg^{-1} at 210, 390, 570 and 1,110 DAT. The highest S level in 'Prata-Anã' was 2.8 g kg^{-1} at 390 DAT. In 'BRS Platina', the highest K levels were 37.0 and 37.1 g kg^{-1} at 210 and 390 DAT, respectively. The highest S level, 3.0 g kg^{-1}, was recorded at 390 DAT. Mean leaf K and S levels were either above or within their respective sufficiency ranges.

Donato et al. (2010) report similar leaf K and S levels at 180 and 360 DAT under similar conditions. Damatto Junior et al. (2006) also report K and S levels in 'Prata-Anã' at flowering and harvest of the first cycle. Cultivars Prata-Anã and BRS Platina differed from one another (P≤0.05) at 210, 390, 570 and 750 DAT for K and at 210, 390 and 930 DAT for S. Cultivar BRS Platina showed greater K levels at every evaluation period, except at 570 DAT (Table 2). Donato et al. (2010) report higher K levels in 'BRS Platina' at 180 and 360 DAT. Borges et al. (2006) find lower values of K and S in 'Prata-Anã' when compared to those in "Prata" banana hybrids in the first cycle. This might be explained by Silva et al. (2014), who verify a better performance of 'BRS Platina' seedlings compared to 'Prata-Anã', both grown without macronutrient supply.

There were interactions between cultivars and evaluation periods for the leaf micronutrient levels. Using the Scott-Knott criterion (P≤0.05), we observed mean Cu levels split into three and five groupings for 'Prata-Anã' and 'BRS Platina', respectively. Regarding Zn, there were three and four groupings for 'Prata-Anã' and 'BRS Platina', respectively. Means of leaf Fe levels formed two groupings for 'BRS Platina' (Table 2). The highest mean Cu levels recorded in 'Prata-Anã' were 10.59 and 10.03 mg kg^{-1} at 210 and 390 DAT. For Zn, the highest level was 25.18 mg kg^{-1} at 390 DAT. The highest Cu and Zn levels in 'BRS Platina' were 11.10 and 30.36 mg kg^{-1}, respectively, both recorded at 390 DAT. For Fe, the highest value of 278.80 mg kg^{-1} was recorded at 1,110 DAT in 'BRS Platina'. These values are within their respective sufficiency ranges. Damatto Junior et al. (2006) observe lower mean leaf levels for Cu and Zn than those in this research. Donato et al. (2010) report similar Zn levels and lower Cu levels compared to those of the present study. Fertilizations with Zn and Cu carried out on the rhizome of suckers contributed to justify the leaf contents, despite the high pH that favors the adsorption of these nutrients in the soil.

There were differences between 'Prata-Anã' and 'BRS Platina' (P≤0.05) for leaf Cu, Zn, and Fe levels (Table 2). Cultivar BRS Platina showed higher levels than 'Prata-Anã' for Cu and Zn at 390 DAT. Cultivar BRS Platina had higher levels of Zn and Fe at 1,110 DAT, while 'Prata-Anã' had higher levels of Cu at 570 and 930 DAT. Borges et al. (2006) find lower values of Cu, Zn, and Fe in 'Prata-Anã' when compared to "Prata" banana hybrids. Donato et al. (2010) report higher Cu levels in 'BRS Platina' compared to 'Prata-Anã' (360 DAT).

Increasing linear models were fitted to leaf N, P and Cu levels of 'Prata-Anã' and 'BRS Platina' as a function of rates of K_2O kg ha^{-1} per year supplied by bovine manure and rock powder. A cubic model was fitted to the leaf Ca level response to K_2O rates (Figure 3). Leaf Ca levels were higher, 7.2 and 7.1 g kg^{-1}, at the K_2O rates of 0 and 400 kg ha^{-1} (Figure 3C), which were within the sufficiency range (SILVA, 2015).

Melo et al. (2014) report a decrease in the leaf Ca level with increasing K_2O rates; the values were in the deficiency range and lower than those of this study. Banana plants are sensitive to the imbalance between cations in the soil. The ideal ratio of Ca to (K + Ca + Mg) ranges from 0.6 to 0.8 (SILVA, 2015). In this study, the initial ratio was 0.6 (Table 1). However, supplying K_2O leads to a greater uptake of monovalent cations over bivalent cations, even with an increased Ca supply; this justifies the decreases in leaf Ca levels at higher K_2O rates. The K_2O rates of 0, 200, 400, 600 and 800 kg ha^{-1} per year supplied 0, 228, 456, 685 and 913 kg ha^{-1} of Ca, respectively. These Ca rates, 74.93% from rock powder and 25.07% from manure, contributed to the maintenance of leaf Ca level within its sufficiency level. Furthermore, nutrient recycling plays an important role in providing Ca to plants as about 72 to 95% of Ca taken up by bananas returns to the soil (HOFFMANN et al., 2010b).

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The model estimated an increment of 0.0028 g kg^{-1} of N for each kg ha^{-1} of K$_2$O added (Figure 3A). Increases in the leaf N level were associated with its presence in manure. Leaf N levels were above the sufficiency range at N rates of 525 and 700 kg ha^{-1}. These levels are too high (SILVA, 2015), which may lead to luxury consumption, i.e., nutrient level in leaves increases above the sufficiency range without causing either toxicity or significant changes in yield. Once again, nutrient recycling is a contributing factor (HOFFMANN et al., 2010b) with up to 83% of the N in 'Prata-Anã' being released into the soil after harvest. Damatto Junior et al. (2011a) apply 0, 157.6, 315.2, 464.8, and 630.4 kg ha^{-1} per year of K$_2$O to 'Prata-Anã' over five cycles, using organic compost and found a mean leaf N level of 25.0 g kg^{-1} that is lower than the values of this study.

The model estimates an increment of 0.000287 g kg^{-1} of P for each kg ha^{-1} of K$_2$O added (Figure 3B). Leaf P levels increased with increasing rates above its sufficiency range. This was associated with the P contained in manure and rock powder. Of the K$_2$O rate of 800 kg ha^{-1}, 1,603 kg ha^{-1} of P$_2$O$_5$ was supplied, 91.8% of which come from manure. Silva and Rodrigues (2013) observe a linear increase of soil P levels from 4.6 mg dm^{-3} to 140 mg dm^{-3} by applying 300 kg ha^{-1} of P$_2$O$_5$ to 'Prata-Anã' over four cycles. Unlike our results, the application of P had no influence on the leaf nutrient level, remaining at 1.6 g kg^{-1}, within the sufficiency range. These authors concluded that 'Prata-Anã' responds to soil P application only in the first cycle, even under reduced P supply.

Furthermore, the high soil P level, 468.33 mg dm^{-3} (Table 1) allows providing values above the sufficiency range even without fertilizer applications. Just as for N, this may cause luxury consumption. Applying manure and other organic sources to the soil reduces phosphorus adsorption and increases available P levels and P mobility in the soil (PADILHA JÚNIOR et al., 2020). Nutrient recycling also contributes (HOFFMANN et al., 2010b), as about 78% of the P found in 'Prata-Anã' plants is released into the soil.

The model estimated an increase of 0.0016 mg kg^{-1} of Cu for each kg ha^{-1} of K$_2$O added (Figure 3D). These increases in leaf Cu level that remained within its sufficiency range were associated with the Cu contained in manure and rock powder. Copper sulfate was also applied to suckers in the second cycle with the aim of avoiding possible Cu deficiencies induced by high soil pH and organic matter adsorption, common to metallic cations (MARSCHNER, 2012). Applications of Zn and Cu to rhizomes of suckers that were later removed might explain these leaf micronutrient levels, despite the high soil pH favoring the uptake of these micronutrients. Hoffmann et al. (2010a) report that up to 82% of Cu taken up by 'Prata-Anã' can be recycled. Donato et al. (2010) obtain similar Cu levels in 'Prata-Anã' and 'BRS Platina' banana plants by applying Cu via the rhizomes. Damatto Junior et al. (2011a) report no differences in leaf Cu levels in bananas fertilized with organic compost.

Mean leaf levels of N, P, Ca, and Mg in "Prata" banana plants were different across evaluation periods, forming four groupings for N and Ca, and three groupings for P and Mg (P≤0.05) (Table 3). The levels above the respective sufficiency range occurred at 390 DAT. High initial soil levels of P, Ca and Mg coupled with fertilizer application supplying high amounts of N and P led to luxury consumption until 390 DAT.

Mean leaf levels of B and Mn in 'Prata-Anã' and 'BRS Platina' banana plants were separated into four groups according to the Scott-Knott criterion (P≤0.05) (Table 3). The highest B level of 34.25 mg kg^{-1} was recorded at 750 DAT and the highest Mn level of 100.30 mg kg^{-1} was recorded at 390 DAT.

The levels reported herein are above the sufficiency range for B and deficient for Mn. Donato et al. (2010) and Borges et al. (2006) find higher levels of B and Mn. The higher leaf B level at 750 DAT is due to the constant B fertilizer application via rhizome every 60 d.

The mean yield of hands and bunches independently increased (P≤0.05) in "Prata" banana plants across cycles. The third cycle was the most productive with mean values of 39.23 t ha^{-1} for bunch weight and 35.48 t ha^{-1} for hand weight. As reported in the methodology, the mean yield was adjusted to the actual yield by multiplying the effectively harvested population (76%) by the initial planting density (2.000 plants ha^{-1}), as there were plant losses due to strong winds and other treatment-unrelated factors.

Donato et al. (2015) argue that well-managed banana plantations growing on improved soil conditions have yields higher than 40 t ha^{-1} per year (high productivity>32 t ha^{-1} per year). Silva and Simão (2015) report a similar bunch weight, but a lower yield per unit area owing to a lower planting density, 1.235 plants ha^{-1}. Damatto Junior et al. (2011b), working with organic fertilization, report an increase in bunch weight from the first to the second cycle, but bunch weight decreases in the third cycle due to soil nutrient depletion. Despite this, the greatest contribution of organic fertilizers to banana crops cultivation in soils with improved fertility is the maintenance the physical and biological attributes of the soil, that is, favoring soil health and productive sustainability.

5. CONCLUSIONS

K and S levels in leaves of "Prata" banana plants increased with increasing K$_2$O rates supplied by manure and rock powder in interaction with the evaluation periods. Levels of N, P and Cu increased independently with increasing K$_2$O rates.

High soil fertility coupled with manure and rock powder application were insufficient to maintain the leaf Mn levels within the sufficiency range in 'Prata-Anã' and 'BRS Platina' banana plants.

Applying manure and rock powder as organic fertilizers did not increase the yield of 'Prata-Anã' and 'BRS Platina' banana plants grown on soils with improved fertility during four production cycles.

6. ACKNOWLEDGMENTS

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