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

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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

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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 K₂O) 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 K₂O interacting with the evaluation periods. The levels of N, P, and Cu increased with increasing rates of K₂O. 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 K₂O) 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 K₂O em interação com os períodos de avaliação. Os níveis de N, P e Cu aumentaram com o aumento das doses de K₂O. 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.
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). Valentinelli 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 improved fertility. Marques et al. (2012) investigated the nutritional status of banana treatment. 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).

Plants were irrigated using pressure compansing microsprinklers (Netafim Israel, Kibutz, Hatzirn, 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 (Ke). 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 (0.00-0.00-0.00-0.00; 400-228-105-77; 800-456-211-155; and 1600-900-130.0 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 K₂O, and six evaluation periods (210, 390, 570, 750, 930 and 1110 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 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 K₂O, 10.0 g kg⁻¹ of P₂O₅, 52.0 g of kg⁻¹ CaO, 30.0 g of kg⁻¹ MgO, 63.0 g of kg⁻¹ Fe₂O₃, 1.5 g of kg⁻¹ MnO, 630 g of kg⁻¹ SiO₂, 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, the annual N rates were determined: 700, 525, 350, 175, and 0 kg ha⁻¹. For K₂O, the rates were 800, 600, 400, 200 and 0 kg ha⁻¹. The ratio of N to K₂O 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 K₂O annually were supplied. Finally, based on the K₂O 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 K₂O, for a total of 800 kg ha⁻¹ of K₂O (the highest rate).

The same procedures were carried out to determine the remaining nutrient rates per year (kg ha⁻¹) for P₂O₅-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).

### RESULTS

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.

| Depth of soil layer | pH¹ | OM² | P³ | K⁴ | Na⁵ | Ca⁶ | Mg⁷ | Al⁸ | H + Al⁹ | SB | t | T² |
|---------------------|-----|-----|----|----|-----|-----|-----|-----|---------|----|---|---|
| m                   |     |     |    |    |     |     |     |     |         |    |   |   |
| B1 0.0-0.2          | 7.2 | 12.0 | 46.7 | 43.9 | 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 | 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 | 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 | 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 | 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 | 0.1 | 3.4 | 1.1 | 0.0 | 0.7 | 5.4 | 5.4 | 6.1 |
| B1 0.0-0.2          | 91.0 | 0   | 0.7  | 2.1  | 19.4 | 47.7 | 42.4 | 44.7 | 1.3 | - | - |
| B2 0.0-0.2          | 91.0 | 0   | 1.2  | 2.0  | 18.0 | 46.7 | 51.8 | 43.3 | 1.5 | - | - |
| B3 0.0-0.2          | 91.0 | 0   | 0.9  | 2.6  | 29.4 | 45.1 | 28.3 | 42.8 | 1.6 | - | - |
| B1 0.2-0.4          | 88.0 | 0   | 1.0  | 1.1  | 25.6 | 28.3 | 9.5  | 43.8 | 1.1 | - | - |
| B2 0.2-0.4          | 89.0 | 0   | 0.9  | 1.3  | 19.9 | 26.5 | 10.7 | 43.6 | 1.4 | - | - |
| B3 0.2-0.4          | 89.0 | 0   | 1.1  | 1.2  | 35.0 | 28.4 | 6.0  | 39.3 | 1.3 | - | - |

| Depth of soil layer | V | m | B³ | Ca³ | Fe³ | Mn⁴ | Zn⁵ | Preme⁶ | EC  |
|---------------------|---|---|----|-----|-----|-----|-----|--------|-----|
| m                   | % |     | mg dm³ |      |     |     |     | mg L⁻¹ | ds m⁻¹ |
| B1 0.2-0.4          | 91.0 | 0 | 0.7  | 2.1 | 19.4 | 47.7 | 42.4 | 44.7 | 1.3 |
| B2 0.2-0.4          | 91.0 | 0 | 1.2  | 2.0 | 18.0 | 46.7 | 51.8 | 43.3 | 1.5 |
| B3 0.2-0.4          | 91.0 | 0 | 0.9  | 2.6 | 29.4 | 45.1 | 28.3 | 42.8 | 1.6 |
| B1 0.0-0.2          | 88.0 | 0 | 1.0  | 1.1 | 25.6 | 28.3 | 9.5  | 43.8 | 1.1 |
| B2 0.0-0.2          | 89.0 | 0 | 0.9  | 1.3 | 19.9 | 26.5 | 10.7 | 43.6 | 1.4 |
| B3 0.0-0.2          | 89.0 | 0 | 1.1  | 1.2 | 35.0 | 28.4 | 6.0  | 39.3 | 1.3 |

| pH in water; ¹colorimetry; ²Mehlich-1 extraction; ³KCl 1 mol L⁻¹; ⁴pH SMP (Shoemaker-McLean-Pratt method); ⁵BaCl₂ extractor; ⁶equilibrium solution of P; ⁷OM - organic matter; ⁸SB - sum-of-bases; ⁹t - effective cation exchange capacity; ¹⁰V - base saturation; ¹¹m - Aluminum saturation; ¹²t - effective cation exchange capacity; ¹³Al - Alumunum saturation; ¹⁴Prem - remaining phosphorus; ¹⁵E - electrical conductivity; mg dm⁻³ = ppm; cmol dm⁻³ = meq 100 cm⁻³.

Leaves were sampled according to Rodrigues et al. (2010) at 210, 390, 750, 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 used. For measurement periods, means were used. Data 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).

### DISCUSSION

Using the response surface method, leaf K levels (Figure 1A) were fitted to 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.
Marques et al.
Nativa, Sinop, v. 10, n. 1, p. 60-68, 2022.

\[ K(\text{Leaf}) = 36.229 - 0.01070(K) + 0.000006472(K)^2 + 0.006240(DAT) - 0.000002455(K,O) - 0.00000039484(DAT)^2 \]

\[ S(\text{Leaf}) = 2.2179 + 0.001078(S) - 0.000000122(S)^2 + 0.00003695(DAT) - 0.0000000457(K,O) - 0.00000002976(DAT)^2 \]

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 K\(_2\)O rates (kg ha\(^{-1}\) per year) supplied by bovine manure and rock powder and evaluation periods (DAT).

\[ (\bar{Y} - \text{‘Prata – Anã’}) = 80.11930 - 0.0875589**(K,O) + 0.000111088**(K,O)^2, r^2 = 0.75 \]

\[ (\bar{Y} - \text{‘BRS Platina’}) = 78.88 \]

Figure 2. Leaf Manganese levels (mg kg\(^{-1}\)) in ‘Prata-Anã’ and ‘BRS Platina’ banana plants as a function of K\(_2\)O 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.

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 K\(_2\)O rates (kg ha\(^{-1}\) per year) supplied by bovine manure and rock powder at different evaluation periods (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’ | ‘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  | 135.8Aa  | 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  | 4.93Eb  | 15.86Ca  | 14.52Da  | 64.52Aa  | 82.05Ba  |
| 1110 | 32.5Aa  | 33.3Ba  | 2.1Ca  | 2.0Da  | 7.40Ba  | 7.78Ca  | 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.
Nutritional status and production of ‘Prata-Anã’ (AAB) and ‘BRS Platina’ (AAAB) banana plants with organic fertilization

The nutritional status of 'Prata-Anã' (AAB) and 'BRS Platina' (AAAB) banana plants was evaluated with organic fertilization. The dry mass (g) of leaves was fitted to the following models:

\[ \hat{y} \text{ (N in Leaf)} = 29.24549 – 0.0028357^{\text{(K2O)}}, r^2 = 0.76 \]

\[ \hat{y} \text{ (P in Leaf)} = 2.09667 – 0.0002875^{\text{(K2O)}}, r^2 = 0.93 \]

\[ \hat{y} \text{ (Ca in Leaf)} = 7.11552 – 0.00554018^{\text{(K2O)}} + 0.000018944^{\text{(K2O)^2}} – 0.00000001640^{\text{(K2O)^3}}, r^2 = 0.73 \]

\[ \hat{y} \text{ (Cu in Leaf)} = 7.281830 – 0.001606^{\text{(K2O)}}, r^2 = 0.78 \]

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.

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).

| Leaves levels | Evaluation periods – days after transplant (DAT) | CV (%) |
|---------------|-----------------------------------------------|--------|
|               | 210 | 390 | 570 | 750 | 930 | 1110 |
| N g kg⁻¹      |     |     |     |     |     |     |
| 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 g kg⁻¹     | 5.1 D | 9.5 A | 5.8 C | 6.3 C | 5.8 C | 8.1 B | 17.92 |
| Mg g kg⁻¹     | 3.5 C | 6.7 A | 4.4B | 4.2B | 3.9C | 4.8B | 24.10 |
| B mg kg⁻¹     | 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 (kg ha⁻¹ per year) 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 K₂O 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 K₂O 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 K₂O, and the maximum leaf Mn level of 82.50 mg kg⁻¹ at the K₂O 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 K₂O 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, 3.0 g kg⁻¹ 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 K₂O kg ha⁻¹ per year supplied by bovine manure and rock powder. A cubic model was fitted to the leaf Ca level response to K₂O rates (Figure 3). Leaf Ca levels were higher, 7.2 and 7.1 g kg⁻¹, at the K₂O rates of 0 and 400 kg ha⁻¹ (Figure 3C), which were within the sufficient range (SILVA, 2015).

Melo et al. (2014) report a decrease in the leaf Ca level with increasing K₂O 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 K₂O 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 K₂O rates. The K₂O 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 sufficient 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).
high amounts of N and P led to luxury consumption until sufficiency range occurred at 390 DAT. High initial soil levels plants were different across evaluation periods, forming four levels in bananas fertilized with organic compost.

82% of Cu taken up by ‘Prata-Anã’ can be recycled. Donato micronutrients. Hoffmann et al. (2010a) report that up to 2012). Applications of Zn and Cu to rhizomes of suckers that were later removed might explain these leaf micronutrient 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 deficiencies induced by high soil pH and organic matter adsorption, common to metallic cations (MARSCHNER, 2012).

The model estimated an increase of 0.000287 g kg⁻¹ of P for each kg ha⁻¹ of K₂O 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 K₂O rate of 800 kg ha⁻¹, 1,603 kg ha⁻¹ of P₂O₅ 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 P₂O₅ 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 K₂O 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 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 K₂O 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.

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 bunches 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 K₂O rates supplied by manure and rock powder in interaction with the evaluation periods. Levels of N, P and Cu increased independently with increasing K₂O 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.

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