Yield, Uptake, and Retranslocation of Nutrients in Banana Plants Cultivated in Upland Soil of Central Amazonian

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ABSTRACT

Banana cultivation is considered one of the most important agricultural activities of economic and social importance in Brazil. The objective of this work was to investigate the uptake, retranslocation and the effect of fertilization on the yield and uniformity of banana bunches (Musa spp.) cultivated in Central Amazonian, region with approximately 1.5 million km² or 150 million hectares. Two experiments were conducted in a Xanthic Ferralsol (dystrophic Yellow Latosol), the predominant soil of the region, examining: i) the nutrient uptake and translocation rate in twelve plants; and ii) the efficiency of zinc use, in a completely randomized blocks in a 4 × 2 factorial scheme in split plot design with four zinc sulfate (ZnSO₄) rates (0, 30, 60, and 120 g plant⁻¹ cycle⁻¹) and two application times (in the hole together with the seedling or as surface broadcast in the fifth month after planting), with four replicates. Uptake of macronutrients was in the order of potassium (K) > nitrogen (N) > calcium (Ca) > magnesium (Mg) > phosphorus (P) and micronutrients in the order of manganese (Mn) > iron (Fe) > boron (B) > zinc (Zn) > copper (Cu). The N, P, K, Mg, and Cu have a high retranslocation rate compared to other nutrients investigated. The bunch yield increased significantly in a quadratic fashion with increasing Zn rate and hole application method of zinc was more efficient compared to broadcast application. At high concentration, Zn presents a low mobility in the phloem from the leaves to the fruits. The critical leaf concentration of zinc at the start of inflorescence was 12.9 mg kg⁻¹.

Keywords: Musa spp., plant nutrients, mobility nutrients, critical zinc concentration

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INTRODUCTION

Banana plantation growing is an important agricultural activity in Brazil. Statistical data show a national annual production around 5.5 million metric tons, less than Ecuador (6.4 million tons), and India (11.0 million tons). The area under banana cultivation in Brazil is greater than in these two countries, however, the lower productivity reflects lower average yield per unit area in Brazil mainly due to lower use of chemical fertilizers. The soils used for banana plantations in the country are infertile and acidic. Hence, the use of adequate rates of fertilizers and liming are essential inputs to improve yield of banana plantation crop. Adequate amounts of essential nutrients in appropriate balance are fundamental for various physiological processes in plants (Fageria et al., 2006).

The mineral nutrition is the process of addition, translocation, and utilization of essential nutrients by plants (Fageria et al., 2006). In this process, the translocation of nutrients in fruit-bearing plants is very important in the various physiological processes, such as ripening, growth and development, and senescence (Epstein and Bloom, 2005; Fageria et al., 2006). The knowledge of nutrient uptake, transport, and distribution within plants is important to improve their uptake and utilize efficiency. In addition, nutrient source and application method are also important for improving crop yields and nutrient use efficiency.

The mineral composition of the leaves is a consequence of factors that influence the absorption, long-distance transport, and distribution within plant parts (Fageria et al., 1997; Epstein and Bloom, 2005). Leaf chemical analysis can be used both as a way to diagnose nutritional disorders and to adjust application timing, mainly in perennial plants. The remobilization of nutrients is particularly important during the reproductive phase, when seeds, fruits, and storage organs are formed. At this stage, the root activity usually decays as a result of the decrease in supply of carbohydrates (sink competition) (Marschner, 1995; Fageria et al., 2006).

Zinc (Zn) deficiency is widely reported in Brazilian soils (Fageria et al., 2006). The zinc is partially mobile within the plant, and its transport occurs not just only passively through transpiration flow (Mengel and Kirkby, 2001; Epstein and Bloom, 2005). Nevertheless, the transport mechanisms of sap in the xylem are subjects of considerable debate (Longnecker and Robson, 1993). Zinc deficiency in banana plants stunts their growth and causes their leaves to become lanceolate, narrow and yellowed, with chlorotic striping between the secondary veins and yellow coloration on the under leaf surface, mainly in the primary vein (Fageria et al. 2006). The symptoms are more evident in the fruits, with reduced length and diameter, as a rule in the top and bottom thirds of the bunches. Besides the reduced size, the fruits have a cigar-shape, with green tips (Lahav, 1995), and the distance between hands is reduced, giving the bunches a compact appearance (Brown et al., 1993).
In soils where there is a deficiency of Zn, the amounts and physiological timing of correct application of the nutrient are essential to increase the yield, with a greater number of marketable fruits. There are limited studies on nutrient uptake and translocation behavior in banana plants under the Brazilian Amazonian region conditions. The objectives of this study were to i) establish critical leaf level of zinc, in the edaphoclimatic conditions of the central Amazon, ii) determine macro- [nitrogen (N), phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg), and sulfur (S)] and micronutrients [boron (B), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn)] uptake and remobilization rate, and iii) define the best physiological stage to apply the nutrient in the soil.

**MATERIAL AND METHODS**

**Study Site and Experiment Layout**

The experiments were conducted in clayey texture (719 g kg$^{-1}$), kaolinthic dystrophic Yellow Latosol (Brazilian classification)—Xanthic Ferralsol (FAO, 1990), with low natural fertility (Table 1). The experimental site was located at the Embrapa Western Amazonian experimental station, at coordinates 3°8′ S and 59°52′ W, in the municipality of Manaus, Amazonas State, Brazil. The natural vegetation was a tropical rainforest. The region’s predominant climate is humid tropical, classified as Af by the Köppen system, with relatively abundant rainfall throughout the year (mean of 2622 mm). The amount of rainfall in the driest months (July to September) is always above 60 mm, and the wettest months are February to April. The average air temperature is about 26°C and atmospheric humidity around 85% (mean values 1971–1993, Schroth et al., 1999).

For the calculation of data as the stock of nutrients per hectare, the bulk density of the soil was measured with volumetric cylinders in a soil pit to 0–10 cm depth. Five cylinder of 100 cm$^3$ were collected. The mean bulk density of the Xanthic Ferrasol lays between 0.79 and 1.02 Mg m$^{-3}$ (mean = 0.88 Mg m$^{-3}$).

**Experiment 1**

The field experiments were established in January on an upland area (*terra firme*) of about 0.5 ha which first had been cleared for a rubber plantation in 1978, but this had been abandoned with development into secondary forest. The experiment had the objective of determining the nutrient uptakes and their rate of remobilization in banana plants using twelve banana plants FHIA 18 cultivar (AAAB), grown from tissue culture, in a non-irrigated regime, with periodic defoliations and pruning. At the start of inflorescence, the central part of the leaf blade of the third leaf counted from the apex (designated phase F$_1$)
Table 1

Soil chemical properties of a Xanthic Ferralsol (dystrophic Yellow Latosol) located in the municipality of Manaus, Amazonas State, Brazil

<table>
<thead>
<tr>
<th>Chemical property</th>
<th>0–10</th>
<th>10–20</th>
<th>20–40</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH (CaCl₂)</td>
<td>3.43</td>
<td>3.50</td>
<td>3.65</td>
</tr>
<tr>
<td>P (mg kg⁻¹)</td>
<td>2.94</td>
<td>2.28</td>
<td>2.02</td>
</tr>
<tr>
<td>K (mg kg⁻¹)</td>
<td>25.60</td>
<td>17.67</td>
<td>14.33</td>
</tr>
<tr>
<td>Ca (cmolₑ kg⁻¹)</td>
<td>0.19</td>
<td>0.11</td>
<td>0.10</td>
</tr>
<tr>
<td>Mg (cmolₑ kg⁻¹)</td>
<td>0.19</td>
<td>0.15</td>
<td>0.15</td>
</tr>
<tr>
<td>H⁺+Al (cmolₑ kg⁻¹)</td>
<td>8.80</td>
<td>10.08</td>
<td>8.30</td>
</tr>
<tr>
<td>CEC (cmolₑ kg⁻¹)</td>
<td>9.24</td>
<td>10.38</td>
<td>8.59</td>
</tr>
<tr>
<td>Al (cmolₑ kg⁻¹)</td>
<td>2.12</td>
<td>1.58</td>
<td>1.09</td>
</tr>
<tr>
<td>S (mg kg⁻¹)</td>
<td>19.52</td>
<td>19.55</td>
<td>32.03</td>
</tr>
<tr>
<td>SOM (g kg⁻¹)</td>
<td>42.77</td>
<td>31.04</td>
<td>23.50</td>
</tr>
<tr>
<td>B (mg kg⁻¹)</td>
<td>0.34</td>
<td>0.30</td>
<td>0.25</td>
</tr>
<tr>
<td>Cu (mg kg⁻¹)</td>
<td>0.11</td>
<td>0.10</td>
<td>0.08</td>
</tr>
<tr>
<td>Fe (mg kg⁻¹)</td>
<td>170.07</td>
<td>166.67</td>
<td>144.57</td>
</tr>
<tr>
<td>Mn (mg kg⁻¹)</td>
<td>1.90</td>
<td>1.25</td>
<td>1.26</td>
</tr>
<tr>
<td>Zn (mg kg⁻¹)</td>
<td>0.67</td>
<td>0.47</td>
<td>0.35</td>
</tr>
</tbody>
</table>

¹The P, K, Cu, Fe, Mn, and Zn available were extracted with Mehlich 1 extractant solution; exchangeable Ca, Mg, and Al were determined after extraction with KCl 1.0 mol L⁻¹; exchangeable H⁺+Al was extracted with calcium acetate 0.01 mol L⁻¹; SOM (soil organic matter) = C × 1.724—Walkley Black method; B available with hot water; S available was extracted with Ca(H₂PO₄)₂·H₂O; CEC (Cation Exchangeable Capacity) Σ(K, Ca, Mg, H⁺+Al).

was removed (Robinson et al., 1997—diagnostic leaf), and symmetrically from the same leaf, another part at the time of harvesting the bunches (designated phase F₂), was also removed. After collecting, the leaf parts were dried in a ventilated oven at ±65°C until they reached constant weight and then were ground in a 0.40-mm mesh sieve. The total N was extracted by sulfur digestion and determined by the micro-Kjeldahl method (Nelson and Sommers, 1972), total B by dry-ashing digestion in a muffle furnace in 500°C for 1.5 h, while P, K, Ca, Mg, S, Cu, Fe, Mn, and Zn were extracted by nitroperchloric digestion. P, S, and B were determined by spectrophotometry with the blue molybdenum photometry, turbidimetry methods, (Novozamsky et al., 1983) and colorimetry (Walinga et al., 1995), respectively. The K, Ca, Mg, Cu, Fe, Mn, and Zn were analyzed by atomic absorption spectrophotometry according to the method described by Walinga et al. (1995).
To determine the internal retranslocation rate of the nutrients (N, P, K, Ca, Mg, S, B, Cu, Fe, Mn and Zn) the fraction of nutrient retranslocated (FNR) was calculated, using the following equation, adapted from Ares et al. (2003):

\[
\text{Macronutrients} - \text{FNR} = 1 - \left( \frac{\text{NF}_1}{\text{Ca content in NF}_1} \frac{\text{NF}_2}{\text{Ca content in NF}_2} \right);
\]

where

\[\text{NF}_1 = \text{N, P, K, Ca, Mg and S uptake in the leaf part at the start of flowering};\]

\[\text{NF}_2 = \text{N, P, K, Ca, Mg and S uptake in the leaf part at the time of harvesting};\]

\[
\text{Micronutrients} - \text{FNR} = 1 - \left( \frac{\text{NF}_3}{\text{B content in NF}_3} \frac{\text{NF}_4}{\text{B content in NF}_4} \right);
\]

where

\[\text{NF}_3 = \text{B, Cu, Fe, Mn and Zn uptake in the leaf part at the start of flowering};\]

\[\text{NF}_4 = \text{B, Cu, Fe, Mn and Zn uptake in the leaf part at the time of harvesting};\]

The use of the content Ca (g kg\(^{-1}\)) for the macronutrients (N, P, K, Mg, and S) and B (mg kg\(^{-1}\)) for the micronutrients (Cu, Fe, Mn, and Zn) as a comparison (reference) variable was due to the low mobility within the plant (Marschner, 1995; Epstein and Bloom, 2005).

**Experiment 2**

Zinc is one of the most yield limiting nutrients in Brazilian soils (Fageria et al., 2006) and its importance in the formation of uniform bunches in banana plants is widely recognized (Lahav, 1995). This experiment was set up using Thap Maeo cultivar (AAB), employing a completely randomized blocks in a 4 × 2 factorial scheme in split plot design, with four replicates. The plots were constituted of four rates of ZnSO\(_4\) (0, 30, 60 and 120 g plant\(^{-1}\) cycle\(^{-1}\) or 0, 50, 100 and 200 kg ha\(^{-1}\)—20% of Zn), while the subplots were the two application times (in the hole at the time of planting the seedling and in the broadcast in the fifth month after planting). The data were collected from the five central plants of each replicate.

In both experiments, the spacing was three meters between rows and two meters between plants (1667 plants per hectare). Forty-five days before planting, five liters of chicken manure and 500 grams of dolomitic limestone (effective calcium carbonate = 90%) were applied in the holes (60 cm × 60 cm × 60 cm). In the nutrient uptake and remobilization experiment, 60 grams
of P₂O₅ (simple superphosphate—20% of P₂O₅) and 50 grams of fritted trace elements [FTE BR12®—B, 1.8%, Cu, 0.8%, Fe, 3.0%, Mn, 2.0%, molybdenum (Mo), 0.1% and Zn, 9.0%], were also applied together with the seedlings, at the time of planting, while in the ZnSO₄ rate experiment (2), the amount of FTE BR12 was 10 grams, only to supply the plants’ original development needs. The broadcast fertilizations consisted of 256 g plant⁻¹ of urea (44% of N) and 1,600 g plant⁻¹ of potassium chloride (58% of K₂O), distributed in four applications: in the second, fourth, seventh and tenth month after planting (Moreira et al., 2005). The first three fertilizations were done around the plant in a range of 50 cm, and the last in a semicircle beside the daughter plant.

In the fourth month after planting, 100 grams of magnesium sulfate (9% of Mg), 20 grams of copper sulfate (13% of Cu), 20 grams of iron sulfate (19% of Fe), 10 grams of manganese sulfate (26% of Mn), and 30 grams of boric acid (17% of B), and 30 grams of zinc sulfate (20% of Zn) were also supplied in broadcast application (Moreira et al., 2005). Zinc was applied only in the remobilization experiment (1).

As in the remobilization experiment, Zn uptake was determined in the leaves in phases F₁ and F₂. At the time of harvesting the bunches, central fruits were removed of hands 2, 6, and 10 to measure the length, diameter and zinc content. In phases F₁, critical level of Zn was also determined, according to the methodology described by Cate and Nelson (1971).

### Statistical Analyses

The results were analyzed by analysis of variance (ANOVA—F test), comparison of minimum significant differences between means (Tukey test, P ≤ 0.05), and regression analysis at 5% significance (Hicks, 1973).

### RESULTS AND DISCUSSION

The results of soil analysis (Table 1) showed that extractable levels of macro- and micronutrients were low for banana plants as defined by Moreira et al. (2005) for soils of Amazonas State of Brazil, while the aluminum (Al) and exchangeable H+Al were high, independent of soil depth. Lehmann et al. (2001) and Moreira and Gonçalves (2006) reported that 90% of soils in the Amazon region have low fertility. Furthermore, the soil chemical property data in Table 1 indicate that the soils of the experimental area were appropriate for the study of mineral nutrition of plants.

The analysis of variance of the yield and the leaf zinc content in phases F₁ and F₂ indicated that there was a significant effect of the ZnSO₄ rates (P ≤ 0.05), time of application and interaction of rates versus timing of fertilizer application (Table 1, Figure 1). The significant interaction between zinc rate
and timing of its application indicates that zinc requirements of banana plants varied with the timing of application. The bunch yield increased in a quadratic fashion with the increasing ZnSO$_4$ rate in both the methods of application (Figure 1). However, the yield was greater with fertilization in the planting hole at the lower Zn rate, even with application of 10 g of FTE BR12 in all treatments to maintain the minimum level of nutrients required for initial development of the seedlings (Figure 1). To obtain better estimated yield in the local edaphoclimatic conditions, it would be necessary to apply 100.8 kg ha$^{-1}$ in the hole to obtain 48.3 t ha$^{-1}$ per cycle, while in surface broadcast the quantity applied would be 129.2 kg ha$^{-1}$, with estimated yield of 47.0 t ha$^{-1}$ per cycle.

The results show the superiority of zinc sulfate placed in the planting hole compared to the broadcast application. Besides acting on the formation of the fruits (Lahav, 1995), with elongation of the cells caused by the synthesis of tryptophane, a precursor of indoleacetic acid (Marschner, 1995; Malavolta et al., 1997), zinc is also important during the initial root formation and vegetative growth stages (Mengel and Kirkby, 2001). In addition to the nutritional aspects, the application in the hole is less expensive, requiring less fertilizer and fewer crop treatments.

Based on the fertilization indicated by Moreira et al. (2005) for similar conditions, on the concentrations of Ca and B (Epstein and Bloom, 2005) and on the rate of increment, we found that the retranslocated fractions of Ca, Fe,
Table 2
Foliar concentration, increment and fraction of retranslocation of nutrients in banana plants cultivated in Central Amazon, Amazonas State, Brazil

<table>
<thead>
<tr>
<th></th>
<th>NF1</th>
<th>NF2</th>
<th>Δ %</th>
<th>FNR</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>g kg⁻¹</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N</td>
<td>26.1</td>
<td>21.7</td>
<td>-16.9</td>
<td>-0.73</td>
</tr>
<tr>
<td>P</td>
<td>1.7</td>
<td>1.4</td>
<td>-17.6</td>
<td>-0.72</td>
</tr>
<tr>
<td>K</td>
<td>27.5</td>
<td>22.5</td>
<td>-18.2</td>
<td>-0.74</td>
</tr>
<tr>
<td>Ca</td>
<td>4.7</td>
<td>6.6</td>
<td>40.4</td>
<td>0.00</td>
</tr>
<tr>
<td>Mg</td>
<td>2.9</td>
<td>2.2</td>
<td>-24.1</td>
<td>-0.83</td>
</tr>
<tr>
<td>S</td>
<td>1.7</td>
<td>1.9</td>
<td>11.8</td>
<td>-0.24</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>NF3</th>
<th>NF4</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mg kg⁻¹</td>
<td></td>
<td></td>
</tr>
<tr>
<td>B</td>
<td>19.3</td>
<td>17.5</td>
<td>-9.3</td>
</tr>
<tr>
<td>Cu</td>
<td>5.5</td>
<td>3.4</td>
<td>-38.2</td>
</tr>
<tr>
<td>Fe</td>
<td>52.4</td>
<td>92.6</td>
<td>76.7</td>
</tr>
<tr>
<td>Mn</td>
<td>280.0</td>
<td>540.1</td>
<td>92.9</td>
</tr>
<tr>
<td>Zn</td>
<td>13.0</td>
<td>14.0</td>
<td>7.7</td>
</tr>
</tbody>
</table>

¹NF₁ and NF₃—foliar nutrients concentration at the beginning of inflorescence; NF₂ and NF₄—foliar nutrients concentration at the bunches yield; Δ—increment of foliar level-macronutrients = (NF₂-NF₁)/100 or micronutrients = (NF₄–NF₃)/100; FNR—fraction of nutrient retranslocated.

and Mn have low remobilization to the fruits, with most being retained in the leaves (Table 2), while B, Zn, and S had an intermediate retranslocation rate. Regarding the macronutrients, the high rates found for Mg, N, P, and K agree with the results obtained by Turner and Barkus (1983) and Ares et al. (2003), and confirm the degree of mobility of these nutrients within the plants described in the literature.

In plants grown in conditions of Zn deficiency, the fruits are stronger sinks, creating a greater demand for the nutrient. These observations corroborate the results obtained by Longnecker and Robson (1993) and Martinez et al. (2005), that tissues undergoing growth, in the case of fruits (Webb and Loneragan, 1990), are preferred zinc sinks in relation to mature tissues. The authors reported that in plants grown with the highest Zn rates, the sink effects of the growing tissues are not as strong. Our results showed a low retranslocation rate of zinc to the growing organs (Table 2, Figure 2), and the higher concentration observed in the leaves collected at phase F₂ in the control, along with the greater Zn content in the central fruit of hand two, the next-to-last hand produced
Figure 2. Fruits concentration of Zn (mg kg$^{-1}$), length (cm) and diameter (mm) of fruits inside of ZnSO$_4$ rates (0, 30, 60 and 120 g plant$^{-1}$), according to the application times. *Significant at 5% level of probability. (Figure 2), also indicates the presence of a low mobility of zinc in banana plants.

The timing of application and the rates of Zn significantly influenced the content of the element in the leaves, and there was also an interaction between these two variables (Table 3). Despite the significance in the two sampling times, the collection done at the start of flowering with incremental rates of ZnSO$_4$ provided a better response than those obtained at the harvest of the
Table 3

Analysis of variance of banana yield and foliar Zn concentration obtained in the beginning of inflorescence (F1) and in harvest of bunches (F2)\(^1\)—Experiment 2

<table>
<thead>
<tr>
<th>Sources of Variation</th>
<th>Degree of freedom</th>
<th>Yield</th>
<th>F1</th>
<th>F2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blocks</td>
<td>3</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Rates</td>
<td>3</td>
<td>13.41***</td>
<td>71.89***</td>
<td>4.74**</td>
</tr>
<tr>
<td>Residue A</td>
<td>9</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Plots</td>
<td>15</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Application time</td>
<td>1</td>
<td>5.18*</td>
<td>3.36*</td>
<td>4.90**</td>
</tr>
<tr>
<td>Rates \times Application time</td>
<td>3</td>
<td>5.66**</td>
<td>5.60**</td>
<td>2.69*</td>
</tr>
<tr>
<td>Residue B</td>
<td>12</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>Total</td>
<td>31</td>
<td>—</td>
<td>—</td>
<td>—</td>
</tr>
<tr>
<td>CV% (A)</td>
<td></td>
<td>6.52</td>
<td>3.26</td>
<td>14.07</td>
</tr>
<tr>
<td>CV% (B)</td>
<td></td>
<td>7.67</td>
<td>4.59</td>
<td>17.13</td>
</tr>
</tbody>
</table>

\(^1\), **, and ***: significant at 10%, 5% and 1% by F test, respectively. CV—coefficient of variation.

bunches. The highest concentrations of zinc were obtained in the estimated rates of 111.3 g plant\(^{-1}\) per cycle and 120 g plant\(^{-1}\) per cycle, with application in the hole and in broadcast application, respectively (Figure 3a).

The concentrations of Zn obtained in the leaves collected together with the bunches presented a negative interaction with increasing rates (Figure 3b). Despite the significance of the data, the concentrations obtained at rates of 30, 60, and 120 g plant\(^{-1}\) per cycle in broadcast application showed similarities, differing only in the control. The efficiency of zinc utilization, defined as the quantity of the element absorbed to increase yield (Tyney and Weeb, 1946), showed that increasing rates diminished the utilization factor in the two application periods. However, this efficiency was highest when the fertilizer was applied in the planting hole (Figures 2 and 3c), indicating that even though there was nutrient mobilization from “mother” to “daughter” plan (Lahav, 1995), it is more advantageous to accumulate the nutrient in the tissue (redistribution—Malavolta et al., 1997) than to fertilize the plant at the start of its metabolism to form bunches.

Regarding the application timing, we observed that except for the rate of 60 g plant\(^{-1}\), the quantities of Zn in the tissue were similar. On this point, the only work in the literature is Moreira et al. (2005), which suggests 16 to 22 mg kg\(^{-1}\) as the critical range for zinc in third leaf of banana plants grown in Amazonas State. Using this index as a reference, we found that only the
Figure 3. Effect of zinc sulfate on foliar Zn concentration at the beginning of inflorescence (F1), harvest of bunches (F2) and increment of nutrient in leaf, according to the sampling time. *Significant at 5% level of probability.
treatments with 120 g plant\(^{-1}\) of ZnSO\(_4\) at the two application times were within this sufficiency range (Figure 3a).

The relation between relative yield and Zn leaf concentration (Figure 4) indicates that the critical level obtained, using the procedure proposed by Cate and Nelson (1971), was 12.9 mg kg\(^{-1}\), a concentration below the 16 to 19 mg kg\(^{-1}\) and 15 to 23 mg kg\(^{-1}\) suggested by Moreira et al. (2005) for the same cultivar. However, taking as a base the high yield obtained, above 35 t ha\(^{-1}\) cycle\(^{-1}\) (Figure 1), only the control remained below this sufficiency level. Besides the effect of dilution (Marschner, 1995; Mengel and Kirkby, 2001) caused by the high productivity, different climate conditions at the time of collecting the leaves for foliar diagnosis could also have influenced the result.

According to the hands produced (2, 6, and 10), there was a significant decrease in fruit length and diameter (Figure 2). Extrapolating the classification of the Prata cultivar, subgroup AAB (ABANORTE, 1998) to the Thap Maeo cultivar, subgroup AAB, the bananas of hand 10 were on average within the second-grade banana classification (length < 14 cm), while for those from hands 2 and 6 the classification was first-grade and export-grade (length > 14 cm). Based on the diameter, the bananas from all three hands analyzed were within the first- and export-grade classification (diameter > 32 mm). The application times had similar results, with the length of the fruits presenting significant statistical differences for the four rates of ZnSO\(_4\), while for the diameter the differences were only significant for the rates of 0 and 30 g plant\(^{-1}\) cycle\(^{-1}\) (Figure 2). This shows that the zinc was retranslocated from the older fruits, located in the tenth and sixth hands, to the second hand (the
penultimate hand produced). Regarding the rates, they did not influence the diameter and length of the fruits.

These results reveal that banana plant yield can be boosted through administration of ZnSO$_4$, in increasing rates according to the market and sales pattern (weight, unit, or bunch), For example, unlike in the Center-South region of Brazil, where the fruit is sold in boxes of detached groups, in the North nearly all are sold by the bunch.

CONCLUSIONS

Banana is an important plantation crop in South America, including Brazil. The use of adequate rate of fertilization is an important aspect of improving yield of banana. The productivity of the banana plant is influenced by the rates of zinc sulfate. In the first cycle, the application of ZnSO$_4$ in the planting hole is more efficient than after planting in broadcast application. In the local edaphoclimatic conditions of Amazonian, the critical concentration of zinc in the banana leaf is 12.9 mg kg$^{-1}$. The zinc presents of a low mobility in the phloem from the leaves to the fruits and from the older to the younger fruits in banana plants. Uptake of macronutrients was in the order of K > N > Ca > Mg > P and micronutrients in the order of Mn > Fe > B > Zn > Cu. The N, P, K, Mg, and Cu have a high retranslocation rate inside the plant compared to other nutrients investigated.

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