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Research Article

Biosolids Application on Banana Production: Soil Chemical Properties and Plant Nutrition

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Biosolids are relatively rich in N, P, and S and could be used to substitute mineral fertilization for banana crop. A field experiment was carried out in a Yellow Oxisol to investigate the effects of biosolids application on soil chemical properties and on banana leaf's nutrient concentration during the first cropping cycle. Soil analysis (pH, organic matter, resin P, exchangeable Ca and K, available B, DTPA-extracted micronutrients, and heavy metals) and index-leaf analysis (B, Cu, Fe, Mn, Zn, Cd, Cr, Ni, and Pb) were evaluated. Biosolids can completely substitute mineral N and P fertilizer to banana growth. Soil exchangeable K and leaf-K concentration must be monitored in order to avoid K deficiency in banana plants. No risk of heavy metal (Cr, Ni, Pb, and Cd) concentration increase in the index leaf was observed when biosolids were applied at the recommended N rate.

1. Introduction

The amount of residues constantly produced during sewage treatment process has significantly increased in the State of São Paulo, Brazil. The sewage sludge (SS), also called biosolids when treated by various methods to remove or reduce pathogens [1], is a residue obtained from the wastewater treatment process, which is a cleanser procedure to remediate polluted waters allowing their safe return to nature. Among the alternatives for the sewage sludge disposal, there is the use as fertilizer for agriculture. According to Melo and Marques [2], sewage sludge is a potential source of nutrients for plants and might be a soil conditioner by improving soil physical, chemical, and biological properties. Silveira et al. [3] mentioned that biosolids application in agriculture has already become a common practice because it may improve some soil chemical (pH and organic matter) and physical properties as increase crop yields as well.

Since biosolids contain high amount of N, it is usually employed as N source to plants, and several studies have shown that it can completely substitute N fertilizer for several crops such as sugar cane [4], heart of palm [5], sunflower [6, 7], and corn [8]. Furthermore, it also can supply part of P, Ca, Mg, S, and Zn required by the crop [9, 10]. However, because of its low K content, it is necessary to supplement this nutrient as mineral fertilizer [9, 11].

Biosolids also contain contaminants such as heavy metals which must be taken into account in their agricultural use [12]. Hence, it has created a demand for information on the suitability of soil extractants, such as DTPA-TEA (diethylene-triamine-pentaacetic acid), that could predict plant-available heavy metals in soils [13]. Bovi et al. [5] found a linear increase of DTPA-extractable Zn, Cu, Fe, Mn, Cd, Pb, and Ni with increased rate of biosolids application at 0–20 cm soil depth, and Alcantara et al. [14] also reported an increase in DTPA-extracted Zn, Cu, Ni, and Cd at 20–40 cm depth in SS-amended soils, but DTPA-extractable Ni and Cd were found only at high SS rates.

Soil fertility is the main factor guaranteeing the banana cropping sustainability. Teixeira [15] pointed out that nutrient exportation by banana bunch, nutrient losses by lixiviation and superficial runoff, and the soil profile acidification

Table 1: Soil chemical analysis[(1)] of the experimental area (average values) before banana cropping.

Soil layer	pH($CaCl_2$)	OM	$P_{(resin)}$	K^+	Ca^{2+}	Mg^{2+}	H+Al	SB	T	V
cm		g dm^{-3}	mg dm^{-3}			mmol$_c$ dm^{-3}				%
0–20	4.0	23	3	1.6	8	2	90	12.1	101.1	12.3
20–40	4.0	18	2	1.2	7	2	92	9.6	101.4	10

(1) Soil pH measured in 0.01 mol $L^{-1}CaCl_2$ solution; soil : solution = 1 : 2.5 (v/v); resin extraction of exchangeable cations and phosphorus (P), according to Raij et al. [25].

Table 2: Description of treatments with biosolids (SS) and mineral fertilizers.

Treatment	Fertilization[(1)]	Rates		
		Biosolid (SS)		N[(2)]
		t ha^{-1} (humid SS)	t ha^{-1} (dry SS)	Kg ha^{-1}
Control	P-K mineral fertilizer (without N)	—	—	—
SS 1	Biosolid + K mineral fertilizer	74	21.3	219
SS 2	Biosolid + K mineral fertilizer	147	42.6	435
SS 3	Biosolid + K mineral fertilizer	294	85.2	870
N 1	Mineral fertilizer (N + P + K)	—	—	400
N 2	Mineral fertilizer (N + P + K)	—	—	800

(1) P and K rates calculated according to recommendations for the State of São Paulo recommended by Soto Ballestero [22]. (2) Biosolids N rate estimated according to available N calculated according to Bovi et al. [5].

require careful soil fertility management in order to maintain high yielding, such as 60 t ha^{-1} $year^{-1}$.

According to several authors [16–21], the banana plant inner nutrient status regulates the plant growth, susceptibility to pests and diseases, and fruit quality and quantity, with straightforward effects on commercial profits.

Bananas are fast growth plants and demand high levels of available soil nutrients for their normal development and production. According to Soto Ballestero [22] and Lahav [23], the amount of nutrients provided by the soil and soil-plant recycling system is not enough to supply the crop demands, and therefore, the application of fertilizers in adequate quantities is required.

The objective of this work was to determine the changes in chemical attributes of a soil amended with biosolids and their effects on banana crop nutrient levels, during the first cropping cycle.

2. Materials and Methods

The experiment was carried out from September 2001 to September 2002 at the regional research pole of Pariquera-Açu, State of São Paulo, Brazil (24°39′S; 47°55′W). According to Köppen classification, the region climate is Am type (tropical monsoon), with excessive rainfall during the year, but dry winter. As published by Sakai and Lepsch [24], the soil was classified as a clayey texture (34% clay, 9% silt, and 57% sand) A horizon alic Yellow Oxisol-Pariquera Unity I.

Before planting, composite soil samples were collected from 0–20 and 20–40 cm depth, consisting of six subsamples per plot. Soil analysis was performed for the determination of soil fertility, according to procedures recommended by Instituto Agronomico, Campinas, State of São Paulo, and described by Raij et al. [25]. Soil analysis results (average values) obtained for each soil depth are presented in Table 1.

The experimental design was in randomized complete blocks with five replications. The treatments consisted of three biosolid rates, two mineral nitrogen (N) fertilizer rates, and one control without N.

The available N in the sewage sludge was calculated by the formula

$$\begin{aligned}\text{SS available N} = {} & \left(\frac{\text{MF}}{100}\right) \times (\text{Kjeldahl-N} - \text{NH}_3\text{-N}) \\ & + \text{NH}_3\text{-N} + \left(\text{NO}_3{}^-\text{-N} + \text{NO}_2{}^-\text{-N}\right),\end{aligned} \tag{1}$$

where Kjeldahl-N = total nitrogen (mg kg^{-1}), NH_3-N = nitrogen as ammonia (mg kg^{-1}), $NO_3{}^-$-N = nitrogen as nitrate (mg kg^{-1}), $NO_2{}^-$-N- = nitrogen as nitrite (mg kg^{-1}), and MF = mineralization fraction (30%), for aerobically digested sludge. This calculation is used for the SS application with subsequent soil incorporation, according to recommendation of the Company of Environment Sanitation Technology (CETESB) in the 4.230 directive [26].

All biosolids (SS) rates were manually applied using a volume correspondent to the treatment mass quantity, as described in Table 2. SS was applied into the furrows, between the planting holes, and carefully incorporated. Samples of the applied biosolids material were collected for chemical analysis and characterization of parameters defined in CETESB [27]. Organic carbon, Kjeldahl-N, and inorganic-N were determined according to methods described by Raij et al. [25]; other elements (macro- and micronutrients and heavy metals) were extracted by digestion according to the method 3051 described in US-EPA [28] and determined by ICP-AES. Biosolids pH was determined in 1 : 5 water extract (residue : water) using a potentiometer, and % humidity and volatile solids were determined by mass loss at 60°C and

500°C, respectively, (Table 3). The biosolids were originated from the Sludge Treatment Plant of Bichoró controlled by the Company of Basic Sanitation of the State of São Paulo (SABESP), located at Mongaguá, State of São Paulo.

Dolomitic limestone was applied to soil for reaching 60% base saturation (V%). Soil preparation consisted of disc plowing, harrowing, and furrowing to a depth of 35 cm. Phosphorus (P) was applied at planting (150 kg ha^{-1} of P_2O_5 in the furrow) and broadcasted in 2003 (200 kg ha^{-1} of P_2O_5 as triple superphosphate, 41% P_2O_5). Potassium (K) was applied (570 kg ha^{-1} of K_2O) as KCl (60% K_2O), and nitrogen (N) as NH_4NO_3 (32% N) at quantities specified in Table 2. Both K and N fertilizers were split in four applications.

Banana plants were spaced 2.5 m between rows and 2.0 m between plants, using *in vitro* plantlets (obtained from micropropagation under controlled conditions) of Grande Naine cultivar (AAA group, Cavendish subgroup).

Composite soil samples were collected to evaluate the biosolids effects on the chemical soil attributes (soil fertility and DTPA extractions) as described by Raij et al. [25]. The initial soil sampling was collected in September 2001 at 0–20 and 20–40 cm depth layer. After the first cropping cycle (September 2002), soil samples were taken at 0–20, 20–40, and 40–60 cm depth.

Banana plant nutrient status was evaluated by means of leaf tissue analysis, and for that, the third leaf from the apex was collected during the period of male flowering (two to three open male flowers), and the blade central portion was used for chemical analysis according to Martin-Prével [29]. Leaf samples were prepared for chemical analysis according to procedures described by Bataglia et al. [30].

The analysis of variance was performed on the data, and means were separated by Student's t-test ($P > .05$) or Dunnett's test ($P > .05$).

Table 3: Chemical analysis of biosolids used in the experiment (average results).

Variable	Unity	Value
Phosphorus (P)	g kg^{-1*}	15.4
Potassium (K)	g kg^{-1*}	0.9
Sodium (Na)	g kg^{-1*}	0.6
Arsenium (As)	mg kg^{-1*}	<0.1
Cadmium (Cd)	mg kg^{-1*}	10.3
Lead (Pb)	mg kg^{-1*}	83.6
Copper (Cu)	mg kg^{-1*}	139.6
Chromium (Cr)	mg kg^{-1*}	43.8
Mercury (Hg)	mg kg^{-1*}	<0.1
Molybdenum (Mo)	mg kg^{-1*}	<0.1
Nickel (Ni)	mg kg^{-1*}	22.2
Selenium (Se)	mg kg^{-1*}	<0.1
Zinc (Zn)	mg kg^{-1*}	573.4
Boron (B)	mg kg^{-1*}	22.9
Carbon (organic)	g kg^{-1*}	222.7
pH		9.9
Humidity	%	71.2
Volatile solids	%*	52.5
Total N (Kjeldahl)	g kg^{-1*}	32.0
$NH_{4-}N$	mg kg^{-1**}	558
$NO_{3-}N + NO_{2-}N$-	mg kg^{-1**}	13.6
Sulfur	g kg^{-1*}	7.7
Manganese	mg kg^{-1*}	778
Iron	g kg^{-1*}	106
Magnesium	g kg^{-1*}	5.9
Aluminum	g kg^{-1*}	7.0
Calcium	g kg^{-1*}	174
Available N***	g kg^{-1**}	2.96

*Total concentrations in a dry matter basis; **original residue element concentrations; ***available N calculated according to Bovi et al. [5].

3. Results and Discussion

Significant effects ($P < .05$) of treatments were observed on soil pH values, organic matter, available phosphorus, (P) and exchangeable potassium (K) and calcium (Ca) concentrations after the first cropping cycle (Figure 1). As also observed by many authors [10, 11, 31], SS addition increased all soil chemical attributes under investigation except for exchangeable K which had its concentration significantly decreased till 60 cm depth. Great increases were found in the first 20 cm layer because SS was thoroughly mixed with the soil till 35 cm depth. The increases observed mainly for soil pH, available P, and exchangeable Ca at the 40–60 cm depth suggest that the addition of SS had already altered these soil properties in the first crop cycle, probably due to neutralizing reactions which favors ion leaching such as HCO_3^- and OH^- [32] and by the increase in the amount of dissolved organic matter in soils [33, 34]. Dissolved organic matter can facilitate metal transport in soil by acting as a carrier through formation of soluble metal-organic complexes [35].

The conventional mineral N fertilization caused light soil acidification (<0.3 pH unity) compared to the control treatment. On the other hand, soil pH increase was observed in plots treated with biosolids. Soil acidification observed in plots treated with mineral N fertilizers was a result of nitrification of NH_4^+ present in the ammonium nitrate to NO_3^- [36] and was also reported by Teixeira et al. [21] under the Plateau Paulista conditions and by Saes [37] at the Ribeira Valley, both located in the State of São Paulo.

Results obtained from soil extractants for micronutrients and heavy metals showed that SS addition significantly increased the availability of Cu, Mn, Zn, and Ni in the 0–20 cm depth and Cu, Fe, Mn, and Zn in the two subsequent soil depths under investigation (Table 4). Concentration of Ni extracted by the DTPA method was higher only when SS was applied at the highest rate, which is two times the amount of N recommended to banana crop.

Plant demand for N was completely supplied only by the soil organic matter mineralization, since the plant leaf N

Table 4: Boron and DTPA-extractable metals from SS-treated soil after the first crop cycle at three sampling depths.

Treatment(1)	B(5)	Cu(6)	Fe(6)	Mn(6)	Zn(6)	Cd(6)	Cr(6)	Ni(6)	Pb(6)
					mg dm^{-3}				
					0–20 cm				
T0	0.21 b(2)	0.2 c	142 a	1.4 d	0.6 d	0.08 b	0.08 a	0.12 b	0.44 a
T_L1	0.21 b	1.3 b	173 a	4.3 c	4.9 c	0.11 ab	<0.01 b	0.17 b	0.49 a
T_L2	0.21 b	1.9 b	150 a	6.7 b	8.0 b	0.11 ab	0.04 ab	0.21 ab	0.75 a
T_L3	0.27 a	3.0 a	177 a	8.4 a	12.0 a	0.15 a	0.02 ab	0.34 a	0.68 a
T_M1	0.20 b	0.1 c	143 a	0.9 d	1.1 d	0.09 b	0.04 ab	0.09 b	0.47 a
T_M2	0.22 b	0.2 c	160 a	0.8 d	0.5 d	0.08 b	<0.01 b	0.15 b	0.50 a
VC (%)(3)	18.4	45.6	22.5	27.5	43.2	33.0	154.2	55.2	54.7
Initial(4)	0.36	0.3	182	1.8	0.6	0.09	0.05	0.07	0.09
					20–40 cm				
T0	0.17 a	0.2 cd	85 c	0.8 d	0.6 d	0.05 ab	<0.01b	0.08 a	0.46 a
T_L1	0.18 a	0.6 bc	134 a	2.1 c	2.3 c	0.08 ab	0.03 ab	0.12 a	0.75 a
T_L2	0.16 a	0.9 b	114 abc	3.0 b	3.8 b	0.05 ab	0.03 ab	0.14 a	0.52 a
T_L3	0.18 a	1.4 a	127 ab	3.9 a	5.9 a	0.09 a	0.05 a	0.18 a	0.62 a
T_M1	0.17 a	0.2 d	96 c	0.9 d	0.6 d	0.07 ab	0.04 ab	0.11 a	0.61 a
T_M2	0.22 a	0.2 d	99 bc	0.7 d	0.9 d	0.05 b	0.02 ab	0.11 a	0.40 a
VC (%)(3)	22.5	58.5	21.5	33.9	43.6	47.7	97.5	65.9	55.7
Initial(4)	0.32	0.2	127	1.2	0.6	0.07	0.03	0.06	0.08
					40–60 cm				
T0	0.17 ab	0.2 c	68 c	0.7 c	0.8 c	0.05 bc	<0.01 a	0.12 ab	0.76 a
T_L1	0.20 a	0.5 bc	110 a	1.8 b	2.2 c	0.07 abc	0.03 a	0.09 ab	0.63 a
T_L2	0.15 b	0.9 b	100 ab	2.8 b	4.1 b	0.08 ab	0.04 a	0.15 ab	0.53 ab
T_L3	0.17 ab	1.4 a	120 a	4.4 a	6.5 a	0.10 a	0.02 a	0.19 a	0.62 a
T_M1	0.17 ab	0.1 c	80 bc	0.8 c	0.9 c	0.05 bc	<0.01 a	0.07 b	0.61 a
T_M2	0.18 ab	0.1 c	78 c	0.7 c	1.5 c	0.04 c	0.02 a	0.07 b	0.31 b
VC (%)(3)	15.8	66.7	16.6	39.9	47.7	48.0	179.7	67.5	37.9

(1) See Section 2. (2) Averages followed by the same letters in columns and soil layer do not differ statistically by the Student's t-test ($P > .05$). (3) Variation coefficient. (4) Soil sampling prior to the experiment startup (September/01). (5) Hot water extract. (6) DTPA method.

concentration in the control treatment (no N applied) was above the critical level [26 g kg^{-1} of N, according to Lahav [23] (Figure 2). This was probably due to the prolonged fallow period before the field experiment beginning. Even so, significant effect of N application as biosolid or mineral N was observed. N concentration of banana index leaves for treatment SS2, which supplied the recommended amount o N, was not statistically different from its equivalent mineral source (treatment N1) indicating that the available N in the sewage sludge calculated by the formula commended by CETESB [26] can also be successfully used for banana cropping.

Leaf K concentration significantly decreased with the biosolids addition in the first harvesting year (Figure 2) when compared with control and N1 treatment. Since all treatments received the same amount of K added as KCl (570 kg ha^{-1} of K_2O) during crop growth, it suggests that less K was available to the plants in the SS treatments, or this nutrient was more diluted during shoot development [15]. The application of biosolids increases the amount of Ca present in the soil, superior to 10 t ha^{-1} in the SS-3 treatment, which can induce K deficiency, since Ca and K uptake by plants are antagonistic processes [38]. Also, soil exchangeable Ca concentration increase can induce K displacement in the soil profile [39], favoring K lixiviation and hence decreasing exchangeable K concentration in all soil layers in response to biosolid application, as observed in Figure 1.

The plant leaf K : N ratio decreased in response to biosolid application as well as to mineral N fertilization (Figure 3) when compared to the control treatment. The index-leaf K : N ratio was below 1.4, except for the control plants. According to Teixeira et al. [21], a value of 1.4 or greater would indicate greater leaf longevity due to a better K/N balance. Therefore, although no visual K deficiency symptoms or lesser leaf duration was observed in the present work, the results suggest that soils treated with biosolids require periodical monitoring to check out the soil exchangeable K and leaf K concentration levels by means of soil and plant leaf chemical analysis.

Leaf P concentrations were around the critical level of 2 g kg^{-1}, according to Lahav [23], for all treatments (Figure 3). It is pointed out that P fertilizer was applied only in the control and plots treated with mineral fertilizers, and therefore, it can be concluded that biosolids supplied not

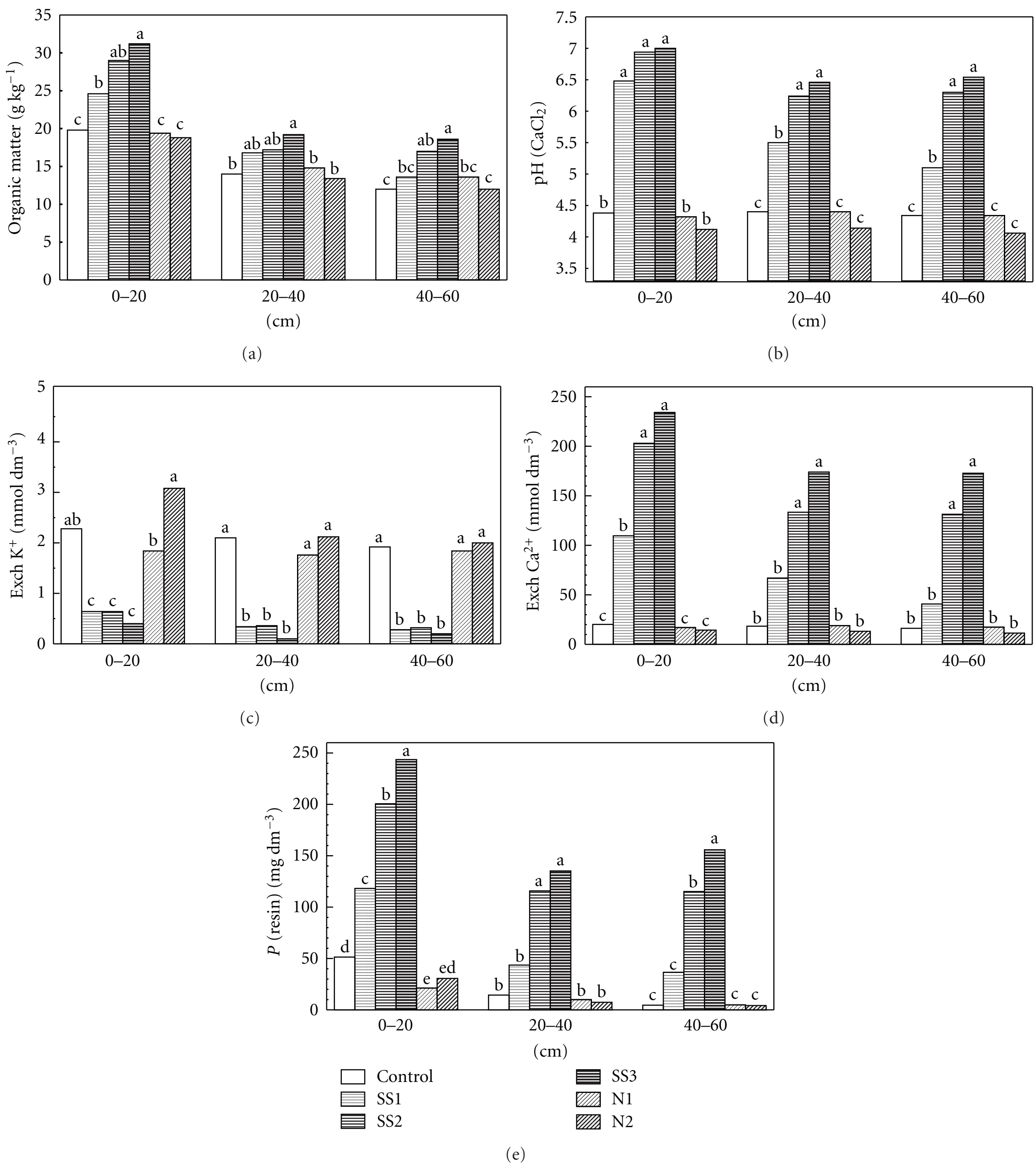

Figure 1: Soil chemical attributes in plots treated with biosolids (SS) and mineral N fertilizer (N) in three different soil depths. Columns with the same letters indicate that values do not differ by the Student's t-test ($P > .05$).

only N but also available P to banana plants, evidenced by the significant increase in resin P observed in all depths for the SS treatments.

Leaf Ca and Mg concentrations were above the critical level, respectively, $5\,g\,kg^{-1}$ and $3\,g\,kg^{-1}$ according to Lahav [23], for all treatments (Figure 4). These results denote that both nutrients were sufficiently supplied by the application of dolomitic limestone at the beginning of the experiment, before the banana planting. They also indicate that the increase in exchangeable Ca due to the application of a Ca-enriched SS (Figure 1) did not alter significantly leaf Ca concentration in banana plants.

Despite the increase observed in DTPA-extracted Cu, Mn, Zn, Fe, and Ni (Table 4), leaf micronutrients and heavy metals showed no significant variation as a result of biosolids addition when compared to the control and the mineral

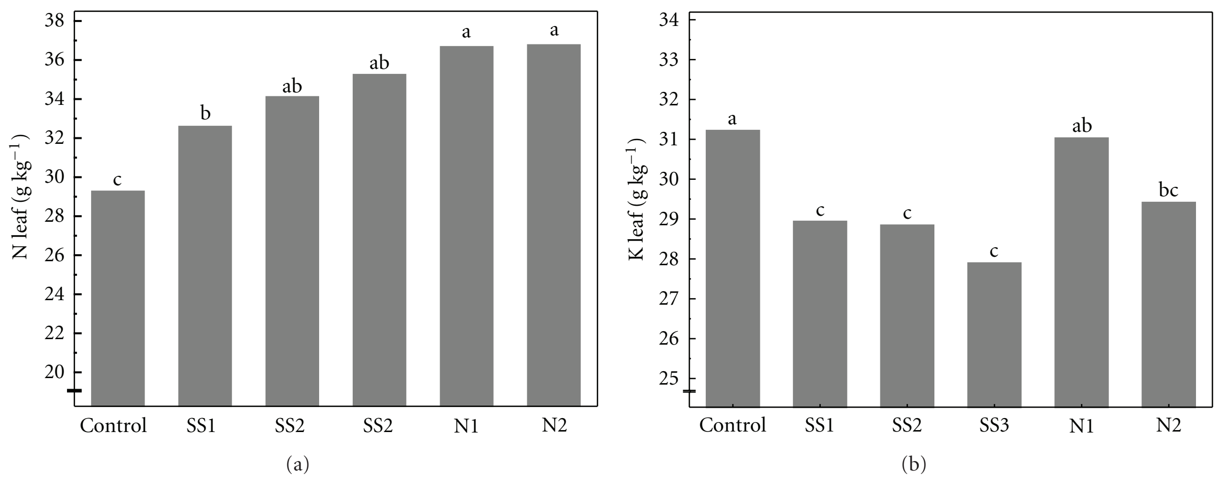

Figure 2: Nitrogen (N) (a) and potassium (K) (b) concentrations of banana index leaves from plots treated with biosolids (SS) and mineral N fertilizer (N). Columns with the same letters indicate that values do not differ by the Student's t-test ($P > .05$).

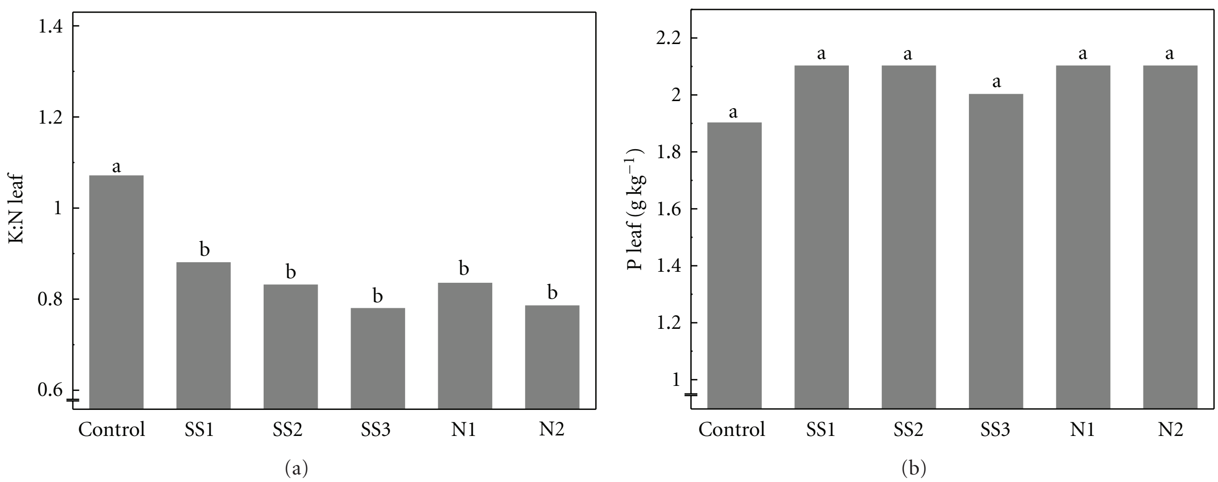

Figure 3: Potassium/nitrogen ratio (K : N) (a) and P concentration in banana index leaves (b) from plots treated with biosolids (SS) and mineral N fertilizer (N). Columns followed by the same letters indicate that values do not differ by the Student's t-test ($P > .05$).

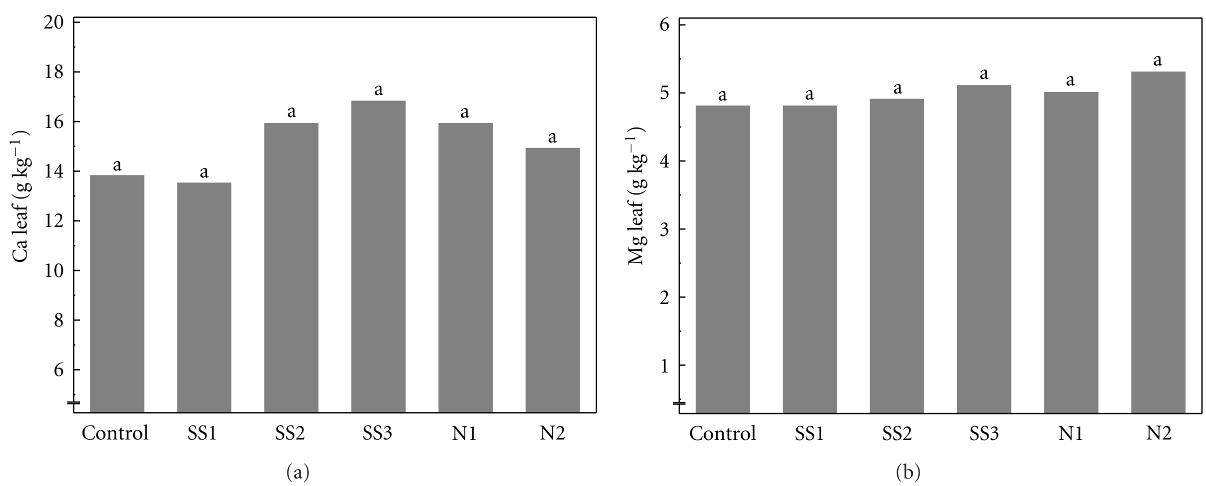

Figure 4: Calcium (Ca) (a) and magnesium (Mg) (b) in banana index leaves from plots treated with biosolids (SS) and mineral N fertilizer (N). Columns followed by the same letters do not differ by the Student's t-test ($P > .05$).

Table 5: Micronutrient and heavy metal concentrations in the index-leaf of banana plants from plots treated with biosolids (SS) and mineral N fertilizer (N).

Treatment	B	Cu	Fe	Mn	Zn	Cd	Cr	Ni	Pb
					mg/kg				
Control	16.6	13.0	202	343	23.9	<0.1	<0.1	3.1	10.2
SS 1	16.0n[(1)]	13.2n	132n	559n	23.6n	<0.1	<0.1	4.3n	7.5n
SS 2	15.5n	13.3n	150n	436n	23.9n	<0.1	<0.1	4.2n	8.9n
SS 3	16.3n	12.3n	137n	441n	23.4n	<0.1	<0.1	5.4n	6.4n
N 1	15.4n	13.3n	129n	339n	23.8n	0.9	<0.1	5.2n	11.5n
N 2	15.3n	13.1n	197n	439n	24.0n	<0.1	<0.1	5.2n	5.3n
CV (%)[(2)]	14.2	17.1	42.6	30.3	7.2	—	—	33.1	55.3

[(1)] Means followed by "n" do not differ from control (without SS) by Dunnett's test ($P > .05$); [(2)] Coefficient of variation.

N source treatments (Table 5), differently from what is observed by Anjos and Mattiazzo [40] who found that DTPA was an effective extractor in predicting Cu, Zn, and Mn availability to corn in two soils amended with biosolids. All leaf micronutrient concentrations were above the critical level determined by LAHAV [23] and within the adequate range reported by the Boletim 100 [41].

4. Conclusions

(1) Biosolids can be used as a single N and P source to banana plants.

(2) Soil exchangeable K and leaf K concentration must be monitored in order to avoid K deficiency in plants grown on Ca-enriched biosolids amended soil.

(3) In the first crop cycle, there is no risk of heavy metal (Cr, Ni, Pb, and Cd) concentration increase in the index leaf, when biosolids are applied at the recommended N rate.

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