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Banana crop nutrition: insights into different nutrient sources and soil fertilizer application strategies

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ABSTRACT: Considerable attention has been given to the development of new nutritional management strategies that can contribute to banana production be overestimated. The present study was motivated by the possibility that fertilizer application in front of the daughter plant might be more effective than application to the total banana production area. This study aimed to determine the most suitable site for soil collection to evaluate the chemical properties when fertilizer is applied in front of the daughter plant; to evaluate the efficacy of organic-mineral fertilizer in terms of soil nutrient availability, and to evaluate the effect on banana production. The experiment was conducted in three consolidated areas of banana plantation in Santa Catarina State. The effects of the combination of two main factors were evaluated: three fertilizer sources (mineral, mineral + organic compost or organic-mineral) and two application management (total area or in front of the plants), together with time (three years) and location (three municipalities). Each treatment was evaluated using a grid containing 20 banana plants (spaced at 2.5 × 2.5 m), with three replications of two plants in the central part. The experiment was arranged in a completely randomized design with three replicates. The use of a mineral source reduced the pH over the years, regardless of the application technique. Application of fertilizers in front of the daughter plant increased available P and K in the soil, compared to the application of fertilizers to the total area "uniformly distributed between banana planting lines and between plants". In addition, the increase in soil P content was higher using organic-mineral sources. The nutrient contents in the banana leaves did not differ according to the fertilization source. The application of fertilizers in front of the daughter plant optimized banana fertilization and increased fruit production. Under these fertilization conditions, soil for chemical analyses should be collected at around 0.70 m from the site of fertilizer application.

Keywords: fertilizer sources, organic-mineral fertilizer, fertilization management, fruit production.

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INTRODUCTION

Banana plants have a relatively high nutrient demand, compared to other crops, so applications of high dosages of K and N are required in banana orchards to replenish the nutrients exported (average values: N 1.66 kg Mg^{-1}, P_2O_5 0.36 kg Mg^{-1}, and K_2O 4.33 kg Mg^{-1} by banana fruit exported) by fruit harvest (Ratke et al., 2012; Nomura et al., 2016). Considerable attention has been given to the development of new nutritional management strategies that can contribute to banana production in a more economical and sustainable way (Nomura et al., 2016).

In Santa Catarina State, banana orchards are fertilized throughout the year, with dosages divided up to five times to reduce nutrient losses and increase fertilization efficiency (Livramento and Negreiros, 2017; CQFS RS/SC, 2016). In the case of the adult banana plant, it has been recommended that the fertilizer should be applied in the form of a half-moon, approximately 0.30-0.40 m from the daughter plant (Borges et al., 2015; Livramento and Negreiros, 2017), or in a circle around the plant (CQFS RS/SC, 2016). Alternatively, the fertilizer may be distributed over the total area, which is “uniformly distributed between banana planting lines and between plants”. Despite the recommendations proposed by Borges et al. (2015) and Livramento and Negreiros (2017) as being most suitable for Santa Catarina orchards, many banana growers still use fertilization over the total area. The aim of fertilizer application in front of the daughter plant is to optimize fertilization in the area where the root system of the plant is most active. It also aims to reduce nutrient losses due to the processes of adsorption, leaching, or surface runoff, following contact of the fertilizer with the soil (Neves et al., 2009). However, there have been no consistent results to prove that the application of fertilizer in a half-moon in front of the daughter plant leads to greater banana production, compared to the application of fertilizers to the total area. The localized application of fertilizers provides a gradient of nutrient concentrations in the soil (Neves et al., 2009), with concentrations higher near the site of application and decreasing with distance. Hence, it is necessary to establish the most suitable site for the sampling of soil to determine the chemical properties, avoiding overestimation or underestimation of nutrient concentrations.

In addition to the fertilizer application technique, the nature of the nutrient source also influences nutritional management and banana production. Recently, there has been an increase in the use of organic and organic-mineral fertilizers. However, the use of traditional mineral sources is still predominant in banana cultivation, due to the high nutrient dosages required throughout the year. For instance, doses of 200 kg N, 80 kg P_2O_5, and 400 K_2O are generally recommended for commercial banana orchards. Factors that determine the efficiency of a fertilizer include its nutritional composition and the nutrient release profile (Bley et al., 2017; Umesha et al., 2017). Organic sources provide gradual release, due to the mineralization process required to convert the nutrients from the organic form to the mineral form (Cantú et al., 2017). On the other hand, soluble mineral sources provide readily available nutrients to the plants, but this can result in momentary excess of nutrients in the soil, which can cause losses and impair root growth (Rosolem and Steiner, 2017; Yang et al., 2017).

Organic-mineral fertilizers are able to provide a more continuous supply of nutrients since there is the immediate release of nutrients from the soluble mineral source, followed by a later supply of nutrients from the organic source. In addition, the association of nutrients with organic fractions (such as humic substances) may increase soil nutrient availability (Guimarães et al., 2016). The high cation exchange capacity (CEC) and specific surface area of humic substances can reduce P fixation (Mehrizi et al., 2015; Teixeira et al., 2016), K leaching (Rosolem et al., 2017), and N losses by NH_3 volatilization (Paiva et al., 2012; Guimarães et al., 2016). However, there are no results to prove the higher efficiency of organic or organic-mineral fertilizers, relative to mineral sources, in banana production.

The present study was motivated by the possibility that fertilizer application in front of the daughter plant might be more effective for banana production, compared to the application of fertilizer over the total area. Therefore, the objectives of the work were to establish the best site for soil sampling to evaluate the chemical parameters, when fertilizer is applied in front of the daughter plant; to evaluate the efficacy of organic-mineral fertilizer in terms of soil nutrient availability; and to evaluate the effect on banana production.

MATERIALS AND METHODS

The experiment was conducted in three commercial banana plantations (Cavendish subgroup, around 15 years old) in Santa Catarina State, located in the following municipalities: Luiz Alves (26° 43′ 14″ S, 48° 55′ 58″ W), Corupá (26° 25′ 31″ S, 49° 14′ 35″ W), and Massaranduba (26° 36′ 39″ S, 49° 00′ 28″ W). The Soil Group in these three areas is classified as Cambisols (IUSS Working Group WRB, 1998) or *Cambissolos Háplicos Tb Distróficos* (Santos et al., 2013). The fieldwork was performed during the 2013/2014, 2014/2015, and 2015/2016 seasons. Accumulated rainfall and air mean temperature distribution from August 2013 to July 2016 for the three municipalities were shown in figure 1, according to Epagri/Ciram.

Three fertilizer sources were tested: mineral (formulation 14-07-28 and potassium chloride); mineral + organic compost (urea, potassium chloride, and composted poultry litter); and organic-mineral (formulation 08-04-19, provided by Adubos Ferticel®, Coronel Freire, Santa Catarina, Brazil), consisting of composted poultry litter mixed with synthetic fertilizers (ammonium sulfate, single superphosphate and potassium chloride) (Table 2). All treatment plots received a base fertilization in August of 2013, 2014, and 2015, followed by four additional applications in October, December, January, and April. An exception was for phosphate fertilizer, which was added entirely in the base application when the orchard was fertilized with the mineral or mineral + organic compost sources. The fertilizers were added to the soil using two application techniques: total area "uniformly distributed between banana planting lines and between plants" or in front of the plants (approximately 0.40 m in front of the daughter plant, in a half-moon line with a curvature of approximately 1.00 m).

The effects of combining of the two main factors (three fertilizer source: "mineral, mineral + organic compost or organic-mineral" and two application management: "either uniformly distributed between banana planting lines or in front of the plants") were evaluated together with time (three years) and location (three municipalities). The variables considered were banana bunch weight, banana plant nutrition, and soil sampling location. At each site, the two main factors were combined in six treatments (3 fertilizer sources × 2 application management) and evaluated by three production cycles. Each treatment was evaluated using a grid containing 20 banana plants (spaced at 2.5 × 2.5 m), with three replications of two plants in the central part. The experiment was arranged in a completely randomized design with three replicates.

The recommended fertilization was based on the properties of a soil sampled at a layer of 0.00-0.20 m, previously collected in the experimental banana area before starting the trial (Table 1). Limestone was applied on the soil surface in the total area of the banana orchards in Luiz Alves and Massaranduba, prior to laying out the experimental plots, according to the recommendation of CQFS RS/SC (2016). All the treatments received the same fertilization N, P, and K (in kg ha^{-1}) (Table 2), following the recommendation of CQFS RS/SC (2016). The aim was to provide the amounts of N, P_2O_5, and K_2O required for an estimated banana production of 50,000 kg ha^{-1} yr^{-1}. The fertilization using the mineral source was performed with an initial application (base fertilization) followed by four further applications of urea and potassium chloride (Table 2). The fertilization using the mineral + organic compost source was performed with poultry litter (3.8, 3.5, and 2.5 %

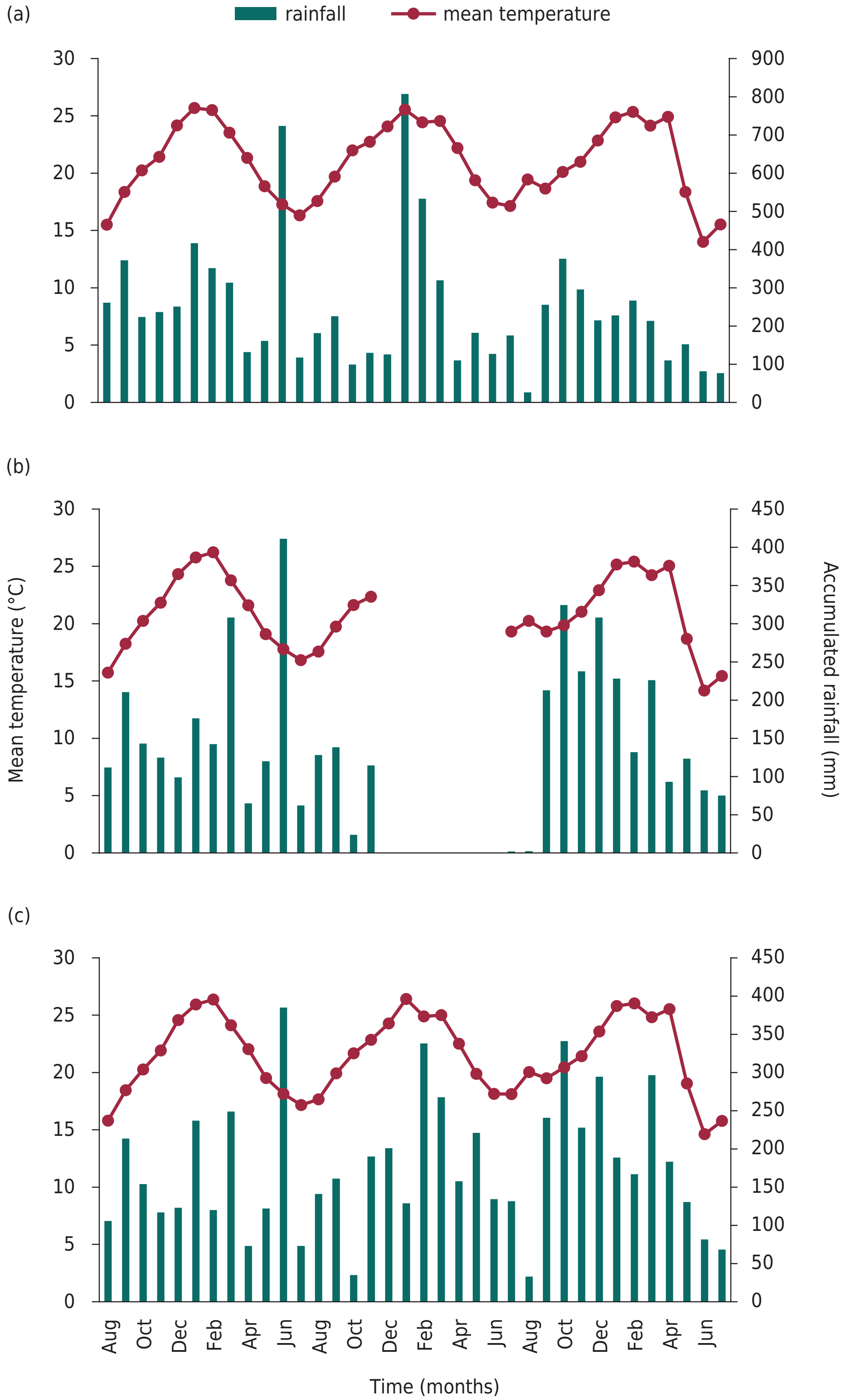

Figure 1. Accumulated rainfall and air mean temperature distribution from August 2013 to July 2016 for the municipalities of Corupá (a), Massaranduba (b), and Luiz Alves (c). Data discontinuity for the municipality of Massaranduba from December 2014 to July 2015. Data from Epagri/Ciram.

of N, P_2O_5, and K_2O, respectively) at the beginning of the experiment (base fertilization), fulfilling the phosphorous requirements, followed by four additional applications of urea and potassium chloride. According to CQFS RS/SC (2016), poultry litter presents a dry matter content of 75 %, N mineralization rate of 70 % of total N yr^{-1}, and P_2O_5 and K_2O

Table 1. Chemical analyses of the soil sampled in July 2013 at a layer of 0.00-0.20 m in the experimental areas with banana located in three different municipalities of Santa Catarina State

Experimental location	$pH(H_2O)$[1]	P	K	Ca^{2+}	Mg^{2+}	H+Al	CEC[2]	OM[3]	V[4]	Clay[5]
		mg dm^{-3}		cmol$_c$ dm^{-3}				%		g kg^{-1}
Corupá	6.5	37.8	153.4	7.4	2.9	2.0	12.7	2.0	84.4	287
Massaranduba	5.3	35.9	150.0	3.2	1.2	3.2	7.9	2.1	59.8	257
Luiz Alves	5.1	14.5	103.1	3.2	1.9	4.1	9.5	2.9	56.4	302

(1) pH determined in H_2O (soil:water ratio equal to 1:2.5); (2) CEC: cation exchange capacity; (3) OM: organic matter by the Walkley-Black method; (4) V: percentage of soil base saturation. (5) Densimeter method.

Table 2. Characterization of fertilizers applied in base and in additional applications in banana crops of Santa Catarina State

Fertilizer source	Base fertilization	Additional fertilization[1]	Total applied		
			N	P_2O_5	K_2O
	kg ha^{-1}				
Mineral	800 (14-07-28)	915 (14-07-28) + 150 (KCl)	240	120	570
Mineral + organic	4600 (poultry litter)[2]	330 (urea) + 806 (KCl)	240	120	570
Organic mineral	600 (08-04-19)[3]	2400 (08-04-19)	240	120	570

(1) The additional application was divided into four applications; (2) Dry matter content 75 %; N content 3.8 %, P_2O_5 content 3.5%, K_2O content 2.5 %. (3) Composted poultry litter mixed with synthetic fertilizers (ammonium sulfate, single superphosphate, and potassium chloride).

mineralization rates of 100 % yr^{-1}. Finally, the fertilization using the organic-mineral source was divided into an initial application (base fertilization) and a further four applications of the same source. These procedures were adopted for all years of the study. Finally, banana plantation management was carried out according to technical recommendations for this crop (Livramento and Negreiros, 2017).

Soil samples were collected in the years of 2013, 2014, and 2015, in the month (July) preceding the beginning of fertilization of the following harvest, as well as in the last year of the study (July 2016). The sampling was performed between the plant lines, when the fertilizers were applied over the total area, or at distances of 0.30, 0.60, 0.90, and 1.20 m from the site of fertilizer application, when the treatments were applied in front of the plants. For each area evaluated, five sub-samples were collected (at the layer of 0.00-0.20 m), to obtain average values for the nutrient contents in the fertilized area. In the years 2015 and 2016, analysis of nutrients contents in the leaves (average N, P, K, Ca, and Mg contents) was performed using the third youngest banana leaf, collected during the flowering stage, as described by Martin-Prével (1984). Two plants per replicates were evaluated, totaling six plants per treatment. The soil and leaf samples were analyzed according to Tedesco et al. (1995) and Malavolta et al. (1997), respectively. The banana yield was evaluated for all the treatments during the three harvest periods. The harvesting and weighing of the bunches were conducted when banana fruits were showed suitable diameter for commercialization according to Lichtemberg et al. (2016).

An exponential model was fitted to the soil P and K contents as a function of soil collection distance, to determine the location of soil collection that represented the mean nutrient contents, when the fertilizers were applied in front of the daughter plant. Linear regression analysis was used to evaluate changes in soil properties caused by the fertilizer sources or the application strategies, as a function of successive soil fertilizations during three production cycles, adopting a significance level of 10 %. The data for the available nutrients in the leaves and the fruit yield were subjected to analysis of variance (ANOVA) and Tukey's test when it was appropriate. Tests for normality and variance homogeneity were applied. In addition, Person correlation analysis was applied to the soil K contents, the leaf N, P, and K contents, and the fruit yield. Statistical analyses were performed using Statistica 7.0 software, adopting a significance level of 5 %.

RESULTS

The concentration gradients of soil available P and K, as a function of distance from the location of fertilizer application in front of the daughter plant were presented in figure 2. The nutrient concentrations decreased exponentially until reaching values close to those in the bulk soil. Considering the P and K contents for all the samples, the distance of the midpoint of the P content (67.5 cm from the daughter plant) was shorter than the distance of the midpoint for K (71.2 cm from the daughter plant).

The soil parameters that were influenced by the different sources or by the fertilizer application strategy, as a function of the successive soil fertilization, were shown in table 3. The mineral source reduced the pH over the years. An additional point to note is that the application of the fertilizers in front of the daughter plant did not intensify the soil acidification.

Regardless of the source used, the soil P levels only increased over the years when the fertilizers were applied in front of the daughter plant (Table 3), with the highest increase of the P content for the soil fertilized with the organic-mineral source, as indicated by the greater slope of the line (parameter "b"). On the other hand, there was no increase

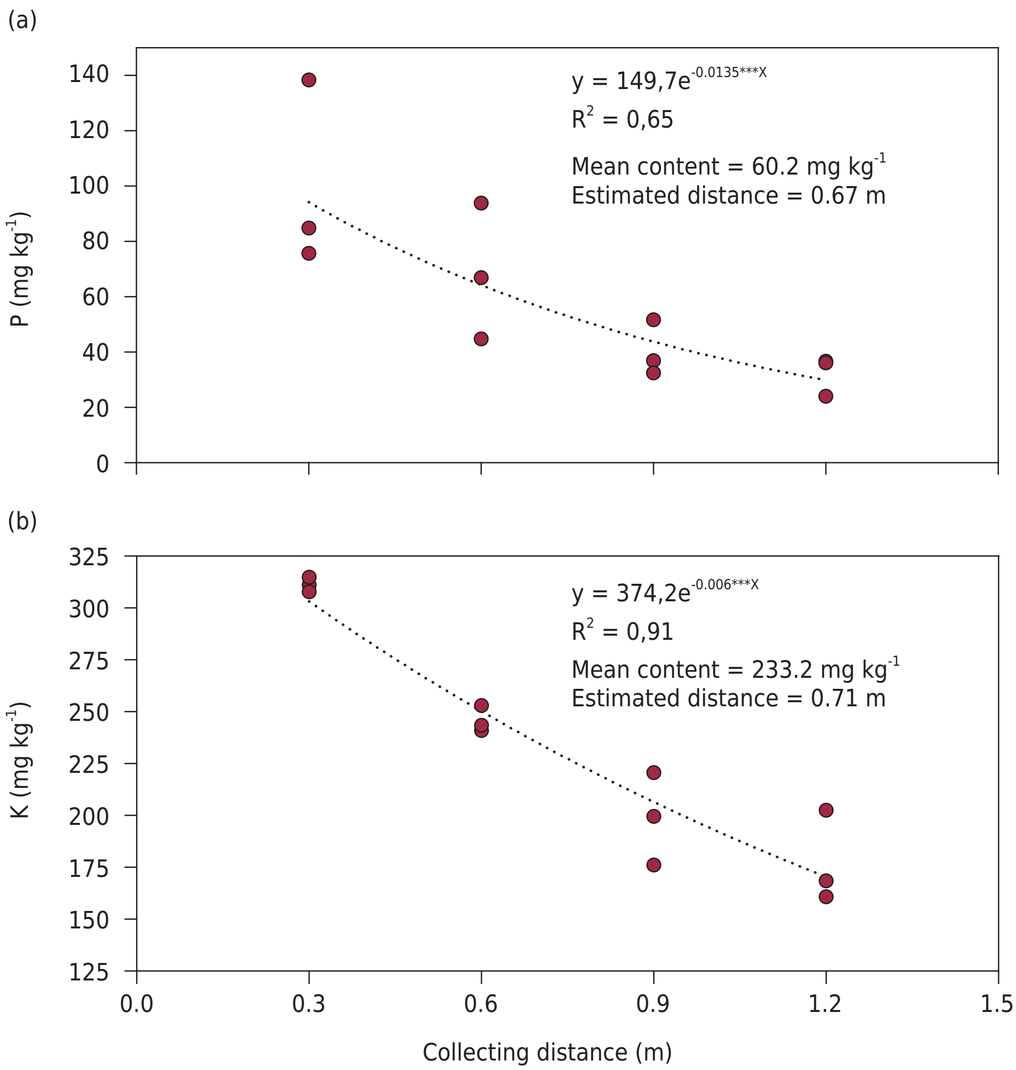

Figure 2. Phosphorus (a) and potassium (b) contents as a function of distance that fertilizer was applied soil. Mean content of P and K (available in Mehlich-1) between 0.30-1.20 m and estimated distance for soil collecting that represents the mean content in front of the banana plant. Estimated distance "*x*" was calculated using the equation: $x = [-ln(y)-ln(a)]/b$, where *y* correspond to the mean concentration, *a* and *b* are exponential equation parameters.

Table 3. Equation parameters to soil pH, soil available P and K (Mehlich-1), and soil organic matter (OM), of different fertilizer sources or application form as a function of successive soil fertilization (2013/2014, 2014/2015, and 2015/2016), evaluated in three locations of Santa Catarina State

Fertilizer source[(1)]	Parameters[(2)]	pH	P	K	OM
Mineral	Intercept (a)	504.07	-14971.2	-	-
	Slope (b)	-0.25***	7.45**		
	r^2	0.66	0.60		
Mineral + organic compost	Intercept (a)	-	-18153.4	-110843.6	-
	Slope (b)		9.04*	55.12***	
	r^2		0.34	0.80	
Organic mineral	Intercept (a)	-	-42090.6	-132844.5	-
	Slope (b)		20.93***	66.05***	
	r^2		0.76	0.89	
Application technique[3]					
Total area	Intercept (a)	-	-	-77537.8	-
	Slope (b)			38.58***	
	r^2			0.53	
Front of daughter plant	Intercept (a)	-	-27634.9	-126324.0	-610.5
	Slope (b)		13.75**	62.81***	0.30*
	r^2		0.40	0.91	0.21

[(1)] Means of locations and application techniques; [(2)] Equation: $y=a+bx$, where "x" is time in years. [(3)] Means of locations and sources. Significant correlations at probability of ≥99 % (***), ≥95 % (**), and ≥90 % (*); model not fitted (-).

in the soil P concentration where the total area was fertilized for three consecutive years. Only the soil fertilized with the mineral source did not show an increase in soil K concentration during the trial period (Table 3). The other treatments led to increased K concentrations in the soil, regardless of the application technique. However, the increase was more intense when the fertilizer was applied in front of the daughter plant.

Although fertilization with the mineral + organic compost and organic-mineral sources included the addition of organic compounds, no increases in soil organic matter content were observed during the trial period when the fertilizers were applied to the total area. On the other hand, a small increase in soil organic matter was observed when the fertilizers were applied in front of the daughter plant (Table 3). Despite the differences related to the management and age of the banana orchard, the original characteristics of the soil (Table 1), and the climatic conditions of experimental sites, the N, P, K, Ca, and Mg leaf contents presented small variations for the different treatments (Table 4). Regarding the time factor (years), an increase in foliar N, P, and K content was observed from 2015 to 2016, in response to fertilization. However, no difference was observed in relation to the fertilizer sources used. On the other hand, the strategy of fertilization in front of the daughter plant led to increased K and decreased Ca in the banana leaves.

In terms of banana production, there was an increase in the weight of bunches harvested in the year of 2015, compared to the previous crop (2014) (Table 5), which could be associated with the improvement of the soil fertility provided by the fertilization treatments (Table 3). However, no increase was observed between the 2015 and 2016 harvests. The orchards fertilized only with the mineral source presented the highest bunch weights, as compared to the other fertilizer treatments. The application of the fertilizer in front of the daughter plant led to an increase in yield, compared to the application in the total area, independent of the fertilizer source or the experimental site.

Table 6 shows the Pearson correlation coefficients (r) for variables, considering the soil K (K-Soil), the leaf K, Ca, and Mg concentrations (K-leaf, Ca-leaf, and Mg-leaf), and the

Table 4. Leaf contents of N, P, and K in banana plants as a function of time (year), fertilizer source, and fertilizer application technique, evaluated in three locations of Santa Catarina State

Factors	N	P	K	Ca	Mg
	g kg^{-1}				
Time[1]					
2015	**18.45 b***	**1.84 b**	**34.46 b**	**6.90 a**	**3.66 a**
2016	**22.97 a**	**2.45 a**	**49.09 a**	**5.28 b**	**2.90 b**
Fertilizer source[2]					
Mineral	21.27 a	2.18 a	40.23 a	5.56 a	3.15 a
Mineral + organic compost	20.70 a	2.13 a	40.23 a	6.61 a	3.45 a
Organic-mineral	20.16 a	2.14 a	43.91 a	6.10 a	3.24 a
Application technique[3]					
Total area	20.81 a	2.14 a	**38.86 b**	**6.58 a**	3.36 a
Front of daughter plant	20.61 a	2.15 a	**44.69 a**	**5.60 b**	3.20 a

[1] Means of locations, sources, and application techniques; [2] Means of locations, years, and application techniques; [3] Means of locations, years and sources. *: means followed by the same letter in a column indicate no significant difference (Tukey's test, p≤0.05).

Table 5. Banana bunch weight as a function of time, fertilizer source, and fertilizer application technique, evaluated in three locations of Santa Catarina State

Factors	Banana bunch weight
	kg plant^{-1}
Time[1]	
2014	29.59 b*
2015	34.80 a
2016	35.95 a
Fertilizer source[2]	
Mineral	36.17 a
Mineral + organic compost	33.07 b
Organic-mineral	31.10 b
Application technique[3]	
Total area	31.85 b
Front of daughter plant	35.04 a

[1] Means of locations, sources and application techniques; [2] Means of locations, years, and application techniques; [3] Means of locations, years, and sources. *: means followed by the same letter in the column indicate no significant difference (Tukey's test; p≤0.05).

Table 6. Pearson correlation coefficients[1] (r) for variables soil K concentration (K-soil), and leaf K, Ca, and Mg concentrations (K-leaf, Ca-leaf, and Mg-leaf), and bunch weight, evaluated in three locations of Santa Catarina State

Parameters	K-leaf	Ca-leaf	Mg-leaf	Bunch weight
K-soil	0.449**	-0.576**	-0.245^{ns}	-0.358*
K-leaf		-0.642**	-0.693**	0.068^{ns}
Ca-leaf			0.581**	0.071^{ns}
Mg-leaf				-0.186^{ns}

[1] Coefficients adjusted from means of locations, years, sources, and application techniques. Note: significant correlation at the probability of ≥99 % (**) and ≥95 % (*); ns: not significant.

bunch weight. The positive correlation of K-soil with K-leaf, indicating that the increase of the soil K concentration led to increased K accumulation in the plant. However, there was a negative correlation between K-soil and bunch weight, suggesting that the increase of the K concentration in the soil caused banana productivity to decrease. In addition, K-leaf showed negative correlations with Ca-leaf and Mg-leaf. Finally, non-significant correlations were observed between bunch weight and the variables K-leaf, Ca-leaf, and Mg-leaf.

DISCUSSION

The decreasing in the soil pH observed after the application of mineral fertilizers could be attributed to the acid character of the components of synthetic fertilizers, especially nitrogen compounds such as urea (Tian and Niu, 2015). The process of nitrification of NH_4^+ is one of the main factors responsible for soil acidification caused by the application of these fertilizers (Rice and Herman, 2012; Cantú et al., 2017). On the other hand, the presence of organic matter in the mineral + organic compost and organic-mineral sources prevented the effect of acidification, possibly due to the acid buffering capacity of organic substances (Caires et al., 2015). This acidity buffering capacity is related to the chemical diversity of the functional groups present in the organic compounds, such as carboxylic and phenolic groups, which are able to remove H^+ from the soil solution by protonation of the functional groups (Silva and Mendonça, 2007).

The P and K concentrations in soil samples collected at 1.20 m from where fertilizers were applied in front of the plants were similar to the average bulk soil concentrations (Table 1; Figure 2). This suggested that under these conditions, the availability of nutrients was altered up to 1.20 m from the place where the fertilizer was applied. The average concentrations for the area evaluated (between 0.30 and 1.20 m from the place where the fertilizers were applied) were representative of the nutrient levels in the soil region corresponding to the majority of the root system of the banana plant (Silva et al., 2018).

Based on the data of figure 2, it was possible to estimate the collection distance at which the soil fertility corresponded to the average for the fertilized area (up to 1.20 m from the point where the fertilizers were applied in front of daughter plants). The distance of the midpoint for the K concentration (0.72 m) was 0.04 m greater than the midpoint for the P content (0.68 m). Under these conditions, it could, therefore, be proposed that soil sampling for chemical analysis should be carried out at around 0.70 m from the point of fertilizer application. The greater distance observed for the midpoint of the K concentration could be explained by the higher diffusion coefficient for K in the soil, compared to P (Novais and Mello, 2007).

The results of this study could provide the basis for future recommendations concerning the collection of soil samples to establish fertilization dosages when fertilizers are applied in a half-moon in front of the daughter plant. Currently, different fertilization manuals recommend the collection of soil at random points in the total area or in the plant line at the site of fertilization (Borges et al., 2015; CQFS RS/SC, 2016; Natale and Rozane, 2018). There is no established recommendation for the case of fertilization in a half-moon in front of the daughter plant. In this situation, erroneous sampling, such as random sampling, could result in errors in establishing fertility and soil fertilization recommendations, leading to economic losses (Ratke et al., 2012; Nomura et al., 2016) and environmental impacts (Cantú et al., 2017). It should be noted that there were no changes in the concentrations of the other nutrients evaluated in the soil analysis since the recommended fertilization was performed only with N, P, and K during the experimental period. In addition, the mineral N content was not quantified due to the lack of routine laboratory analyses.

The greater increases of the soil P concentration observed with organic-mineral (slope of 22.9) and mineral + organic compost (slope of 9.0) treatments, compared to the mineral treatment (slope of 7.4) could be related to the interaction of P with the organic components of the fertilizers. The colloids of the humic substances have high CEC and high specific surface area, which can reduce the adsorption sites for P in the soil, leading to greater diffusion and consequently higher availability of this nutrient in the soil solution (Mehrizi et al., 2015; Teixeira et al., 2016). In the same way, the presence of the humic substances in the organic-mineral and mineral + organic compost sources provided a greater availability of K, compared to the mineral fertilizers. The CEC associated with the organic compounds contributes significantly to the adsorption of exchangeable K in the soil, reducing its leaching and consequently increasing its concentration in the soil (Neves et al., 2009; Rosolem et al., 2017).

Increases in the levels of soil P, K, and organic matter for the treatments with fertilizer applied in front of the plants, relative to the fertilizer applied over the total area, could be attributed to the higher concentration of the application in front of the daughter plant. In addition, the localized application of the fertilizer reduced the contact area with the soil surface, so there was a lower loss of P by adsorption (Fontoura et al., 2010; Jing et al., 2012). These results demonstrated that the strategy of fertilization in front of the daughter plant was able to optimize the availability of nutrients, prioritizing the area that supplied the greater part of the nutritional demand of the banana plant. However, further studies will be needed to review the recommended dosages of nutrients when using this application technique is required, to avoid unnecessary accumulation of the elements in the soil.

The similar values of nutrient concentrations in the banana leaves indicated that the evaluated fertilizers adequately met the plant demand, regardless of the composition of the source. According to CQFS RS/SC (2016), only N leaf contents (~20 g kg^{-1}) were below the range considered satisfactory (27 to 36 g kg^{-1}) for banana plants. However, considering the high dosages of N applied to the soil and since no visual symptoms of N deficiency were observed during the experiments, the N dosages suggested by CQFS RS/SC (2016) may be overestimated for banana growing conditions in Santa Catarina State. Pauletti and Motta (2017) suggested lower minimum values and a wider range of leaf N contents (17 to 36 g kg^{-1}).

In the second harvest (2015), the increases of P and K leaf contents (Table 3) could have contributed to higher fruit production, as reported by Nomura et al. (2016). On the other hand, even with the increased foliar levels of N, P, and K between 2015 and 2016 (Table 5), there was no significant increase in the bunch weight in 2016. These results reflected the low response of the banana plants to P and K fertilization from the moment that soil P and K levels reached very high levels. Although the leaf N, P, and K contents were similar for the different fertilizer sources used (Table 4), the orchards fertilized only with the mineral source presented higher bunch weight (Table 5). This suggested that the productivity was not related to the amounts of nutrients that were supplied to the plants, but rather to the supply strategy. The supply of nutrients exclusively using the soluble source, as well as the splitting of the dosages during the greatest demand of the plant, may have contributed to the higher fruit production. The sources that contained part of the nutrients in organic forms required mineralization of this fraction before it became available to the plants (Cantú et al., 2017). Furthermore, the mineralization of nutrients from organic compounds depends on several factors, such as temperature, humidity, the composition of the organic material, application form, microbiota, and soil pH (Cantú et al., 2017).

As expected, the higher K content in the soil led to increased absorption of this nutrient by the banana plants. However, a fraction of the nutrients absorbed by plants may become accumulated in the vacuoles of the cells without exerting physiological functions (Chapin, 1980). Excess absorption of nutrients by plants is commonly termed “luxury consumption” and can cause nutritional imbalance. Intense K absorption can reduce the absorption of other cations, such as Ca and Mg, due to antagonism between the elements (Natale and Rozane, 2018). In the present work, the increased K content and the decreased Ca and Mg contents in the leaves between the years 2015 and 2016 (Table 4) could be due to such antagonism between these elements.

Considerable attention has been given to the nutritional balance for fruit production (Parent, 2011; Deus et al., 2018). The absolute nutrient content in the plant does not guarantee high yields in fruit production (Natale and Rozane, 2018). The balance of nutrients (proportionality among the nutrients) plays a more important role in determining the productive potential of the plant. Hence, the absence of correlation and even negative correlation observed between bunch weight, and the parameters K-soil, K-leaf, Ca-leaf, and Mg-leaf could be related to nutritional imbalance.

The higher yields obtained with the application of the fertilizer in a half-moon in front of the daughter plant could be attributed to the higher concentration of new roots distributed in front of the daughter plant (Donato et al., 2016), which have a greater capacity for absorption of nutrients, compared to the roots of the mother plant, located on the opposite side. The mean increase in bunch weight of 3.2 kg obtained with application in front of the daughter plant, compared to the application over the total area, representing an increase in productivity of 5120 kg ha^{-1} for a banana orchard with 1600 plants ha^{-1}. This relevant increase in fruit production could increase the income of the producer, without any additional costs, only by optimizing the fertilized area to achieve greater fertilizer efficiency.

CONCLUSIONS

The application of fertilizer in front of the daughter plant can improve banana nutritional management and increase fruit production. Under this fertilization management strategy, soil sampling for chemical analysis should be performed at around 0.70 m from the site of fertilizer application. Banana orchards fertilized exclusively with mineral sources presented higher fruit yields, compared to fertilization with organic-mineral sources. However, the use of the organic-mineral sources provided lower acidification and greater P and K availability of the soil. There was also evidence that an excessive increase in soil K concentration could induce plant nutritional imbalance and reduce the productive potential. Therefore, further studies of banana fertilization management strategies are required, focusing on improving the nutritional balance.

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