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Rock biofertilizer and earthworm compost on sugarcane performance and soil attributes in two consecutive years

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ABSTRACT: The deployment of soluble fertilizers has been one of the most commonly applied agricultural practices in the bid to increase crop yield. However, the production of soluble fertilizers has a considerable economic cost and consumes a substantial amount of energy. In general, soil organic matter provides the nutrients needed for plant growth in organic agriculture. However, these nutrients are not sufficient if the best yield is to be obtained. The aim of our field experiment was to evaluate the effectiveness of phosphate and potassic sources (rocks, biofertilizers and soluble fertilizers) based on several sugarcane characteristics and soil attributes. Our experiment was conducted over two consecutive years, and we assessed the effect of using sugarcane filter mud cake (SFMC). In addition, we mixed the phosphate and potassic sources with earthworm compost enriched in N by inoculation with diazotrophic bacteria (OM) and applied at 50, 100 and 150 % of the recommended dosage rate (RDR). The PK biofertilizer with OM enriched in N positively affected sugarcane height, yield, and industrial characteristics. The application of SFMC greatly increased available P and K in the soil and plant characteristics with residual effect in the two consecutive harvests. We conclude that the biofertilizer has the potential to increase sugarcane characteristics and may represent an alternative to soluble fertilizers.
Keywords: *Acidithiobacillus*, organic fertilization, organic matter, soil nutrients, sulfur oxidation

Introduction

In northeastern Brazil, the state of Pernambuco is an important sugarcane center for the production of ethanol and sugar. The total cropped area is approximately 284 thousand hectares, with low productivity equivalent to 50.6 t ha^{-1}. In addition to increased yields, the application of soluble fertilizers has been the most commonly used agricultural practice. However, the production of soluble fertilizers not only has a considerable economic cost but also consumes a substantial amount of energy and may lead to environmental problems due to the leaching of soluble nutrients through to deeper soil layers (Straaten, 2007). Despite these facts, tropical soils generally have low available P and K nutrient levels, and renewable sources of natural products are absolutely necessary for the rational use of fertilizers for this agriculture (Elsayed et al., 2008). Furthermore, P and K minerals must be solubilized by specific microorganisms to release their nutrients in forms that are available to plants. A viable alternative to P and K soluble fertilizers is the use of rocks to produce biofertilizers, which can be mixed with elemental sulfur inoculated with *Acidithiobacillus* bacteria. This species is a sulfur oxidative bacterium that releases nutrients from minerals because of the sulfuric acid produced by its metabolic reactions (El Tarabily et al., 2006).

Unfortunately, rocks do not contain nitrogen, and PK rock biofertilizer must be mixed with organic matter to introduce the N required both for plant growth and to neutralize the acidic biofertilizer reaction (Lima et al., 2010). The effectiveness of PK rock biofertilizers mixed with organic matter has been reported in experiments using annual plants, such as cowpea (Stamford et al., 2008, 2011) and melon (Oliveira et al., 2014), grown in both acidic and alkaline soils.

The goal of this study was to evaluate the effectiveness of biofertilizer produced from P and K rocks with elemental sulfur inoculated with *Acidithiobacillus* bacteria and with earthworm compost. In addition, we tested the use of sugarcane filter mud cake (SFMC) to provide nutrients for plant growth and to neutralize the acidity of the PK rock biofertilizer. The PK sources (rocks and biofertilizers) applied at different dosage rates were compared with soluble fertilizers, and their effects on the growth and industrial characteristics of sugarcane and several soil attributes were assessed based on two consecutive crop seasons.

Materials and Methods

A field experiment was conducted on a sugarcane field located in Goiana, Pernambuco, Brazil (07° 33' S and 35° 00' W; altitude 13 m). A sandy loam soil, representative of the Typic Fragiudult from the tableland rainforest region with low available P and K levels, was used. Based on Embrapa methodology (2009), a soil analysis from samples collected from the experimental area (0-30 cm layer) produced the following values: pH (H_2O 1.0:2.5) of 6.0, total N of 0.6 g kg^{-1}, organic C of 8.7 g kg^{-1}, and available P of 4.2 mg kg^{-1}. The exchangeable cation concentrations were as follows: Ca^{2+} of 10.0 mmol$_c$ kg^{-1}, Mg^{2+} of 8.8 mmol$_c$ kg^{-1}, and K^+ of 1.2 mmol$_c$ kg^{-1}. A physical analysis revealed the following: soil particle density of 2.65 g kg^{-1} and bulk density of 1.54 g kg^{-1}. Finally, a granulometric analysis showed the following characteristics: coarse sand, fine sand, silt, and clay concentrations of 740.0 g kg^{-1}, 210.0 g kg^{-1}, 10.0 g kg^{-1}, and 40.0 g kg^{-1}, respectively.

The rock biofertilizers used in this study were produced from P natural phosphate and K rock (biotite), using two furrows (each 10.0-m long, 1.0-m wide and 0.5-m deep). For each biofertilizer, 4000 kg of natural phosphate (total P = 240.0 g kg^{-1}) purchased from Irecê (Bahia, Brazil) and 4000 kg of potash rock (biotite; total K = 100.0 g kg^{-1}) from Santa Luzia (Paraiba, Brazil) were mixed with 400 kg of elemental sulfur inoculated with *Acidithiobacillus thiooxidans* following the methodology of Stamford et al., (2008).

The sulfur oxidative bacteria grew in 2000 mL Erlenmeyer flasks containing 1000 mL of specific culture medium (El Tarabily et al., 2006); the culture was sterilized for 30 min at 120 °C and shaken (150 rpm) for 5 days at 30 °C. These materials (phosphate, potash rocks and elemental sulfur inoculated with *Acidithiobacillus*) were incubated for 60 days, and water content was maintained at a level that was near the field holding capacity. To avoid the effects of excessive moisture due to rain and to increase the efficiency of the oxidative bacteria, the furrows were covered every day using black plastic. An analysis of BP and BK extracted by (A) Mehlich 1 solution and (B) citric acid according to Embrapa (2009) yielded the following results: BP-biofertilizer pH = 3.8, available P (A) = 60 g kg^{-1}, available P (B) = 48 g kg^{-1}, BK biofertilizer pH = 3.3, available K (A) = 10 g kg^{-1} and available K (B) = 0.5 g kg^{-1}.

The soil was prepared for sugarcane cultivation, cutting and removal of all vegetation in the experimental area that had not been cultivated for five years following conventional tillage with one plow and two disk operations. Afterwards, rows were simultaneously opened for sugarcane stalk planting and fertilizer application. Each plot had five 10-m-long rows separated by 1 m; data were collected from the two central rows (10 m^2) only. Irrigation and other management practices followed the recommendations of the Sugarcane Industry.

The experiment was conducted in an incomplete factorial (3 × 3 + 1) + 3 randomized block design with four replicates. We used 3 sources of PK (rocks, biofertilizers and soluble fertilizers) applied at 50, 100 and 150 % of the recommended dosage rate (RDR). The PK sources were mixed with organic matter (OM) produced from earthworm compost enriched with N produced by selected free-living diazotrophic bacteria in accordance with Lima et al., (2010). The fertilization treatments were tested in two consecutive crop seasons with and without SFMC. The SFMC was applied at a dosage rate of 40 t ha^{-1}.

The amount of PK biofertilizer was calculated based on P and K soluble mineral fertilizers by using the same amount for each corresponding treatment and following the RDR for sugarcane in Pernambuco (IPA, 2008). Based on experimental results, the fertilizer and biofertilizer application dosage rates were the same: dosage 1 = 80 kg ha^{-1}, dosage 2 = 160 kg ha^{-1} and dosage 3 = 240 kg ha^{-1}. For rocks, the dosage rates were the following: dosage 1 = 160 kg ha^{-1}, dosage 2 = 320 kg ha^{-1} and dosage 3 = 480 kg ha^{-1}.

The P and K soluble fertilizers contained simple superphosphate (20 % P_2O_5) and potassium sulfate (50 % K_2O), respectively. We determined the plant yields and heights. Moreover, several sugarcane characteristics were assessed, such as the soluble solid concentration (Brix), apparent sucrose (Pol), purity (Pur) and total recoverable sugars (TRS). Technical analyses were conducted following the methodology used in the Sugarcane Industry. Several soil chemical attributes were analyzed (Embrapa, 2009), to test the effects of the different fertilization treatments in two consecutive harvests with and without SFMC.

A statistical analysis was performed utilizing SAS (SAS Institute, 2011) version 11.0 using Tukey's test to compare the means ($p > 0.05$).

Results and Discussion

The heights of sugarcane plants subjected to the different fertilization treatments are shown in Table 1. Significantly positive effects of sugarcane fertilization were observed, especially in plants that received biofertilizer applications at greater rates. The effects of sugarcane residues were described by Dario et al., (2003), who found an increase in sugarcane yield under field conditions. Kaur et al., (2005) also described significant effects of nutrients in the shoot height of sugarcane. However, our results show that plants that received the biofertilizer treatment were taller and significantly different from plants that received the mineral soluble fertilizer treatment for all application rates. These results demonstrate the potential of biofertilizer application for sugarcane.

The sugarcane yields in the two cropping years are presented in Table 2. The effectiveness of the PK rock biofertilizers mixed with earthworm compost is evident; the best results were obtained when applied at the highest dosage rates. These results are in agreement with Santos et al., (2010), who found a correlation between sugarcane yield and fertilizer application. Moreover, Santos et al., (2010) found that organic matter promoted a higher yield in sugarcane, probably because the organic matter released P, Ca and other nutrients that are necessary for plant nutrition. Likewise, these results are in agreement with the greenhouse studies of Stamford et al., (2006, 2008). These authors concluded that a PK rock biofertilizer mixed with earthworm compost may be an alternative to mineral soluble fertilizers. Furthermore, residual fertilizer effects may be observed, especially when applying PK rock biofertilizer mixed with sugarcane mud cake.

Table 1 – Plant height as affected by PK (phosphate and potassium) fertilization, at different times (days after plantation) of growth, mixed with OM – Organic Matter (earthworm compost) applied in different rates with and without sugarcane filter mud cake (SFMC).

Growth time (days) Fertilization	100	150	200	250	300
	Plant height				
	cm per plant				
SFMC (40 t ha^{-1})					
PK Fertilizer$_1$ 80 + OM 5	29.3 a	61.4 ab	94.0 b	134.5 ab	188.0 ab
PK Fertilizer$_2$ 160 + OM 10	34.6 a	62.3 ab	103.5 a	143.0 a	185.0 ab
PK Fertilizer$_3$ 240 + OM 15	30.1 a	63.4 ab	102.5 a	142.5 a	191.7 a
PK Biofertilizer$_1$ 80 + OM 5	29.9 a	61.8 ab	102.0 a	123.2 b	177.5 b
PK Biofertilizer$_2$160 + OM 10	27.6 a	68.1 a	99.0 ab	144.7 a	180.7 b
PK Biofertilizer$_3$ 240 + OM 15	30.3 a	69.6 a	97.8 ab	138.7 ab	185.0 ab
Rocks$_1$ 160 + OM 5	28.2 a	59.0 b	89.0 b	112.7 b	173.0 b
Rocks$_2$ 320 + OM 10	29.0 a	60.6 b	91.0 b	112.5 b	176.2 b
Rocks$_3$ 480 + OM 15	27.9 a	61.1 ab	92.5 b	122.7 b	172.0 bc
Control (P_0K_0) + OM 15	24.6 a	47.0 c	72.0 c	91.5 c	136.2 d
Without SFMC					
PK Fertilizer$_2$ 160 + OM 10	28.6 a	56.2 b	89.0 b	125.0 b	187.0 ab
PK Biofertilizer$_2$ 160 + OM 10	26.9 a	60.4 ab	92.1 b	124.0 b	179.5 b
Rock$_2$ 320 + OM 10	32.8 a	59.4 b	94.0 b	118.2 b	160.5 c
C.V. (%)	20.42	11.70	10.65	9.30	4.17

RR (Recommended rate – IPA, 2008). PK Fertilizers and PK biofertilizers applied in rates (50, 100 and 150 % Recommended rates - RR), equivalent to (kg ha^{-1}): 1 = 80; 2 = 160 and 3 = 240. For Rocks 1 = 160; 2 = 320 and 3 = 480. C.V. (Coefficient of Variation). Data with the same letter are not significant as per Tukey's test ($p \leq 0.05$).

Table 2 – Total sugarcane productivity- TSP (t ha^{-1}) in two consecutive harvests as affected by PK fertilization treatments, with OM – Organic Matter (earthworm compost) with and without sugarcane filter mud cake (SFMC).

Fertilization treatments	Total Sugarcane Productivity (TSP - t ha^{-1})	
	First harvest	Second harvest
SFMC (40 t ha^{-1})	t ha^{-1}	
PK Fertilizer$_1$ 80 + OM 5	$70.5^{Ba} \pm 1.21$	$69.5^{Ca} \pm 2.30$
PK Fertilizer$_2$ 160 + OM 10	$71.2^{Ba} \pm 1.00$	$73.2^{Ba} \pm 0.85$
PK Fertilizer$_3$ 240 + OM 15	$78.7^{Ba} \pm 1.98$	$80.2^{Ba} \pm 1.33$
PK Biofertilizer$_1$ 80 + OM 5	$65.7^{Bb} \pm 2.57$	$75.8^{Ba} \pm 3.30$
PK Biofertilizer$_2$ 160 + OM 10	$72.2^{Bb} \pm 2.32$	$80.8^{Ba} \pm 0.77$
PK Biofertilizer$_3$ 240 + OM 15	$89.7^{Ab} \pm 2.76$	$94.2^{Aa} \pm 2.80$
Rocks PK$_1$ 160 + OM 5	$50.0^{Ca} \pm 2.86$	$50.9^{Da} \pm 2.76$
Rocks PK$_2$ 320 + OM 10	$62.0^{Ca} \pm 1.61$	$61.8^{Ca} \pm 1.00$
Rocks PK$_3$ 480 + OM 15	$62.0^{Ca} \pm 1.21$	$64.5^{Ca} \pm 1.23$
Control (P_0K_0) + OM 15	$43.5^{Ea} \pm 2.57$	$41.5^{Ea} \pm 2.80$
Without SFMC		
PK Fertilizer$_2$ 160 OM 10	$56.2^{Da} \pm 2.86$	$56.6^{Da} \pm 2.82$
PK Biofertilizer$_2$ 160 + OM 10	$65.5^{Ca} \pm 2.81$	$65.9^{Ca} \pm 2.56$
Rock PK$_2$ 320 + OM 10	$50.5^{Da} \pm 1.98$	$49.2^{Ea} \pm 1.98$

Data with the same letter are not significantly different (capital letters comparing the fertilization treatments and low letters compare the two crop harvest) as per Tukey's test ($p \leq 0.05$).

The effects of the fertilization treatments on the industrial characteristics of the sugarcane crops are shown in Table 3. The application of organic biofertilizer exhibited no significant difference ($p > 0.05$) with regard to purity and fiber characteristics when compared with other fertilization treatments. In general, the PK rock biofertilizer exhibited better plant parameters, probably due to the effects of nutrient availability in the soil. The biofertilizer and the mineral soluble fertilizer applied at the highest dosage rate exhibited the best results when compared with other fertilization treatments. Stamford et al., (2008) reported significant effects of PK rock biofertilizers inoculated with *Acidithiobacillus* on some characteristics of sugarcane and observed the best effectiveness when compared with mineral NPK fertilizer.

The data regarding total soluble solids (Brix) and apparent sucrose (Pol) for the different fertilization treatments are also shown in Table 3. The best Brix and Pol sucrose values were produced by the treatment with PK rock biofertilizer, which agrees with Santos et al., (2010), who also found greater Brix and Pol values when sugarcane was fertilized with mud cake. The Brix results demonstrate the advantage of applying biofertilizer at 100 and 150 % of the RDR, especially at the higher dosage rate. The Pol values were greater when the PK rock biofertilizer was applied at a dosage rate of 150 % and mixed with sugarcane mud cake. In summary, the Brix and Pol analyses revealed the effectiveness of the PK rock biofertilizer mixed with sugarcane mud cake, which promoted a good nutritional response in the sugarcane crop.

The total Pol per hectare (TPH) and total sugar (TS) reflected the effects of the fertilization treatments; the effects were considerable for the PK rock biofertilizer and the mineral soluble application compared with other treatments, especially when applied at the higher dosage rates. These results agree with Santos et al., (2010).

The effects of the fertilization treatments on several soil attributes during the two consecutive harvests are shown in Table 4. A low soil pH may influence the development of plants, which was observed by Stamford et al., (2006), who used P rock biofertilizers and sulfur inoculated with *Acidithiobacillus* bacteria. However, in the present study, the effects of low pH on sugarcane were not observed because the rock biofertilizer was mixed with OM (earthworm compost), which has a naturally neutral pH. The biofertilizer treatment with sugarcane mud cake had no effect on the soil pH in our experiment. Several studies have reported the effects of PK rock biofertilizers on soil pH, especially when applied in high doses. These effects are due to the sulfuric acid produced by the oxidative bacteria *Acidithiobacillus* and because the biofertilizer has a low pH (approximately 3.0-3.5). However, our PK rock biofertilizer was mixed with sugarcane mud cake in a proportion of OM: BP + BK, equivalent to 3.0:0.5 + 0.5, and the OM (earthworm compost) had a pH of approximately 7.9, which neutralized the PK rock fertilizer acidity. Stamford et al., (2006, 2007) described the effects of a mixed biofertilizer on soil pH reduction when applied in higher doses.

Table 3 – Quality of sugarcane juice and total sugar production of the first harvest as affected by PK fertilization treatments, with OM (earthworm compost) at three dosage rates with and without sugarcane filter mud cake (SFMC).

Treatments	Quality of Juice and total sugar production				
	Brix[1]	Purity	Fiber	TPH[1]	TS[1]
SFMC (40 t ha^{-1})	—————— % ——————			Pol t ha^{-1}	t ha^{-1}
PK Fertilizer$_1$ 80 + OM 5	13.09 a	89 a	14.5 a	9.1 b	135.6 a
PKFertilizer$_2$ 160 + OM 10	13.74 a	89 a	14.0 a	11.2 a	138.3 a
PKFertilizer$_3$ 240 + OM 15	13.67 a	85 a	14.1 a	11.1 a	138.9 a
PKBiofertilizer$_1$ 80 + OM 5	13.25 a	84 a	14.1 a	9.8 ab	134.8 a
PKBiofertilizer$_2$ 160 + OM 10	13.71 a	84 a	14.4 a	11.9 a	144.0 a
PKBiofertilizer$_3$ 240 + OM 15	13.75 a	85 a	14.6 a	11.4 b	139.5 a
Rock PK$_1$ 160 + OM 5	12.15 b	85 a	14.0 a	7.9 c	123.7 b
Rock PK$_2$ 320 + OM 10	12.66 b	83 a	14.6 a	7.8 c	128.0 b
Rock PK$_3$ 480 + OM 15	12.74 b	86 a	14.7 a	7.9	129.8 b
Control (P_0K_0) + OM 15	10.03 d	86 a	14.8 a	5.6 d	109.9 c
Without SFMC					
PKFertilizer$_2$ 160 + OM 10	10.94 c	82 a	14.5 a	7.7 c	121.0 b
PKBiofertilizer$_2$160 + OM 10	10.92 c	84 a	14.2 a	6.0 d	120.7 b
PKRocks$_2$ 320 + OM 10	10.75 c	85 a	14.9 a	6.0 d	120.4 b

[1]Data with the same letter are not significantly different as per Tukey's test ($p \leq 0.05$); TPH = Total Pol per hectare; TS = Total Sugar.

Table 4 – Soil attributes (pH, available P and K) as affected by different PK fertilization treatments on sugarcane crops (first and second harvest), with and without sugarcane filter mud cake (SFMC).

Treatments*	pH	P (mg dm^{-3})	K (cmol$_c$ dm^{-3})	pH	P (mg dm^{-3})	K (cmol$_c$ dm^{-3})
	——— First harvest ———			——— Second harvest ———		
SFMC (40 t ha^{-1})						
PK Fertilizer$_1$ 80 + OM 5	5.60	17 bB	0.76 cB	5.60	35 cA	2.8 aA
PK Fertilizer$_2$ 160 + OM 10	5.61	24 aB	1.28 aB	5.77	36 cA	2.8 aA
PK Fertilizer$_3$ 240 + OM 15	5.62	23 aB	1.38 aB	5.62	72 abA	2.8 aA
PK Biofertilizer$_1$ 80 + OM 5	5.81	18 bB	0.74 cB	5.72	39 cA	2.8 aA
PK Biofertilizer$_2$ 160 + OM 10	5.45	24 aB	1.22 aB	5.70	68 bA	2.9 aA
PKBiofertilizer$_3$ 240 + OM 15	5.41	27 aB	1.37aB	5.27	95 aA	2.8 aA
PK Rock$_1$ 160 + OM 5	5.98	17 bA	1.09 bA	5.75	30 cA	0.7 cB
PK Rock$_2$ 320 + OM 10	5.87	20 bA	1.17 abA	5.72	35 cA	0.8 cB
PK Rock$_3$ 480 + OM 15	5.88	20 bB	1.23 abA	5.78	37 cA	0.8 cB
Control P_0K_0 + OM15	5.52	14 bA	0.90 bA	5.60	12 dA	0.8 cA
Without SFMC						
PK Fertilizer$_2$ 160 + OM 10	5.76	20 bB	1.24 abB	5.87	35 cA	1.8 bA
PK Biofertilizer$_2$ 160 + OM 10	5.87	21 bB	0.92 bB	5.85	72 abA	1.9 bA
PK Rock$_2$ 320 + OM 10	5.75	16 bB	0.94 abA	5.47	72 abA	0.9 cA

*Data with the same letter are not significantly different (small letters comparing the fertilization treatments and capital letters compare the crop harvest) as per Tukey's test ($p \leq 0.05$).

In relation to available P and K, a significant effect was identified when we applied the PK biofertilizer and mineral soluble fertilizer (Table 4). It is important to describe the residual effect of these PK sources, especially the biofertilizer mixed with sugarcane mud cake, which exhibited higher amounts of available P and K in the two consecutive crop harvests. The PK biofertilizer had the best available P and K levels in the soil, and the biofertilizer and soluble fertilizer without OM (earthworm compost) had superior residual effects compared with the PK rock treatment, and these results agree with Berger et al., (2013). The application of P and K biofertilizers in tableland soils (Stamford et al., 2006) increased the sugarcane stalk yield and affected several soil chemical attributes, especially when applied at the recommended dosage rates.

Conclusions

The PK rock biofertilizer influenced plant parameters and technical characteristics of the sugarcane harvests studied. The PK rock biofertilizer and earthworm compost promoted the best results. We conclude that biofertilizers produced from PK rocks with the addition of sulfur from *Acidithiobacillus* and earthworm compost may be a viable alternative to soluble fertilizers for sugarcane grown in soils with low available P and K.

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