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Availability of Residual and/or Applied Inorganic Phosphorus for Sugarcane Uptake and Growth in a Post-Mined Reconstituted Soil

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Abstract

Mineral sands mining is worldwide an environmental issue and also at the Hillendale mine in KwaZulu-Natal, South Africa. The post-mined soil is to be rehabilitated to sugarcane cropping. One of the concerns with the post-mined soil which is reconstituted with a 70:30 mixture of sand: slimes (silt-plus-clay fraction), is its low phosphorus (P) status, which could be limiting for optimum sugarcane production. A field experiment was conducted on a reconstituted soil at Hillendale to establish the availability of either residual or applied inorganic P to the plant and first ratoon sugarcane crop. Four treatments were evaluated including those where P fertilizer was omitted, applied at half the recommended rate or introduced equal to the recommended rate according to chemical analysis of the soil. In the fourth treatment, no fertilizer was applied at all, whereas nitrogen (N) and potassium (K) were added at recommended rates in the first three treatments. Phosphorus application had a significant effect on sugarcane fractional light interception and aboveground biomass yield of the plant and first ratoon crops, and stalk length and diameter of the first ratoon crop. Pol, brix, purity and fibre content and tiller number were not affected by P application. The application of P increased the foliar N, P, K, calcium (Ca), magnesium (Mg) and sulphur (S) contents of both crops. However, foliar N, P and K were deficient in the first ratoon crop even in the case where fertilizer was applied at the recommended rates, which could have been because of waterlogging. The possible effect of waterlogging on P uptake needs to be addressed in future studies in this reconstituted soil.

Keywords

Nutrient Uptake, Soil Rehabilitation, Surface Mining, Water Table, Mineral

Sand Mining

1. Introduction

Surface mining is an activity that results in the destruction of the natural topography and a severe disturbance of soil (e.g. Lubke & Avis, 1999; Rate et al., 2004; Shrestha & Lal, 2006; Chaudhuri et al., 2013; Pallavicini et al., 2013; Pitchaiah, 2017; Gao et al., 2020) which in turn has social, economic and environmental impacts (Haigh et al., 2013; Martín-Moreno et al., 2013; Khan & Suzic, 2015; Mngeni et al., 2017a). Mineral sand mining, during which heavy minerals are extracted from coastal sand dunes, is one form of surface mining that is common in many places around the world (Moore, 2011; Gavriletea, 2017). In this form of mining, heavy minerals are typically extracted from soil by a mechanical process and thus no chemicals are added to the soil (Mngeni et al., 2017b). In South Africa, mineral sands are mined at the Hillendale mine situated along the northeast coast of the KwaZulu-Natal province (Van Jaarsveld, 2013). The mining activities at this particular mine have led to much environmental concern by the local community who has questioned the rehabilitation success at Hillendale (Odendaal, 2011; Erasmus, 2013).

The pre-mined land use was sugarcane cropping and the mining company is therefore legally obligated to rehabilitate the post-mined land back to profitable sugarcane production (Dlamini & Zulu, 2019). Despite of this obligation, the post-mined soil is very low in organic matter with some nutrient deficiencies and imbalances that render it unsuitable for sustainable sugarcane production (Van Jaarsveld et al., 2016). For example, low P levels have been identified in the post-mined soil (Van Jaarsveld, 2013) and P will have to be supplemented at an adequate rate if sugarcane is to be re-established on the soil successfully.

Sugarcane removes between 0.22 and 0.26 kg of P per ton of cane (Barnes, 1974; Meyer & Wood, 1989). The threshold P of soil for optimum sugarcane growth in South Africa is 31 $mg \cdot kg^{-1}$ for plant cane and 11 $mg \cdot kg^{-1}$ for ratoon cane, based on Truog extraction (Meyer et al., 2004). In South Africa, the optimum range for P in sugarcane leaves between 3 and 9 months old is 0.19% to 0.32% (Anderson & Bowen, 1990).

Phosphorus plays an important role in metabolism and cell division and is often found in high concentrations in meristematic tissues. When sugarcane is deficient in P, the leaves typically turn dark-green, blue-green, red or purple. The leaves are slender and older leaves may turn yellow. The stems are short and slender and plant vigor and tillering are reduced (Anderson & Bowen, 1990; Gascho et al., 1993; Fernando et al., 2015; Dos Santos et al., 2018). Both cane and sucrose yields decrease, especially in ratoon cane (Gascho et al., 1993; Caione et al., 2015; Patil et al., 2020).

There exist well-established guidelines for fertilization of sugarcane in South

Africa (Meyer et al., 2004). These guidelines dealt unfortunately not with sugarcane cultivated on post-mined soil that offers special challenges. Thus, the aim of this study was to determine to what extent either residual or different levels of applied inorganic P would be available for sugarcane uptake and growth in a post-mined soil of Hillendale when fertilized with N and K at recommended rates. In this paper, we reported on the response of fractional light interception, foliar nutrient content, yield, yield attributes and cane quality for fertilized soils when a non-fertilized soil served as reference.

2. Materials and Methods

2.1. Study Site and Mining Method

The Hillendale mine, the location of this study, is situated at 28˚50'S and 31˚56'E on the north coast of the KwaZulu-Natal Province (KZN) of South Africa. It is situated about 9 km south east of the town of Empangeni and is bordered by the uMhlatuze River in the northwest (**Figure 1**).

The mining method at the Hillendale mine starts with stripping and stockpiling of topsoil from sand dunes (**Figure 2(a)**). Water is sprayed onto the remaining soil under high pressure to create a slurry. The slurry is then pumped to

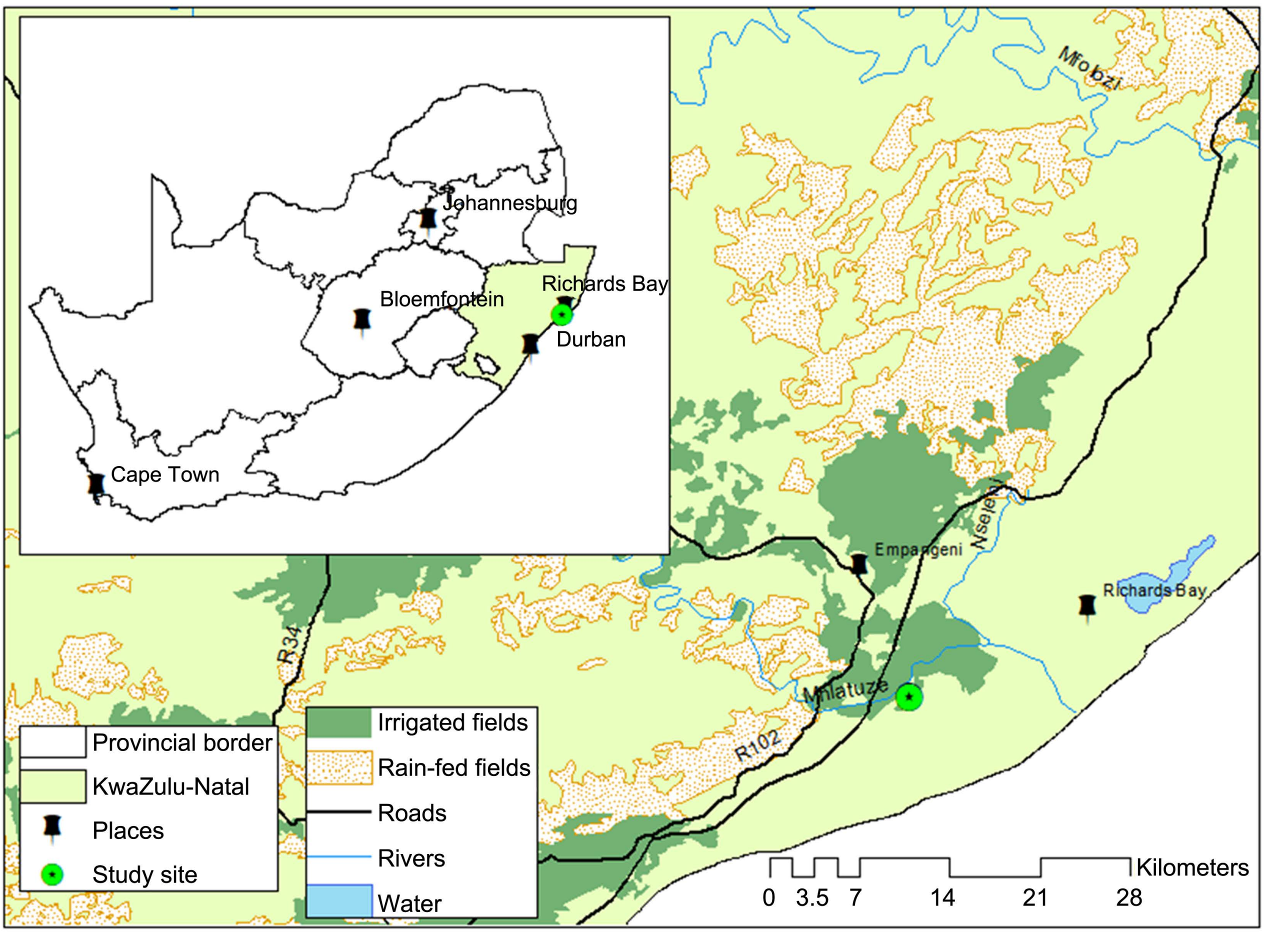

Figure 1. Location of study site at Hillendale mine near Empangeni, South Africa.

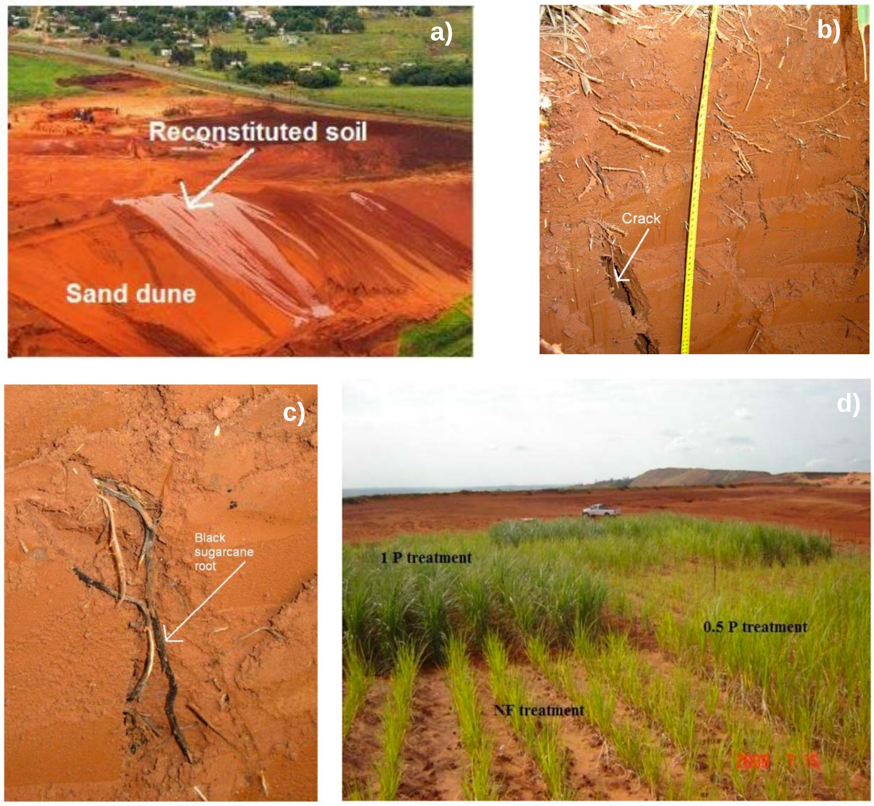

Figure 2. Photographs of study site showing a pre-mined sand dune and post-mined reconstituted soil (a), post-mined reconstituted soil profile (b), black sugarcane roots indicative of waterlogging (c), and sugarcane experiment with 0% (NF), 50% (0.5 P) and 100% (1 P) of recommended phosphorus application rate.

a separation plant where mechanical methods are employed to separate it into three products, namely, sand, slimes (silt and clay fraction combined) and heavy minerals. The heavy minerals are transported by truck to another plant for further processing. The sand is used for backfilling the void land, while the slimes are pumped to a storage facility. A portion of the sand and slimes is mixed to create a so-called reconstituted soil which is deposited as slurry on the back-filled land to a thickness of 1.5 m or more and left for a few months to dry (**Figure 2(b)**). The ratio of sand to slimes in the reconstituted soil is similar to the composition of the soil prior to mining (Van Jaarsveld, 2013).

2.2. Treatments and Crop Management

The experiment was conducted on a mined-out area that was back-filled with a 70:30 sand-slimes (silt + clay fraction) mixture to a depth of 1.8 m. Some of the properties of the soil are shown in **Table 1**. There were four fertilizer application treatments laid out in a complete randomized design with four replicates and a plot size of 10 m × 8 m. Each plot had 8 rows. In one treatment no fertilizer was applied ("NF treatment"). In the other three treatments P was either omitted ("0 P treatment") or applied as single superphosphate (10.5% P) at half the recommended rate ("0.5 P treatment") or at the recommended rate ("1 P treatment").

Table 1. Soil fertility status and particle size distribution of the post-mined soil determined from a composite soil sample taken to a depth of 200 mm before the experiment.

Property	Value
Particle sizes	
Sand (%)	90.19
Silt (%)	5.19
Clay (%)	14.06
Soil pH (H_2O)	6.90
Organic matter (%)	0.20
Macronutrients	
P (mg/kg)[x]	6.30
K (mg/kg)[y]	61.30
Ca (mg/kg)[y]	372.90
Mg (mg/kg)[y]	512.00
Micronutrients	
Mn (mg/kg)[z]	1.60
Fe (mg/kg)[z]	4.40

[x]Truog extraction; [y]Ammonium acetate extraction; [z]EDTA-$(NH_4)_2CO_3$ extraction.

Nitrogen and K were applied in the 0 P, 0.5 P and 1 P treatments either as the compound fertilizer 2:0:3 (49) or separately as urea (46% N) and potassium chloride (50% K). The recommended rates by Fertiliser Advisory Service (FAS) of the South African Sugarcane Research Institute (SASRI) as based on soil analysis were 100 kg·ha^{-1} N, 70 kg·ha^{-1} P and 175 kg·ha^{-1} K for the plant crop and 140 kg·ha^{-1} N and 175 kg·ha^{-1} K for the first ratoon crop. All fertilizer was band placed in the furrow at planting and top-dressed in the first ratoon crop.

Sugarcane cultivar N41, which is well suited for dry-land cultivation in the area (SASRI, 2010), was planted in 1 m inter-row spacing during February. The first sugarcane harvesting was done seven months after planting and the first-ratoon crop harvested fourteen months after ratooning. Sugarcane was not burned at harvesting.

2.3. Data Collection

2.3.1. Fractional Light Interception

A ceptometer (SF-80 model, Degagon Devices, Pullman, WA, USA) was used to measure the fractional interception of photosynthetically active radiation (FI_{PAR}) in each plot for six days. On each of these days, 10 PAR readings below and above the green sugarcane canopy were taken at midday on a day with clear skies. Average FI_{PAR} values were calculated as one minus the ratio of the below to above PAR readings.

2.3.2. Foliar Nutrient Content

Approximately 40 youngest mature leaves (also called top visible dewlap leaves) were randomly collected approximately 4 months after planting and 5 months after ratooning, from sugarcane plants from the 4 inside rows of each plot. For both harvesting events, the mid-ribs of the leaves were removed and the leaf blades washed. The leaf blades were then analysed in the FAS laboratory of SASRI for their mineral content (P, K, Ca, Mg, S, Si, Zn, Mn, Cu and Fe) using X-ray fluorescence, and for N using near-infrared spectroscopy (Schroeder et al., 1993).

2.3.3. Yield, Yield Attributes and Cane Quality

At the first harvesting event 7 months after planting sugarcane was collected from a net plot of 16 m^2 in each treatment plot and weighed to determine the fresh mass. Leaves and stalks of a 1 m^2 subsample of each 16 m^2 net plot were weighed fresh and then dried at 80˚C till stable weight and weighed again. The fresh mass of the 1 m^2 subsamples was adjusted according to the fresh mass of the 16 m^2 samples and the dry mass was also corrected accordingly. The dry mass, which is referred to as the aboveground biomass (ABM) yield, was extrapolated from $kg \cdot m^{-2}$ to $Mg \cdot ha^{-1}$. For this harvesting, only ABM yield was determined, because of the small size of the plants.

At the second harvesting event fourteen months after ratooning, cane stalks were collected from a net plot of 16 m^2 in each treatment plot and weighed to determine the cane yield, which was calculated by converting the stalk fresh mass of the 16 m^2 samples to $Mg \cdot ha^{-1}$. Tiller number, stalk length and stalk diameter were however determined as yield attributes from 1 m^2 subsamples of the 16 m^2 net plots. The stalks of 1 m^2 subsamples were shredded and cane juice quality parameters (pol, brix and purity) were determined by the Cane Testing Service Laboratory of SASRI. Sucrose yield was extrapolated to $Mg \cdot ha^{-1}$.

2.4. Statistical Analysis

All experimental data were subjected to analysis of variance (ANOVA) using GenStat12 software (VSN International, 2009). When the ANOVA showed significant ($P < 0.05$) differences, means were separated by the LSD (least significant difference) test.

3. Results and Discussion

For this study, backfilling of mined-out land with reconstituted soil took longer than anticipated and sugarcane was planted therefore late. On account of this were parameters of the plant crop in some instances not measured and in other instances measured but not at the recommended time. Thus a comparison of absolute values for parameters between the plant and first ratoon crops are impossible. However, some trends evolved worth to present and discuss.

3.1. Fractional Light Interception

For both the plant and first ratoon crops were the FI_{PAR} values significantly the lowest in the NF treatment where no N, P and K were applied (Table 2). In the 1 P treatment where N, P and K were applied at recommended rates, the FI_{PAR} values were significantly the highest. The FI_{PAR} values for the other two treatments (where N and K were applied at recommended rates with either no P or P at half of the recommended rate) were intermediate with no significant difference between them. These results confirm the visual observation of plant growth during the experiment, implicating the importance of P application to this reconstituted soil in addition to N and K for vigorous growth of sugarcane.

3.2. Foliar Nutrient Content

For the plant crop, compared to the non-fertilized treatment (NF) increased the fertilized treatments (0 P, 0.5 P or 1 P) foliar N, P, K and Ca significantly in some instances but not that of foliar Mg (Table 3). Unfortunately, foliar S, Zn, Mn, Cu and Fe for the NF treatment were not determined and a comparison with any of the three fertilized treatments is therefore impossible.

As can be expected, the foliar P was significantly the highest in the 1 P treatment with a content of 0.35% (Table 3). The 0 P and 0.5 P treatments did not differ significantly amongst each other in their foliar P content. In these two treatments, the foliar P content was equal or lower than the threshold value of 0.19%. However, P application rate correlated significantly with the foliar P content ($r^2 = 0.81$, $P < 0.01$).

Root growth of the plant crop was not measured but it is generally accepted that application of P stimulates root growth and hence absorption of other nutrients also (Matin et al., 1997). This was supported by the positive correlations between P application rate and foliar N ($r^2 = 0.90$, $P < 0.01$), K ($r^2 = 0.62$, $P < 0.05$), Ca ($r^2 = 0.50$, $P < 0.05$), Mg ($r^2 = 0.58$, $P < 0.05$), S ($r^2 = 0.77$, $P < 0.01$) and Mn ($r^2 = 0.73$, $P < 0.01$). The applied P is probably not solely responsible for these positive correlations with foliar nutrient content since single superphosphate which was used as P source contains 20% Ca and 11% S, and some other

Table 2. Effect of fertilizer application on the fractional interception of photosynthetic active radiation (FI_{PAR}) for the plant and first ratoon crops. Values are the means of 24 replicates.

Fertilizer application[x]	FI_{PAR}	
	Plant crop	First ratoon crop
NF	0.35a	0.35a
0 P	0.58b	0.74b
0.5 P	0.66b	0.78b
1 P	0.85c	0.95c
Mean	0.61	0.71
$LSD_{0.05}$	0.07	0.12

[x] = Means followed by the same letter in a column are not significantly different at $P < 0.05$.

Table 3. Effect of fertilizer application on the foliar nutrient content of the plant crop in May 2009, 4 months after planting. Values are the means of 4 replicates.

Treatment	N %	P %	K %	Ca %	Mg %	S %	Zn (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Fe (mg/kg)
NF	1.36a	0.18a	1.23a	0.26a	0.14	-	-	-	-	-
0 P	1.61a	0.16a	1.31ab	0.30b	0.15	0.16a	17.25	71.75a	6.00	195.25
0.5 P	2.09b	0.19a	1.35b	0.31b	0.16	0.21b	17.75	87.50b	6.00	263.00
1 P	2.49c	0.35b	1.38b	0.31b	0.17	0.23b	16.75	128.25b	6.00	222.50
Mean	1.89	0.22	1.32	0.30	0.16	0.20	17.25	95.83	6.00	226.92
Threshold value[y]		0.19	1.05	0.15	0.08	0.12	13.00	15.00	3.00	75.00
LSD ($P = 0.05$)	0.33	0.07	0.09	0.04	ns[z]	0.04	ns	38.88	ns	ns

[x]Means followed by the same letter in a column are not significantly different at $P < 0.05$; [y]After Schroeder et al.(1993); [z]NS = Not Significant.

nutrients as impurities. It is noteworthy that foliar Zn, Cu and Fe did not correlate positively with P application rate although these three nutrients usually occur as impurities in local single superphosphate which is manufactured from igneous rocks (FERTASA, 2016). Moreover, only the foliar P contents of the NF and 0 P treatments were lower than the thresholds (**Table 3**). The implication of this is that in the other treatments nutrients were available in adequate amounts for uptake and growth of the plant crop in the post-mined reconstituted soil. This is especially true for the 1 P treatment where N, P and K were applied at recommended rates. In this treatment, no visual symptoms of any nutrient deficiency were observed.

The foliar nutrient contents of the first ratoon crop (**Table 4**) were, except for Ca, equal or lower than those of the plant crop (**Table 3**) regarding the same treatments. Like in the case of the plant crop, increased the fertilized treatments (0 P, 0.5 P or 1 P) the content of foliar N, P, K, Ca, Mg, S and Mn significantly in the first ratoon crop in some instances when the NF treatment served as reference. The contents of foliar Zn, Cu and Fe were not affected significantly by any of the fertilized treatments.

The foliar P of the first ratoon crop was significantly the highest in the 1 P treatment with a content of 0.17% which was surprisingly lower than the threshold of 0.19% (**Table 4**). No significant difference for foliar P content between the 0 P and 0.5 P treatments was calculated. For the first ratoon crop, P application rate only correlated significantly ($P < 0.01$) with foliar K ($r^2 = 0.53$) and S ($r^2 = 0.55$).

In spite of the increase in P application, based on the foliar thresholds several nutrients were deficient in the first ratoon crop (**Table 4**), including N, P (all treatments) and K (all treatments except the 1 P treatment). Deficiencies in N

Table 4. Effect of fertilizer application on the foliar nutrient content of the first ratoon crop in February 2010, 5 months after ratooning. Values are the means of 4 replicates.

Treatment	N %	P %	K %	Ca %	Mg %	S %	Zn (mg/kg)	Mn (mg/kg)	Cu (mg/kg)	Fe (mg/kg)
NF	1.01a[x]	0.13a	0.88a	0.29a	0.10a	0.04a	15.00	69.00a	5.75	192.25
0 P	1.46b	0.13a	1.00b	0.31a	0.11ab	0.08b	15.25	47.50b	6.00	172.75
0.5 P	1.38b	0.14a	1.04b	0.31a	0.11ab	0.09b	15.25	56.75ab	5.75	173.25
1 P	1.60b	0.17b	1.08b	0.34b	0.12b	0.13c	16.25	73.25a	6.00	182.75
Mean	1.36	0.14	1.00	0.31	0.11	0.09	15.44	61.63	5.88	180.25
Threshold value[y]	1.70	0.19	1.05	0.15	0.08	0.12	13.00	15.00	3.00	75.00
LSD ($P = 0.05$)	0.23	0.02	0.09	0.02	0.02	0.03	ns[z]	12.58	ns	ns

[x]Means followed by the same letter in a column are not significantly different at $P < 0.05$; [y]After Schroeder et al. (1993); [z]NS = Not Significant.

and P were not expected in the 1 P treatment, where fertilizer application was at the recommended rate and also not for K in the 0 P or 0.5 P treatments. It is speculated that these unexpected nutrient deficiencies might have been caused by waterlogging. Waterlogging was visually observed during the experiment and was also reported in another study which was conducted at the same time in the same soil (Van Jaarsveld et al., 2016). In addition, sugarcane roots in the current study were black in color (**Figure 2(c)**), which is further indication of waterlogging (Mengel & Kirkby, 1987; Sumner, 2011). Sumner (2011) pointed out that such roots are inefficient at absorbing nutrients. It has been shown that waterlogging can result in deficiencies of several nutrients and particularly N, P and K in plants (Ponnamperuma, 1972; Huang et al., 1995; Steffens et al., 2005). The waterlogging could have been caused by poor drainage as result of layering of the reconstituted soil over sand (Miller & Gardner, 1962).

Uptake of Mn and Fe are often increased by waterlogging (Ponnamperuma, 1972; Rowell, 1988). Iron toxicity in sugarcane was reported by Van Jaarsveld et al. (2016) in a study on a reconstituted soil under similar conditions. In the current study, the Mn and Fe content of the leaves were 2 to 4 times higher (**Table 3** and **Table 4**) than their respective thresholds values, yet it could not be shown from the data that Mn or Fe toxicity significantly affected sugarcane growth.

It was not possible to explain with the available data why nutrient deficiencies did not occur in the plant crop, since waterlogging was also observed. The availability of P for plant uptake in waterlogged soils is, however, complex and could have changed over time (De Mello et al., 1998; Zhang et al., 2003). A reduced availability of P could have affected root growth and thus the ability of the roots to absorb nutrients.

3.3. Yield, Yield Attributes and Cane Quality

In this study cane quality parameters were determined only for the first ratoon crop (**Table 5**). Analysis of these data showed that the fibre content, brix (soluble solid content) and purity were not significantly affected by P application. The average fibre content, brix content and purity were 13.3%, 19.0% and 89.6%, respectively. The pol (sucrose content) varied significantly ($P < 0.05$) among treatments with the NF treatment having the lowest pol (16.4%), followed by the 1 P (16.8%), 0.5 P (17.4%) and 0 P (17.5%), treatments. This supports Caione et al. (2015), who did not find any effect of P application on cane quality. Several other studies (Shankaraiah & Kalyana Murthy, 2005; Bokhtiar et al., 2008; Devi et al., 2012; Tsado et al., 2013; De Albuquerque et al., 2016) reported, however, that cane quality was improved by P application.

For both the plant and first ratoon crops were the ABM yields (**Figure 2(d)** and **Table 6**) significantly the lowest in the NF treatment (where no N, P and K were applied) and significantly the highest in the 1 P treatment (where N, P and K were applied at recommended rates). The ABM yields for 0 P and 0.5 P treatments (where N and K were applied at recommended rates with either no P or P

Table 5. Effect of fertilizer application on cane quality parameters for the first ratoon crop. Values are the means of 4 replicates.

Treatment^x	Fibre (% of juice)	Brix (% of juice)	Pol (% of juice)	Purity (% of juice)
NF	12.91	18.57	16.36 a	88.10
0 P	13.61	19.31	17.47 d	90.46
0.5 P	13.02	19.21	17.39 c	90.55
1 P	13.78	18.85	16.82 b	89.24
Mean	13.33	18.99	17.01	89.59
$LSD_{0.05}$	NS^y	NS^y	0.07	NS^y

^{x} = Means followed by the same letter in a column are not significantly different at $P < 0.05$; ^{y}NS = Not Significant.

Table 6. Effect of fertilizer application on aboveground biomass yield for the plant and first ratoon crops.

Fertilizer application	Plant crop ($Mg \cdot ha^{-1} \cdot yr^{-1}$)	First ratoon crop ($Mg \cdot ha^{-1} \cdot yr^{-1}$)
NF	1.92a^x	3.96a
0 P	11.28b	18.60b
0.5 P	13.56b	24.00b
1 P	31.44c	32.88c
Mean	14.55	19.86
LSD ($P = 0.05$)	8.40	7.08

^{x}Means followed by the same letter in a column are not significantly different at $P < 0.05$.

at half of the recommended rate) were intermediate with no significant difference between them. The results confirmed the relative differences in plant size among treatments which were visually observed. It is interesting to note that despite of lower foliar nutrient contents in the first ratoon crop (**Table 4**) than in the plant crop (**Table 3**), ABM yields were higher for the first ratoon crop than for the plant crop (**Table 6**) concerning similar treatments.

The ABM yield correlated significantly and positively with the foliar N (r^2 = 0.61, $P < 0.01$), P (r^2 = 0.83, $P < 0.05$), K (r^2 = 0.71, $P < 0.01$), Ca (r^2 = 0.55; $P <$ 0.5), S (r^2 = 0.67, $P < 0.01$) and Mn (r^2 = 0.82; P = 0.5) content. The positive response of ABM indicates that at least some of these nutrients were not optimal in spite that N, P, K, Ca and S were applied to the reconstituted soil in the form of fertilizer. Only Mn may be not applied.

Yield attributes were determined only for the ratoon crop (**Table 7**). For this crop, differences in tiller number (TN) among treatments were not significant (**Table 7**). Significant differences amongst treatments were observed for the stalk length (SL) and stalk diameter (SD). The NF treatment had lowest SL of 49.9 cm and SD of 1.5 cm of all treatments. The SL was highest in the 1 P treatment (201.5 cm), but SD was similar for the 0 P, 0.5 P and 1 P treatments.

The observed differences in ABM yield were determined mostly by SL and SD since ABM yield correlated significantly ($P < 0.01$) with SL (r^2 = 0.55) and SD (r^2 = 0.51) but not with TN. This contradicts findings by Caione et al. (2015) who reported that P application did not affect stalk length and diameter, but did have a significant effect on tiller number. Tsado et al. (2013) reported also that tiller number was promoted by P application while Matin et al. (1997) observed no difference in tiller number at different soil P levels in their study. El-Tilib et al. (2004) reported that P application increased stalk length, but not stalk diameter. The response of tiller number, stalk length and stalk diameter seems therefore inconsistent to P application.

Table 7. Effect of fertilizer application on the tiller number (TN), stalk length (SL) and stalk diameter (SD) of the first ratoon crop. Values are the means of 4 replicates.

Fertilizer application[x]	Tiller number (TN)	Stalk length (SL)	Stalk diameter (SD)
	per·m^2	cm	
NF	10.98	49.91 a	1.49 a
0 P	11.17	149.00 b	1.86 b
0.5 P	10.70	163.54 b	1.89 b
1 P	10.18	201.54 c	1.87 b
Mean	10.76	141.00	1.78
$LSD_{0.05}$	NS[y]	47.56	0.17

[x] = Means followed by the same letter in a column are not significantly different at $P <$ 0.05; [y]NS = Not significant.

3.4. Limitations

This study as most other has some limitations that should be take note of. The response of sugarcane to only P was measured on the post-mined reconstituted soil. Other nutrients like N and K could influence also the growth and development of sugarcane. Either antagonism or synergism between these three primary plant nutrients are well established (Havlin et al., 2014; FERTASA, 2016). In future studies factorial experiments with N, P and K should be done therefore in determining optimum application rates. Such rates do not exist for sugarcane production on post-mined reconstituted soil. The observed waterlogging of these soils further complicated the nutrition of sugarcane. Hence, quantification of waterlogging is of great importance when fertilization experiments are done to explain the response of sugarcane on post-mined reconstituted soils, compared to pre-mined soils of Hillendale mine. This kind of information could probably enhance the extrapolation of results obtained in this study to other premises of sand dune mining.

4. Conclusion

The results of this study that manifested in fractional light interception, foliar nutrient content, yield, yield attributes and cane quality of either the plant crop or first ratoon crop confirmed that proper fertilization of the reconstituted soil is essential for profitable sugarcane production as was the case before mining. Very poor growth of both crops was observed without application of N, P and K. Sugarcane growth improved when recommended rates of N and K were combined with either residual P alone or supplemented with fertilized P at half of the recommended rate, with no difference between the two treatments. The application of N, P and K at recommended rates resulted in the best growth of the plant crop and the first ratoon crop. Though N, P and K application at recommended rates were the foliar N and P below and foliar K just above the thresholds, probably due to waterlogging of the constituted soil. This aspect requires further investigation as well as the recommended rates on which N, P and K applications were based. The recommended rates were not developed for the reconstituted soil.

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Credit Author Statement

Van Jaarsveld C M: Conceptualization, Methodology, Validation, Formal analysis, Writing original draft. Zharare G E: Methodology, Editing. Smit M A: Methodology, Editing. Du Preez C C: Conceptualization, Methodology, Review, Editing.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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