IMPACT OF HIGH RATES OF COAL FLYASH ON SOME PERTINENT SOIL CHARACTERISTICS AND SUGARCANE YIELD IN MAURITIUS

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Abstract

THE COMBUSTION of coal for cogeneration of electricity by the sugarcane industry in Mauritius generates annually some 20 000 tonnes of ash that need to be disposed of in an environmentally sound manner. As large scale application of ash has been reported to impart agronomic benefits but data under conditions prevailing in Mauritius are lacking, the impact of disposing 50 to 100 t/ha coal flyash in sugarcane fields on soil quality and on sugarcane production was studied in field trials at Belle Rive (>3500 mm/y rainfall), Union Park (>3000 mm/y rainfall), Pamplemousses (>1500 mm/y rainfall) and Médine (900 mm/y rainfall). Though coal ash did not affect soil pH, soil salinity and even soil exchangeable bases, its application at 100 t/ha, when compared to mineral fertilizers, resulted in a reduction of sugar yield at three sites by an average of 1.18 t sugar/ha. At the lower rate of 50 t/ha coal ash, in spite of a significant yield decrease observed at Belle Rive, sugarcane production at Pamplemousses, Union Park and Médine was not significantly different from the control. The N and K uptake by sugarcane was not influenced by the coal ash, though P uptake was enhanced on account of the supplementary P provided in the ash. Additionally, because of its low heavy metal content, coal ash did not increase the heavy metal uptake by the sugarcane plant. In view of the adverse effects observed on sugarcane production, the disposal of rates of coal ash as high as 100 t/ha in sugarcane lands should not be contemplated.

Introduction

In Mauritius, sugarcane is cultivated on some 69 000 ha which represents 85% of the arable land in the country.

The average annual production of five million tonnes cane is currently processed by seven sugar mills to produce on average 500 000 tonnes sugar and 1.5 million tonnes of bagasse.

Through the combustion of bagasse during the crop season, and that of 440 000 tonnes coal during the intercrop season, the sugarcane industry exports some 1300 GWh of electricity to the national grid, representing around 60% of the country's need. However, cogeneration with coal generates around 20 000 tonnes coal ashes which have to be disposed of judiciously.

Various means of disposal of the ash exist. For example, ash is useful as a construction material or it can be used to decontaminate effluents, but the application of coal ash to agricultural land is believed to represent the most sensible option from both the economic and environment points of view.

Coal ash is in fact a finely divided, amorphous ferro-alumino silicate material, containing all the essential elements that occur naturally in soil except humus and nitrogen (Sear *et al.,* 2003).

It has a pH around 9–10 and possesses certain physical and chemical properties that can be useful, for example, to neutralise soil acidity (Stevens and Dunn, 2004).

Ash has thus been used as a soil amendment (Adriano *et al.*, 2002) and as a source of plant nutrients (Wong and Wong, 1986). Studies on the effects of coal ash on sugarcane yield, however, remain scanty. Since 20 000 tonnes of coal ash need to be disposed of every year by the sugarcane industry in Mauritius, a study was initiated to assess (i) their impact on soil chemical properties and (ii) their effect on sugarcane yield when high rates are applied.

Materials and methods

Field experiments

Field trials were laid down in four different agro climatic regions of Mauritius, namely at *Belle Rive* on a Dystropeptic Gibbsiorthox receiving more than 3500 mm of rain per year, at *Union Park* on a Lithic Humitropept with an annual rainfall of 3300 mm, at *Pamplemousses* on an Oxic Humitropept receiving 1500 mm rain per year and at *Médine*, on an Ustic Eutropept with less than 1000 mm rain per year. Some relevant characteristics of the soils at the four experimental sites are shown in Table 1.

Table 1—Some characteristics of the soils (0–45 cm depth) at field trial sites.

Site	Soil type	pH	Total N	Available P	Available K	Organic C	CEC	Electrical conductivity
	USDA classification		(g/kg)	(g/kg)	(me%)	(g/kg)	($cmol^+$ /kg)	(µS/cm)
Belle Rive	Dystropeptic gibbsiorthox	5.0	1.8	0.05	0.20	25.9	12.8	23.4
Union park	Lithic Humitropept	5.1	3.7	0.20	0.45	39.9	25.7	57.6
Pamplemousses	Oxic Humitropept	5.3	2.1	0.12	0.96	21.7	20.4	163.6
Médine	Ustic Eutropept	7.4	1.3	0.17	2.20	15.5	25.4	80.2

Coal ash was applied before planting at two rates (50 and 100 t/ha on a fresh weight basis, 66.42% dry matter). The control treatment received only N and K fertilizers at rates recommended for sugarcane (145 kg N/ha and 190 kg K_2O/ha).

No P fertilisation was applied as soil tests indicated sufficiency in P at all four sites. The N level in the two coal ash treatments was adjusted to the recommended rate of 145 kg N/ha using urea.

All treatments were replicated four times in a randomised complete block design at each experimental site and each treatment plot consisted of four 10 metre rows of sugarcane spaced 1.5 m apart.

Sugarcane was planted at the four sites using three bud cuttings and the resulting plant cane crop was harvested 12 months later in July 2006. The first and second ratoons were harvested in the month of August 2007 and 2008 respectively.

At harvest every year, the cane stalks from the two central rows of each plot were weighed to obtain the cane yields and then sampled for determination of sucrose content with an automatic saccharimeter.

The uptake of NPK and heavy metals (Cu, Zn, Ni, Mn, Pb, and Hg) in the different parts of the cane plant (stalk, top and trash) were measured for the plant cane crop. The NPK in the different plant parts was determined according to the method described by McDonald (1978) while heavy metals were analysed as outlined by Novozamsky *et al.* (1986).

Results and discussion

Elemental composition of coal ash

The mean elemental composition of the coal flyash collected every three months over a period of three years at three different power stations is shown in Table 2.

As expected, as shown by the range of values obtained, a great variability existed in the elemental characteristics of the coal ash. As reported by Adriano *et al,* (1980), the chemical composition of ash depends on the source of coal, combustion conditions in the power station and the type of emission control devices used.

Coal ash has an alkaline pH ranging between 7.5 and 11.5 and contains significant amounts of P and K which are essential plant nutrients. The exchangeable calcium which may be as high as 66.1 $cmol^+$/kg in coal ash is responsible for its alkaline nature.

The concentrations of heavy metals obtained in coal ash are, on the other hand, generally much lower than the United States Environmental Protection Agency (USEPA) ceiling limits for wastes (Zn: 420 mg/kg, Ni: 7500 mg/kg, Cu: 4300 mg/kg, Pb: 840 mg/kg, Cd: 85 mg/kg and Hg: 57 mg/kg), (USEPA, 1992).

Specifically the elemental composition of coal ash applied at planting was 1.1 g N/kg, 2.7 g P/kg and 2.2 g K/kg. The composition of coal ash analysed in this study in fact concurs with that reported by Carlson and Adriano (1993) who found that ash in general is quite high in plant nutrients except for N which is lost by volatilisation during combustion.

Table 2—Main elemental characteristics of coal ash sampled from three different power stations in Mauritius.

Parameter	Units	Coal ash	Range
pH		9.4	7.5–11.5
Electrical conductivity	mS/cm	3.6	1.8–5.7
Exchangeable Ca		32.7	3.5–66.1
Exchangeable K	$cmol^{+/}kg$	7.6	0.2–21.4
Exchangeable Mg		8.1	1.8–17.2
Total N	g/kg	1.9	0.7–5.9
Total P		5.1	3.9–6.8
Total K		6.2	1.9–14.2
Si		4.3	2.1–9.7
Fe		20.8	8.1–46.7
Mn		0.6	0.03–0.8
Zn	mg/kg	93.7	1.0–381.4
Ni		53.2	10.1–109.8
Cu		59.5	20.9–132.8
Pb		51.9	2.0–144.4
Cd		0.5	0.2–0.9
Hg		1.1	0.01–8.8

Coal ash used in this study has also been found to have non-detectable levels of polyaromatic hydrocarbons and polychlorinated biphenyls (GC MSD detection limits 0.02 mg/kg), probably due to the high combustion temperatures which had caused these organic compounds to be degraded. However, as reviewed by Reijnders (2005), coal ashes can also contain quite significant amounts of persistent organic compounds.

Effect of coal ash on soil pH

The results obtained in this study showed no major changes in soil pH even after the addition of 100 t/ha coal ash (Table 3). The inherent buffering capacity of soils has probably resisted the changes in pH. In view of the high rates of coal flyash that would be needed to raise significantly the soil pH, coal ash would therefore not be economically viable as an amendment to correct soil acidity in the soils of Mauritius. This finding is in agreement with that reported by Sikka and Kansal (1994) who have also observed no change in soil pH following application of high rates of flyash.

Table 3—Effect of high rates of coal ash on soil pH (mean of 4 sites ± SE).

Application	NPK fertilizers	100 t/ha coal ash
Before	5.14 ± 0.10	5.14 ± 0.10
One month after	5.33 ± 0.30	5.42 ± 0.07
12 months after	5.33 ± 0.08	5.46 ± 0.22
24 months after	5.36 ± 0.02	5.73 ± 0.10

In fact as explained by Cline *et al*, (2000), the poor liming effect of coal ash is due in part to the low amount of mineralogical lime since a significant portion of its CaO is present in the vitreous components of the ash and is generally released very slowly.

Effect of coal ash on soil electrical conductivity

Soil salinity, as reflected by soil electrical conductivity, increased substantially one month after the application of 100 t/ha coal ash (Table 4). But after 12 and even 24 months, the soil electrical conductivity had returned close to its original value of 81.2 µS/cm. Even with the increase in electrical conductivity of the soil observed after one month, the electrical conductivity remained much lower than the maximum value of 1700 µS/cm that sugarcane can tolerate (Rhoades and Loveday, 1990).

It has been reported that the decrease in soil electrical conductivity with time is the result of weathering processes of the coal ash such as hydration and carbonation which play important roles in transforming the primary minerals in coal ash such as CaO and MgO into less reactive secondary mineralogical products that contribute little towards raising soil salinity (Adriano *et al.,* 1980).

Table 4—Effect of high rates of coal ash on soil electrical conductivity (µS/cm, mean of 4 sites ± SE).

Application	NPK fertilizers	100 t/ha coal ash
Before	81.2 ± 29.9	81.2 ± 29.9
One month after	125.4 ± 40.6	166.8 ± 33.9
12 months after	49.4 ± 8.1	83.1 ± 23.5
24 months after	49.5 ± 5.3	63.5 ± 12.9

Effect of coal ash on soil exchangeable bases

Based on its K content, the application of 100 t/ha of coal ash supplied 220 kg K/ha or 265 kg K_2O/ha as opposed to 190 kg K_2O/ha in the control treatment where only mineral fertilizers were used. This higher rate of K from coal ash had been insufficient to significantly raise the exchangeable K in the soils. Indeed, soil exchangeable K one month after application of 100 t/ha at all sites was similar to that obtained when 320 kg muriate of potash was used. Likewise, the amounts of Na (17 kg Na/ha) and Mg (97 kg Mg/ha) added to the soil by coal ash applied at 100 t/ha did not significantly increase exchangeable Na and Mg in soil as compared to mineral fertilizers. On the other hand, the addition of 654 kg Ca/ha that the soils received from 100 t/ha coal ash did raise soil exchangeable Ca in the soil (Table 5), particularly one month after application, but this increase still remained within the limits of the standard error (SE).

Table 5—Effect of high rates of coal ash on soil exchangeable Ca (cmol$^+$/kg mean of 4 sites ± SE).

Application	NPK fertilizers	100 t/ha coal ash
	Exchangeable Ca	
Before	4.78 ± 0.8	4.78 ± 0.8
One month after	4.73 ± 1.7	5.90 ± 1.7
12 months after	3.18 ± 1.2	4.78 ± 1.4
24 months after	3.41 ± 1.5	4.09 ± 0.9

Cane and sugar yields

Cane and sugar yields in the study followed the same pattern as shown in Figure 1. The addition of coal ash at 100 t/ha decreased cane and sugar yields when compared to the control treatment except at the experimental site of Médine, where no significant difference was found among the treatments.

The application of 50 t/ha of coal ash on the other hand did not in general result in lower yields when compared with mineral fertilizers. At Union Park, a significant increase in sugar yield was even obtained with this lower rate of coal ash. However, certain soils such as at Belle Rive would not tolerate the application of as low as 50 t/ha coal ash as evidenced by the decrease in cane and sugar yields obtained.

The findings of the present study confirmed that, with ash at high dosage, such conclusions as those reported by Siddiqui and Singh (2005) that ash would increase yields of crops such as wheat, barley, soybeans and rice, because of the rich content of essential plant nutrients it contains, would not necessarily be true.

In the present study, though the coal ash applied contained appreciable amounts of plant nutrients in particular P (Table 2), a negative impact was observed on sugarcane yield at 100 t/ha. This detrimental effect of coal ash on yield cannot be attributed to a single factor, but rather to a combination of many factors both in the soil and plant systems. In fact, Jala and Goyal (2006) concluded that in general crop response to coal ash is influenced by the physical and chemical characteristics of the soil and also by the crop itself.

Detrimental effects of high rates of coal ash when observed on plant growth were attributed by Singh and Yunus (2000) to a shift in the chemical conditions of the soil due to the highly alkaline pH and the high levels of soluble elements released from the coal ash.

As shown by the pH and electrical conductivity data in Tables 3 and 4, there was no major increase in soil pH and electrical conductivity 12 months after the application of 100 t/ha of coal ash. This implied that, if the detrimental effect of 100 t/ha of coal ash on sugarcane yields as shown in Figure 1 were indeed caused by a change in the chemical environment of the soil, that change cannot be attributed to the high levels of soluble elements in the coal ash.

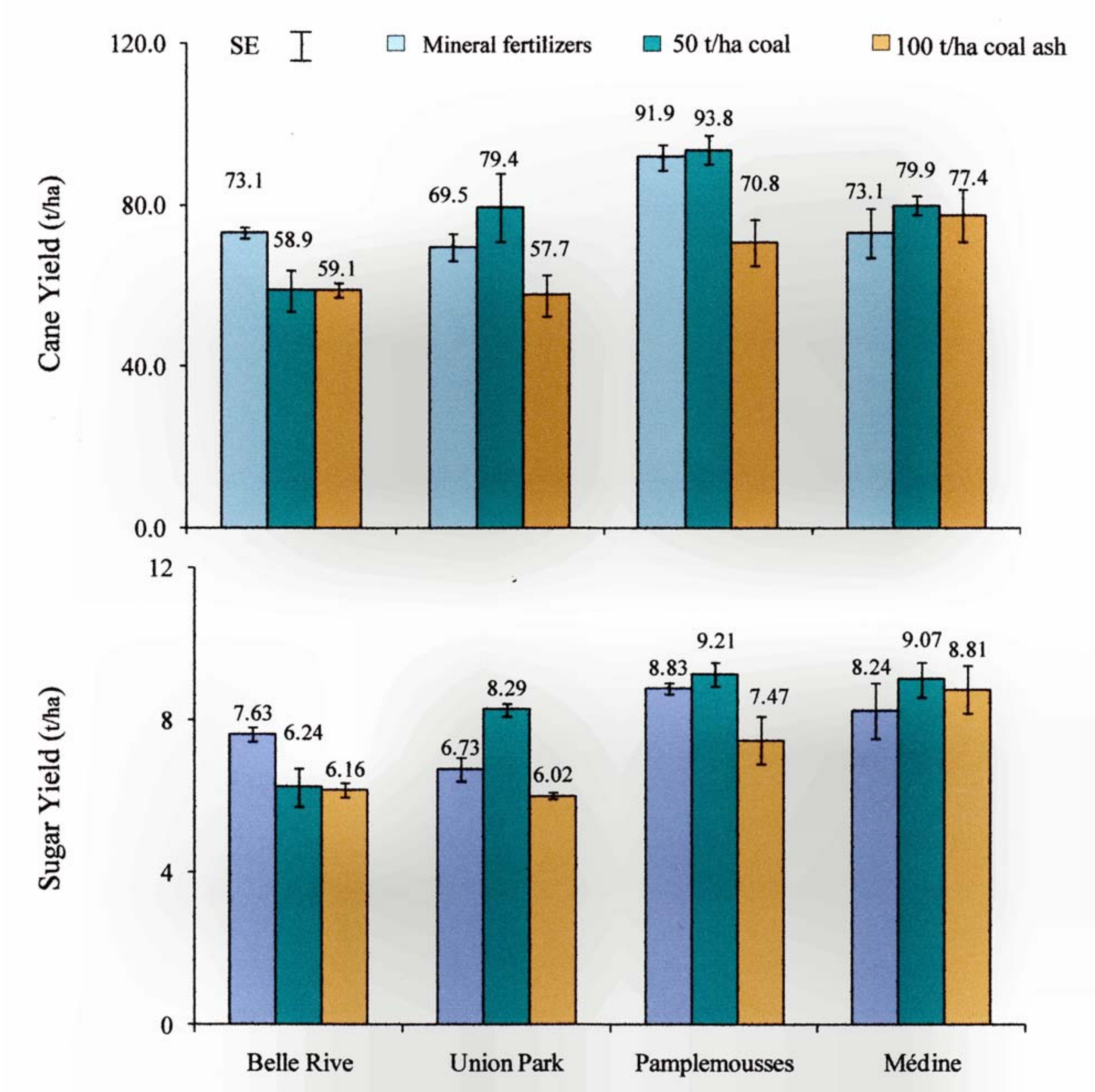

Fig. 1—Cane and sugar yields (mean of plant cane and two ratoons) at Belle Rive, Union Park, Pamplemousses and Médine upon application of coal ash at 50 and 100 t/ha.

NPK uptake

There was no significant difference in the uptake of N and K by the cane plant when coal ash at 100 t/ha was compared with mineral fertilizers. The lack of any difference in N uptake was expected as the amount of N applied was the same for all treatments.

The data nevertheless showed that N in the coal ash was just as available as the N in the mineral fertilizers.

The absence of any difference in K uptake on the other hand confirmed that the additional 75 kg K_2O/ha supplied by the 100 t/ha coal ash has been so diluted in the large volume of soil constituting one hectare, that with no significant difference in soil exchangeable K discerned as reported above, no difference in K availability could be perceived by the sugarcane crop when compared to mineral fertilizers.

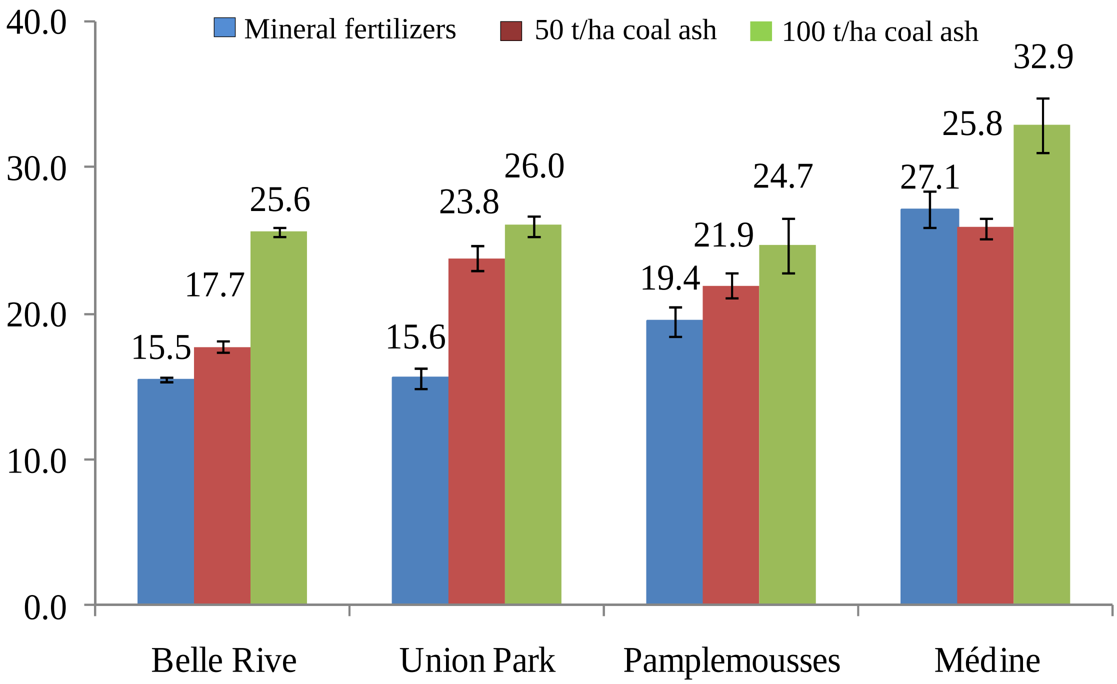

Fig. 2—P uptake by sugarcane (mean of plant cane and first ratoon) at Belle Rive, Union Park, Pamplemousses and Médine upon application of coal ash at 50 and 100 t/ha.

In general, P uptake was higher with coal ash at 100 and even at 50 t/ha. This was to be expected because no mineral P was added to the control treatment while coal ash at 100 t/ha supplied an additional 270 kg P/ha.

Moreover, as reported by Lee *et al.* (2008) silicate released from coal ash enhanced the availability of soil phosphate by displacing P from ligand exchange sites thus rendering P more available to be taken up by sugarcane plants.

Furthermore, it has also been reported by the same authors that phosphate sorption decreased in the presence of silicate which caused P to remain in a more available state. The higher availability of the P as translated by the increased uptake of P with coal ash by sugarcane was, however, not reflected in sugarcane yield (Figure 1) indicating that P was not a limiting nutrient to growth.

Heavy metal uptake

There was no significant difference in the uptake of the different heavy metals by the plant cane at the four different sites. The concentrations of heavy metals (Cu, Zn, Ni, Mn, Pb and Hg) in the aboveground parts of the cane crop (stalk, top and trash), 12 months after the application of coal ash at 50 and 100 t/ha, remained low and were not significantly different from the concentrations found in the sugarcane plants that received only mineral fertilizer.

This lack of difference in uptake can be explained by the fact that these heavy metals are large cations which are not very mobile in soil. Other studies have attributed the low uptake of heavy metals by crops as being due to a reduced mobility of heavy metals in an alkaline medium brought about in the vicinity by the ash and by an increase in the sorption of these heavy metals in soil (Ram *et al.*, 2007).

Conclusion

Though high rates of coal ash will have little impact on the soil chemical properties as reflected by soil pH, soil salinity and soil exchangeable bases, the present study showed that disposal of coal ash at rates of 100 t/ha should not be entertained in soils under sugarcane in Mauritius. Though the heavy metals present in the coal ash will pose little concern since their uptake by sugarcane will be little affected, the shift in the chemical conditions in the soil brought about by ash will in general lead to a decline in sugarcane production in Mauritius.

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IMPACT DE FORTES DOSES DE CENDRE DE CHARBON SUR CERTAINES CARACTERISTIQUES DU SOL ET SUR LE RENDEMENT DE LA CANNE A SUCRE

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MOTS-CLES: Déchets, Cogénération, Éléments Nutritifs, Métaux Lourds, Prélèvement.

Résumé

LA COMBUSTION de charbon pour produire l'électricité par l'industrie sucrière à Maurice génère annuellement quelque 20 000 tonnes de cendres qui doivent être éliminées d'une manière écologiquement rationnelle. Il a été rapporté que l'application à grande échelle de cendres présente des avantages agronomiques; cependant les données dans des conditions prévalant à Maurice n'étant pas disponibles, l'impact de l'élimination de 50 à 100 t/ha de cendres de charbon dans les champs de canne à sucre sur la qualité des sols et le rendement de la canne à sucre a été étudié dans des essais implantés dans quatre sites aux conditions agroclimatiques différentes, notamment à Belle-Rive (>3500 mm de pluie/an), Union Park (>3000 mm de pluie/an), Pamplemousses (> 1500 mm de pluie/an et Médine (pluie 900 mm de pluie/an). Bien que la cendre de charbon n'a pas eu d'incidence sur le pH, la salinité et même les bases échangeables du sol, son application à 100 t/ha par rapport aux engrais minéraux, a entraîné une réduction du rendement en sucre d'environ 1.18 t/ha dans trois des essais. Au taux inférieur de 50 t/ha de cendre de charbon, en dépit d'une baisse significative des rendements observés à Belle Rive, la production de canne à Pamplemousses, Union Park et Médine n'a pas été significativement différente de celle du contrôle. L'absorption de N et de K par la canne à sucre n'a pas été influencée par la cendre de charbon, bien que celle de P a été renforcée en raison d'un apport supplémentaire de P provenant des cendres de charbon. De plus en raison de sa faible teneur en métaux lourds, la cendre de charbon n'a pas augmenté l'absorption de métaux lourds par la canne à sucre. Compte tenu des effets indésirables observés sur la production de canne à sucre, l'élimination de la cendre de charbon à des taux aussi élevés que 100 t/ha dans les champs de canne à sucre ne devrait pas être envisagé.

IMPACTO DE ALTAS CANTIDADES DE MATERIAL PARTICULADO DE CHIMENEAS EN ALGUNAS CARACTERÍSTICAS DEL SUELO Y EN LOS RENDIMIENTOS DE LA CAÑA DE AZUCAR EN MAURITIUS

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PALABRAS CLAVE: Residuos, Cogeneración, Nutrientes, Metales Pesados, Captación.

Resumen

LA COMBUSTIÓN de carbón para la cogeneración de electricidad por parte de la industria azucarera en Mauricio genera anualmente unas 20 000 toneladas de material particulado de chimeneas que deben ser eliminados de manera ambientalmente racional. Se han reportado beneficios agronómicos de la aplicación a gran escala de ceniza, pero la información para las condiciones que prevalecen en Mauricio es escasa. El impacto de la aplicación de 50 a 100 t/ha de material particulado sobre la calidad del suelo y en la producción de caña de azúcar, ha sido evaluado en ensayos a campo realizados en Belle Rive (lluvia>3500 mm/año), Union Park (lluvia>3000 mm/año), Pamplemousses (lluvia>1500 mm/año) y Médine (900 mm de lluvia mm/año). A pesar de que las cenizas de carbón no afecta el pH del suelo, la salinidad del suelo, ni las bases intercambiables, aplicaciones de 100 t/ha, en comparación a aplicaciones de abonos minerales, se tradujo en una reducción promedio del rendimiento de azúcar, de 1.18 t/ha, en tres sitios. La dosis más baja de 50 t/ha de cenizas produjo un descenso significativo de los rendimientos en Belle Rive, mientras que la producción de caña de azúcar en Pamplemousses, Union Park y Médine no fue significativamente diferente del testigo. La absorción de N y K por parte de la caña de azúcar no se vio afectada por el material particulado, a pesar de que la absorción de P fue mayor a causa de los P complementarios provistos por la ceniza. Además, debido a su bajo contenido de metales pesados, el material particulado no aumentó la captación de metales pesados por parte de la planta de caña de azúcar. En vista de los efectos adversos observados en la producción de caña de azúcar, la disposición de cantidades de cenizas de carbón, tan altas como 100 t/ha no deben ser contempladas en campos cañeros.