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MASS AND COMPOSITION OF ASH REMAINING IN THE FIELD FOLLOWING BURNING OF SUGARCANE AT HARVEST

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Abstract

Approximately 90% of the South African sugarcane crop is subjected to pre-harvest burning, resulting in the generation of large amounts of ash. Variable amounts of ash may be deposited on the field, with this depending largely on prevailing winds at the time of burning. The objective of this work was to provide some insight into the extent of in-field ash deposition and its chemical composition. The study was conducted on burnt treatments of the oldest sugarcane trial in the world, BT1. During the burn, ash was collected in steel trays (0.4m by 2.0 m) and analysed for N, P, K, Ca, Mg, S, Si, Cu, Mn, Zn and Fe. The mass of ash ranged from 0.03 to 0.24 t/ha, which was typically around 1% of the dry weight of dead leaves. Ash had an inverse relationship with soil fertility, ranging from 0.16 tons ash/ha for the most nutrient depleted treatment to 0.10 ton ash/ha for a well fertilised treatment. Ash from well fertilised treatments was also richer in nutrients. The only exception was Si (the most abundant nutrient in ash) which was present in higher quantities in ash of the nutrient depleted treatments (due to the larger biomass removed from well fertilised treatments third leaf Si was below threshold levels, which was not the case for the unfertilised treatments). The mean ash yield for a well fertilised field was 130 kg/ha, containing 19 kg Si/ha and 0.47, 0.22 and 1.17 kg/ha of N, P and K respectively. Importantly, the amount of Si recycled might be very different for crops grown on soils low in Si. Based on the small quantities of ash remaining in the field (after wind-removal) the economic value in terms of nutrient recycling is negligible.

Keywords: sugarcane burning, ash, silicon, nutrients

Introduction

About 90% of the sugarcane harvested annually in South Africa is burnt in preparation for harvesting. Often questions are asked with regard to the amounts of nutrients left in the field in the ash following a burn. With a lack of published information the answer to this question has always been ‘a best guess’.

Most of the references obtained in searches with regard to sugarcane ash are for bagasse and a smaller quantity deals with the impact of burning sugarcane on allergies and human health. For example Le Blond *et al*. (2010) analysed the ash following a burn but the focus of the paper was to report on the potential link between the exposure to crystalline silica and the chronic disease silicosis – a respiratory health hazard. Using an infrared camera Le Blond *et al.* (2010) recorded that burning of sugarcane in preparation for harvesting could reach a temperature in excess of 1000^{o}C. Mitchell *et al*. (2000) used furnace temperatures of 600 and 900^{o}C for their studies. Vega (1982) estimated that about 30% of the total N taken up by the sugarcane crop is lost during pre-harvest burning. Comparing ashing to the nutrients in mulch residue Mitchell *et al*. (2000) measured the following nutrient recoveries after burning sugarcane in preparation for harvesting: N (23%), P (23%), K (30%), Ca (11%), Mg (17%) and S (18%). Only 23% of the dry matter was recovered. In the paper by Le Blond et al. (2010) it was reported that sugarcane ash contains between 10% and 25% crystalline silica (SiO_2) by weight, with trace amounts of Mg, Al and Fe in the silica particles in the ash.

The objective of this paper is to quantify the amount of ash left in the field after a burn and to report on its composition, with a particular focus on the potential value of ash as a source of recycled nutrients.

Materials and Methods

Data for this paper were collected from BT1, the oldest sugarcane trial in the world, situated at the South African Sugarcane Research Institute (SASRI) at Mount Edgecombe near Durban (31°04'20"E, 29°04'20"S). The climate of the region is humid subtropical and is characterized by summer (October to March) rainfall. The average annual precipitation is 950 mm, and the average annual temperature is 20.4°C (Graham *et al*., 2002). The site is located on a south-west facing aspect with a slope of 13.5% and 18.5% for the upper and lower parts of the trial site, respectively. On the upper slope, the soil was classified as a Mayo form, and as a Bonheim form on the lower slope (Soil Classification Working Group, 1991). Both soil types have a clay content of approximately 50% in the topsoil.

Established on 25 October 1939, the treatments are green cane harvesting and burnt in preparation for annual harvesting in September. The latter treatment is further divided into spreading and removal of the unburnt residue. A further treatment is to apply or not to apply fertiliser to the residue management treatments. The fertiliser used annually is 140 kg N/ha, 28 kg P/ha and 140 kg K/ha as 5:1:5 (46) applied approximately 40 days after harvesting (van Antwerpen *et al*., 2001).

Each plot in the trial is 18 m long and has seven cane rows with a spacing of 1.4 m between rows. Net plots are 16 m long with three cane rows. The trial was harvested manually in September of each year and yield per plot was determined by weighing the stalks from three net plot rows, each 16 m long. The main parameters measured with every crop harvested is crop yield and quality, fertility properties of the topsoil (0-20 cm) collected immediately after harvest and nutrient content of the third leaf sampled at the age of four months. Many other parameters are also measured but on an *ad hoc* basis based on the objectives of projects making use of the BT1 trial as a source of data. Examples are soil structural stability in 1998 and again 2015, soil Si since 2011, the stalk borer *Eldana saccharina* Walker (Lepidoptera: Pyralidae) infrequently in the 1980s and 1990s, microbial biomass in the early 2000s, biomass partitioning in 2009, ash infrequently since 2005 and many more. Data collection for this paper was not from a project where all the parameters required are measured over a fixed period but was taken from the *ad hoc* data and might therefore come from various periods in the life of the BT1 trial.

Since 1939 seven varieties were used at BT1, of which the last two were N27 (2002 to 2013) and currently N41 (planted in October 2014). The plant and first ratoon crops of N41 were harvested on 13 October 2015 and 9 September 2016 at the ages of 12.1 and 11.1 months, respectively. This paper will focus on N41 and, on occasion, data from N27 is used.

BT1 is not irrigated and rainfall received per crop therefore has a significant impact on yield. Rainfall for N41 plant and ratoon crops used in this study were 853 mm and 1043 mm respectively. For this paper only data collected from the burnt treatments (replicated four times) were considered (see Table 1).

Table 1: Treatments and their abbreviations.

Residue treatment	Fertiliser treatment	Abbreviation
Unburnt tops removed	Not fertilised	BtoFo
Unburnt tops retained	Not fertilised	BtFo
Unburnt tops removed	Fertilised	BtoF
Unburnt tops retained	Fertilised	BtF

Representative soil samples per plot were collected as prescribed by the Fertiliser Advisory Service (FAS) at SASRI taking ten 0-20 cm samples from the interrow and one each from the three net plot cane rows. These samples were analysed for pH ($CaCl_2$), and P (Troug), K, Ca, Mg and S by XRF and Si using a 0.01 M $CaCl_2$ solution.

Twenty 'third leaf' samples were taken from each plot and after the midrib was removed the blades were submitted to the FAS for analysis. To collect the ash following a burn, two metal trays (0.4 m wide x 2.0 m long x 0.1 m deep) were placed about two meters from the plot edge on either side of the plots and between two consecutive net plot interrows immediately before the burn. Immediately after the burn the contents of each metal tray were transferred into paper bags, the contents of which was split in the laboratory into unburnt residue and ash. Only the ash was quantified. The ash was weighed before it was submitted to the FAS for analysis.

A partitioning study was conducted on the sixth ratoon of variety N27 which was burnt in preparation for harvesting on 9 October 2009 at the age of 12.9 months. Prior to harvest, the cane was green harvested over a distance of 1 m from the third net plot cane row on 21 September 2009. These were partitioned into green leaves, brown leaves and number of stalks. All were dried at 70°C and the dried weight determined before it was sent to FAS for analysis. Ash after burning was collected as described in the previous paragraph.

Leaf samples were analysed for N by NIR and P, K, Ca, Mg, S, Si, Cu, Mn, Zn and Fe by XRF. Ash samples were analysed for N by automated (Dumas) dry combustion using a Leco Analyzer (Leco Corporation, St Joseph, Michigan), and other elements by ICP following acid digestion.

The data were analysed by analysis of variance (ANOVA) with the F-test at 5%, using Genstat for Windows programme (GenStat, 2015). Fisher's Least Significant Difference (LSD) at 5% was conducted as a *post-hoc* to compare the means.

Results

The plots receiving fertiliser annually after harvest tend to have a lower pH and higher exchangeable acidity and acid saturation compared to the plots receiving no fertiliser (Table 2). Treatments of the first ratoon crop receiving fertiliser generally seemed to have a higher mean extractable P and K content, while Ca and Mg tended to be lower. This trend was not observed in the plant crop, probably due to the mineralisation of nutrients following the disturbance of the soil in preparation for planting. Mean extractable Si, Cu, Mn and Fe from both crops also tended to be higher for the treatments receiving fertiliser (Table 2). None of these trends in the soil were statistically significant.

Table 2: Analytical data for soil samples taken after harvesting the plant and first ratoon crops. Samples were taken on 19 November 2015 and 8 December 2016 at a depth interval of 0-20 cm. Least significant differences (LSD) were determined at p = 0.05.

Nutrient	Plant crop					First ratoon crop				
	BtoFo	BtFo	BtoF	BtF	LSD	BtoFo	BtFo	BtoF	BtF	LSD
pH ($CaCl_2$)	4.32	4.52	4.39	4.22	0.79	4.61	4.79	4.32	4.30	0.87
Exch Acidity (cmol/L)	1.13	0.35	1.34	1.38	2.28	0.97	0.73	1.40	1.69	2.53
Acid Saturation (%)	7.6	2.5	10.2	11.6	17.8	4.6	3.3	6.4	8.1	12.5
Truog P (mg/L)	17	17	13	16	32	10	9	17	24	25
K (mg/L)	92	78	98	67	78	107	132	162	209	125
Ca (mg/L)	2263	2335	2254	1761	1029	3811	4247	3329	3388	1556
Mg (mg/L)	382	423	410	382	228	658	594	528	513	159
Si (mg/L)	44	32	34	39	4	49	48	49	54	8
Cu (mg/L)	13.5	12.9	14.2	13.4	3.1	19.2	18.0	22.4	22.3	4.9
Mn (mg/L)	34.5	15.1	20.5	21.8	26.1	33.7	38.2	45.5	48.9	35.5
Zn (mg/L)	2.3	2.1	2.0	2.1	1.7	2.0	2.7	2.9	4.2	2.2
Fe (mg/L)	300	196	258	344	270	268	249	421	472	371

Leaf samples collected from plots receiving fertiliser at the age of 4.6 and 3.6 months for the plant and first ratoon crops, respectively, had significantly higher N (plant crop only), P and K contents, while Ca, Mg, S (plant crop only) Si and Zn were significantly lower compared to plots receiving no fertiliser (Table 3). The latter results illustrate the continuous nutrient mining of non-fertiliser nutrients by the larger biomass of the crop in response to the applied fertiliser (van Antwerpen and Meyer, 2002).

Table 3: Leaf analysis (variety N41) of samples taken from the plant crop and first ratoon on 3 March 2015 and 29 January 2016, respectively. Least significant differences (LSD) were determined at p=0.05.

Nutrient	Plant crop					First ratoon crop				
	BtoFo	BtFo	BtoF	BtF	LSD	BtoFo	BtFo	BtoF	BtF	LSD
N (%)	1.81	1.89	2.08	2.04	0.08	2.03	2.03	1.97	2.06	0.13
P (%)	0.16	0.18	0.25	0.28	0.02	0.16	0.18	0.23	0.26	0.02
K (%)	0.75	0.81	1.18	1.42	0.10	0.65	0.79	1.21	1.41	0.15
Ca (%)	0.27	0.25	0.22	0.19	0.05	0.35	0.33	0.25	0.24	0.03
Mg (%)	0.16	0.17	0.16	0.14	0.01	0.25	0.25	0.19	0.19	0.04
S (%)	0.16	0.16	0.19	0.19	0.01	0.22	0.21	0.19	0.20	0.03
Si (%)	0.79	0.79	0.56	0.49	0.12	1.81	1.63	0.69	0.75	0.21
Cu (ppm)	4.5	4.6	4.9	4.8	0.5	9.3	8.5	7.6	7.2	0.8
Mn (ppm)	50.5	41.4	56.5	54.3	8.2	36.9	36.6	43.9	51.1	12.5
Zn (ppm)	26.7	26.2	22.0	21.1	2.6	21.5	20.7	19.2	18.3	1.9
Fe (ppm)	136.8	134.2	121.5	114.4	28.2	99.4	105.6	102.9	99.7	24.6

Ash samples collected after burning sugarcane in preparation for harvesting contained significantly more P, K, Cu (plant crop only) and Mn in the fertilised plots than the unfertilised plots (Table 4). No significant differences between unfertilised and fertilised treatments were observed with respect to N, Ca, Mg, S, Si, Zn and Fe. An outstanding feature of the analysis of the ash from both plant and ratoon crops was the high Si content of about 19%, which was on average five and eight times larger than the Ca and Fe contents, respectively (Table 4).

This Si content compares well with the 10% to 25% crystalline silica (SiO_2) reported by Le Blond *et al*. (2010).

The low N and S values in ash were expected due to possible volatilisation losses of these elements with burning. Vega (1982) estimated that about 30% of the total N uptake by sugarcane is lost during pre-harvest burning. The concentrations of N, P, K and S in the third leaf and ash samples were comparable. The ratios of Ca (14), Mg (8), Si (25), Cu (10), Mn (15), Zn (121) and Fe (187), however, were all in favour of ash relative to the third leaf (Tables 3 and 4). The strong fertiliser treatment effect on Si content observed in leaf samples (Table 3) was not observed in the ash (Table 4).

Mass of the ash collected ranged from 0.03 to 0.24 tons/ha, with the mass for the plant crop only about a quarter of that collected from the first ratoon crop (Table 5). The obvious source of an explanation for the large difference between the two seasons is crop yield. However, crop yields of the plant and ratoon crops were remarkably similar, despite the much lower rainfall received for the plant crop (Table 5). Despite the higher rainfall, cane yield of the first ratoon crop from the 'burn with a bare surface' scenario that was fertilised (BtoF) was 18% lower compared to the plant crop. Analysis of the rainfall patterns revealed that, despite the lower total rainfall, the plant crop received 20% more rain during the summer period and before canopy closure compared to the first ratoon crop. Similar yields between the unfertilised crops (Fo) of the plant and first ratoon (Table 5) are an indication that, not water, but nutrients were limiting yields. The lower yield of the first ratoon from the BtoF treatment did not appear to have affected the nutrient content of the ash (Table 4).

A more likely explanation for the much lower ash mass from the plant crop was the dry winter it experienced. Prior to burning at harvest the plant crop received only 331 mm over the previous seven months compared to 615 mm in the case of the ratoon crop (Table 5). Burning of the first ratoon crop early in the morning was poor due to the wet conditions and had to be re-burnt later in the day. The 'good burn' of the plant crop might have been responsible for the export of significant amounts of ash by the draft created by the fire resulting in the much reduced mass of ash left on the ground for the plant crop in 2015 (Table 5). Ash recovery data from the previous variety (N27) grown on the BT1 trial site was used to determine the effect of rainfall on the ash recovered after burning (Figure 1); this appears to support the suggestion that less ash is recovered if the period after reaching canopy till harvest (March till September) was dry. It is, however, assumed that rain or dry weather the day before burning would be equal if not more decisive in the amounts of ash that will be retained in the field after a fire.

Following on from the trend in Figure 1 the interest was to establish the relationship between the amount of ash recovered and the amount of brown (dead) leaves that were burnt at harvest. The only data available to determine this relationship was from the sixth ratoon of variety N27, which was burnt in preparation for harvesting on 9 October 2009 (Table 6). The percentage ash relative to the amount of brown leaves ranged from 0.65% for the BtF treatment, to 1.96% for the most nutrient starved treatment (BtoFo) with the overall mean at about 1%. Although the unfertilised treatment will probably never be practised by farmers, it did allow for an opportunity to note that an inverse relationship is most likely to exist between ash retention and the amount of brown leaves that are available for burning (Table 6). This implies that, with more brown leaves available for burning, it can be assumed that the fire was more intense and created a stronger thermal draft with more ash being carried into the air for transportation away from the burning field. Thus, more nutrients are potentially lost in a cane fire where the amount of burnable material is more abundant.

Using the percentage of ash (Table 4) and the mass of ash (Table 5) the amount of nutrients (kg/ha) contained in ash retained in the field were calculated (Table 7). It is clear that the amounts of nutrients deposited in the field as ash after a fire are insignificant and will not benefit the sugarcane crop meaningfully. However, the dominating nutrient in ash is Si ranging from 10.3 to 37.4 kg/ha for fertilised sugarcane (Table 7). Ash that contains 30 kg Si/ha is roughly equivalent to about 8% of the Si taken up by an average yielding crop of 74 t/ha (Ross *et al*., 1974). Sugarcane ash therefore recycles a small amount Si which is not expected to have a significant impact on the Si supplied to the crop. It is however, assumed that ash from cane grown on soils low in plant available Si (i.e. very sandy coastal soils and humic soils in the midlands; van der Laan and Miles, 2010) will contain even smaller amounts of Si.

Table 4: Analysis of variety N41 ash samples collected after burning in preparation for harvesting. Samples collected on 13 October 2015 and 9 September 2016 were from the plant and first ratoon crops respectively. Least significant differences (LSD) were determined at p=0.05.

Nutrient	Plant crop					First ratoon crop				
	BtoFo	BtFo	BtoF	BtF	LSD	BtoFo	BtFo	BtoF	BtF	LSD
N (%)	0.80	0.75	0.87	0.74	0.15	0.38	0.44	0.48	0.45	0.11
P (%)	0.18	0.12	0.28	0.23	0.10	0.13	0.14	0.22	0.23	0.06
K (%)	0.58	0.59	1.99	2.37	0.56	0.40	0.40	0.60	0.68	0.28
Ca (%)	4.09	3.85	4.93	4.17	1.64	2.13	3.08	2.97	2.98	1.35
Mg (%)	1.73	1.58	1.96	1.71	0.75	0.76	1.16	0.96	0.95	0.44
S (%)	0.69	0.46	0.77	0.55	0.36	0.19	0.26	0.22	0.22	0.10
Si (%)	22.49	20.73	18.93	22.15	4.00	13.57	20.70	16.88	15.35	2.84
Cu (%)	0.005	0.005	0.007	0.008	0.001	0.005	0.004	0.006	0.005	0.001
Mn (%)	0.05	0.05	0.11	0.12	0.04	0.05	0.05	0.07	0.07	0.02
Zn (%)	0.37	0.17	0.29	0.16	0.48	0.13	0.24	0.37	0.35	0.48
Fe (%)	1.12	1.08	0.92	1.67	1.94	3.66	1.82	3.30	2.47	1.88

Table 5: Ash and cane stalk yield (ton/ha) with rainfall data for two crops. Least significant differences (LSD) were determined at p=0.05.

Parameter		Plant crop	First ratoon crop	Mean
Ash yield (t/ha)	BtoFo	0.03	0.19	0.178
	BtFo	0.05	0.21	0.162
	BtoF	0.05	0.19	0.135
	BtF	0.06	0.24	0.141
	LSD (p=0.05)	0.03	0.08	-
Cane yield (t/ha)	BtoFo	24.5	23.0	23.8
	BtFo	39.7	39.9	39.8
	BtoF	85.0	67.9	76.5
	BtF	84.7	80.7	82.7
	LSD (p=0.05)	13.4	16.1	-
Total rain (mm)		853	1043	
Rainfall received before canopy closure (%)		61.2	41.0	
Rainfall received before canopy closure (mm)		522	427	
Rainfall received after canopy closure (mm)		330	616	

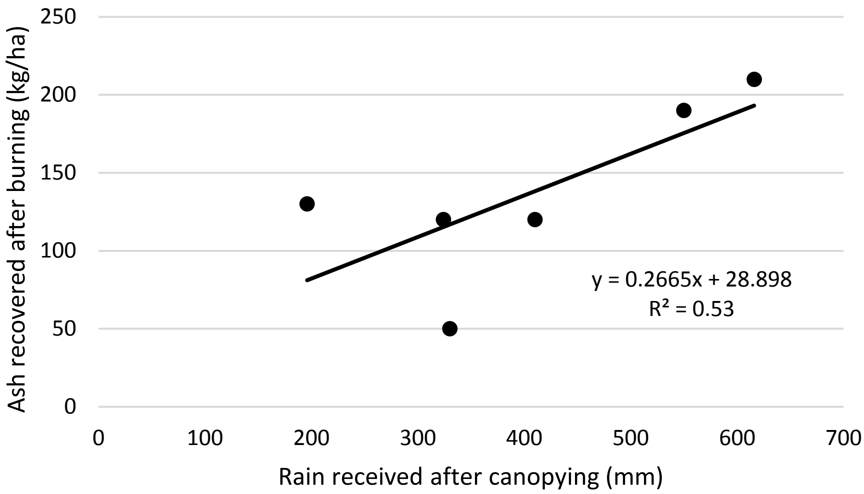

Figure 1: Effect of the amount of rain received after canopying (March – September) on the amount of ash recovered after burning N27 ratoon crops (3, 4, 5 and 6) and N41 ratoon crops (plant and first ratoon) in preparation for harvesting.

Table 6: Mean mass of brown leaves (collect on 21 September 2009) before burning and ash (collected on 9 October 2009) after burning in preparation for harvesting the sixth ratoon of variety N27 at the BT1 trial site. Least significant differences (LSD) were determined at p=0.05.

Parameter	Brown leaves before burning (t/ha)	Ash after burning (t/ha)	Ash as % of brown leaves
BtoFo	6.12	0.16	1.96
BtFo	7.40	0.12	0.96
BtoF	9.30	0.10	0.81
BtF	11.53	0.10	0.65
LSD (p = 0.05)	3.24	0.05	0.80
Mean of unfertilised treatments (Fo)	6.76	0.14	1.46
Mean of fertilised treatments (F)	10.42	0.10	0.73
Mean of all treatments (Fo + F)	8.59	0.12	1.09

Table 7: The nutritional content (kg/ha) of the ash retained in the field for variety N41. Least significant differences (LSD) were determined at p=0.05.

Nutrient	Plant crop					First ratoon crop				
	BtoFo	BtFo	BtoF	BtF	LSD	BtoFo	BtFo	BtoF	BtF	LSD
N (kg/ha)	0.26	0.35	0.48	0.46	0.28	0.70	0.91	0.89	1.07	0.34
P (kg/ha)	0.08	0.06	0.14	0.15	0.10	0.23	0.29	0.40	0.55	0.18
K (kg/ha)	0.20	0.31	1.07	1.60	0.79	0.70	0.85	1.11	1.64	0.72
Ca (kg/ha)	1.31	1.81	2.64	2.93	1.92	3.74	6.60	5.56	7.21	4.21
Mg (kg/ha)	0.53	0.77	1.06	1.20	0.79	1.36	2.49	1.78	2.31	1.43
S (kg/ha)	0.27	0.20	0.35	0.38	0.30	0.32	0.55	0.40	0.54	0.34
Si (kg/ha)	7.38	9.63	10.34	14.45	8.54	25.63	43.67	31.25	37.36	15.62
Cu (kg/ha)	0.002	0.002	0.004	0.005	0.003	0.009	0.008	0.011	0.011	0.006
Mn (kg/ha)	0.02	0.02	0.06	0.08	0.04	0.09	0.10	0.14	0.17	0.06
Zn (kg/ha)	0.20	0.08	0.10	0.10	0.31	0.29	0.42	0.66	0.86	0.85
Fe (kg/ha)	0.51	0.48	0.41	0.80	0.83	3.46	3.46	6.11	5.81	3.91

Conclusions

Management interventions, such as the application of fertilisers, have a significant effect on the nutrients taken up by the crop. Nutrients applied with fertiliser (N, P and K) were present in higher concentrations in the green leaves. However, the crop is also an indicator of nutrients that are less available. These nutrients (e.g. Ca, Mg and Si) are still available from soil reserves though in reduced quantities. Fortunately, sufficient quantities of these nutrients are being taken up to maintain levels in the leaves at or above threshold values. They do, however, illustrate the nutrient mining effect as a result of the consistent application of treatments at BT1 over the past 77 years.

Two factors were identified as having an impact on the amounts of ash retained in the field after a burn. Firstly, the data tend to show that the amount of rain received in the previous seven months prior to harvest is a factor. With lower rain less ash remains after a fire which is more intense compared to a pre-burn in a wetter period. The second factor was the amount of brown (dead) leaves present at harvesting. With more brown leaves present the fire is assumed to be larger, creating stronger draft and thus more ash will be carried on the thermals away from the field. It is therefore recommended to practise 'cool burns' to minimise the transport of ash and nutrients from the harvesting site. This aspect, however, needs to be confirmed.

The value of ash as a source of nutrients is diminishing with an increase in the distance that the particulate matter is transported due to dispersion over a much larger area. Deposition of the ash over urban areas is considered to be a nuisance and burning a source of air pollution. The location to find the most concentrated ash is in the field that was burnt. Thus, although in terms of nutrient recycling, the ideal is to contain all the ash from a burn in the field, it is not ideal with regard to the health of cutters (Le Blond *et al*., 2010). Here it is best to have no ash in the field and although the export of ash on thermals is reducing the concentration of ash in the field, the best is to have no ash in the field being cut. This condition is obtained where cane is harvested green.

The assumption was made that the Si content in ash is probably similar to that contained in brown (dead) leaves just before burning. This assumption could not be confirmed from the available data because it was found that the intensity of the burn might have had an effect on the amount of recoverable ash. Despite this it was calculated that the mass of ash equates to approximately 1% of the mass of brown leaves at time of harvest.

The total ash yield obtained ranged between 30 and 240 kg/ha and it is therefore unrealistic to expect ash to recycle meaningful amounts of nutrients. This holds true for all nutrients for which ash samples were analysed in this work.

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