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Effect of Residue Management and N and S Fertilisation on Cane and Sugar Yield of Plant and Ratoon Cane

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ABSTRACT

Residue management in sugar-cane cultivation is crucial for improving soil health, as it positively impacts the increase of sugar cane productivity. The study aimed to describe the effect of sugar-cane residue management using ammonium sulfate fertiliser and its substitute on cane and sugar yield in plant and ratoon cane. A pot experiment was conducted using a factorial block randomised design. The first factor is N and S fertilisation, consisting of ammonium sulfate (AS), urea, gypsum and bio-compost. The second factor is the residue management consisting of four levels, namely burnt residue, residue incorporated into the soil, residue put on the soil surface and composted residue. These treatments were tested on the first and second cane. The results showed that the composted residue gave the highest increase in cane and sugar yield by 83.7% and 81.2%, respectively on the ratoon cane when compared with the plant cane. Fertilisation using urea, bio-compost and gypsum showed the highest cane yield. The results suggested that composted residue can be applied in sugar-cane cultivation in dry land to increase nutrient uptake and cane and sugar yield in plant and ratoon cane.

Keywords: Cane and sugar yield, fertilisation, plant cane, ratoon cane, residue management

INTRODUCTION

In the sugar-cane cropping system, the burning of residue after harvest is a customary practice worldwide including in Indonesia, which, in 2015, had 461,732 hectares of sugar-cane plantation (Directorate General of Estate Crops, 2016). The most crucial factor that must be considered before removing crop residue is its impact on soil

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organic matter. Nurhidayati (2013) reported that the average sugar-cane residue left on the field is 10-15% of the total biomass of sugar cane. Sugar-cane trash can provide 40 to 120 kg N ha^{-1} $year^{-1}$ (Franco et al., 2010; Oliveira et al., 2002; Robertson & Thorburn, 2007). The C-to-N ratio of sugar-cane trash is 100:1, meaning that sugar-cane trash has a high organic-C content. Thus, on average, 1 kg sugar-cane trash contains 450 g C and 4.5 g N. In one study, the recovery rates of N from residue incorporated into the soil varied from 2% to 15% of the total N contained in sugar-cane residue (Ambrosano et al., 2005; Meier et al., 2016; Vitti et al., 2010).

In addition to the problem of residue burning, sugar-cane farmers in Indonesia often face the problem of soil acidification, which results in low nutrient availability. Hartemink (1998) reported that soil acidification occurred because of the application of ammonium sulfate fertiliser in the long-term. Nurhidayati et al. (2011) reported that soil pH of sugar-cane land in East Java, Indonesia ranged from 4.5-6.5. This condition impacted the decline of soil fertility and the increase of the fertiliser application rate. Azman et al. (2014) stated that soil acidity is a major agronomic problem due to the presence of Al, decrease of P availability and nutrient deficiencies. Application of soil amendment materials such as lime is needed to overcome soil acidity and improve soil fertility. Nurhidayati and Basit (2015) reported that application of bio-char of sugar-cane trash gave better results on soil derived from sugar-cane land than other soil amendment like lime-calcite and boiler ash. Application of bio-char of sugar-cane trash can increase N uptake by sugar cane. Thus, utilisation of sugar-cane residue as soil amendment provides the best management practice, including the application of bio-char from sugar-cane residue to improve soil pH and composted residue to enhance soil organic matter content.

Organic soil amendment contributes directly to nutrient availability as well as nutrient and water-holding capacity of soil. It also plays a key role in both soil health and the formation of water stable aggregates in the soil that affect infiltration, aeration and drainage (Bot & Benites, 2005). It provides carbon and energy for soil microorganisms that are essential for the nutrient cycle in the soil. Some microorganisms form mutually beneficial relationships with plant roots and provide nutrients for plants in exchange for energy through the formation of simple sugar (Cooperband, 2002).

Sugar-cane residue management practices have been widely applied in sugar-producing countries, including Australia. Over the last few years, sugar-cane growers have increasingly adopted a system of green cane trash blanketing (GCTB), where trash is retained as an undisturbed layer on the soil surface and cultivation is greatly reduced (Kingston & Norris, 2001). However, in Indonesia, residue management is not common. Indonesian sugarcane growers always burn sugar-cane residue after harvest. This practice decreases soil quality, as indicated by low soil C-organic content, ranging from 1.04-1.85% (Nurhidayati et al., 2011). Management of sugar-cane residue has been extensively studied, especially its effect on runoff and soil erosion (Prove et al., 1995), soil organic carbon on the upper 10-20 cm of soil (Franzluebbers, 2010), soil organic carbon in deeper soil layers (Jobbagy & Jackson, 2000), soil respiration and crop productivity of sugar cane (Kennedy & Arceneaux, 2006), soil C and fertility of cane lands (Robertson & Thorburn, 2007) and the contribution of N (Fortes et al., 2013), but little is known about the effects of sugar-cane trash management combined with chemical fertilisation on nutrient uptake and cane and sugar yield.

Nurhidayati and Basit (2014) reported that the application of compost of sugar-cane trash increases the rate of N mineralisation due to increasing earthworm activity. When crop residue was incorporated into soil in the process of soil tillage, it not only improved soil biology related to the availability of plant nutrients; it also involved soil aggregation (Holland, 2004). According to Malhi et al. (2006), residue management simultaneously improves soil and increases crop yield in order to maintain high crop production and minimise adverse impact on the environment. However, it did not significantly affect the availability of N in the topsoil, although it can reduce the aggregate amount that is sensitive to erosion. Agricen (2014) reported that valuable nutrients for the next season's crops come from previous crop residue. The objective of this study was to describe how sugar-cane trash and fertilisation management affect nutrient uptake and cane and sugar yields. This study was conducted over two planting seasons of sugar cane (plant and ratoon cane).

MATERIALS AND METHOD

Study Site and Soil Characteristics

A pot experiment was conducted at the experimental field of the Agriculture Faculty, University of Islam Malang from December 2014 to March 2016. The experimental field is 505 m above sea level and has an average temperature ranging from 20-28°C, while rainfall is 1,750 mm per year. The ratoon cane was grown after harvesting plant cane in August 2015 until March 2016. Soil samples were collected from sugar-cane land in Karangploso district, Malang regency, East Java. The soils were chosen to be representative of the group of soils from sugar-cane land with low pH. The samples (0-10 cm) were taken from areas with more than 10 years of sugar-cane monoculture. The soil consisted of 18.1% clay, 61.4% silt and 20.5% sand, and is classified as silty loam in texture. It was analysed for its chemical properties. The results are presented in Table 1. These samples were used in a pot experiment in which the sugarcane was grown.

Table 1
Chemical properties of the different types of soil used in this study

Soil Type	pH 1:1		C-organic (%)	N total	C/N	OM content %	P-Bray1	SO_4	K	CEC
	H_2O	KCl					(mg kg^{-1})		(mg/100 g)	
Incep-tisols	4.9	4.5	1.0	0.12	8.3	1.73	60.56	6.20	0.16	18.65

Experiment Design and Treatments

The experiment was laid out in a randomised factorial block design. The first factor was N and S fertiliser from several fertilisers consisting of ammonium sulfate, urea and gypsum and had six levels as presented in Table 2. The second factor was the residue management consisting of four levels: the residue was burned (M1); the residue was incorporated into the soil (M2); the residue was placed on the soil surface (M3); and the residue was composted (M4). The combination of the two factors made 24 kinds of treatments and one control (no fertiliser and residues) and they were repeated three times to obtain 75 experiment pots. In addition to residue management treatments, sugar-cane residue bio-char was added as a soil amendment to increase soil pH except for the control. Nurhidayati and Basit (2015) reported that the bio-char of sugar-cane trash is the best soil amendment to improve soil chemical properties of sugar-cane land. The residue application rate was 5 t ha^{-1}. The percentage of the components of the composted sugar-cane trash was: organic-C, 28.1%; total N, 0.81%; C/N ratio, 34.7; lignin, 13.3 %; ash, 10.2%; cellulose, 40.1%; polyphenol, 2.01%; and gross energy, 3,028 kcal/kg.

Table 2
The treatment combinations used in this study

Treatments	N Doses (kg ha^{-1})	S Doses (kg ha^{-1})	AS (kg ha^{-1})	Urea (kg ha^{-1})	Bio-Compost (kg ha^{-1})	Gypsum (kg ha^{-1})
Control (No Fertilisation)	-	-	-	-	-	-
N1+S1 (AS)	100	120	500	-	-	-
N2+S2 (AS)	140	168	700	-	-	-
N1+S1 (U+G)	100	120	-	223	-	522
N2+S2 (U+G)	140	168	-	312	-	730
N1+S1 (U+B+G)	100	120	-	110	1950	730
N2+S2 (U+B+G)	140	168	-	155	2750	938

Note: N=Nitrogen; S=Sulfur; AS=Ammonium Sulfate; G=Gypsum; B=Bio-compost; U=Urea; N and S content in AS=20% and 24%; S content in gypsum=19%; N content in urea=45%; N content in bio-compost=2.57%; gypsum was used as S fertiliser source and Ca content in gypsum was not calculated in the dose of the treatments

Experiment Procedure

The soil sample used in the medium was air-dried and ground. An amount of 40 kg dry soil was put into 75 plastic pots (top diameter=47 cm, bottom diameter=40 cm and height=32 cm). Each plastic pot had 20 holes for perforation. The residue was added to the soil one week before planting at 5 t ha^{-1}, equivalent to 100 g per 40 kg soil on dry weight basis. The composted residue was prepared by grinding sugar-cane trash and composting it using EM4 (Effective Microorganism) for 30 days. The residue was applied in accordance with the treatment in the second factor. Sugar-cane bud chips of BL-red are the most widely planted sugar-cane cultivar in East Java, planted after seedling for one month. One bud chip was placed in each pot, 10 cm into the soil. Basal fertiliser of P and K (15:15) at dose of 400 kg ha^{-1} was applied to each pot. The chemical fertiliser was applied after two weeks of planting. Its dose was adjusted to pre-determined treatments. The plant cane was harvested after seven months and cut, while the ratoon cane was continued for seven months. The bio-compost and gypsum were applied three weeks after cutting. In addition to the treatments, P and K fertilisers were applied four weeks after cutting at 400 kg ha^{-1} for all the treatments. Half of the urea and ammonium sulfate were applied four weeks after cutting the stalk of sugar cane. The remaining urea and ammonium sulfate were applied eight weeks after cutting.

Measurement of Observation Variables

Leaf samples from top of the plants were collected for analysis of leaf N and S content at four months of plant age. The leaf samples were chopped, homogenised and dried at 70°C in a hot-air oven. The dried samples were ground in a stainless steel mill. The wet-acid oxidation of the leaf samples was based on Kjeldahl oxidation in concentrated H_2SO_4 for determination of total N and turbidimetry methods using $BaCl_2$ reagent for determination of S-SO_4 (Okalebo et al., 2002). The N and S uptake was calculated from the nutrient content; it was multiplied by the dry weight of the total biomass. The variables of sugar-cane yield consisted of the fresh weight of cane and total biomass and the dry weight of the total biomass measured by yield per pot (kg) and then converted in t ha^{-1}. The sugar content (%) was determined using a refractometer to measure its brix value and a polarimeter to measure its pol value (Bokhtiar & Sakurai, 2007). The sugar yield (t ha^{-1}) was calculated from the sugar content multiplied by the cane yield (t ha^{-1}).

Statistical Analysis

The analysis of variance (ANOVA) for various crop characteristics was performed following F test. When F was significant at the $p \leq 0.05$ level, treatment means were separated using the Tukey test (Version 14.12).

RESULTS AND DISCUSSION

The Effect of Sugar-Cane Residue Management and N and S Fertilisation on Cane Yield

The N and S fertilisation and the type of residue management had a significant influence on sugar-cane yield (Figure 1). The yield of ratoon cane was higher than that of the plant cane. This was caused by higher N and S nutrient uptake of ratoon cane than in plant cane (Table 3). The highest increase of cane ratoon yield (61%) was in the treatment using a mixture of urea, bio-compost and gypsum. The treatment of N2+S2 using AS fertiliser showed the highest yield (99.7 t ha^{-1}), which was statistically identical to N1+S1 and N2+S2 using a mixture of urea, bio-compost and gypsum by 96.7 and 98.6 t ha^{-1} for ratoon cane (Figure 1). The maximum cane yields might have been due to high N uptake. The highest N uptake was found in N2+S2 using AS fertiliser (Table 3). However, N uptake is not the only factor determining cane yield. A high S uptake can increase cane yield as well as N1+S1 treatment using a mixture of U+B+G (Table 3).

Table 3
N and S uptake by sugar cane influenced by fertilisation and residue management

Treatments	N uptake (kg ha^{-1})		S uptake (kg ha^{-1})	
	PC	RC	PC	RC
Fert. management				
N1+S1 (AS)	426,70 a	630,83 a	12,09 a	52,23 a
N2+S2 (AS)	591,38 c	834,22 c	32,17 d	54,40 ab
N1+S1 (U+G)	439,88 ab	680,68 ab	21,11 c	50,48 a
N2+S2 (U+G)	456,66 ab	703,39 b	22,55 c	48,35 a
N1+S1 (U+B+G)	435,56 ab	690,45 ab	16,69 b	84,50 c
N2+S2 (U+B+G)	479,44 b	714,90 b	21,11 c	64,10 b
HSD 5%	45.34	67.41	1.92	9.73
Residue management				
M1	447,62 a	545,44 a	21,63 bc	42,36 a
M3	460,50 a	727,35 c	19,61 a	62,23 c
M4	535,23 b	934,59 d	22,23 c	79,04 d
HSD 5%	33.22	49.39	1.41	7.13

Means followed by different letters for each factor in the same column are statistically significantly different as shown in the Tukey test at p=0.05
Note: HSD=Honest Significant Difference

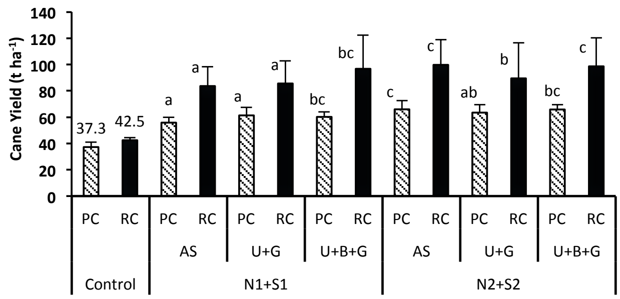

Figure 1. Effect of N and S fertilisation on cane yield of plant cane (PC) and ratoon cane (RC). (The figures accompanied by the same letters for each sugar-cane plant are not significantly different at HSD 5%
Note: AS=Ammonium sulfate, U=Urea, B=Bio-compost, G=Gypsum)

The N and S fertiliser from the mixture U+B+G in low dose gave an equal yield as the AS treatment in the higher dose of N and S fertiliser. This treatment also showed a higher yield than did the mixture U+G in the higher dose of N and S fertiliser (Figure 1). Overall, the residue management in the first planting increased the yield and ratoon cane. The composted residue management increased the yield of ratoon cane as high as 83.7% (116.3 t ha^{-1}) compared to plant cane (63.3 t ha^{-1}) (Figure 2). The results of this study also indicated that burning the residue can increase the yield of plant cane, as occurred in this experiment when compared with the control, but it did not significantly increase the yield of ratoon cane (Figure 2). Hesammi et al. (2014) reported that burning residue can release nutrients rapidly and increase nutrient uptake and crop production in a brief time, but it increases the loss of soil moisture in future plantings. Sugar-cane residue has a very high C/N ratio. Residue made from sugar cane compost can reduce the C/N ratio, and this helps soil microorganisms to degrade the compost of sugarcane residue for release of plant nutrients into the soil.

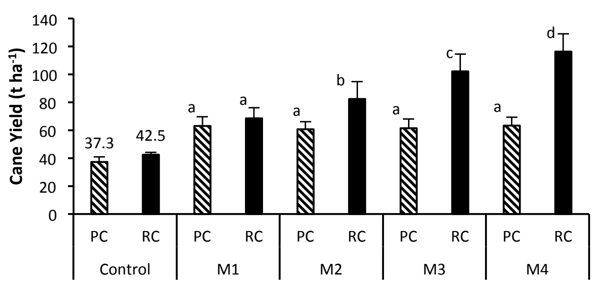

Figure 2. Effect of residue management on cane yield of plant cane (PC) and ratoon cane (RC). The figures accompanied by the same letters for each sugarcane plant are not significantly different at HSD 5%
Notes: M1=Residue burnt; M2=Residue incorporated into the soil; M3=Residue put on the soil surface; M4=Residue composted)

The interaction between fertiliser and residue management influenced significantly on sugarcane yield. The treatment using a high dose (N2+S2) of U+B+G mixture with composted residue management tended to give the highest cane yield on the PC, but the value was not significantly different from other treatments. The treatment using a low dose (N1+S1) of U+B+G mixture showed the highest cane yield on the RC (Table 4). This showed that the treatment was more efficient for sugar-cane cultivation.

Table 4
Cane yield as influenced by interaction between fertilisation and residue management

Treatments		Cane Yield (t ha^{-1})			
		PC		RC	
Fert. Management	Residue Management				
N1+S1 (AS)	M1	52.00	* a	67.83	* ab
	M2	57.08	* abc	80.44	* abcd
	M3	54.33	* ab	82.92	* bcde
	M4	59.83	* abcde	103.33	* efgh
N2+S2 (AS)	M1	59.08	* abcde	78.40	* abcd
	M2	66.83	* def	88.17	* cdef
	M3	68.33	* ef	110.97	* ghi
	M4	69.58	* ef	121.42	* hi
N1+S1 (U+G)	M1	67.75	* def	68.17	* abc
	M2	60.67	* bcdef	72.25	* abc
	M3	56.25	* abc	96.33	* defg
	M4	60.67	* bcdef	105.58	* efgh
N2+S2 (U+G)	M1	69.25	* ef	60.71	* a
	M2	55.58	* abc	71.50	* abc
	M3	67.83	* def	109.52	* ghi
	M4	61.08	* bcdef	116.19	* ghi
N1+S1 (U+B+G)	M1	65.50	* cdef	67.17	* Ab
	M2	60.58	* abcde	83.72	* bcde
	M3	57.25	* abc	106.25	* fgh
	M4	57.42	* abcd	129.83	* i
N2+S2 (U+B+G)	M1	64.50	* bcdef	68.58	* abc
	M2	63.17	* bcdef	98.00	* defg
	M3	64.42	* bcdef	106.67	* fgh
	M4	71.17	* f	121.25	* hi
Control (No Treatment)		37.25		42.46	
HSD 5%		10.53		20.64	
Dunnet 5 %		5.97		13.78	

Means followed by different letters in the same column are statistically significantly different using the Tukey test at p=0.05
Note: HSD=Honest Significant Difference; *: significantly different from control using the Dunnet test at p=0.05

Singh et al. (2005) reported that the residue management of the previous crop either placed on the soil surface or put into the soil played an essential role in the nutrient cycle. It altered the soil environment, which in turn influenced the microbial population and activity in the soil and influenced subsequent nutrient transformation. Thus, crop residue management is beneficial for soil quality as it adds organic substance to the soil, increasing water infiltration and retention capacity of the soil. It also supports the pH and facilitates the availability of nutrients for soil biology and plant absorption activity (Bot & Benites, 2005).

Bot and Benites (2005) added that crop residue management can capture the rainfall volume on the surface, increasing infiltration and soil moisture, while reducing evaporation and preventing soil surface desiccation. This condition can provide a favourable growing medium for plants. The improvement of the soil's physical qualities due to crop residue management influences crop performance (Verhulst et al., 2009).

The Effect of Sugar-Cane Residue Management and N and S Fertilisation on Sugar Content and Yield

The results of this study showed that sugar content and sugar yield in plant cane ($p<0.05$) was not significantly influenced by N and S application (Table 5). The findings of this study were consistent with the results of Bologna-Campbell et al. (2013), who reported that parameters of brix, fibre content and sucrose in sugar-cane juice were

Table 5
Sugar content and sugar yield as influenced by fertilisation and residue management

Treatments	Sugar Content (%)		Sugar Yield (t ha^{-1})	
	PC	RC	PC	RC
Fert. management				
N1+S1 (AS)	10.63	10.00 a	5.96	8.46 a
N2+S2 (AS)	9.98	10.24 a	6.60	10.34 c
N1+S1 (U+G)	10.49	10.82 c	6.41	9.31 ab
N2+S2 (U+G)	10.32	10.80 c	6.54	9.62 bc
N1+S1 (U+B+G)	10.60	11.03 c	6.37	10.39 c
N2+S2 (U+B+G)	10.21	10.45 b	6.73	10.26 c
HSD 5%	NS	0.36	NS	1.08
Residue management				
M1	9.58 a	10.55 ab	6.04 a	7.21 a
M2	10.24 b	10.67 b	6.21 a	8.76 b
M3	10.85 c	10.36 a	6.69 b	10.61 c
M4	10.77 bc	10.64 b	6.81 b	12.34 d
HSD 5%	0.58	0.26	0.54	0.79

Means followed by different letters for each factor in the same column are statistically significantly different using the Tukey test at p=0.05.
Note: HSD=Honest Significant Difference; NS=Not significant

not influenced by N and S in the plant cane for 16 months. However, the results of the calculation of sugar production potency increased along with the higher N doses as the result of increased weight of sugarcane yield. Residue management significantly influenced sugar content and sugar yield on the plant cane, where M3 and M4 showed the highest sugar content and sugar yield (Table 5).

The sugar content of sugarcane is influenced by a complex combination of various factors such as climatic conditions, genetic factors (sugar-cane varieties) and the crop management in the ripening phase, when sugar accumulation in sugar-cane crop happens (Keating et al., 1999). Soil moisture and temperature are the main variables involved in the ripening process, and the combination of both factors can stimulate the intensity of the sugar-cane ripening process (Cardozo & Sentelhas, 2013). In the ripening phase, ratoon cane had a higher soil temperature than plant cane. The growth of ratoon cane lasted during the dry season (Table 6). Therefore, the soil temperature was higher while the soil moisture was lower than in the plant cane. This condition can increase sugar content. Residue management affects the soil's physical conditions, especially soil moisture and temperature. Lingle and Irvine (1994) reported that environmental conditions affected active enzyme (enzyme invertase) in the sugar-cane growth and ripening process.

Table 6
Soil temperature and moisture during ripening process as influenced by the fertilisation and residue management

Treatments	Soil Temperature (°C)		Soil Moisture (%)	
	PC	RC	PC	RC
Fert. management				
N1+S1 (AS)	24.88	25.58	44.33 bc	32.18 a
N2+S2 (AS)	25.31	25.33	44.17 bc	36.21 b
N1+S1 (U+G)	24.96	25.49	45.41 c	38.88 c
N2+S2 (U+G)	25.06	25.72	44.28 bc	38.88 c
N1+S1 (U+B+G)	25.20	25.73	42.09 b	38.80 c
N2+S2 (U+B+G)	24.79	25.71	39.42 a	34.85 ab
HSD 5%	NS	NS	2.53	3.77
Residue management				
M1	25.38 c	26.09 b	39.47 a	34.23 a
M2	25.19 b	25.33 a	42.94 b	36.50 ab
M3	24.73 a	25.49 a	45.45 c	37.26 b
M4	24.83 ab	25.49 a	45.28 c	38.55 b
HSD 5%	0.37	0.62	1.85	2,76

Note: Means followed by different letters for each factor in the same column are statistically significantly different using the Tukey test at p=0.05
HSD=Honest Significant Difference; NS=Not significant

Concerning the ratoon cane, N and S fertilisation were significantly different ($p<0.05$) and influenced the sugar content and sugar yield. The highest sugar content and sugar yield were found in the treatments using low doses of a mixture of U+G and U+B+G and the treatment using a high dose of a mixture of U+G (Table 5). Bologna-Campbell et al. (2013) reported that sugar production was increased after the implementation of N doses that led to an increased production of stalks. The sugar yield of the N1+S1 treatment using a mixture of U+B+G was not significantly different from the treatment of N2+S2 using the AS fertiliser and the mixture of U+G and U+B+G for ratoon cane (Table 5). This meant that the treatment of N1+S1 using a mixture of U+B+G was more efficient than the treatments using other fertilisers due to the low rates of application that produced a high yield of sugar cane. Residue management using compost showed the highest sugar yield for plant and ratoon cane (Table 5). These results showed that residue management influenced the quality of ratoon cane positively. This condition according to Chan et al. (2002) is caused by the retention of crop residue on the soil surface, preventing surface crust formation by enhancing the water stable aggregate; this is not the case when burnt residue is used, even by using zero tillage.

CONCLUSION

The treatment of urea+bio-compost+gypsum produced the highest sugar-cane yield in ratoon cane. The treatment of a fertiliser mixture combination of 110 kg ha^{-1} urea + 1950 kg ha^{-1} bio-compost + 522 kg ha^{-1} gypsum and the composted residue management was the most efficient treatment with the highest sugar yield for ratoon cane. These results suggest that composted residue can be applied in the sugar-cane field to increase nutrient uptake and produce a higher cane and sugar yield in plant and ratoon cane.

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