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Estimating Effect of Vinasse on Sugarcane through Application of Potassium Chloride at Metahara Sugarcane Plantation

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Abstract

A study was conducted at Metahara Sugar Estate in Ethiopia to assess effect of vinasse disposal on sugarcane fields. The experiment was laid out in a randomized complete block design with five replications. To simulate the amount of vinasse to be disposed, three levels of potassium chloride (0, 340, and 580 kg ha^{-1}) were tested on three different soil types (brown clay loam, black non-vertic clay and black vertic clay). Soil analysis result showed that available K in the soil was ranged from 311-547 ppm. Potassium chloride application on cane fields had non-significant (P<0.05) effect for cane and sugar yields. Similarly, non-significant (p<0.05) effect was found for juice K2O and leaf nutrient contents (N, P and K%). Therefore, the level of potassium chloride applied at the proposed vinasse disposal rates didn't affect nutrient uptake, yield, and juice quality in the subsequent crop; thus at Metahara Sugar Plantation, sugarcane fields can be used as disposing site for vinasse. However, long-term effect of vinasse to sugarcane crop and dynamics of K in relation to availability and fixation in the soils of the plantation should be further investigated through vinasse application to sugarcane fields.

Keywords: Sugarcane; Ratoon crop; Vinasse; Juice quality; Cane yield; Sugar yield

Introduction

Vinasse contains high levels of organic matter, potassium, calcium and moderate amounts of nitrogen and phosphorus [1]; particularly it is rich in potassium [2]. Vinasse produced at Metahara ethanol distillery is acidic in reaction, and contained 0.69 g/l nitrogen and 0.025 g/l phosphorus. In many countries, vinasse is applied to sugarcane fields as a substitute for conventional potassium fertilizer [1,3]. It is also a common practice to dispose vinasse on agricultural fields due to its technical simplicity and economic advantages [3]. Vinasse can modify temporarily some soil chemical characteristics such as pH, organic carbon, and exchangeable acidity [4]. However, in the long term, intensive application of vinasse is reported to increase soil salinity [3].

N, P and K are essential for healthy growth and development of sugarcane; K is required for synthesis of carbohydrate in the leaves and the subsequent translocation of sucrose to parenchyma of the stem. Potassium occurs in highest amount in sugarcane, thus sugarcane is included in the group of high potassium demanding plants [5,6]. Uptake of K varies from 1.0-2.5 kg K_2O to produce one tone of cane [7]. Moreover, there is a positive interaction between N and K. The reduction in sugar content caused by high rates of N is ameliorated by an adequate supply of K. Potassium deficiency impairs sucrose transport from the leaf to the stalk. Excessive dosages of K may exert negative effect on apparent sucrose percent in cane (pol % cane) and may promote an increase in the ash content of juice. Increased ash content in cane juice has a negative influence on sugar processing.

The soil potassium unlike to other dominant soil cations is fixed by some clay minerals in the form which renders at least temporarily unavailable to crops [8]. In Ethiopia, fixation of potassium was reported in many soils studied. In spite of the fixation of K in the Awash Valley soils, the soil K is naturally very high and there is no requirement for potassium fertilizer application [9].

High amount of K in the soil may result in higher content of K in sugarcane and cane juice [10]. However, these effects are assumed and could not be confirmed until field trials are established to measure the real effect of added potassium on soil and plant potassium levels.

Metahara Sugar Factory ethanol distillery is generating large amount of vinasse as by-product. It was proposed to apply vinasse produced from the distillery to cane fields as one means of disposal, and initiated a field study by simulating vinasse application with KCl. The objective of the study was to estimate effect of vinasse on nutrient uptake, cane and sugar yields, and juice quality through application of potassium chloride.

Materials and Methods

The study was conducted for plantcane and ratoons (2nd and 4th ratoons) on three soil types specifically brown clay loam, black non-vertic clay and black vertic clay at Metahara sugarcane plantation. The plantcane experiment was established on brown clay loam while the 2nd and 4th ratoon experiments were established on black non vertic clay and black vertic clay soils, respectively. The test varieties were NCo334 and B52-298 for plantcane and ratoons, respectively. To simulate the proposed amount of vinasse to be disposed, the plots were treated with KCl at 0, 340 and 580 kg ha^{-1} assuming that the second and the third rates represent K supply by 50,000 t of vinasse disposal to 75% suitable area and K applied to achieve 1:1 salt ratio balance, respectively.

The treatments were arranged in randomized complete block design with five replications. The plot size was 104.4 m^2 i.e., 6 rows of cane with 1.45 m wide and 12 m long each in which the central 4 rows were used for parameter measurements. Initial composite soil samples were taken from the surface layer (0-30 cm) and analyzed for pH (1:2.5), EC (1:2.5), organic carbon, total nitrogen, Olsen P, and available K.

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Organic carbon (OC) and total nitrogen (Total N) were determined using Walkley-Black method and Kjeldhal method, respectively.

Leaf sample from each plot was taken at 5 months cane age (2.5 months post KCl application), and analyzed for nitrogen, phosphorus, and potassium [11]. At harvest, stalk length, stalk girth, stalk weight and S% C were taken. Cane yield was calculated from stalk number and stalk weight while sugar yield were calculated from cane yield and S%C. Juice quality parameters such as brix, pol percent cane, and purity were also determined by crushing the cane using Jeffco grinder within two hours after harvest using standard analytical methods [12]. The purity of a juice sample was determined by the percentage ratio of pol in juice to brix in juice [2]. Juice P_2O_5 and K_2O at 10th and 20th month for plantcane were also analyzed using recommended analytical methods [11]. Finally, all the data were subjected to statistical analysis using MSTATC computer software.

Results and Discussion

Physico-chemical properties of the soils

The mean values of pH and EC indicated that the soils were alkaline in reaction and salt free, respectively. Organic carbon and total nitrogen contents of the soil ranged from 0.10-0.12% and 1.29 to 1.91%, respectively (Table 1), and the contents were found to be low.

Nitrogen content is rated as low if the values are between 0.091 and 0.18% [13] while OC of soil is rated as very low if the values less than 2% [14]. Available K was ranged from 311-547 ppm and rated as high.

Effect of potassium on yield attributes and Yield of sugarcane

All measured parameters including millable stalk length, stalk weight, stalk girth, cane and sugar yields, sucrose percent cane, and juice quality (brix, pol and purity) obtained at harvest for plantcane and ratoon crops (2nd and 4th ratoons) were statistically non-significant ($p<0.05$).

For plantcane, on black non-vertic clay soil, application of KCl was not significant ($p<0.05$) for juice quality parameters (brix, Pol % cane, purity) but the trend was decreasing as the KCl rate increased (Table 2).

Juice P_2O_5 and K_2O levels were not significant ($p<0.05$) due to the application of KCl. However, at 10 months cane age juice P_2O_5 was significantly reduced towards higher rate of KCl (Table 2). Critical value of 300 ppm P_2O_5 in juice is required for proper juice clarification [15]. The present finding indicated that the juice P_2O_5 levels, harvested at 20 months cane age, were below the critical value for proper juice clarification. However, as KCl level increased, even if the difference was statistically non-significant, improvement in juice phosphate and potassium was observed (Table 2).

Even if the difference was statistically non-significant ($p<0.05$), juice K_2O showed increasing trend with increasing rate of KCl. Moreover, unlike juice P_2O_5, juice K_2O showed a dramatic increase when the cane gets matured (Table 2). Thus, juice K_2O levels at the age of 20 months were about 29, 31, and 31 times higher than at the age of 10 months for 0, 340 and 580 kg ha^{-1} KCl rates, respectively.

The juice K_2O levels of the study ranged from 2245-2631 ppm for NCo334 which is in agreement with mean juice K_2O levels of many sugarcane varieties ranging from 1265-2867 ppm [16]. There is great variation in juice K_2O levels in different part of the world, thus there is no acceptable juice K_2O level established for all regions. The normal range of K_2O in mixed juice showed, 800-1500 ppm in Java [17]. This study indicated that even at the highest KCl rate the juice K_2O level at

Soil types	KCl (Kg ha^{-1})	pH (1:2.5)	EC (1:2.5) (dS m^{-1})	OC (%)	Total N (%)	Av P (ppm)	Av K (ppm)
Brown clay loam	0	7.47	0.09	1.26	0.11	7.10	319
	340	7.53	0.09	1.28	0.10	8.40	322
	580	7.75	0.09	1.32	0.10	6.10	392
	Mean	**7.58**	**0.09**	**1.29**	**0.10**	**7.20**	**344**
Black non-vertic clay	0	8.10	0.16	1.51	0.09	6.10	373
	340	8.21	0.14	1.58	0.10	7.50	374
	580	8.19	0.15	1.35	0.10	3.60	562
	Mean	**8.17**	**0.15**	**1.48**	**0.09**	**5.73**	**436**
Black vertic clay	0	8.07	0.22	2.01	0.12	5.60	311
	340	8.14	0.22	1.79	0.13	10.20	372
	580	8.10	0.24	1.93	0.12	7.70	547
	Mean	**8.10**	**0.23**	**1.91**	**0.12**	**7.83**	**410.0**

Table 1: Effect of KCl on soil chemical properties.

Soil type	KCl (kg ha^{-1})	Yield (t ha^{-1})		Sucrose percent cane (%)	Juice quality							Length (m)	Girth (cm)	Weight (kg)
		Cane	Sugar		P_2O_5 (ppm)	K_2O (ppm)	P_2O_5 (ppm)	K_2O (ppm)	Brix (%)	Pol (%)	Purity (%)			
Brown clay loam	0	202.90	28.98	14.30	317a	77.8	160.0	2245	22.99	20.01	91.82	3.35	2.55	1.64
	340	185.88	25.84	13.89	315b	80.5	238.8	2467	21.24	19.50	91.76	3.53	2.54	1.73
	580	204.18	27.66	13.56	215c	83.8	289.6	2631	20.80	18.94	91.04	3.38	2.42	1.53
	Mean	197.65	27.49	13.92	282	80.7	229.5	2448	21.68	19.48	91.54	3.42	2.50	1.63
	C.V (%)	8.03	6.80	3.70	19.98	11.44	16.15	-	7.02	3.01	1.80	4.85	3.23	10.44
	Sig	NS	NS	NS	*	NS	NS	NS	NS	NS	NS	NS	NS	NS

NB: NS= non-significant; * = significant at 5%

Table 2: Effect of KCl on yield attributes, yield and juice quality.

Metahara did not exceed the acceptable range reported from most of the sugarcane growing countries.

For 2nd ratoon crop, on black non-vertic clay soil, the trend showed improvement of sucrose percent cane whereas a reduction in cane yield, sugar yield, and stalk girth were observed as the KCl rate increased. Pol % cane, purity (%) and stalk length revealed better improvement for 340 kg ha^{-1} than 580 kg ha^{-1} KCl (Table 3). For 4th ratoon crop, black vertic clay soil, no definite trend was observed for cane and sugar yields due to KCl application; however, brix, stalk length, and stalk weight showed declining trend as the rate increased (Table 3). Absence of significant differences among the treatments could be attributed to the adequate amount of soil potassium. The result of this study is in agreement with the report indicated that KCl application had non-significant effect on cane and sugar yields when soil available K was in the sufficient range for sugarcane [18].

Effect of KCl on leaf nutrient contents

Leaf tissue analyses indicated that application of potassium chloride was not significant ($p<0.05$) for leaf nutrient concentrations (N, P, and K%) on the three soil types.

Leaf N% and P% showed increasing trend by KCl application when compared with untreated plots, but KCl application had no definite trend on leaf K% on plantcane. Even though there is adequate amount of available K in the soil, it was not expressed in ratoon crops as it was observed in plantcane. This might be due to reduced nutrient utilization efficiency of ratoon crops. The analyses had also indicated that with the exception of leaf P in 2nd and 4th ratoon crops, leaf N and K% were above the critical values. Critical values and optimum ranges were 1.8 and 2.0-2.6%, 0.19 and 0.22-0.30%, and 0.9 and 1.0-1.6% for N, P and K, respectively [19]. The foliar K% of the study ranged from 1.38-1.65% (Table 4) which is found in the optimum range. This is also in agreement with a study that reported sugarcane grown on soil with sufficient potassium had 1.5% of foliar K [20]. It is rated as medium for growth and development of sugarcane [21]. This indicated that though there was high amount of available potassium in the soil, it couldn't be absorbed by the crop. This might be due to K fixation or antagonistic effect of Ca and Mg.

Conclusion

Soil analysis revealed that available K was ranged from 311-547 ppm which is rated as high. The leaf K content was ranged from 1.38-1.61% which is rated as medium. Even though, there was high amount of available K in the soil, it couldn't be absorbed by the crop.

Soil types	KCl (kg ha^{-1})	Yield (t ha^{-1})		Sucrose percent cane	Juice quality (%)			Length (m)	Girth (cm)	Weight (kg)
		Cane	Sugar		Brix	Pol	Purity			
Black non-vertic clay	0	147.66	20.28	13.78	22.36	20.20	90.32	2.034	2.524	1.42
	340	143.60	19.86	13.84	22.23	20.80	90.88	2.168	2.534	1.47
	580	141.66	19.60	13.89	22.41	20.31	90.64	2.112	2.514	1.42
	Mean	144.31	19.91	13.84	22.33	20.44	90.61	2.10	2.52	1.44
	C.V (%)	9.48	7.99	4.06	1.92	2.19	2.46	3.75	5.16	5.86
	Sig	NS	NS	NS	NS	NS	NS	NS	NS	NS
Black vertic clay	0	97.48	14.46	14.85	22.53	20.83	92.44	1.990	2.540	1.32
	340	112.42	16.70	14.89	22.47	20.85	92.78	1.976	2.506	1.29
	580	110.74	16.30	14.75	22.45	20.72	90.32	1.944	2.508	1.25
	Mean	106.88	15.82	14.83	22.48	20.80	91.85	1.97	2.518	1.29
	C.V (%)	12.42	11.86	1.82	1.68	1.28	2.51	7.05	5.55	8.59
	Sig	NS	NS	NS	NS	NS	NS	NS	NS	NS

NB: NS = non-significant

Soil types	KCl (kg ha^{-1})	Leaf nutrient contents, %		
		N	P	K
Brown clay loam	0	2.24	0.22	1.59
	340	2.26	0.24	1.65
	580	2.24	0.23	1.58
	Mean	2.25	0.23	1.61
	C.V (%)	4.97	6.42	5.43
	Sig	NS	NS	NS
Black non-vertic clay	0	1.81	0.15	1.40
	340	1.87	0.16	1.39
	580	1.87	0.16	1.40
	Mean	1.85	0.16	1.40
	C.V (%)	5.29	4.99	4.92
	Sig	NS	NS	NS
Black vertic clay	0	1.58	0.16	1.35
	340	1.65	0.14	1.42
	580	1.67	0.14	1.38
	Mean	1.63	0.15	1.38
	C.V (%)	8.13	20.21	4.71
	Sig	NS	NS	NS

Table 3: Effect of KCl on yield attributes, yield and juice quality.

Soil types	KCl (kg ha^{-1})	Leaf nutrient contents, %		
		N	P	K
Brown clay loam	0	2.24	0.22	1.59
	340	2.26	0.24	1.65
	580	2.24	0.23	1.58
	Mean	2.25	0.23	1.61
	C.V (%)	4.97	6.42	5.43
	Sig	NS	NS	NS
Black non-vertic clay	0	1.81	0.15	1.40
	340	1.87	0.16	1.39
	580	1.87	0.16	1.40
	Mean	1.85	0.16	1.40
	C.V (%)	5.29	4.99	4.92
	Sig	NS	NS	NS
Black vertic clay	0	1.58	0.16	1.35
	340	1.65	0.14	1.42
	580	1.67	0.14	1.38
	Mean	1.63	0.15	1.38
	C.V (%)	8.13	20.21	4.71
	Sig	NS	NS	NS
	NB: NS = non significant			

Table 4: Effect of KCl on leaf nutrient contents.

This might be due to K fixation or antagonistic effect of Ca and Mg in the soil. Application of vinasse as simulated by KCl on sugarcane grown on brown clay loam, black non-vertic clay, and black vertic clay soils showed non-significant ($p<0.05$) effect for cane and sugar yields, juice quality parameters and leaf nutrient contents. Juice K_2O levels from both treated and untreated were within the acceptable range for efficient juice clarification. Moreover, the levels of KCl applied at the proposed vinasse disposal rates didn't affect nutrient uptake, yield and juice quality in the subsequent crops. Thus, at Metahara sugarcane plantations, cane fields can be used as disposing site for vinasse. However, the long term effect of vinasse to sugarcane crop and dynamics of K in relation to availability and fixation in the soils of the plantation should be further investigated using vinasse application.

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