S. Pac. J. Nat. Sci., (2002), Vol. 20, pp. 15 - 21
Section A: Featured Article

Potassium Studies on Some Sugarcane Growing Soils in Fiji

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Abstract

This study investigated the potassium (K) status of sugarcane growing soils in Fiji, using samples taken from fields under cultivation and also from sites that had not been cultivated for at least 30 years. Five sites were on highly weathered oxyhydroxide soils where the total K contents and K retention capacities were generally low. The two less weathered soils containing significant amounts of 2:1 expanding clay minerals had much higher total K and non-exchangeable K. Exchangeable K and soil solution K contents varied significantly, but were generally low for most soils. Exchangeable K contents were lower in the regularly cultivated fields at five sites out of the eight, were higher at 2 sites, while for one site there was no change. These variations may be due to different levels of K input, uptake by crop and losses due to leaching and erosion. The two less weathered soils (Sigatoka and Nawaicoba) had lower contents of both non-exchangeable and exchangeable K in the cultivated soil when compared with the fallow sites suggesting net loss of K due to cultivation. These soils, however, also had high surface negative charge and thus a better capacity to retain K. Since the K requirement of sugarcane is characteristically high and large amounts of K are removed in the harvested crop, K fertilizer practices need to be scrutinized carefully in Fiji.

1 Introduction

Sugarcane has been the major agricultural production in the Fiji Islands for over 100 years. Current production levels are 3-4 million t cane/yr from 80-90,000 ha farmed. Initially production was on highly fertile alluvial and coastal plain soils, but in the mid-1970s, a major expansion of the industry occurred onto strongly weathered, less fertile soils. Many of these latter soils have low chemical fertility and high levels of potentially toxic metals such as Al and Mn are often present (Gawander and Naidu, 1989). Efficient sugarcane production is dependent on appropriate water and nutrient inputs, and the use of K fertilizer in the sugar industry in Fiji started in the early nineteen hundreds (Anon, 1929). Twyford and Wright (1965), based on data collected in the 1950s, reported that exchangeable 'potash' values tended on the whole to be moderate and high rather than low. Potassium usage in the Fiji sugar industry in 1970 was approximately 2.4 kg/ha (Morrison *et al*., 1985). This amount may have been sufficient to maintain crop production in the flat coastal plain areas, but the expansion of cane growing into the highly weathered Oxisols and Ultisols necessitated higher rates of potash use.

The low use of potash and phosphorus fertilizers by growers observed in the 1970s and 1980s, necessitated the formulation of blended fertilizers for the sugar industry to overcome the imbalance in fertilizer usage (Morrison *et al*., 1985). Since the introduction of blended fertilizers in 1990, there has been a dramatic increase in the amount of K fertilizer usage from an average of 26 kg/ha in 1991 to 69 kg/ha for the 1996 crop. There is a lack of information on the soil K status, mineralogical composition, K dynamics and K efficiency on major cane growing soils in Fiji. This study was initiated to investigate: the long term effects of cultivation on the K status of major cane growing soils of Fiji; the effect of varying rates of K fertilizer on cane and sucrose yields; and a study of soil and plant samples to quantify aspects of the K budget for sugarcane cropping (Gawander, 1998). This paper reports the results of the investigations completed on the K status of cane growing soils in Fiji.

2 Materials and Methods

2.1 Soils

For laboratory studies, eight locations in the major sugar-cane growing areas were selected at Batiri, Drasa, Legalega, Lalakoro, Naduri, Nawaicoba, Seaqaqa and Sigatoka on two major islands in Fiji, as shown in Figure 1. The soils from these sites were further divided into two categories: fallow (virgin or uncultivated for at least 30 years) and cultivated land (under cultivation for at least 30 years). Soil sampling consisted of taking at least 20 sub-samples to a depth of 20 cm from each location, thoroughly mixing them and taking a representative composite sample for the location. At each location, sampling of both cultivated and uncultivated soils was made. The soils were air-dried and ground to pass a 2 mm sieve. The ground samples were stored until required for analysis.

2.2 Laboratory Methods

Soil pH was determined in 1:2.5 soil to $CaCl_2$ (0.01 mol/L) suspensions using a pre-calibrated pH meter (Metrohm 744 Model) following equilibration for 16 hours (Blakemore *et al*., 1981). Organic carbon was determined by the Walkley-Black method (Nelson and Sommers, 1982). Soil solution K was determined by shaking air-dried soil (5 g) with distilled water (25 mL) overnight, followed by centrifugation and filtration. The extract was analysed for K using atomic absorption spectrophotometry (AAS, Shimadzu Model AA-670). Exchangeable K and Ca were measured by shaking soil (<2 mm, 10 g) with ammonium acetate (buffered at pH 7, 1 mol/L, 25 mL) for 10 mins in a multi-shaker. The solution was centrifuged at 7000 rpm for 20 min (Chilspin Model), filtered and K and Ca were analysed using AAS (Knudsen *et al*., 1982).

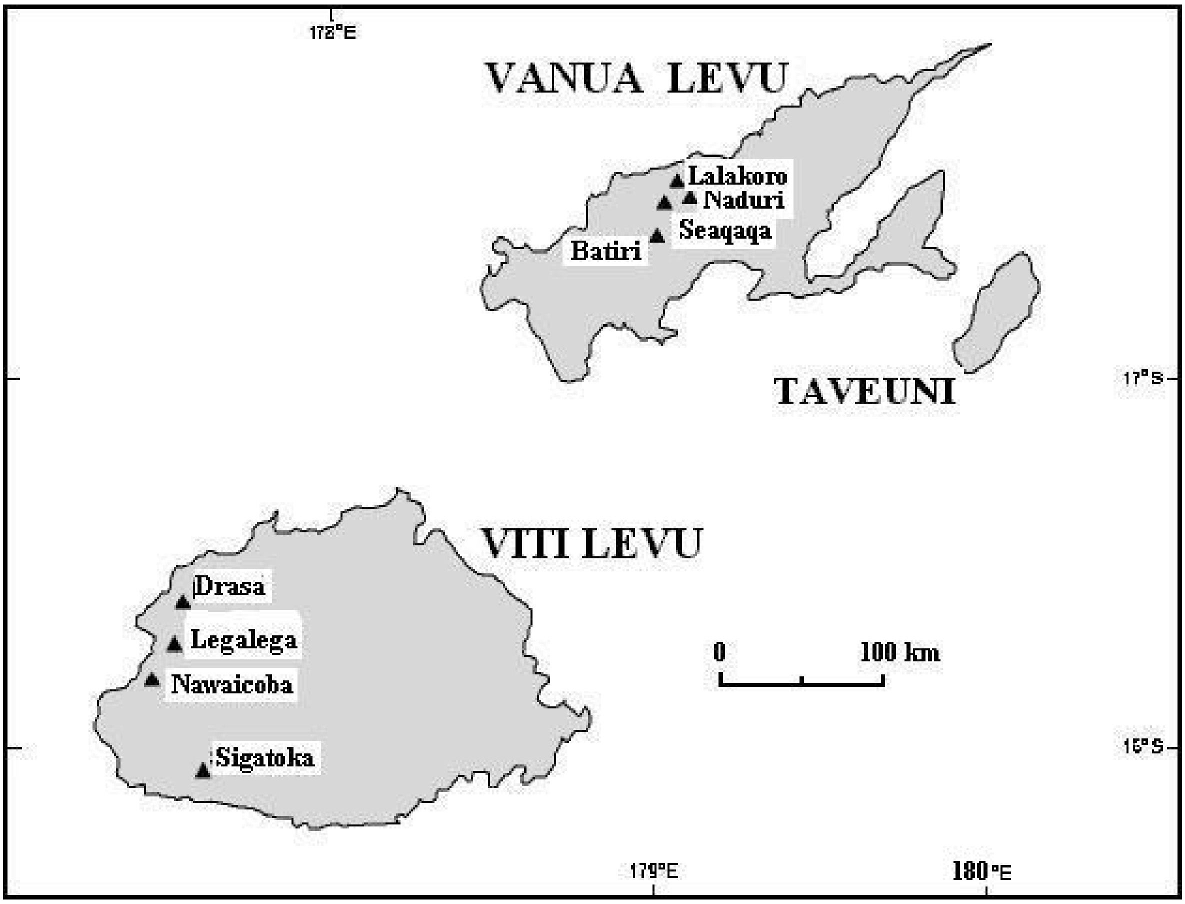

Figure 1 Location of sampling sites in Fiji

Non-exchangeable K was determined by boiling soil (<2 mm, 2.5 g) with HNO_3 (1 mol/L, 25 mL) for 10 minutes and analysing the extracted K using AAS (Knudsen *et al*., 1982). Potassium exchangeable at 450°C was measured by heating soil (5 g) at 450°C in the furnace for 16 hours, followed by extraction of the exchangeable K using NH_4OAc (pH 7, 1 mol/L, 12.5 mL) and analysis of K by AAS. Total K was determined at the CSIRO Division of Land and Water Laboratories in Adelaide, Australia, using X-ray fluorescence (Norrish and Hutton, 1969).

Potassium sorption studies involved shaking soil samples (2 g) with solutions of $CaCl_2$ (0.002 mol/L, 20 mL) containing different amounts (0 to 1000 µg) of K. The samples were equilibrated on an end-over-end shaker for 16 hours and then centrifuged at 10,000 rpm before filtration through Millipore (0.45 µm) filter paper. The supernatant solutions were analysed for K and Ca using AAS.

Positive and negative electric charges on the soils were determined by measuring the adsorption of K^+ and Cl^- as a function of pH to obtain the Point of Zero Charge (PZC), using the method of Naidu *et al*. (1990). Soil mineralogy was assessed using clay fractions isolated following the sedimentation procedure of Jackson (1969) except that dispersing agents were not added to minimise changes in the composition of poorly ordered minerals. Following repeated sedimentation, the suspensions were centrifuged and the residues dried in a fan forced oven at 80°C. X-ray diffractograms were obtained using both random oriented aggregates and powder specimens. Smectite was characterised by the expansion of the basal spacing of Mg^{2+} saturated clays from 14 to 18 Å on glycerol solvation and collapse to 10 Å on heating at 550°C.

3 Results and Discussion

Some properties of the soils utilised in this study are given in Table 1 while the K data are summarised in Table 2.

3.1 Total Potassium

The total K content of the soils varied considerably from 1.7 to 161.8 mmol/kg. This is dependent on the parent material and the subsequent degree of weathering of the parent material. It is generally accepted that soils of temperate regions have higher K contents than the more weathered acid soils of the humid tropics (Schroeder, 1978). Castro *et al*. (1972) verified that higher total K content appears in less weathered soils and in soils subject to lower rainfall.

Table 1 Some properties of the soils studied

Soil		*USDA Classification*[#]	*Mineralogy of clay fraction*[*]	*pH 0.01 mol/L $CaCl_2$*	*Organic C (%)*	*Charge (mmol kg^{-1})*	
						Negative	Positive
Batiri	fallow	Lithic	K, Gib, Goeth	4.5	2.4	49.9	42.0
	cultivated	Ustropept		4.3	5.5	96.2	13.7
Drasa	fallow	Oxic	K, Gib, Goeth	4.4	3.0	38.4	15.4
	cultivated	Haplustult		4.1	1.2	35.3	40.4
Legalega	fallow	Typic	K, Gib, Goeth	4.2	2.9	32.2	9.2
	cultivated	Eutrustox	Q	4.7	2.6	36.4	20.6
Lalakoro	fallow	Ustoxic	K, Gib, Goeth	4.2	5.5	104.0	15.1
	cultivated	Tropohumult	Q	4.4	1.4	61.2	27.6
Naduri	fallow	Typic	S, K, Gib, Goeth	4.4	6.0	59.0	14.5
	cultivated	Acrustox		4.0	4.5	47.0	22.2
Nawaicoba	fallow	Typic	S, K	6.2	3.5	439.8	4.4
	cultivated	Pellustert		6.0	2.9	579.6	3.0
Sigatoka	fallow	Typic	S, K	6.3	2.6	206.1	2.8
	cultivated	Hapludoll		6.0	2.3	297.5	1.7
Seaqaqa	fallow	Tropeptic	K, Gib, Goeth	4.0	3.0	162.7	17.3
	cultivated	Haplustox		4.3	4.2	202.6	17.6

[*] S = Smectite, K = Kaolin, Gib = Gibbsite, Goeth = Goethite and Q = Quartz
[#] Soil Survey Staff (1975)

Two broad groups were recognised within the 8 study soils. The Batiri, Drasa, Legalega, Lalako, Naduri and Seaqaqa soils represented acidic, strongly weathered oxyhydroxide soils whilst Nawaicoba and Sigatoka were younger, less weathered soils that had a considerably higher pH than the others (Table 1). The total K content of strongly weathered soils was low, ranging from < 2 mmol/kg for the fallowed Batiri soil to 13.3 mmol/kg for the cultivated Legalega soil. In contrast, the less weathered Nawaicoba and Sigatoka soils had total K contents in excess of 90 mmol/kg.

Bear *et al*. (1945) reported that for 20 soil samples from New Jersey, the average total K content was > 450 mmol/kg and in a more recent study, Sharpley and Smith (1988) showed that the total K contents for eight soils from major agricultural areas of the USA ranged from 20 mmol/kg to > 400 mmol/kg. It is therefore evident that soils in this study, except for Nawaicoba and Sigatoka, have a very low total K content. This would be expected since many Fiji soil parent materials are relatively low in K, due to lack of K bearing primary minerals like feldspars, mica or biotite (Mineral Resources Division, Fiji, pers. comm., 1996).

The effects of intensive cultivation on total K content of soils were variable with increases being recorded in two cases, decreases in five cases, and in one case (Nawaicoba) no change. Changes in total K content are related to the total inputs and losses of K that have occurred during agricultural activity. Given that K fertilizer rates have generally been very low in Fiji, increases in the total K in cultivated soils were unexpected. Possible reasons could include the recent addition of K fertilizer before the time of sampling, the uncultivated sites were actually from highly degraded parts of the landscape that had been ‘retired’ from farming due of low fertility, or that samples were taken from a different soil type (that is, a boundary must have been crossed), although every attempt was made in the field to try and locate an uncultivated site and a cultivated site on the same soil type. It is also possible that erosion may have contributed to the results with some sites receiving run-on (which will often be topsoil material enriched in K) while other sites may lose K through surface run-off.

It is essential to note that the fertilizer history of soils needs to be known to accurately determine a net gain or loss of K for the growing period. Unfortunately this data was unavailable for the sites in this study. Where net K inputs have occurred (i.e., fertilizer and run-on inputs have exceeded losses through crop removal and/or erosion and leaching) there will be a gain of soil K, while where losses have exceeded fertilizer inputs a decrease in K content due to intensive cultivation will occur.

Table 2 The potassium status of the soils studied

Soil		Total K	Exchangeable K	Non-exchangeable HNO_3-K	Non-exchangeable 450℃-K	Soil solution K (mmol)/L
		<---------------------- mmol kg^{-1} ----------------->				
Batiri	fallow	1.92	0.38	0.21	0.12	0.06
	cultivated	5.11	2.02	2.21	0.28	0.32
Drasa	fallow	5.43	0.47	1.05	0.26	0.06
	cultivated	2.50	0.96	1.09	0.11	0.39
Legalega	fallow	10.00	1.32	1.74	0.75	0.47
	cultivated	13.30	2.06	1.71	1.18	0.66
Lalakoro	fallow	9.30	4.44	3.78	0.17	1.05
	cultivated	5.16	2.30	<0.05	0.69	0.45
Naduri	fallow	3.51	1.86	0.94	0.24	0.15
	cultivated	2.23	0.71	0.80	0.09	0.32
Nawaicoba	fallow	93.40	1.33	15.10	18.20	0.11
	cultivated	94.50	0.44	11.40	8.18	0.08
Sigatoka	fallow	161.80	19.20	23.50	10.80	1.59
	cultivated	147.10	0.97	5.91	6.73	0.08
Seaqaqa	fallow	3.83	2.18	0.90	0.57	0.31
	cultivated	1.70	1.35	0.77	0.45	0.18

3.2 Exchangeable Potassium

Exchangeable K plays a very important part in the growth of plants because it is only the exchangeable and soil solution K that are readily available to plants. The exchangeable K content is generally higher in the upper soil layers.

Concentrations of exchangeable K varied greatly between soils and between sites on the same soil (Table 2). On the cultivated sites exchangeable K levels ranged from 0.44 to 2.3 mmol/kg with a mean value of 1.35 mmol/kg. These values are low compared with those normally recommended for sugarcane growing soils. Orlando Filho (1989), for example, observed that critical exchangeable K levels for sugarcane are quoted as 2.6 for Hawaii, 3.2 for Barbados and 2.0 mmol/kg for Australia. For South African soils, Meyer and Wood (1985) suggested a critical exchangeable K level of 2.9 for light and medium textured soils and 5.8 mmol/kg for heavy textured soils. In an overview of the soil resources of Fiji, Twyford and Wright (1965) suggested that for an average cane yield of 112 tonnes per hectare, critical exchangeable K levels ranged from 6.4 to 7.7 mmol/kg. It seems likely, therefore, that K was deficient in most of the sampled fields, particularly those under intensive cultivation.

Intensively cultivated sites had lower exchangeable K levels than fallow sites for five of the soils but the reverse was the case for the Batiri, Drasa and Legalega soils. As noted previously, these changes will be related to the exchangeable K. When soil solution K concentrations become low, the clay lattice may partially open and non-exchangeable K can be released to exchangeable forms. relative size of inputs (mainly fertilizer K or run-on) versus losses (mainly crop removal, erosion, runoff and leaching). In order to maintain soil K status the amount of K removed in the harvested crop (i.e., 125-220 kg K/ha per 100 t/ha cane crop) must be applied annually (Husz, 1972). In addition, in tropical soils, K leaching can be a problem so that substantially higher dressings of K may need to be applied in order to maintain the soil K status. The Batiri, Drasa, Legalega, Lalakoro and Naduri soils all have a relatively low net negative charge (i.e., < 90 mmol/kg) and therefore will tend to have low capacity to retain K.

A modifying factor is the amount of reserve K present in non-exchangeable forms since this can be released to exchangeable forms as exchangeable K is lost. Thus the K fertilizer recommendation for the smectitic Nawaicoba and Sigatoka soils (50-150 kg K/ha) is lower than that for the other study soils (e.g., 250 kg K/ha) (Yang and Chen, 1989). It is worth noting, however, that in smectitic soils, exchangeable as well as non-exchangeable K is being removed at a greater rate than it can be replenished from non-exchangeable forms. Fertilizer K rates at these sites may need to be raised. A complicating factor may well be that some added fertilizer K could be fixed into non-exchangeable forms on these essentially K-deficient smectitic soils.

3.3 Non-exchangeable Potassium

In this study, non-exchangeable K was estimated by two different methods. Firstly, inter-layer K was extracted with boiling nitric acid (Pratt, 1965). An additional method of measurement was also used, where soil was heated to 450°C. This causes exfoliation of micaceous soil materials exposing K that was formerly inaccessible in contracted inter-layers to the ammonium acetate extractant (Smith and Scott, 1974).

In the majority of soils, non-exchangeable K contents were low, some being < 1 mmol /kg (Table 2). The notable exceptions were the Nawaicoba and Sigatoka soils both of which contained substantial amounts of HNO_3-K and 450°C-K. Analysis of the mineralogy of the clay fraction of these soils (Table 1) showed that both the vertic Nawaicoba soil and the alluvial Sigatoka soil contained significant amounts of the 2:1 mineral smectite. Such soils are characteristically known to have a high K status (Yang and Chen, 1989) as 2:1 type clay minerals such as micas and illites contain K as part of their mineral structure. The K is held strongly within the inter-layers of these minerals and is known as non-exchangeable K. When soil solution K concentrations become low, the clay lattice may partially open and non-exchangeable K can be released to exchangeable forms. Thus soils with a high 2:1 clay content may often lead to a good K supply. Nonetheless, when the K status of such soils is low and when soil solution K is increased through fertilizer additions, added K may refill the inter-layer sites and become 'fixed' in non-exchangeable forms.

The nitric acid non-exchangeable K in most of the cultivated soils was less than in the fallow soils. A similar trend is shown in the 450°C non-exchangeable K. This clearly indicates that cultivation has a marked effect in the depletion of K from areas where cane is continuously cropped. It is notable that even the vertic Nawaicoba soils and alluvial Sigatoka soils which had substantial levels of non-exchangeable K showed a significant decrease due to long term cultivation. This indicates that there is a net loss of K from both these sites under intense cultivation.

At the Batiri and Legalega sites that have low contents of K, there was an increase in not only non-exchangeable and exchangeable K but also total K possibly due to high rates of application of fertilizer or the other factors discussed above. It is not clear, however, as to how these soils have increased the K content as they have low net negative charge and therefore are likely to have a relatively weak ability to retain K against leaching.

3.4 Soil Solution Potassium

Soil solution K gives an indication of the K intensity factor (i.e., K that is immediately available for plant uptake). Concentrations of K in soil solution ranged from 0.06 mmol/L to 1.59 mmol/L with a mean value of 0.31 mmol/L for intensively cultivated soils. The values obtained for the soils studied are low in comparison with the soil solution data compiled from tropical and subtropical region (Fried and Shapiro, 1961) where the range was 0.2 to 10 mmol/L, with an average value of 0.7 mmol/L.

In view of the low levels of exchangeable K found in this study and the fact that soil solution K is in equilibrium with exchangeable K, low concentrations of soil solution K were not surprising. As expected, soil solution K showed similar broad trends to those of exchangeable K, i.e., intensively cultivated fields had higher levels of soil solution K than undisturbed sites for the Batiri, Drasa and Legalega soils but the reverse was true for the other five soils.

3.5 Potassium Sorption

The soils differed markedly in their ability to adsorb K. In general, sorption increased in the order Legalega < Drasa < Naduri < Lalakoro < Batiri < Seaqaqa < Sigatoka < Nawaicoba (Figure 2). These differences were most likely due to the large variations in the net negative charge and in the nature and amounts of silicate clay minerals present in the various soils. For instance, the high sorption observed in the Nawaicoba and Sigatoka soils was most likely due to their high net negative charge and the presence of significant amounts of expanding 2:1 smectite minerals. The parameter that may responsible for increased sorption for Seaqaqa is probably a large negative charge (Table 1) associated with this soil.

Intensive cultivation markedly decreased K sorption in the Batiri, Drasa and Legalega soils. This is to be expected since these are the same soils where intensive cultivation resulted in a significant buildup of exchangeable K. For the Lalakoro, Naduri, Sigatoka and Seaqaqa soils where exchangeable K was decreased by intensive cultivation, the K sorption capacity was correspondingly increased. For the Sigatoka soil, the effect of intensive cropping in increasing K sorption was extremely marked. It is notable, however, that for this soil there was also a marked decrease in exchangeable K associated with intensive cropping. For Nawaicoba soil, K sorption was virtually unaffected by cropping history. As already noted, this soil had the second-largest total K and the greatest K sorption capacity, and as a consequence cropping history apparently had only a small effect.

4 Conclusions

A study of the K status of a range of Fijian cane growing soils has been completed. The majority of soils were strongly weathered and had a low content of total, non-exchangeable, exchangeable and soil solution K. These soils also tended to have a low net negative charge and therefore are likely to have a weak ability to retain K against leaching. Rates and timing of K fertilizer will therefore be important for these soils. The two less weathered soils with higher contents of total and non-exchangeable K also had a relatively high net negative charge and therefore a high capacity to retain K. Thus, fertilizer K rates required for adequate cane growth in these soils are likely to be less than those for the strongly weathered soils. Nonetheless, the intensively cultivated sites of these two less weathered soils had lower levels of both non-exchangeable and exchangeable K than fallow counterparts suggesting that a net loss of K sites (presumably mainly through crop removal) was occurring.

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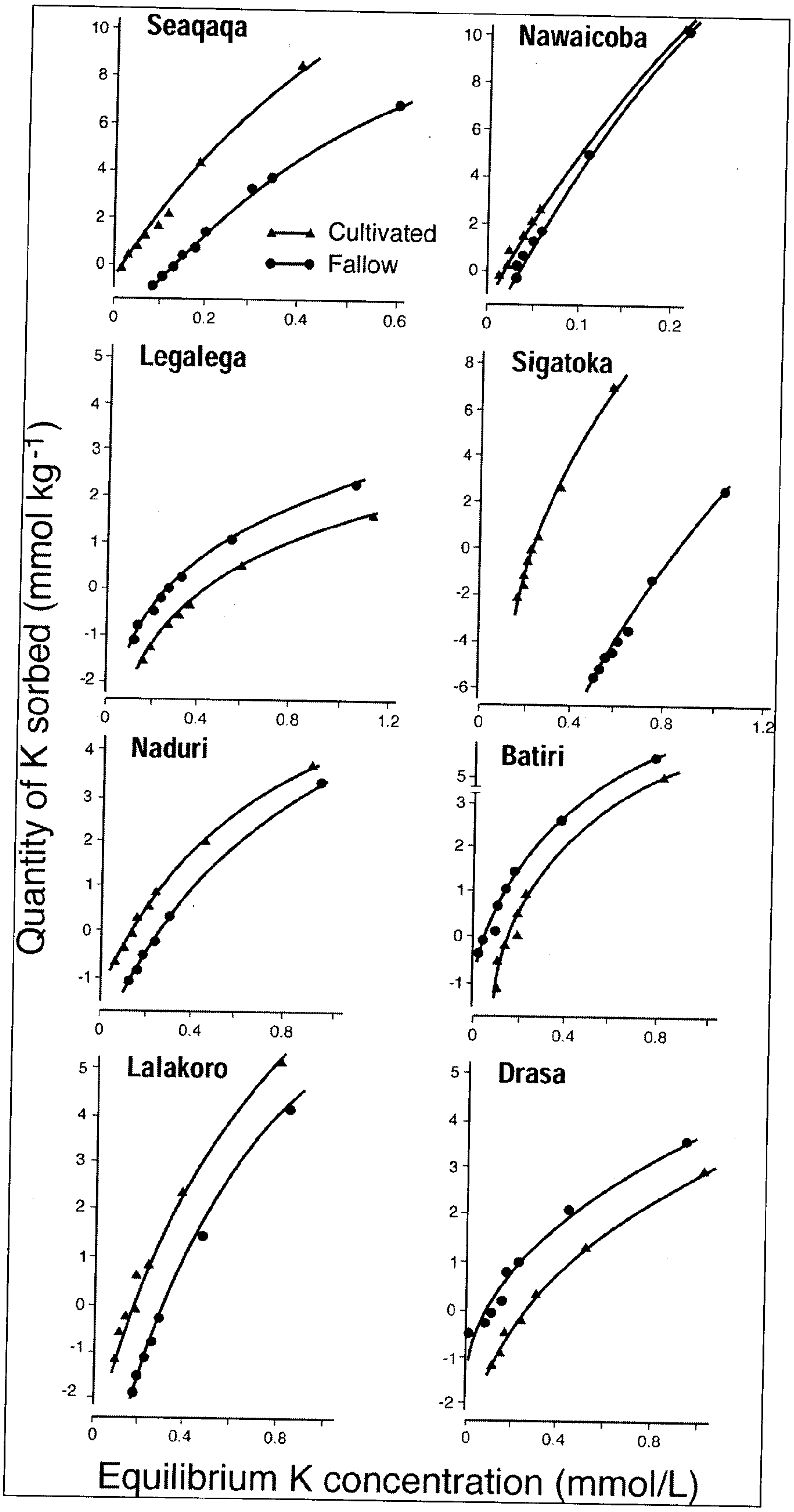

Figure 2 Potassium adsorption isotherms for the soils studied

Since the K requirement of sugarcane is characteristically high and large amounts of K are removed in the harvested crop, K fertilizer practices need to be scrutinized carefully in the Fiji environment. Visual symptoms of K deficiency in sugarcane have been noted in a number of areas by staff of the Fiji Sugar Corporation and this has been confirmed by plant tissue analysis. Further research is required to improve the effectiveness and economic efficiency of K fertilizer practices in the Fiji sugar industry.

5 Acknowledgement

The senior author thanks Dr Ravindra Naidu of CSIRO, Adelaide for providing laboratory assistance and advice during a study leave. Financial support from the Fiji Sugar Corporation Limited is gratefully acknowledged.

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