

Changes in Soil Fertility and Leaf Nutrient Concentration at a Sugar Cane Plantation in Papua New Guinea

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ABSTRACT

Commercial sugar cane (*Saccharum officinarum*) cultivation in Papua New Guinea started in 1979 at a plantation in the Ramu valley where Udifluvents and Hapluderts are the dominant soil types. The sugar cane is not irrigated and receives only nitrogen (N) fertilizers ($\pm 90 \text{ kg N ha}^{-1} \text{ y}^{-1}$). Changes in soil chemical fertility were assessed by comparing soil fertility data from the mid-1980s and 1990s and by comparing soil fertility data from sugar cane and adjoining natural grassland. Between the mid-1980s and 1990s the topsoil pH had declined significantly ($p < 0.001$) by 0.3 units and this was accompanied by a decline in cation exchange capacity (CEC) of $34 \text{ mmol}_c \text{ kg}^{-1}$. Total N levels in the topsoils declined ($p < 0.001$) from 2.5 to 1.9 g kg^{-1} and available P from 36 to 27 mg kg^{-1} during the same period. Exchangeable potassium (K) also declined significantly ($p < 0.05$) with $1.3 \text{ mmol}_c \text{ kg}^{-1}$, but changes in exchangeable calcium (Ca) and magnesium (Mg) were not significant. The decline in soil fertility was highest in the topsoil although significant changes occurred up to 0.6 m depth. Total N decreased in the 0-0.15 and 0.15-0.30 m soil horizons, but increased in the lower horizons, possibly because of nitrate leaching. A similar degree of soil fertility decline was observed when soils under sugar cane and adjoining natural grassland were compared. However,

the interrow had a slightly lower fertility level in comparison to within sugar cane rows. The decrease in total N, available phosphorus (P) and exchangeable K in the soil coincided with a decrease in the leaf N, P, and K concentrations of the sugar cane over the past 10 years. It was concluded that soil fertility had markedly declined under sugar cane monocropping although levels remained favorable for sugar cane cultivation. For sustainable soil management, nutrient inputs as well as small applications of lime may eventually be needed.

INTRODUCTION

There are probably few plantation crops in the tropics that put such heavy demands on the soil resources as sugarcane. Most commercial sugarcane in the tropics is grown at a large scale with many of the husbandry practices similar to intensive agricultural systems in the temperate regions (Hartemink and Wood, 1998). For land preparation, planting, spraying, and harvesting heavy machinery is often used which may result in soil deformation. The use of biocides to control pests and diseases, herbicides to control weeds, and inorganic fertilizer applications to sustain yields may seriously affect the environment (Coale et al., 1993; Southwick et al., 1995). Furthermore, sugar cane makes heavy demands on the soil nutrient reserves as large amounts of nutrients are removed with the harvest (De Geus, 1973; Hunsigi, 1993; Srivastava, 1992).

There is fair a body of literature on changes in soil fertility under continuous sugar cane cultivation. One of the first reports on soil changes under sugar cane was from King et al. (1953) who worked in the Bundaberg area (Australia). They found that N contents were 4.8 g kg^{-1} in a virgin soil and 2.2 g kg^{-1} after 22 years of sugar cane cultivation accompanied by organic matter contents of 7.8 and 36 g kg^{-1} , respectively. In North Queensland, Maclean (1975) took soil samples in cultivated and adjacent uncultivated land and found a significant decline in pH and available phosphorus. Wood (1985) and Bramley et al. (1996) followed the same study methods as Maclean (1975), and also reported significant soil fertility decline under sugar cane in North Queensland. Humbert (1959) reported from Hawaii that the observed decline in sugar cane yields resulted from a combination of soil compaction, acidification, nutrient depletion and changes in biological properties of the soils. Changes in soil chemical properties were also reported from sugar cane areas in Fiji (Masilaca et al., 1985), Philippines (Alaban et al., 1990), India (Sundara and Subramanian, 1990; Yadav and Prasad, 1992), South Africa (Schroeder et al., 1994), and Puerto-Rico USA (Vélez-Ramos and Muñoz, 1991). In summary, these studies have shown that prolonged sugar cane cultivation may result in soil acidification, dwindling organic matter contents, and nutrient depletion.

Most of the studies on soil fertility changes under sugar cane compared soil properties under uncultivated land with land under continuous sugar cane

cultivation. With this method, errors are likely to occur if the soils under cultivation are different from the adjoining site and if the history of the uncultivated site is unknown. Consequently, results generated by this method are often inconsistent (e.g., Bramley et al., 1996). It is, therefore, preferable to monitor soils under cultivation over time, but very few such data sets exist for tropical soils (Greenland, 1994).

In this paper, changes in soil fertility at a sugar cane plantation in Papua New Guinea are presented comparing soil data from the 1980s with data from the 1990s and soil data from sugar cane fields and adjoining natural grassland. The objectives were to investigate changes in soil fertility under continuous sugar cane cultivation, in relation to changes in leaf nutrient concentration of sugar cane during the mid 1980s and 1990s. In addition, investigations were made in field scale heterogeneity of soil chemical properties under sugar cane.

MATERIALS AND METHODS

The Site

The research was conducted on a sugar cane plantation (6°S, 146°E) located in the Ramu valley of Papua New Guinea. The plantation was established in 1979 from natural grassland and it is the only plantation in the country. The sugar cane is not irrigated and receives only N-fertilizer in the form of sulphate of ammonia ($\pm 90 \text{ kg N ha}^{-1} \text{ y}^{-1}$) which is broadcasted over the field. The area under sugar cane at the plantation was 6,030 ha in 1995, and most sugar cane was planted on the alluvial plains of the Ramu River and its tributaries. The altitude of the plantation is about 400 m a.s.l. and slopes are less than 4%.

Average annual rainfall is 1,998 mm, but during the past 15 years, rainfall has varied from 1,531 to 2,560 mm y^{-1} . The amount of rainfall is sufficient for rainfed cultivation (Hartemink and Kuniata, 1996). June to September are the driest months with on average less than 90 mm per month. March is the wettest month with an average rainfall of 284 mm. Evaporation (Class A open pan) is 2,281 mm y^{-1} and exceeds rainfall from May to November. Mean annual temperature at the sugar plantation is 26.7°C with only minor fluctuations through the year.

The Soils

The parent material of the soils at the plantation is alluvium. The soils have been developed in clayey, silty, and sandy sediments and from the weathering products of the water-worn stones and boulders of varying lithology. The stones and boulders originate from sedimentary rocks, but also from basalt and igneous rocks with coarser textures. Although deep and nearly gravel free soils (>1.2 m depth) occur, extensive areas have gravelly (5 to 15%) topsoils and very gravelly (15 to 40%) or stony subsoils. The pH_w (=pH in water) values of most soils are around 6.0 indicating no apparent danger from exchangeable aluminum or excess

CaCO₃. Soil salinity is not a problem in the topsoils, but the deeper subsoils are slightly alkaline. Entisols are the dominant soil order (Soil Survey Staff, 1994) and they cover about 4,100 ha or 73% of the plantation area (Booker Agriculture International, 1987). Most Entisols classify as Mollic and Typic Udifluvents and very locally as Tropopsamments (Bleeker, 1983). The soil temperature regime is isohyperthermic, and the soil moisture regime udic indicating that the soils are dry for less than 90 cumulative days per year. Shrinking and swelling dark clay soils (Vertisols) cover about 1,320 ha of the sugar cane plantation. At the great group level, the Vertisols are classified as Hapluderts (Soil Survey Staff, 1994).

Soil Chemical Data

In total 98 topsoil samples (0-0.15 m) were taken from sugar cane fields between 1984 and 1986. The samples were taken after the third or fourth ratoon when the cane was ploughed-out and were bulked from 20 to 50 locations in a field using an Edelman auger. In 1994, 60 topsoil samples were taken at the plantation using the same procedures. In addition, 30 topsoil samples were taken in 1996, and these were composites from 10 to 15 locations in a sugar cane field. To investigate changes in the fertility of the topsoils the data were grouped in two periods: 1984 to 1986 (98 samples) and 1994 to 1996 (90 samples).

In 1986, 7 sugar cane fields were sampled at four depths (0-0.15, 0.15-0.30, 0.30-0.45, 0.45-0.60 m). These fields were resampled in 1996 for the same depths using bulk samples from 10 to 15 locations within a field. Mini-pits were used for the 0-0.15 and 0.15-0.30m soil horizons, and an Edelman auger for the lower horizons. The samples were taken in the interrow of the sugar cane, and a total of 28 samples were collected.

Also in 1996, sugar cane fields and adjoining grassland areas were sampled were sampled at 5 locations at the plantation. At each location, sugar cane had grown continuously for 12 to 16 years, and the natural grassland had never been cultivated. The natural grassland was dominated by *Imperata cylindrica* and to a lesser extent by *Themeda australis*, *Saccharum spontaneum* and *Ophiuros* sp. Pits were dug (>1 m) to observe soil morphological differences between the sugar cane and the grassland. The distance between the pits was less than 100 m. When the soils were found to be similar they were sampled at the following depths: 0-0.15, 0.15-0.30, 0.30-0.50, 0.50-0.70 and 0.70-0.90 m. In the soil pits under sugar cane, both the interrow and within the rows were sampled, and a total of 75 samples were collected.

Air-dried, ground, and sieved (2 mm) samples were analyzed at the Cambridge Laboratory in Cambridge (New Zealand) and at the National Analytical Chemistry Laboratory in Port Moresby (Papua New Guinea). The procedures for soil analysis were identical at both laboratories, as follows: pH H₂O in 1:5 suspension of soil and water; organic carbon by K₂Cr₂O₇ and H₂SO₄ oxidation (Walkley and Black); total N by Kjeldahl; available P by NaHCO₃ extraction (Olsen); exchangeable Ca,

Mg, K, sodium (Na) and CEC by percolation with 1M NH₄OAc followed by AAS (cations) and titration (CEC).

Leaf Analytical Data

Since 1980, over 500 different varieties from other sugar cane growing areas have been tested at the plantation. The varieties are continuously reviewed especially with respect to their resistance to pests and diseases. About 1,020 foliar samples for the analysis of macronutrients were taken between 1982 and 1996. The samples were usually taken after the onset of the rainy season (December-February) when growth rates were high. For the leaf sampling, 21 rows were selected randomly within a sugar cane field. At 30 to 40 paces the fourth leaf was sampled from a nearby sugar cane stool, the first leaf was the unfurl leaf. About 400 to 600 whole leaves from which the mid-rib was removed were composited from which a subsample was taken. Leaf samples were oven dried at 80°C for 48 h and ground through a 0.15 mm mesh. The leaf samples were analyzed at the Cambridge Laboratory in New Zealand and the National Analytical Chemistry Laboratory in Port Moresby following standard analytical procedures as follows: Kjeldahl digestion for N and perchloric acid (HClO₄) digestion for P and K (Jones et al., 1991).

To investigate changes in leaf nutrient concentration, the data were grouped in two periods: 1985-1987 (93 samples) and 1994-1996 (160 samples). In addition, leaf analytical data from 74 sugar cane fields from different sampling times were available and also used to investigate changes in leaf nutrient concentration.

Statistical Analysis

A conventional t-test to assess statistical differences between the topsoil samples as well as the leaf samples from the mid 1980s and 1990s could not be conducted since the number of samples differed. The statistical method for groups of unequal sizes follows, however, almost exactly the pattern for groups of equal sizes (Snedecor and Cochran, 1989). This method involved calculating the pooled variance for the data of the two periods from the sum of squared deviations within the population. Then, the t-value was calculated taking into account the unequal sample size (Snedecor and Cochran, 1989). The arithmetic mean is presented for the soil and leaf analytical data of each sampling period with the level of statistical difference. Student's t-test was also applied for the paired top- and subsoil samples from 1986 and 1996.

RESULTS AND DISCUSSION

Changes in Soil Fertility

A highly significant decrease of 0.3 pH units occurred in the topsoils between the mid 1980s and 1990s (Table 1). Such decrease is likely to occur under sugar

TABLE 1. Topsoil (0-0.15 m) chemical properties in the period 1984-1986 and 1994-1996.

Period	Number of Samples	pH _w (1:5)	Total N (g kg ⁻¹)	Available P (mg kg ⁻¹)	CEC pH 7 (mmol _c kg ⁻¹)	Exchangeable cations (mmol _c kg ⁻¹)			Base saturation (%)
						Ca	Mg	K	
1984-1986	98	6.2	2.5	36	440	267	103	11.6	87
1994-1996	90	5.9	1.9	27	406	253	108	10.3	91
Difference		<i>p</i> <0.001	<i>p</i> <0.001	<i>p</i> <0.001	<i>p</i> <0.01	ns	ns	<i>p</i> <0.05	ns

ns=not significant.

TABLE 2. Changes in soil chemical properties with depth (n=7 pairs) between 1986 and 1996 and ANOVA.

Sampling depth (m)	pH _w (1:5)	Total N (g kg ⁻¹)	Available P (mg kg ⁻¹)	CEC pH 7 (mmol _c kg ⁻¹)	Exchangeable cations (mmol _c kg ⁻¹)			Base saturation (%)
					Ca	Mg	K	
0-0.15	-0.4	-0.3	-12	-55	-44	-7	-3.5	-2
0.15-0.30	-0.1	-0.1	-6	-67	-53	-10	-1.6	-3
0.30-0.45	-0.2	+0.1	-4	-56	-27	+5	-2.1	-2
0.45-0.60	-0.2	+0.3	-5	-44	-23	+3	-2.0	-4
ANOVA								
depth	<i>p</i> <0.001	<i>p</i> <0.001	<i>p</i> <0.001	ns	ns	ns	<i>p</i> <0.001	ns
time	<i>p</i> <0.001	ns	<i>p</i> <0.001	<i>p</i> <0.001	<i>p</i> <0.001	ns	<i>p</i> <0.001	ns
depth x time	ns	<i>p</i> <0.01	ns	ns	Ns	ns	ns	ns

ns=not significant.

cane because of the fertilizer-N inputs resulting in acidification, the substantial removal of bases with the sugar cane yield, and the leaching of cations (Moody and Aitken, 1995; Hartemink, 1998). Also the CEC decreased significantly which was accompanied by a significant decline in exchangeable K. Such decrease in exchangeable K could be expected as sugar cane is a large K-consumer (De Geus, 1973; Orlando Filho, 1985). Changes in levels of exchangeable Ca and Mg were, however, not significant as was also observed by Maclean (1975) and for Ca by Bramley et al. (1996) under sugar cane in Australia. The total N content of the topsoils decreased from 2.5 to 1.9 g kg⁻¹ whereas available P decreased by 9 mg kg⁻¹ in the topsoils. The decrease in total N is likely to be related to a decrease in organic matter which commonly occurs under sugar cane cultivation (e.g., King et al., 1953; Yadav and Prasad, 1992) and which may also explain the significant decrease in CEC. Organic carbon (C) data from the 1980s were, however, not available to support a decrease in organic matter. The significant decrease in available P is possibly due to the removal with the sugar cane yield in the absence of P-fertilization.

Samples from the same fields but at different sampling times (1986 and 1996) revealed that acidification had also occurred in the subsoil (Table 2). The decrease in the subsoil pH_w was not as high as in the topsoil, and apparently the acidification front is slowly descending, a finding also reported by Pierre et al. (1971) and Stumpe and Vlek (1991). Changes in total N content decreased in the 0-0.15 and 0.15-0.30 m soil horizons but increased in the deeper subsoil. The increase may have resulted from leached nitrate from nitrogen fertilizer, which is an important pathway for nitrogen losses under sugar cane (El Wali, 1980; Ng Kee Kwong and Deville, 1984; Weier, 1994). The decrease in available P and exchangeable K was largest in the topsoil ($p < 0.001$), and no significant depth (time interaction) was found. There were no significant changes in the CEC or exchangeable Ca with depth, but the time effect was highly significant ($p < 0.001$).

Field Scale Heterogeneity

Samples were taken in sugar cane fields in the interrow and within the rows, and in adjoining natural grassland areas which had never been cultivated (Table 3). A pH_w difference of 0.6 units was observed between topsoils (0-0.15 m) under natural grassland and within the sugar cane rows. The pH_w values of the interrow were slightly higher than within the sugar cane rows. Below 0.3 m depth, there were only slight differences between sugar cane and natural grassland.

Organic C levels in the topsoils within the sugar cane rows were about 8 g kg⁻¹ lower than under natural grassland but on average 2.1 g kg⁻¹ higher than within the sugar cane rows. Although the difference between the interrow and within the rows is small, it may significantly affect the susceptibility of the soil to compaction as resistance to deformation and soil elasticity is decreased (Soane, 1990; McGarry, 1996). The interrow had a lower organic C content in the subsoil, whereas organic C in natural grassland and within the row was comparable with

TABLE 3. Soil fertility status under sugar cane (within and interrow) and natural grassland. Values are the arithmetic mean of five samples \pm 1 SD.

	Sampling Depth (m)	Sugarcane within rows	Sugarcane interrows	Natural grassland
pH _w (1:5)	0-0.15	6.1 \pm 0.3	6.2 \pm 0.4	6.7 \pm 0.2
	0.15-0.30	6.4 \pm 0.2	6.6 \pm 0.2	6.8 \pm 0.3
	0.30-0.50	6.8 \pm 0.1	6.8 \pm 0.3	6.9 \pm 0.2
	0.50-0.70	6.9 \pm 0.1	7.0 \pm 0.2	7.1 \pm 0.2
	0.70-0.90	6.9 \pm 0.6	7.0 \pm 0.2	7.1 \pm 0.2
Organic C (g kg ⁻¹)	0-0.15	34.1 \pm 3.6	32.0 \pm 2.4	41.9 \pm 9.1
	0.15-0.30	29.0 \pm 2.8	22.0 \pm 7.4	28.7 \pm 1.9
	0.30-0.50	18.7 \pm 4.6	14.6 \pm 7.4	17.2 \pm 3.3
	0.50-0.70	12.7 \pm 6.6	10.1 \pm 6.6	10.5 \pm 4.2
	0.70-0.90	9.0 \pm 5.1	8.1 \pm 4.2	7.9 \pm 4.2
Total N (g kg ⁻¹)	0-0.15	2.3 \pm 1.6	1.8 \pm 0.3	2.4 \pm 0.7
	0.15-0.30	1.4 \pm 0.2	1.2 \pm 0.5	1.6 \pm 0.1
	0.30-0.50	0.9 \pm 0.3	0.7 \pm 0.4	0.9 \pm 0.2
	0.50-0.70	0.6 \pm 0.3	0.4 \pm 0.4	0.6 \pm 0.2
	0.70-0.90	0.3 \pm 0.3	0.3 \pm 0.1	0.3 \pm 0.2
Available P (mg kg ⁻¹)	0-0.15	22 \pm 10	22 \pm 11	27 \pm 10
	0.15-0.30	17 \pm 10	11 \pm 7	16 \pm 11
	0.30-0.50	7 \pm 5	6 \pm 4	7 \pm 6
	0.50-0.70	6 \pm 4	6 \pm 4	5 \pm 3
	0.70-0.90	4 \pm 2	4 \pm 1	5 \pm 2
Exchangeable Ca (mmol _c kg ⁻¹)	0-0.15	278 \pm 73	280 \pm 49	283 \pm 48
	0.15-0.30	280 \pm 61	249 \pm 74	246 \pm 34
	0.30-0.50	283 \pm 71	262 \pm 70	257 \pm 33
	0.50-0.70	275 \pm 52	274 \pm 57	263 \pm 24
	0.70-0.90	251 \pm 21	250 \pm 17	270 \pm 66
Exchangeable Mg (mmol _c kg ⁻¹)	0-0.15	104 \pm 16	91 \pm 12	92 \pm 15
	0.15-0.30	104 \pm 19	93 \pm 26	83 \pm 18
	0.30-0.50	116 \pm 13	94 \pm 21	97 \pm 18
	0.50-0.70	119 \pm 28	101 \pm 19	109 \pm 21
	0.70-0.90	103 \pm 9	93 \pm 14	106 \pm 40
Exchangeable K (mmol _c kg ⁻¹)	0-0.15	10.8 \pm 4.9	10.3 \pm 5.5	12.8 \pm 6.3
	0.15-0.30	6.4 \pm 5.8	4.1 \pm 1.8	5.8 \pm 4.4
	0.30-0.50	2.5 \pm 1.2	2.9 \pm 1.2	4.5 \pm 4.6
	0.50-0.70	2.5 \pm 0.7	2.5 \pm 0.9	4.3 \pm 4.8
	0.70-0.90	2.0 \pm 0.4	2.5 \pm 0.6	4.6 \pm 5.1

TABLE 4. Macronutrient concentrations (g kg^{-1}) of sugar cane leaves in the period 1985-1987 and 1994-1996.

Period	Number of Samples	N	P	K	Ca	Mg
1985-1987	93	20.3	2.8	14.7	4.4	2.4
1994-1996	160	19.4	2.6	13.8	2.8	1.6
Difference		$p < 0.001$	$p < 0.01$	$p < 0.001$	$p < 0.001$	$p < 0.001$

depth. For the total N contents, a similar pattern was followed with lower content in the topsoils of the sugar cane interrow as compared to within the rows.

Levels of available P in the topsoils were similar in the interrow and within the rows but were lower in the subsoil of the interrow. Soils under natural grassland had higher levels of available P in the topsoil ($+5 \text{ mg kg}^{-1}$), but small differences were found with depth between grassland and within the sugar cane rows. Striking was the considerably higher exchangeable Mg contents within the sugar cane rows as compared to the interrow and natural grassland. Also exchangeable Ca levels appeared to be slightly higher within the sugar cane rows. Exchangeable K was highest under natural grassland and similar in the topsoils within and between the rows of sugar cane. Overall the data suggest a similar degree of soil acidification and fertility decline as was found with the data from different sampling times (Tables 1 and 2).

Changes in Leaf Nutrient Concentrations

Changes in leaf nutrient concentration were investigated by comparing data from the mid 1980s and 1990s, and by analyzing data from 74 fields at different sampling times (paired samples). All major nutrients in the sugar cane leaves had decreased significantly between the mid 1980s and 1990s (Table 4). The largest decrease was found in the Ca and Mg concentrations, which had decreased with 36 and 33%, respectively. Small but highly significant differences were found between the P concentrations of the mid 1980s and 1990s.

For each of the 74 sample pairs the difference in leaf nutrient concentration between the first sample (i.e., from 1984 = t_0) and the second sample (i.e., from 1992 = t_1) was calculated. The difference in leaf nutrient concentration (= y) was plotted against the difference in years between the two samples (i.e., $t_1 - t_0 = x$), and the results are presented in Figure 1. Although the data in Table 4 suggested a decline in leaf N concentration, the analysis of paired samples showed less consistent results. Striking were, however, the changes observed in the leaf P

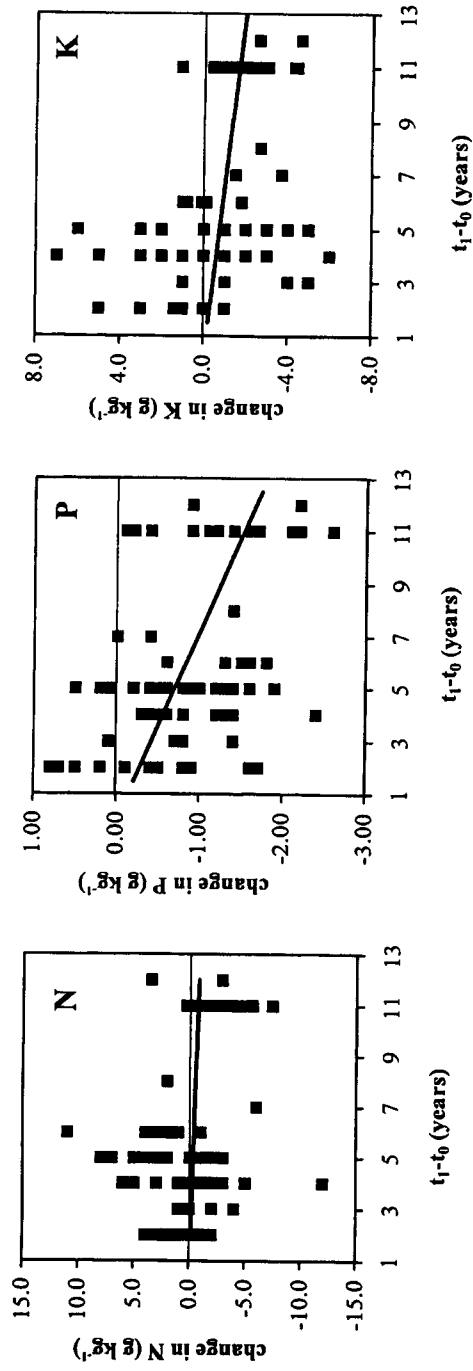


FIGURE 1. Absolute changes in leaf nutrient concentration (g kg^{-1}) of N, P, and K with time. Graphs are based on 74 sample pairs of the same sugar cane blocks at different times.

TABLE 5. Critical nutrient concentration and percentage samples below this level in the period 1958-1987 and 1994-1996.

	N	P	K	Ca	Mg
Critical nutrient concentration ^a (g kg ⁻¹)	19.0	2.0	13.0	1.5	1.0
%samples < critical level in mid 1980s	17	1	23	0	0
%samples < critical level in mid 1990s	40	17	47	1	3

^aBased on data for +4 leaf in: De Geus (1973), Nelson (1980), Orlando Filho (1985), Anderson and Bower (1990), Srivastava (1992), and Malavolta (1994).

concentration, and in 85% of the sample pairs the P concentration had decreased whereas in 53% of the pairs K had decreased.

Several keys to the interpretation of leaf nutrients concentration for sugar cane exist, but much depends on the age of the plant at sampling, the sugar cane variety, the plant part sampled, soil conditions and fertilizer applications. The first row in Table 5 summarizes the critical nutrient concentration for the fourth leaf as compiled from several sources. The mean nutrient concentrations in both the mid 1980s and 1990s (Table 4) were exceeding the critical level (Table 5). However, the percentage samples below the critical level increased dramatically between the mid 1980s and 1990s (Table 5). The increase was particularly high for N and K, and the data showed that in the mid 1990s about 40% of the samples was below the critical N concentration whereas 47% of the samples was below the critical K concentration. Although Ca and Mg concentrations had decreased dramatically (Table 4), there were only very few values in the mid 1990s below the critical levels.

Effects on Sugar Cane Yields

In the past 15 years, average sugar cane yields at the plantation have varied from 28 to 88 Mg ha⁻¹ y⁻¹. Although soils, climate and the sugar cane varieties do allow for much higher yields, they are not achieved because of the sudden and catastrophic incidence of insects pests and diseases (Hartemink and Kuniata, 1996). At times, weeding is also insufficient and yield reductions of 26 Mg ha⁻¹ y⁻¹ have been recorded (Hartemink and Kuniata, 1996).

The soils under sugar cane had acidified significantly, and the chemical fertility had declined. However, the mean pH_w is about 5.9 which is still favorable for sugar cane (Hunsigi, 1993). Levels of total N, available P and exchangeable K in the soil had declined, but also remained at favorable levels for sugar cane cultivation. There was a decrease in leaf N, P, and K concentrations, but mean

levels remained above the critical values for sugar cane leaves. It is expected that the decline in soil fertility and leaf nutrient concentration have currently no large effects since yields are limited by other factors. If the trends continue, however, the soil fertility may decline to levels where it affects production. Small applications of P and K fertilizers to avoid nutrient depletion as well as lime applications to arrest soil acidification may eventually be needed.

CONCLUSIONS

Between the mid 1980s and 1990s soil fertility had declined at the sugar cane plantation in Papua New Guinea. Most striking was the drop in pH accompanied by a decrease in CEC and exchangeable K. Also the organic C levels had decreased accompanied by a decrease in total N. The decline in soil fertility was highest in the topsoil, but significant changes had also occurred in the subsoils. Chemical data from soils under sugar cane and adjacent natural grassland confirmed the decline in soil fertility under sugar cane. Although the data were few and variation was large, it was found that the soil fertility in the interrow was slightly lower than within the sugar cane row. The decline in soil fertility was accompanied by a significant decrease in the concentration of major nutrients in the sugar cane leaves. Mean levels remained, however, above the critical nutrient level for sugar cane leaves. Despite the decline, soil fertility remained favorable for sugar cane production, but in order to sustain yields, small applications of lime and P and K fertilizers may be required.

ACKNOWLEDGMENTS

Mr. Lastus Kuniata and Mr. Johnson Nero of Ramu Sugar Ltd have been very helpful in data collection and their cooperation is kindly acknowledged. The author is further indebted to Mr. Peter Corbett and Mr. Jo Kerage of NACL in Port Moresby for the help in soil analysis, and to his colleagues Prof. Jim Goodwin and Dr. Vele Ila'ava for their useful comments on the draft of the paper.

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