Some Factors Influencing Yield Trends of Sugarcane in Papua New Guinea

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Commercial rainfed sugarcane cultivation in Papua New Guinea was begun in the early 1980s by Ramu Sugar Ltd. Over the last 15 years, annual cane yields have ranged from 28 to 88 tonnes/hectare, this wide variation being largely explained by sudden and catastrophic infestation by moth stem borers, cicadas, white grub and Ramu stunt virus. To a lesser extent yields were affected by weed competition. Changes in soil properties under continuous cultivation included decreases in pH, available phosphorus and exchangeable potassium, and some preliminary data suggest soil compaction. Leaf nutrient concentrations of nitrogen, phosphorus and potassium also declined slightly. It is concluded that yields were largely influenced by insect pests and diseases, but that the management of soil fertility is likely to become increasingly important once those problems have been solved.

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Sugarcane (*Saccharum officinarum*) originated in the South Pacific area, probably in Papua New Guinea (Blackburn, 1984). Portuguese traders collected native sugarcanes from the Markham Valley in the 17th century and proceeded to distribute them widely throughout the world (Chartres, 1981). In Papua New Guinea most small scale farmers grow sugarcane, whereas wild species (*Saccharum robustum* and *Saccharum spontaneum*) occur commonly along river banks and on fallow land. It has been suggested that commercial sugarcane production would be a risky undertaking in Papua New Guinea because this is its centre of origin and therefore has a broad range of pests and diseases (Szent-Ivany and Ardley, 1962; Li, 1985).

Until the early 1980s Papua New Guinea depended on imported sugar for its domestic needs. Several studies in the 1960s and 1970s indicated that commercial sugarcane production was technically feasible. Investigations were carried out in the Markham valley to identify a suitable site which could produce about 30,000 to 40,000 tonnes of sugar annually. Three potential sites were identified (Erap, Kaiapit, Gusap-Dumpu) but the Gusap-Dumpu area on the north bank of the Ramu river was favoured because it did not need irrigation or flood-protection works and land preparation costs were lower (Chartres, 1981). The site was also favoured as it was accessible from the Lae-Madang road (Figure 1). In 1979 a detailed soil survey was undertaken and about 7000 ha of suitable or moderately suitable land in the Gusap-Dumpu area was identified (BAI, 1979). Following this survey, sugarcane was planted and the first commercial sugar plantation of Papua New Guinea, Ramu Sugar Ltd, came into existence. The area under cane grew rapidly from 1592 ha in 1981 to 5011 ha in 1983 (Eastwood, 1990).

Since no government institute in Papua New Guinea deals with sugarcane research, all research is conducted on-plantation by the Research and Development section of Ramu Sugar Ltd. To date, the majority of research has taken place on an *ad hoc* basis, often in response to sudden infestations of pests and diseases. As a result, little time has been spent on the systematic analysis of yield trends or observations on changes in chemical and physical soil properties. The objectives of this paper are therefore to reveal yield trends in relation to the incidence of pests and diseases, and to investigate changes which have taken place in the soils under continuous sugarcane cultivation.

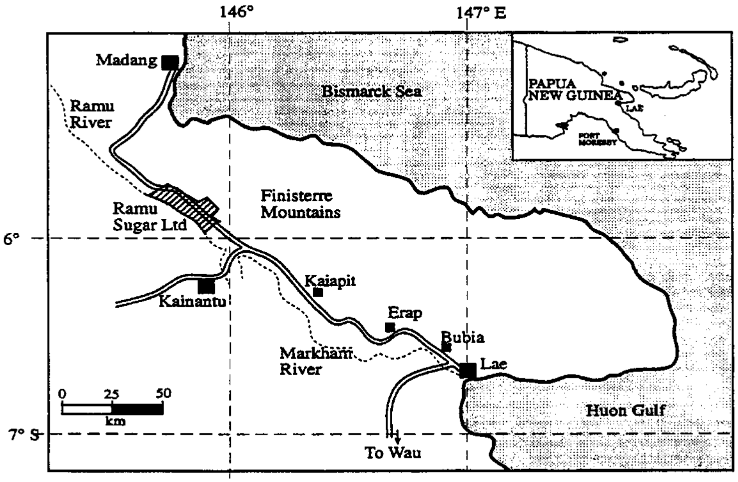

Figure 1 Location of Ramu Sugar Ltd in Papua New Guinea.

The physical environment

Ramu Sugar Ltd (6°S, 146°E) is located 180 km northwest of Lae at an altitude of about 400 m a.s.l. (Figure 1).

Most of the plantation is established on the alluvial plains of the Ramu river with smaller areas on the foothills of the Finisterre Mountain Range. The area is gently undulating with an overall slope of less than 3%. Sheet and gully erosion is a problem in some parts of the plantation.

The soils at Ramu Sugar Ltd are derived from alluvial deposits of the Ramu river and its tributaries. The pH (water) values of the soils are mostly between 5.8 and 6.8, indicating that there is no apparent danger from exchangeable aluminium or excess $CaCO_3$. Soil salinity is not a problem in the topsoils. Common soil types are Fluvisols which are soils with a clear stratification, Vertisols which are heavy clays with swelling and shrinking properties, and Phaeozems which have thick, black topsoils. In some parts of the plantation, Gleysols occur which have stagnating water during the rainy season (Chartres, 1981; BAI, 1987).

Average annual rainfall at Ramu Sugar Ltd is about 1998 mm but during the past 15 years rainfall has ranged from 1531 to 2560 mm. An average of 1500 mm (rain or irrigation) is required to produce 100 tonnes of cane per hectare so the annual rainfall at Ramu Sugar Ltd is generally sufficient. June to September are the driest months with an average of less than 90 mm per month. March is the wettest month with a mean rainfall of 284 mm (Figure 2). Evaporation (class A open pan) is about 2281 mm annually and exceeds rainfall from May to November. Mean annual temperature at Ramu Sugar Ltd is 26.7°C with only minor fluctuations throughout the year.

Sugarcane cultivation

The plantation was established for rainfed production. Feasibility studies for irrigation have been conducted in the past but it was soon realized that other constraints were more important. Since 1980, over 500 different varieties from other sugarcane growing areas have been tested, but currently about 10 are grown on a large scale, of which BT56152 (Barbados-Trinidad), Cadmus, Q135 and Q136 (Queensland) cover more than two-thirds of the plantation. Varieties are continuously reviewed especially with respect to their resistance to pests and diseases. In addition to the screening of existing varieties, a sugarcane breeding programme has recently started.

About 1800 ha of sugarcane are planted annually. Up to 1994, planting took place at the beginning of the wet season (September to November) but it was found that the sugarcane was severely damaged by moth stem borers in the following April to July period. Currently most of the cane is planted from late February to May as soil moisture is decreasing, resulting in a significant reduction of moth stem borers.

The harvesting season lasts from May to October and Australian cutter-chopper-loader harvesters are used with 20-tonne tractors and trailers to transport the cane to the factory. About half of the sugarcane is green-harvested leaving considerable amounts of crop residues after the harvest. Up to five

The sugarcane plantation in the Ramu valley, with the Bismarck mountain range in the background.

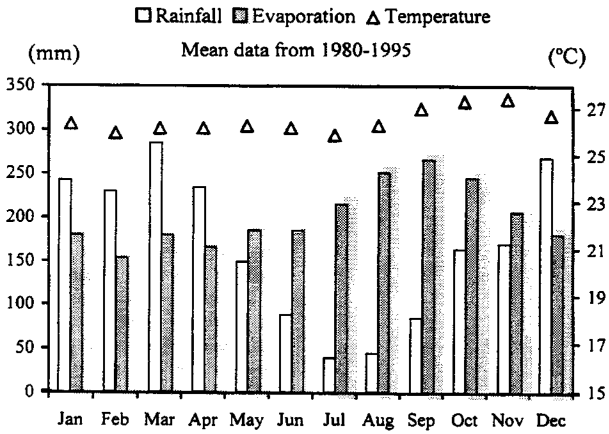

Figure 2 Mean monthly rainfall, evaporation and temperature.

crops (the planted cane and four ratoons) may be obtained, after which the land is replanted or cowpeas are sown.

Prior to 1989, the only fertilizer applied was urea (46% N), which was broadcast. When the policy changed to green-harvesting it was feared that considerable amounts of urea-N would be lost through volatilization as was experienced elsewhere (Wood, 1991). Therefore most of the nitrogen supplied after 1989 was in the form of sulphate of ammonia (21% N) and on average 85 kg N/ha was applied annually during the period 1991 to 1995. Applications of phosphorus and potassium fertilizers are not usual. Fertilizer applications are mostly done between August and November.

Several pests and diseases affect sugarcane production at Ramu Sugar Ltd (Table 1). The most important ones are moth stem borers, cicadas, white grub, and Ramu stunt, which is probably a virus transmitted both by the leaf hopper, *Eumetopina flavipes*, and through infected planting material (Kuniata *et al.*, 1994). Several systems of control measures have been developed throughout the years including biological control, fallow periods and the planting of resistant varieties.

Data collection

Yield data

Ramu Sugar Ltd covers about 6030 ha (1995) and for management purposes the plantation is divided into divisions which consist of blocks of 5 to 15 ha each. Currently there are over 300 sugarcane blocks in six divisions. Yield data are not available from each block over the past 15 years, and therefore annual plantation averages were calculated by dividing the total plantation yield by the total area under sugarcane.

Insect pests and disease data

Observations on pest and disease damage were made throughout the year in most blocks. The damage assessment was compared to the cane yield at harvest and correlations were made which allowed an estimation of the yield losses. The following methods were used. For moth stem borers, 200 stalks randomly selected in a field were split to observe the number of borers, usually two months before harvest. For cicadas, 20 randomly selected stools were dug up and nymphs were counted, between July and September. The same method was used for the assessment of white grubs but usually in February and March. Ramu stunt damage was assessed by expert knowledge and from the difference between the yields of successive seasons. Yield losses through weed competition were made by giving a weed density score to an area of 20 rows by 5 metres in about 100 sugar blocks.

Table 1 Major insect pests and diseases and their control at Ramu Sugar Ltd.

Common name	Latin name	First observed at Ramu	Control measure	Impact on yield if poorly controlled
Moth stem borer	*Sesamia grisescens*	1986	resistant varieties, insecticide spraying, biological control with *Cotesia flavipes* and *Pediobius furvus*	high
Cicadas	*Beaturia papuensis*	1989	ploughout followed by a fallow period	high
Ramu stunt	virus?	1985	resistant varieties	high
White grub	*Lepidiota reuleauxi*	1984	insecticide spraying	high
Weevil borer	*Rhabdocelus obscurus*	1985	resistant varieties	moderate
Internode borer	*Chilo terenellus*	1981	biological control with *Trichogramma* sp.	moderate
Downy mildew	*Peronosclerospora sacchari*	1979	resistant varieties	moderate
Leaf scald	*Xanthomonas albilineans*	1989	resistant varieties	low
Ramu scorch	causal organism unknown	1983	none	low

A sugarcane plant affected by Ramu stunt virus, which once nearly caused the closure of the plantation.

Leaf and soil data

Soil and leaf analytical data were available from most blocks. About 900 foliar samples were taken for the analysis of macronutrients (N, P, K, Ca, Mg, S) between 1982 and 1994. Leaf samples at Ramu Sugar Ltd were commonly taken after the onset of the rainy season (December to February) when growth rates are high. For the leaf sampling, 21 rows were selected randomly within a block. At 30 to 40 paces the 4th leaf was sampled from a nearby stool; the first leaf was the unfurl leaf. About 400 to 600 leaves, with their midribs removed, were composited and a subsample was taken. Leaf samples were dried at 80°C for 48 hours. All leaf samples were analysed at the Cambridge laboratory in New Zealand following standard analytical procedures.

Analytical data on about 500 topsoil samples covering the period 1982 to 1994 were taken. The majority of the samples were also analysed in New Zealand and the following methods were applied: pH water (1 : 2.5), available P (Olsen), CEC and exchangeable cations (1M NH_4OAc at pH 7). Only a few soil samples were analysed for organic carbon (Walkley Black) and total nitrogen (Kjeldahl). Soil samples were composites from 20–50 locations within a block using an auger. Soils were commonly sampled after the last ratoon when the cane is ploughed out.

In addition to the existing soil analytical data, soil pits (1 m depth) were sampled in Fluvisols under natural grassland and in a sugarcane field. The distance between the two pits was approximately 50 m. The sugarcane field had been continuously cultivated since 1988. Ring samples (100 ml) were collected from three horizons (0–0.15 m, 0.15–0.30 m, 0.30–0.50 m) in order to determine the bulk density. Samples were taken in triplicate from each horizon and dried for 72 h at 105°C. In the pit in the sugarcane block, ring samples were taken both in the interrow (between the rows) and directly under the cane plants (within the rows).

Yield trends

Mean sugarcane yields at Ramu Sugar Ltd have varied in the past 15 years from 28 to 88 tonnes/ha and sugar yield from 2.0 to 8.2 tonnes/ha (Figure 3). Regression analysis of cane and sugar yield showed a strong linear relationship, the sugar content of the cane being about 9% (sugar yield = 0.09 × cane yield – 0.29; $r^2 = 0.942$).

Much of the variation in sugarcane yields can be explained by pests and diseases, some of which can have a high impact on yield if poorly controlled (Table 2).

Ramu stunt was first observed in 1985 and in 1986 the disease was widespread in cv. Ragnar which occupied most of the plantation. The rapid decrease between 1982 and 1986 can therefore be explained by the incidence of Ramu stunt disease. The disease was so severe that it almost caused the closure of the plantation (Eastwood, 1990). The white grub was also present in 1984 and 1985 but its effects were not very obvious, although cane losses of up to 36 tonnes/ha can be expected if the infestation is severe (L.S. Kuniata, unpublished data). Because of the Ramu stunt, most of the sugarcane was replanted in 1986 with the resistant variety Cadmus. However, Cadmus appeared to be very susceptible to the moth stem borer and in 1987 a severe outbreak was observed, damaging up to 60% of the crop and resulting in an 18% reduction in sugar production (Kuniata and Sweet, 1994).

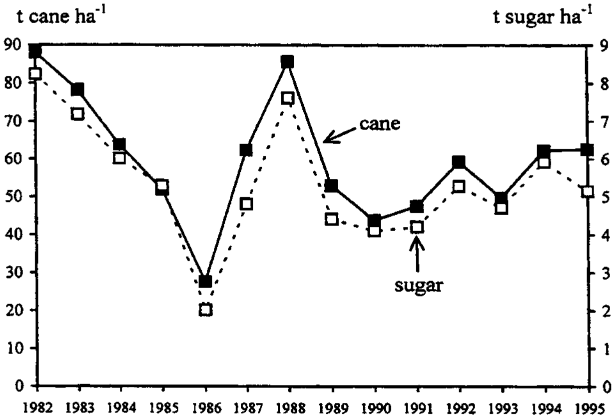

Figure 3 Sugarcane and sugar yield from 1982 to 1995.

Table 2 Estimated average annual yield loss (tonnes/ha) by insect pests, diseases and weeds.

Year	Moth stem borer	Cicadas	White grubs	Ramu stunt	Weeds	Total estimated loss	Actual yield
1984	–[1]	–	7	–	–	–	65
1985	–	–	7	15	–	–	50
1986	18	–	4	27	–	–	27
1987	31	–	0	1	5	–	64
1988	12	–	0	0	1	–	86
1989	8	4	0	0	20	32	53
1990	11	22	0	0	22	55	49
1991	4	16	0	0	18	38	48
1992	3	3	0	0	24	30	59
1993	0	1	0	0	26	27	50
1994	2	0	1	0	17	20	61
1995	10	1	<1	0	5	17	62

[1] Means unknown or not quantified.

Table 3 Soil fertility status (0–0.15 m) of Ramu Sugar Ltd (median values with CV%).

Year	Number of samples	pH water 1:2.5	Organic C ($g\ kg^{-1}$)	Total N ($g\ kg^{-1}$)	Available P ($mg\ kg^{-1}$)	CEC ($mmol_c\ kg^{-1}$)	Exchangeable cations ($mmol_c\ kg^{-1}$)			Base Saturation (%)
							Ca	Mg	K	
1983	213	6.3 (3%)	na	na	36 (30%)	442 (17%)	256 (22%)	101 (22%)	12.2 (23%)	85 (7%)
1985	17	6.2 (4%)	50 (21%)	na	45 (41%)	458 (21%)	269 (24%)	117 (29%)	12.3 (33%)	88 (3%)
1986	28	6.1 (3%)	na	2.1 (13%)	32 (55%)	427 (21%)	253 (25%)	105 (31%)	9.8 (62%)	87 (5%)
1991	25	6.2 (3%)	na	na	21 (57%)	386 (25%)	238 (22%)	87 (52%)	10.5 (30%)	91 (8%)
1994	61	5.9 (2%)	34 (15%)	1.9 (15%)	29 (33%)	405 (17%)	250 (19%)	105 (25%)	11.8 (26%)	91 (12%)

Average cane yields in 1988 were substantially higher as a result of the prolonged droughts in 1987 which significantly reduced the number of stem borers. Also, larvae of the moth stem borers were controlled by applications of carbofuran insecticides in 1988.

Yield dropped again sharply in 1989 due to the outbreak of cicadas (Kuniata and Nagaraja, 1992) which reduced cane yields to about 50 tonnes/ha. The cicadas were controlled by ploughing-out followed by a fallow period of two to four months. This was effectively practised from 1989 onwards.

Since the late 1980s cane yields have stabilized at around 55–60 tonnes/ha. Such low yields can be attributed to the planting of varieties which are resistant to pests and diseases, but which have a generally low yield potential. Highly productive varieties were considered again in 1993 resulting in higher yields but also a higher population of moth stem borers in 1995 and 1996.

Yields are also limited by the competition between sugarcane and weeds. Dominant weeds at Ramu Sugar Ltd are itchgrass (*Rottboellia cochinchensis*) and nutgrass (*Cyperus rotundus*) and weed competition trials have shown that itchgrass can give cane yield reductions of up to 54 tonnes/ha (L.S. Kuniata, unpublished). In commercial fields, an average loss of 26 tonnes/ha was observed in 1993 but losses were reduced to 5 tonnes/ha in 1995 as a result of improved weed control measures (Table 2). This confirms the general belief that sugarcane does not tolerate competition for water and nutrients.

Soil and leaf nutrient trends

Median pH (water) values varied from 6.1 to 6.3 between 1983 and 1991 but were 5.9 in 1994 (Table 3).

Table 4 Macronutrient concentrations (g/kg) of sugarcane leaves at Ramu Sugar Ltd (median values with CV%).

Year	N	Nitrogen		Phosphorus		Potassium		Sulphur		Calcium		Magnesium	
1983	481[a]	22.0	(11%)	3.5	(16%)	15.0	(14%)	1.3	(12%)	2.9	(16%)	1.8	(12%)
1987	69	20.0	(13%)	2.7	(9%)	16.0	(15%)	1.8	(14%)	4.4	(16%)	2.5	(14%)
1989	24	21.0	(12%)	2.9	(17%)	16.1	(15%)	1.8	(30%)	3.5	(21%)	1.7	(13%)
1994	27	19.3	(10%)	2.4	(7%)	12.5	(11%)	na		3.1	(20%)	1.3	(17%)

[a] There were only 11 samples of sulphur, calcium and magnesium in 1983.

Table 5 Soil and leaf analytical data of four sugar cane blocks at different sampling times.

Major soil groupings[a]	Year	Block number	pH water 1:2.5	Available P (mg/kg)	CEC (mmol_c/kg)	Soil data (0-0.15 m) Exchangeable cations (mmol_c/kg)			Base saturation (%)	Year	Leaf data Nutrient (g/kg)		
						Ca	Mg	K			N	P	K
Fluvisol	1983	DS103	6.4	39	420	235	101	11.9	83	1982	17	3.2	15
	1991	DS103	5.6	33	nd[b]	243	94	8.4	–	1994	21	2.3	10
	1983	ES208	6.4	35	370	213	89	10.7	85	1982	19	3.4	16
	1994	ES208	6.0	44	367	217	99	10.2	89	1984	22	3.3	16
Vertisol	1983	AS503	6.4	40	550	341	113	12.7	85	1983	20	4.0	16
	1986	AS503	6.4	26	410	307	57	8.7	91	1987	19	2.8	14
	1982	CS308	6.5	41	510	286	146	16.7	88	1983	20	3.7	15
	1991	CS308	6.1	26	442	297	40	9.2	79	1988	24	2.7	15

[a] FAO-Unesco revised legend.
[b] nd - not determined.

Organic carbon data were only available from 1985 (17 samples) and 1994 (61 samples). The difference between the medians was 1.6% organic carbon which is a considerable decrease. For high yielding sugarcane, however, maintenance of favourable organic matter levels is important (Yadav and Prasad, 1992). Median levels of available phosphorus were 36 and 45 mg P/kg in 1983 and 1985, but 21 and 29 mg/kg in 1991 and 1994, respectively. Although this suggests a declining trend such levels are still favourable. Sugarcane has a very high potassium demand and considerable amounts are removed with the crop, resulting in depletion of soil potassium reserves (Anderson and Bowen, 1990). However, no apparent changes were observed in the exchangeable potassium levels under continuous cane cultivation and the levels were generally high. Exchangeable calcium and magnesium did not change dramatically and remained at favourable levels.

Median nitrogen contents in the cane leaves at Ramu Sugar Ltd varied from 19.3 to 22.0 g/kg during 1983–94 (Table 4). The lowest figure was the median of the 27 leaf samples taken in 1994. Anderson and Bowen (1990) reviewed the world literature on critical nitrogen levels in sugarcane leaf tissue. In most areas, nitrogen levels exceeding 16.5 g/kg are considered in the optimum range. Also De Geus (1972) mentioned that 19.5 g N/kg is optimum for sugarcane, so the median nitrogen concentrations at Ramu are generally sufficient.

There appears to be a declining trend in the phosphorus contents of cane leaves, but the median value of 2.4 g/kg in 1994 is still above the optimum concentration of 1.8 g/kg given by Anderson and Bowen (1990) and 2.1 g/kg given by De Geus (1972). The apparent declining trend in leaf phosphorus coincides with the decrease observed in the levels of available P in the topsoil (Table 3). Leaf potassium contents were favourable from 1983 to 1989 but the median value in 1994 is at the lower margin of the optimum range of 12.5 g/kg (De Geus, 1972; Anderson and Bowen, 1990). Levels of sulphur, calcium and magnesium show no apparent trend and all median values are in the optimum range.

For a few blocks at Ramu Sugar Ltd soil and leaf analytical data were available from different periods (Table 5).

Both examples from the Fluvisols showed a decline in the pH of soil water. Levels of available phosphorus decreased in block DS103 but increased in ES208. Except for a decrease in the exchangeable potassium level in block DS103, there was no clear pattern in the levels of exchangeable cations in both examples. The decrease in available phosphorus and exchangeable potassium of block DS103 coincided with a decrease in leaf phosphorus and potassium levels.

Available phosphorus and exchangeable magnesium and potassium decreased in both sugarcane blocks on

Vertisols. Leaf phosphorus decreased with time but potassium levels hardly changed.

Soil research at the plantation: unravelling the effects of continuous cultivation on chemical and physical soil properties.

Soil acidification

The data in Table 3 suggest a decline in the topsoil pH with time, which may be caused by the use of acidifying fertilizers like sulphate of ammonia. It appears however, that the acidification is not confined to the topsoil. Samples taken under natural grassland and an adjoining sugarcane field (10 years under cultivation) showed a decline with depth (Figure 4). A sugarcane block resampled in 1996 also had a lower pH at depth than in 1986.

Soil compaction

The ring samples taken in the soil pits showed that the bulk density was highest between the rows and lowest within the row for the 0–0.15 and 0.15–0.30 m soil horizons (Figure 5). Bulk densities under natural grassland were intermediate.

The increase in bulk density between the rows is likely to be due to compaction caused by tractor wheels. The lower bulk densities found under the sugarcane (within the rows) is due to tillage operations and rooting. In the soil pit under sugarcane it was observed that cane roots were absent between the rows possibly because of the higher bulk densities. It may therefore be that for the Fluvisols at Ramu Sugar Ltd a bulk density of 1.3 Mg/m^3 is the upper limit for unrestricted root growth. Trouse and Humbert (1961) showed that the limits depended on the soil type and found that for Andosols and Ferralsols in Hawaii bulk densities of 1.08 and 1.52 Mg/m^3, respectively, restricted root growth for sugarcane.

Discussion and conclusions

During the past 15 years a large variation in sugarcane yields was observed at Ramu Sugar Ltd. The variation can be explained by the catastrophic incidence of Ramu stunt, moth stem borers, white grub, and cicadas. These pests and diseases are fairly well under control now although yields are still affected. Other factors causing suboptimal yield levels are the use of low yielding but pest and disease-resistant varieties like BT56152, and weed competition. It is generally perceived at Ramu Sugar Ltd that integrated pest management and the breeding of resistant but high yielding varieties should have high priorities.

The analysis of the soil chemical data has shown a declining trend in both available soil phosphorus and leaf nutrient content. Although the levels in the topsoil and leaves are still adequate it may imply that phosphorus fertilization is needed in the future. Also a decline in leaf potassium concentration was found but no apparent changes in the soil exchangeable potassium levels. There is evidence that soil acidification occurs under continuous sugarcane cultivation but more research is required to eliminate spatial and temporal variability in the measurements.

The compaction observed between the sugarcane rows reduces the rooting volume. The problem is not the physical resistance of the soil *per se* but rather the restricted uptake of water and nutrients or inadequate gaseous exchange (Voorhees, 1992). Moreover it may increase soil erosion through lower infiltration rates, and it reduces the

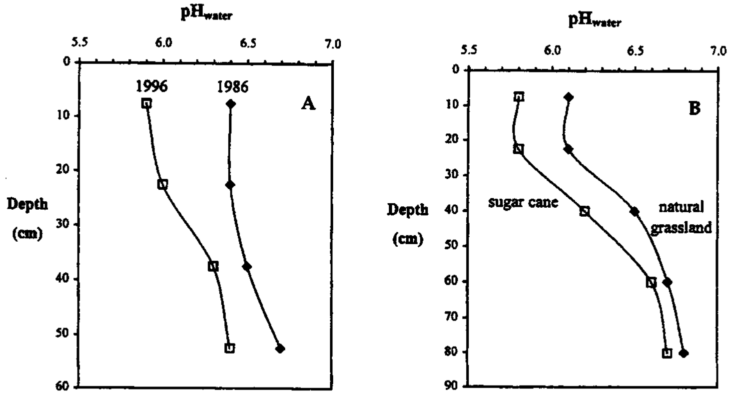

Figure 4 Soil water pH profiles of a sugarcane block sampled in 1986 and 1996 (A), and of grassland and an adjoining sugarcane block (B).

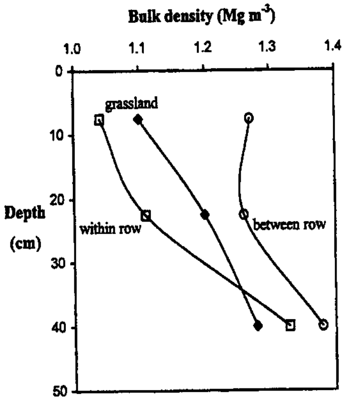

Figure 5 Bulk density under natural grassland and under sugarcane (between and within the rows). Sampling sites were less than 50 m apart.

fertilizer use efficiency as nutrients from the fertilizer spread between the rows are not used. It was also observed that shallow-rooted sugarcane is more prone to lodging, with the result that soil clods enter the cane harvester causing further problems in the factory. Some soil management strategies to control compaction are low tyre pressure and the avoidance of tractor operations when the soil is too wet. Furthermore, controlled traffic whereby plant rows and wheel tracks remain in the same positions for a number of years can be beneficial (Bakker and Davis, 1995).

From this investigation it is not possible to link the decline in soil fertility and increase in acidity and soil compaction to sugarcane yields. The relation between yields and soil properties may be easier to establish when these processes have progressed further.

Overall it can be concluded that yields in the past 15 years have been largely influenced by the incidence of pests and diseases, but that the management of soil chemical and physical properties has become important as a means of sustaining and improving sugarcane yields at Ramu Sugar Ltd.

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