

BUREAU OF SUGAR EXPERIMENT STATIONS  
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SOIL CONSTRAINTS TO  
PRODUCTIVITY IMPROVEMENT

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## INTRODUCTION

Yields of most crops are known to decrease if that crop is grown continuously without fallowing or rotation with other crop species. Sugarcane has been grown continuously on many fields in Queensland for 50-100 years. As early as 1934 soil-borne factors which restricted root and shoot growth were identified in fields which had grown sugarcane for a number of years. During the 1970's nematodes were found to be causing serious losses in Bundaberg on certain soil types and a serious root disease complex known as poor root syndrome was identified in northern Queensland. During the 1980's intensive research into poor root syndrome identified the important new disease *Pachymetra* root rot and a number of minor fungal pathogens. Poor root syndrome has been identified in all regions of Queensland and general poor root health has been noted in all soils which have grown sugarcane for a number of years.

Yield increases of 50-100% were obtained in areas severely affected by poor root syndrome in northern Queensland by soil fumigation with methyl bromide and metham sodium, and by soil solarisation. Recent experiments have recorded yield responses of 20-40% to methyl bromide fumigation in all major sugarcane regions. These experiments suggested that yield losses due to soil-borne factors may be greatly restricting yields throughout the sugar industry. Research to identify the causes of the yield losses has commenced and progress to date is summarised in this paper.

Another problem that has increased in recent years which may be associated with poor root growth is known as 'stool tipping'. Stool tipping refers to uprooting of the sugarcane plant when the crop lodges. The exposed root system and attached soil are picked up by mechanical harvesters, leaving gaps in subsequent ratoon crops, and cause serious processing problems and wear to equipment at sugar mills. Poor root anchorage, caused by the same factors involved in restricting yield, may be a component in the stool tipping problem but cultural and varietal characteristics are also important. A brief outline of stool tipping and how it relates to yield decline caused by soil-borne factors is presented.

## SOIL FUMIGATION AND PASTEURISATION

Soil fumigation is used widely to overcome replant diseases in orchard trees and many horticultural crops. Without soil fumigation the continued growth of these crops on the same fields would not be viable. In many cases the causes of these replant diseases are unknown. Although sugarcane has been successfully grown on the same fields for many years, fumigation with methyl bromide or metham sodium has given spectacular growth responses. Similar responses have been obtained by soil solarisation in the field and soil pasteurisation in the glasshouse. This suggests that the actual yields being obtained in continuously cultivated sugarcane fields are far below the potential yields and that the factors restricting yield are soil-borne.

## Field responses

In northern Queensland yield increases of 20-180% have been obtained by methyl bromide fumigation in the plant crop but the responses were generally in the range 20-50%. In ratoon crops the response in some trials declined markedly but in other trials the yield response was even greater in ratoons compared to the plant crop. The latter case was probably due to the loss of stools in unfumigated plots in the ratoon crops due to stool tipping. The sites used for the fumigation experiments in northern Queensland were selected because of their high levels of the organisms involved in poor root syndrome, in particular *Pachymetra*.

Thirteen small-plot fumigation experiments were planted throughout Queensland sugarcane areas in 1988/89 as a part of the yield decline research program. Two larger strip fumigation trials were planted in northern districts for joint studies into yield decline and stool tipping.

The results of the fumigation experiments harvested to date are shown in Table 1. The four trials in Bundaberg and the two larger strip fumigation trials will be harvested during the 1990 season. These fumigation experiments show that soil-borne factors are responsible for reducing yield by 20-40% in many soils in established cane growing areas of Queensland.

## Reinfestation

The recolonisation of methyl bromide fumigated plots by *Pythium* and nematodes was monitored closely in an experiment planted at Mourilyan in 1986/87. In this experiment a soil mound was built up around the plot to prevent water movement from unfumigated areas. The planting furrows were prepared before fumigation. Plots were 6.5 x 9m in size. After the soil mound and the plots had been fumigated, the plots were planted with cane by hand. Hoes and rakes were sterilised before entering the fumigated plots. The plots were kept free of weeds with herbicides where necessary.

*Pythium* species and nematodes were monitored regularly throughout the plant and first ratoon crops. *Pythium* was first isolated in the fumigated plot three months after planting but did not develop a significant population in the plant crop. In the first ratoon crop, low to moderate populations of *Pythium* were recorded. During harvest of the plant crop, the harvester carried soil between fumigated and unfumigated plots and re-infestation was expected in the fumigated plots. Nematodes were recorded in some fumigated plots five months after planting and were in all plots after seven months. At harvest of the plant crop the nematodes in fumigated plots were higher than in unfumigated plots. Nematodes are known to live deep in the soil profile and can survive fumigation because the gas cannot penetrate compacted soil layers. *Pachymetra* which does not have mobile spores did not return to the fumigated plots during the plant crop.

3 Table 1 1988/89 Yield decline  
fumigation trials

Site	Treat	TCH <sup>a</sup>	CCS	TSH <sup>b</sup>	% Response TCH TSH	
Valmadre,	Fumig	100.6	14.4	14.5	36	35
Proserpine	Unfumig	73.8	14.7	10.8		
Castellanelli,	Fumig	144.4	14.0	20.2	38	47
Burdekin	Unfumig	104.3	13.1	13.7		
Fordyce,	Fumig	94.7	14.0	13.3	15	9
Mackay	Unfumig	82.3	14.8	12.2		
Caurilla,	Fumig	106.0	13.9	14.8	2	-11
Ingham	Unfumig	104.2	16.1	16.7		
Rogers,	Fumig	132.8	15.6	20.7	34	34
Mackay	Unfumig	99.5	15.5	15.4		
Muscat,	Fumig	96.2	15.5	14.9	34	37
Mackay	Unfumig	71.7	15.2	10.9		
Chandler,	Fumig	98.9	-	-	0	
Burdekin	Unfumig	98.6	-	-		
Russo,	Fumig	131.2	14.8	19.5	33	22
Ingham	Unfumig	98.4	16.2	16.0		
Riley,	Fumig	128.9	15.0	19.3	17	17
Proserpine	Unfumig	110.2	15.0	16.5		

Tonnes cane per hectare <sup>b</sup>  
Tonnes sugar per hectare

#### Fumigation and nutrient release

Soil fumigation releases considerable amounts of plant nutrients, in particular, nitrogen, manganese and zinc. However, addition of these nutrients in amounts optimum for plant growth does not give responses equal to that obtained with soil fumigation. Glasshouse experiments which have investigated the role of nutrient release in the fumigation response are discussed below.

## General studies

In the glasshouse more detailed pot experiments have been conducted to obtain a better understanding of the cause of the fumigation and pasteurisation responses. The response to fumigation is specific to sugarcane. Four monocot species and four dicot species were grown in fumigated and unfumigated soil from sugarcane fields. A large growth response was obtained in sugarcane, a slight response in the other monocot species and virtually no response in the dicot species. This experiment needs to be repeated but it is good evidence that the fumigation response is biological and specific to sugarcane.

Soil moisture does not appear to have a significant effect on the fumigation response if the soil is above the wilting point of sugarcane.

All of the known pathogenic fungi, nematodes and other soil fauna which attack sugarcane roots in surface soil (plough depth) are eliminated by soil fumigation. In experiments where different rates of the three soil fumigants methyl bromide, methyl bromide/chloropicrin mix and metham sodium were applied to two fields, large growth responses were obtained with rates greater than those required to eliminate nematodes and *Pachymetra*. Below the rates at which these two pathogens were eliminated there was a significant correlation between the numbers of these pathogens and growth responses. These results suggested that the two pathogens were related to a proportion of the fumigation response, but other factors were also restricting yield. Fumigation of rainforest soils has given only a slight growth response in pots, compared to unfumigated rainforest soil although there was a massive release of nitrogen in this soil. Experiments comparing the fumigation response in 'old' canefields and adjacent 'new' canefields are planned.

## Future research

Soil fumigation has been a useful research tool which has enabled estimates of the yield losses being caused by soil-borne factors. The treatments however are not economic at current prices (methyl bromide \$5 000-7 000/ha broadacre; metham sodium \$1500-2 000 without plastic sheeting, \$3 000-4 000 with plastic sheeting broadacre). Fumigation will continue to be a standard treatment in trials examining the role of various factors in the yield decline problem. Further research with doses of fumigants may allow selective elimination of groups of organisms which may aid in the identification of the major causes of yield decline.

## OLD - NEW LAND

A number of sites in Queensland sugarcane areas have been identified where cane grown on land recently brought into production has outyielded cane grown on adjacent 'old' cane land. This phenomenon has been called the old-new land growth response. Responses have been noted when farmers have extended blocks onto previous headlands, or into virgin woodland or rainforest and planted the site for the first time to sugarcane.

This is not a new phenomenon. A 1935 issue of the Canegrowers' Quarterly Bulletin states 'the [fertiliser] experiment [at Jarvisfield, Ayr] was marred to some extent by the inclusion of an area of new ground in one row of plots; on this portion the crop yields averaged about 67 tons per acre [compared to 51 tons on the old land].'

#### Recent research

The old-new land response was investigated in the mid-1980's in association with the poor root syndrome research program. Sites were located in northern, Burdekin, central, and southern regions. Growth responses were measured in the field and glasshouse tests conducted to determine if the responses could be reproduced in pots, and if the cause could be determined. In addition, soil from a rainforest site adjacent to a block of cane on Tully Sugar Experiment Station was included so that changes to a virgin rainforest soil caused by the cultivation of sugarcane could be determined.

The growth of cane on new land varied considerably. Responses varied from three to over 75 %. However, such responses could not always be reproduced in pots. Physical, chemical, and biological analyses and assays failed to implicate a single factor causing old-new land growth response. However, trends in certain parameters were evident. Old land soils tended to have lower amounts of organic matter, total nitrogen, certain trace elements, and lower cation exchange capacity (CEC). There was evidence of a deterioration in soil physical structure. Generally they had higher amounts of phosphorus, *Pachymetra* root rot, and exchangeable aluminium than new land soils and more severe root disease.

Fumigation of old land soil in pot tests has invariably led to a large improvement in plant growth and the restoration of excellent root health.

A 3 year bare fallow increased cane yield to a similar extent to that obtained by fumigation in an experiment at Babinda. *Pachymetra* numbers were one tenth of the those in adjacent plots growing susceptible varieties.

#### Future research

Field experiments are planned where detailed physical, chemical and biological studies will be carried out on soils from adjacent old and new land sites. Responses to methyl bromide fumigation in the old and new land will be compared as will changes in physical, chemical and biological parameters over time. The effect of fallowing on yield and soil pathogens needs further investigation.

#### *PACHYMETRA* ROOT ROT

*Pachymetra* root rot is caused by the fungus *Pachymetra chaunorhiza*. The fungus was first isolated in 1981 by BSES during the course of research into poor root syndrome in northern Queensland. The fungus was an undescribed species, and BSES researchers cooperated with fungal taxonomists from England and the Netherlands to describe the organism in 1989.

Soon after isolation, pathogenicity testing established that *Pachymetra* was responsible for the rotting of primary roots associated with the syndrome. This rotting was thought to be at least partly responsible for the loss of stool anchorage and yield loss caused by poor root syndrome. Varieties grown widely in northern Queensland in the 1970's and early part of the 1980's were highly susceptible to *Pachymetra*.

Surveys have since shown that *Pachymetra* is widespread in the northern, Herbert River, and central canegrowing districts, and is present in 10% of fields at Bundaberg. The pathogen is known only from Queensland canefields. Blady grass (*Imperata cylindrica*) a common grass in Queensland is highly susceptible to *Pachymetra* in glasshouse inoculation experiments.

#### Yield loss

Initial yield loss investigations centred on the use of fungicides. However, no fungicide could be located with sufficient activity at levels which were not phytotoxic to sugarcane. Screening of commercial varieties in glasshouse tests has shown that resistance to the pathogen varies in the Australian germplasm. This fact is being exploited in yield loss assessment. With the aid of an assay for quantifying soil inoculum, abandoned plant breeding field experiments are being replanted after ploughout with a susceptible variety and the yield at harvest related to initial plot inoculum densities. As the plant breeding trials incorporated varieties of differing varietal resistance, plot inoculum densities in the replanted crop varied considerably.

A yield loss of 33 % has been attributed to *Pachymetra* root rot in a northern Queensland trial. Similar experiments have been planted and will be harvested in 1990.

#### Control

A number of control strategies for *Pachymetra* root rot have been investigated. These include methyl bromide fumigation, soil solarisation, cultural controls such as mounding, addition of organic matter, soil amelioration, addition of trace elements, alteration of soil pH, replanting in the interrow of the previous crop, biological control and the use of resistant varieties. The use of resistant varieties appears to be the most promising economic control. A glasshouse technique has been developed to allow all varieties in the latter stages of the plant breeding program to be screened.

Field experiments have validated the glasshouse assigned ratings and shown that susceptible In northern Queensland, highly susceptible varieties are no longer grown and the most successful varieties have tended to be resistant or have intermediate resistance to *Pachymetra*. In the central district the major varieties are in the intermediate to susceptible range, while in southern Queensland varieties range from resistant to susceptible.

## Stool tipping

Casual observations in the early 1980's of crops affected with poor root syndrome suggested that *Pachymetra* root rot was in part responsible for the large amount of stool tipping accompanying the syndrome. With the growing of more resistant varieties in northern Queensland since that time, the role of *Pachymetra* in stool tipping has become more uncertain. A Sugar Research Council funded project investigating the role of *Pachymetra* root rot in stool tipping is in progress.

## Future research

Yield loss assessment is continuing and has the following objectives:

to investigate the relationship between yield loss and varietal resistance in each affected district;

- (ii) to determine the environmental parameters influencing yield loss; and
- (iii) to determine the importance of *Pachymetra* root rot in the fumigation growth response.

The control of root rot with resistant varieties is also being further examined to determine the degree of resistance required to adequately control the disease. The results from heritability studies will be used to ensure the efficient use of resistant parents in the plant breeding program.

## *PYTHIUM* SPECIES AND OTHER MINOR FUNGAL PATHOGENS

### *P. arrhenomanes* - *P. graminicola*

In the 1920's declining yields in noble varieties of sugarcane in Hawaii, Louisiana and Puerto Rico were thought to be caused by the *Pythium arrhenomanes* - *P. graminicola* complex. These *Pythium* species can severely restrict fine root growth and under certain conditions cause a rot of the primary roots. Strongly pathogenic *Pythium* isolates similar to *P. arrhenomanes* and weakly pathogenic isolates similar to *P. graminicola* have been identified in all regions of Queensland. The weakly pathogenic *P. graminicola* isolates are by far the most common and usually are the dominant pathogenic *Pythium* species.

*P. arrhenomanes* is the dominant species in some soils and can severely restrict root and shoot growth of plants grown in pots of these soils. It is also devastating to plants in sterilised soils inoculated with the fungus.

## P. myriotylum

The fungus *Pythium myriotylum* has been isolated from sugarcane roots and is moderately pathogenic in sterilised soils. This fungus has a very wide host range and is particularly pathogenic to cowpeas, the common green manure crop grown during the short fallow before replanting of sugarcane fields. The fungus appears to decrease in number after replanting with sugarcane.

## Other fungi

A *Rhizoctonia* species has been isolated from a few soils and caused a mild root rot in pathogenicity tests.

## Future research

Research to date would suggest that *Pythium* species are not a major cause of yield decline on their own. However, more research is needed to understand their interaction with other soil pathogens. These fungi may cause significant losses when combined with other organisms.

## NEMATODES

Nematodes have damaged sugarcane crops in Queensland for probably the entire period of the crop's commercial culture with the first record of damage being in 1893. Eight groups of nematodes are associated with sugarcane in Queensland: root-lesion, root-knot, burrowing, spiral, stunt, stubby-root, ring and reniform nematodes. Adult root-knot and reniform nematodes are sedentary internal parasites with other stages living in the soil. All other groups feed externally on roots for at least some of their life cycle.

In Bundaberg yield increases of 20-100% have been obtained on sandy soils from applications of aldicarb and ethoprophos. These chemicals are used commercially in this area. In northern districts responses to non-volatile nematicides have been very variable but EDB has given up to 30% response on some sites. High nematode numbers have been recorded on many soils which do not respond to nematicides.

Symptoms of nematode attack become evident in the field in the young stages of crop growth, particularly in the plant crop. Above ground symptoms include retarded growth, poor or arrested tillering, yellowing of foliage often with leaf tips becoming brownish-purple in winter, and general reactions resembling water shortage. Most symptoms can be related directly to physical damage and premature death of the root system following attack.

Root damage is often complex and is species dependent. It ranges from gross malformation, branching and club-like swellings, to red or purplish scars, pits or necrotic lesions. Secondary fungal or bacterial infections can invade the roots through these

points. In extreme cases young plant cane dies before tillering, but more commonly the crop is sparsely stooled with uneven growth and yellowed foliage.

#### Future research

In Queensland nematodes are usually considered major pests in sandy soils and minor pests in other soils. Root-lesion and root-knot nematodes are considered the most widespread and important species. However, the distribution and importance of the different species are far from clear. The interaction of nematodes and other root pathogens needs further research.

#### SOIL FAUNA

There is a wide range of soil fauna which cause serious damage to sugarcane roots. The major pests include a number of white grub species, soldier flies, pink margarodids and symphyla. These pests usually cause easily recognisable symptoms and their limited occurrence cannot explain the general nature of poor root growth. In the past these pests have been controlled with insecticides. No economic chemical control is available for pink margarodids.

#### OTHER DELETERIOUS SOIL MICRO-ORGANISMS

Studies into replant diseases in other crops have suggested that rhizosphere bacteria may be the cause of the poor growth.

One hundred bacterial isolates and 69 fungal isolates taken from the rhizosphere of sugarcane grown in soils with poor root growth have been screened for deleterious effects on sugarcane. A few bacteria have restricted root growth and are being further tested but the majority of isolates have had no effect on root growth.

Further screening of bacterial and fungal isolates is planned and research into techniques of screening isolates for deleterious effects is required. Biocides which have given large growth responses will be used to aid in the identification of organisms which may be responsible for the inhibition of root growth. Isolations from both treated and untreated soils will be used to identify which organisms are removed by the biocides.

#### SOIL NUTRITION - MACRONUTRIENTS

Fertiliser practices in sugarcane have been restricted mainly to applications of the major nutrients, nitrogen, phosphorus and potassium. The normal practice over the years has been to make annual applications of these three nutrients.

## Nitrogen

Growth of the whole plant is affected if nitrogen is deficient but this is unlikely with normal fertiliser practices. Average response curves for the Burdekin and other districts are presented in Figure 1. Recommended rates range from 120-200 kg N/ha depending whether it is plant or ratoon cane and the current price of sugar.

Growers often use more nitrogen than the economic rate indicated by BSES trials. However, district yield trends support BSES trial data in that, while rates nitrogen application to cane fields rose above recommended rates, there has been no corresponding increase in district sugar yields. Figure 2 shows state-wide nitrogen usage and sugar yields since 1966. It can be seen that sugar yields have not risen significantly although nitrogen usage has been equal to or in excess of recommended rates since the mid 1970's.

Nitrogen fertiliser can have a marked effect on the sugar content (ccs) of the cane and this effect varies with the maturity of the cane, the cane variety and the degree of cane yield response from nitrogen. When cane is immature, amounts of nitrogen to give maximum yields of sugar can lower ccs by as much as two units compared to the unfertilised plots. Excess amounts of nitrogen depress the ccs even further. Vigorously growing crops are more prone to lodging. This can have a deleterious effect on both yield and ccs in some environments if crops are lodged for long periods before harvest.

Both of these factors may partially explain the lack of increase in sugar yields in recent years. However it is not suggested that these are the sole reasons for a lack of response to nitrogen.

Fumigation studies have shown that higher yields can be achieved on many of these soils when nitrogen is used at the recommended levels. It has been suggested that the response to fumigation may result from the nitrogen flush that occurs when soils are fumigated. Results from glasshouse studies showed that yield responses to the nitrogen released in the soil following fumigation were only significant in the absence of applied nitrogen. The effect of the 'fumigation nitrogen' did not appear to be an important factor in the response to fumigation once nitrogen was applied at quantities in excess of 70 kg N/ha.

It was concluded from these studies that the responses being obtained from fumigation in the field could be attributed mainly to biological factors. Nitrogen application rates in these trials were high enough to mask any contribution from the nitrogen flush following fumigation.

## Phosphorus

Most sugar soils have a long history of phosphorus fertiliser application and reserves of phosphorus have built up in the soil. Trials on these old soils have shown very few positive responses to phosphorus. Responses have been recorded on 'new soils' with low soil phosphorus reserves. The normal practice is to apply high rates of P as superphosphate to overcome this deficiency.

It is unlikely that inadequate phosphorus nutrition is limiting yield. The possibility of excess of phosphorus in the soil having an adverse effect on yield should be considered.

#### Potassium

Potassium is generally applied on an annual basis with recommended rates being in the 80-120 kg/ha range.

Trial responses to potassium, although not great, are generally larger than those to phosphorus and are greater in ratoon cane than plant cane. This difference in response is attributed to mineralisation of potassium in the soil during the fallow period.

These trials have indicated that fertiliser inputs can be reduced from recommended rates with minimal risk of yield loss in the short term. The crop's requirements can be met by the potassium reserves in the soil. The reserves of potassium in the soil depend mainly on clay mineralogy and can be estimated using a combination of two soil tests.

Yield responses to potassium are slight at application rates greater than 50 kg K/ha. Since normal usage is in excess of this it is unlikely that inadequate potassium fertilisation is a limitation to yield.

#### Sulfur

Sulfur is present in trace amounts in most fertiliser mixtures. This together with sulfur from rainwater and irrigation is sufficient to prevent deficiency in most soil types. Sulfur deficiency usually occurs where a fertiliser with no sulfur is used, soil reserves are low or where some topsoil has been removed by erosion or earth moving.

Sulfur deficiency has been identified mainly in the central district. In many canegrowing areas, sulfur concentrations in the subsoil are high and this seems to preclude the possibility of sulfur deficiency. Responses to sulfur fertiliser have not been recorded in trials conducted in fields with high subsoil concentrations of sulfur.

#### Calcium and magnesium

There has been considerable research into the calcium and magnesium nutrition of sugarcane. In earlier trials responses to lime were generally inconsistent and did not justify liming as a routine procedure.

More recent research showed good response to liming where soil calcium concentrations were low and the responses were attributed chiefly to correction of calcium deficiency. In northern Queensland soils there was an additional response to magnesium and the response corresponded to low soil magnesium concentrations.

Rates recommended for correction of calcium and/or magnesium deficiencies are based on soil tests. Although there were large areas of northern Queensland which were low

in these two nutrients, remedial measures have been undertaken. Most growers apply liming agents on a routine basis, ie an application of at least 2 t/ha applied in each crop cycle.

Many calcium deficient sites in northern Queensland were those identified as being affected by poor root syndrome. Although correcting the calcium/magnesium deficiency substantially increased yield, there was little concomitant increase in root growth. In some sites the increased growth from liming led to severe lodging and stool tipping because root anchorage was insufficient to support the larger crops.

#### Future research

It is unlikely that deficiencies in macronutrients are a significant factor in limiting yields. However the effect of excesses of phosphorus, potassium and nitrogen on the availability of other nutrients and the plant's ability to resist attack from pathogens need further investigation.

### SOIL NUTRITION - MICRONUTRIENTS

#### Copper

Copper deficiency is relatively common on sandy soils in most districts and is readily recognised by the appearance of typical 'droopy top' symptoms. Leaves droop, the cane stem is rubbery and there may be dark green 'islands' in the leaf. Farms affected by copper deficiency regularly apply copper sulphate to correct the problem.

Soil analytical data indicate low concentrations of copper in certain soils in most districts without the appearance of droopy-top symptoms. In these cases the soil test value and/or a third leaf analysis can be used only as a guide to the need for copper applications. Trial data to date show little or no responses to copper applications in the absence of droopy-top symptoms.

#### Zinc

Zinc deficiency has been identified in cane in certain areas of northern Queensland. Symptom expression differs with cane variety, and soil analysis is the most reliable indicator of zinc deficiency. Typically there is interveinal yellowing of the leaves, reduced growth and stooling and thinner, more elastic stalks. Root growth is also restricted in pot experiments.

Deficiency symptoms can be removed by applying zinc sulfate and large yield responses to zinc have been measured in the field. Symptom expression is accentuated by liming. The extent of zinc deficiency needs further investigation.

Recent research has shown that the DTPA extraction technique for analysis of zinc is not reliable for most sugarcane soils and a hydrochloric acid extract is more reliable.

### Iron

Iron deficiency occurs intermittently in most cane areas of the state but deficiency symptoms are usually only temporary. A typical symptom is yellowing of leaves in young cane. In cases of severe deficiency leaves may become almost white.

The symptoms are removed by spraying with iron sulfate or iron chelate, but no yield responses to soil or foliar applications of iron have been recorded in Queensland. The symptoms disappear without treatment as cane develops, apparently in response to a change in availability of iron in the soil.

### Manganese

There has been no definite identification of manganese deficiency in cane in Queensland despite very low concentrations of manganese indicated in some soils by current soil tests.

### Boron

There has been no definite identification of boron deficiency in cane despite very low concentrations of extractable boron indicated in some soils by current soil tests.

It is likely that soil tests for 'available boron' have little value for cane, as soils with low test values have high total boron concentrations and cane third leaves apparently have adequate boron.

### Aluminium

Aluminium is not considered to be an essential element for plants. The possibility of aluminium toxicity has been investigated and high concentrations of soluble or exchangeable aluminium in soils cause root stubbing and yield loss in crops other than cane.

High concentrations of soluble or exchangeable aluminium are common in highly acid cane soils and can be neutralised by raising the soil pH to 5.3 or above. Commonly, high aluminium concentrations are associated with low calcium concentrations in the soil and it is not known whether high aluminium by itself causes cane yield reduction. High exchangeable aluminium concentrations do not appear to affect growth adversely if soil calcium concentrations are adequate. Under these conditions application of lime, up to 15 tonnes/ha, had no effect on crop growth.

Research carried out by BSES and at the University of Queensland has shown that sugarcane is relatively tolerant to aluminium.

## General

Soil fumigation with methyl bromide and soil pasteurisation have consistently given increased concentrations of available zinc and manganese in treated soils. Initial pot trials have suggested that this increase is not responsible for the growth response to fumigation and pasteurisation.

## Future research

Since micronutrients are removed by the crop each year and they are not replaced by routine fertiliser application, it is essential to monitor the future role of micronutrients in affecting yield of sugarcane. The interaction of symptomless deficiencies of micronutrients and soil-borne root pathogens requires further investigation. The extent and distribution of zinc deficiency need further clarification.

## SOIL PHYSICAL FACTORS

### Compaction

The use of heavy harvesting and transport equipment in sugarcane fields has caused concern that soil compaction may be limiting yield. The increased use of minimum tillage techniques would aggravate this situation. A study conducted in the Herbert River district showed that in the short term there was no significant difference in yields of crops harvested with conventional low flotation, high ground pressure transport equipment and high flotation, low pressure equipment. However, these experiments were harvested under reasonable soil moisture and the situation may change in wetter conditions. Further research is required into the long term effect of soil compaction on crop yields. No information is available on the porosity of sugarcane soils and research in this area is required.

### Soil strength

The shear strength of soils is an important factor in the resistance of soils to root penetration and to the resistance of stools of sugarcane to tipping from the ground. Stool tipping research is currently relating the shear strength of soils to stool tipping.

## BIOCIDES

Extensive investigations have been made into the use for biocides as a means for improving the growth of sugarcane in yield decline affected soils. This research began with the examination of chemicals for control of poor root syndrome. Various fungicides, nematicides, and fumigants were applied to soil in glasshouse and field experiments. Most soil fumigants, at commercial rates, controlled both known and unknown root pathogens, leading to large growth responses and markedly improved root health

## Nematicides

Nematicides applied in glasshouse experiments have generally given very little growth response. Although assays have shown that nematodes were eliminated, root health has remained poor. In field trials, responses to the application of nematicides in northern Queensland have been erratic, ranging from zero to approximately 30%. In soils affected by poor root syndrome, it was thought that other root pathogens (including *Pachymetra*) may have increased following application of nematicides.

In southern Queensland, large field responses to the application of nematicides on certain sandy soils have been obtained and some farmers apply nematicides on a regular basis.

### *Pachymetra* root rot

A range of fungicides has been screened for activity against *Pachymetra* root rot. Although it is an Oomycete, fungicides with specific activity against this group have failed to adequately control *Pachymetra*.

### *Pythium* root rot

Excellent control of *Pythium arrhenomanes* has been achieved in glasshouse tests with the fungicide metalaxyl (Ridomil). Treatment of yield decline affected soils in pot tests has failed to give significant responses to the control of this pathogen.

## General fungicides

The fungicide pentachloronitrobenzene (PCNB) has given partial control of *Pachymetra* root rot and has led to an improvement in shoot and root growth in some glasshouse and field tests. This chemical possesses some activity against root diseases caused by *Rhizoctonia spp.* and pathogens belonging to the actinomycetes group. In recent trials, very high rates of the general fungicides mancozeb and benomyl have given responses similar to that obtained with methyl bromide. Root health has been greatly improved by these treatments. Plants growing in soils from most districts in Queensland have given similar responses. However, it remains to be shown whether this is due to the control of fungal pathogens alone or whether the responses are associated also with the control of other groups of organisms.

## Future research

Field tests are planned to determine the role of known pathogens in yield losses associated with soil-borne disease. Factorial field experiments incorporating controls for *Pythium* root rot and nematodes will be established. Concurrent glasshouse experiments will allow an examination of glasshouse responses and a detailed study of root systems.

Field experiments examining responses to mancozeb are planned for each district of Queensland. Concurrent glasshouse research investigating the mechanism of the

to mancozeb and benomyl will also be conducted. Other fungicides are to be screened for activity against the factors causing yield decline.

## STOOL TIPPING

Stool tipping is an unwelcome side effect when lodging occurs in the mature cane crop. As the cane lodges, it exerts a considerable force on the base of the stalk, at or below ground level. This can result in underground sections of the cane stool and adhering soil being levered out of the ground.

Stool tipping leads to greater quantities of extraneous matter and soil in the cane supplied to raw sugar mills. Soil causes damage to mill and harvesting equipment and reduces sugar content. Ratoons in affected blocks can be gappy, resulting in decreased productivity or increased production costs because fields are ploughed out prematurely.

Factors such as varietal characteristics, cultural methods and environmental conditions may be contributing to the problem. Research into the influence of these factors is currently in progress.

### Varietal characteristics

#### (a) Ratooning habit

One feature which has been noted in field studies is the absence of deep stubble in the ratoon crops of certain varieties which had tipped. In these situations ratooning depth is confined mainly to a depth of 100 mm. In many instances there is little or no evidence of sound cane stubble below this depth.

Although the study is still in progress, current observations suggest that ratooning occurs higher in the profile each year as the crop cycle progresses. However in some varieties (eg Q77) the previous crop's stubble remains intact and apparently healthy and ratoon shoots develop from points lower in the soil profile. This provides a deep, well anchored stool and reduces susceptibility to tipping.

Other varieties (eg Q113) tend to reach a shallow ratooning depth (< 100 mm) earlier in the crop cycle and the deep stubble, where it exists, tends to be unhealthy and rotten. This ratooning habit probably contributes to stool tipping as it provides a weak and shallow foundation for the stool.

Shallow ratooning may not occur over the whole stool. Some varieties eg Q124, appear to have a two-tiered structure of ratoon development. Part of the ratoons develop from within the top 100 mm of the soil profile but some ratoon shoots develop deeper down the profile. Stool tipping occurs mainly in the shallow ratooning sections of the stool.

## (b) Lodging characteristics

Lodging is the catalyst for stool tipping. Vigorous varieties, such as Q124, with tall, thick barrellled stalks and heavy tops are particularly susceptible to tipping.

The lodging habit of varieties appears to be an important factor in their susceptibility to tipping. Some varieties tend to have a rigid lodging habit which can be likened to a tree falling. This exerts considerable leverages at or below ground level and promotes tipping. This is accentuated if stalks are brittle and snap below ground level. Other varieties tend to sag or 'lodge gracefully' with the stalk bending slightly above ground level. In this case leverage at the base of the stool is much less and stool tipping is less.

## Environment

Soil moisture is the major environmental factor influencing stool tipping. There is a positive relationship between tipping and soil moisture. Stool tipping is most common in areas of moist soil and will often be detected first in wetter sections of a field or district. The high rainfall and resultant high soil moisture that occurs for prolonged periods, is a major factor in the incidence of stool tipping in the northern Queensland region.

Tipping has been recorded on all soil types, although it is more prevalent on lighter or coarse textured soils. This could be related to lack of cohesion in these soils under wet conditions.

## Cultural

## (a) Trash blanketing

The practice of trash blanketing/minimum tillage is a major change in the growing of cane. At this stage there are no data to indicate that tipping is more intense under trash blankets. However the trials have not been going long enough to draw definite conclusions. There are indications that *Pachymetra* numbers are higher under the trash blanket system.

Trash blankets increase the retention of soil moisture and promote ratooning from stubble pieces left on the soil surface after harvest. Both of these predispose the crop to tipping.

## (b) Planting depth/mounding-up

Shallow planting and/or incomplete filling-in of plant cane increases the risk of stool tipping. Trials have been initiated to investigate these effects. Preliminary results indicate stool anchorage is improved by deeper planting and also lodging appears to be reduced where rows have been mounded up. These trials are being continued for further evaluation.

### Root anchorage

Although the importance of stool anchorage has been recognised, little work has been done to assess the importance of root anchorage in the stool tipping problem.

Root systems are often poorly developed in plants which have tipped out of the ground. Improved root growth may limit or reduce tipping. A more extensive or healthier root system may even help offset the problem of shallow ratooning varieties. The factors which limit root growth need to be determined. Improved root growth has been recorded following fumigation in these situations. This suggests that biological factors may be limiting root development.

### Future research

Research is continuing into the role of varietal characteristics, cultural practices and the environment in stool tipping. The role of *Pachymetra* in stool tipping is also being investigated. This research is being funded by Sugar Research Council grants and by BSES.

A new project funded by the Sugar Research Council will allow the development of improved techniques to quantify root growth using automated core washing to obtain root samples, and image analysis systems to measure root length.

The role of other root pathogens and parasites including nematodes, other soil fauna and deleterious rhizosphere micro-organisms in stool tipping needs further investigation. It is highly likely that the organisms which restrict root growth and make plants more susceptible to stool tipping will also reduce the yield of crops and therefore be important in yield decline.

### SUMMARY

Evidence from investigations into fumigation, following and growth of sugarcane on recently cultivated soils strongly suggests that yields in established cane growing areas are being restricted by soil-borne biological factors. The yield restriction may be in the order of 20-40%. The soil-borne pathogens *Pachymetra*, *Pythium* and also nematodes probably account for a proportion of this yield loss, but other unknown deleterious micro-organisms may be involved.

In most cases nutrient deficiencies do not appear to be limiting growth. Zinc deficiency which has recently been identified in northern districts may be affecting growth on some soil types. Excesses of some nutrients, such as phosphorus may be interacting with other nutrients and/or soil-borne pathogens.

A multi-disciplinary study of soil-borne limits to yield in sugarcane is needed to identify the major factors involved and to develop satisfactory treatments to ameliorate the problem.

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FIGURE 1.  
SUGAR YIELD RESPONSE TO NITROGEN

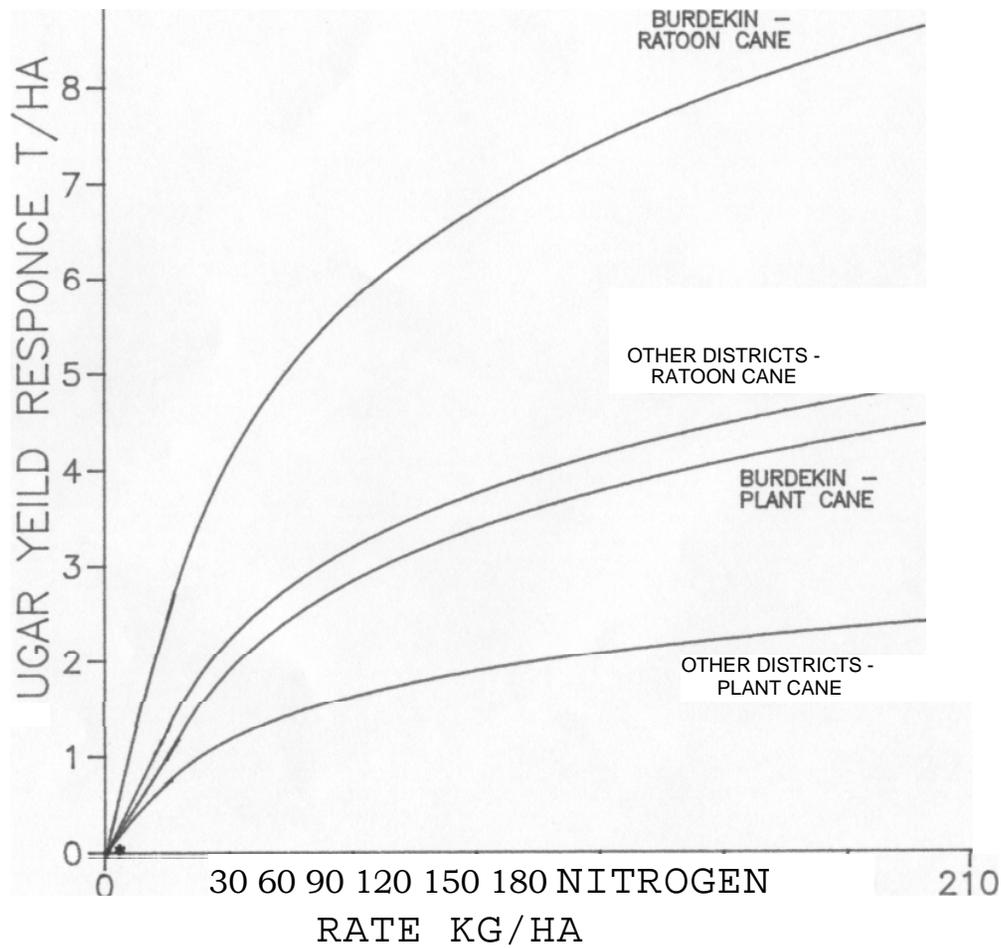


FIGURE 2.

*STATE AVERAGE SUGAR YIELDS WITH AVERAGE  
NITROGEN USAGE 1967-1989*

