

91-0290

**BUREAU OF SUGAR EXPERIMENT STATIONS
QUEENSLAND, AUSTRALIA**

**SOIL CONSTRAINTS TO
PRODUCTIVITY IMPROVEMENT**

by

B J Croft
R C Magarey
A P Hurney
J R Reghenzani

Report No.2

June, 1991

CONTENTS

	Page No.
1. OVERVIEW AND HISTORICAL PERSPECTIVE	1
1.1 Definitions and extent of yield decline	1
1.2 Poor root syndrome and yield decline research	2
1.3 Future research plan	3
2. EVIDENCE FOR SOIL BIOLOGICAL CONSTRAINTS TO SUGARCANE PRODUCTIVITY	4
2.1 Old - new land growth response	4
2.1.1 Recent research	4
2.1.2 Future research	4
2.2 Soil fumigation and pasteurisation	5
2.2.1 Field responses	5
2.2.2 Fumigation and nutrient release	5
2.2.3 General studies	6
2.2.4 Future research	
3. ORGANISMS INVOLVED IN YIELD DECLINE	7
3.1 Pachymetra root rot	7
3.1.1 Yield loss	8
3.1.2 Control	8
3.1.3 Stool tipping	8
3.1.4 Future research	9
3.2 <i>Pythium</i> species	9
3.2.1 <i>P. arrhenomanes</i> - <i>P. graminicola</i>	9
3.2.2 <i>P. myriotylum</i>	9
3.2.3 Future research	10
3.3 Other fungal pathogens	10

CONTENTS (Continued)

	Page No.
3.4 Nematodes	10
3.4.1 Future research	11
3.5 Soil fauna	11
3.6 Unknown deleterious soil microorganisms	11
3.6.1 Root isolations	11
3.6.2 Biocides	11
3.6.3 Root observations	12
3.6.4 Future research	12
4. SOIL NUTRITION - MACRONUTRIENTS	12
4.1 Nitrogen	12
4.2 Phosphorus	15
4.3 Potassium	15
4.4 Sulfur	16
4.5 Calcium and magnesium	16
4.6 Future research	17
5. SOIL NUTRITION - MICRONUTRIENTS	17
5.1 Copper	17
5.2 Zinc	17
5.3 Iron	17
5.4 Manganese	18
5.5 Boron	18
5.6 Aluminium	18
5.7 General	18
5.8 Future research	19

CONTENTS (Continued)

	Page No.
6. STOOL TIPPING	19
6.1 Varietal characteristics	19
6.1.1 Ratooning habit	19
6.1.2 Lodging characteristics	20
6.2 Environment	20
6.3 Cultural	20
6.3.1 Trash blanketing	20
6.3.2 Planting depth/mounding-up	21
6.3.3 Root anchorage	21
6.3.4 Future research	21
7. SUMMARY	21
8. REFERENCES	22

1. OVERVIEW AND HISTORICAL PERSPECTIVE

1.1 Definitions and extent of yield decline

The term yield decline has been used within BSES to describe the observation that soils which have grown sugarcane continuously for many years yield well below their potential. This reduced yield potential occurs even when optimum levels of the known required nutrients are supplied and optimum cultural practices are used. Yield increases of 20-40% and in some cases up to 100% have been recorded in plots fumigated with methyl bromide in fields which have been continuously cropped with sugarcane. Similar responses have been observed when soils which have never grown sugarcane or which have been cropped with another crop for a number of years are planted to sugarcane and growth is compared to soils continuously cropped with sugarcane. The responses to fumigation, new soils and long-term rotations have been recorded in all established sugarcane districts. Root systems of plants grown in continuously cropped sugarcane soils are poorly developed and have a range of root discolouration, root stubbing and root rotting symptoms.

If yields could be increased by 20-40% profits to the industry could be increased by \$300-600 million each year. Even if the problem was only partially alleviated the return to the industry would be great. Soil-borne constraints to sugarcane yields are believed to be one factor which has led to the plateau in yields observed in the industry over the last 20 years.

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.

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.

1.2 Poor root syndrome and yield decline research

Poor root syndrome was recognised as an important disease in the late 1970's and in 1983 BSES invited an external review panel consisting of six members from the CSIRO, QDPI, the University of Queensland and BSES to assist with recommendations for future research. In 1984 a workshop involving nine senior staff from the CSIRO Division of Soils, staff from the QDPI and BSES officers was held in Innisfail to discuss whether there was a scientific and problem-orientated justification for the involvement of CSIRO officers on sugarcane soil problems. From this workshop research on the effect of trash conservation on earthworm activity was initiated by CSIRO with assistance from BSES. The Sugar Research Council convened a workshop on yield decline in 1990 which involved a wide range of scientific and industry representatives to discuss the requirements for research into this problem.

Other researchers working on soil-borne diseases have been invited to assist with research into poor root syndrome and yield decline. These have included Professor F Newhook of the University of Auckland (1984); Dr J Hoy, Louisiana State University (1987), and Dr Z Frank, Agricultural Research Organisation, Israel (1990). Associate Professor John Fisher, Waite Agricultural Institute, spent two months in Tully reviewing the role of nematodes in yield decline in 1990. During 1991 Dr J Krikun, Agricultural Research Organisation, Israel and Professor M Schroth Head of the Plant Pathology Department, University of California, Berkeley, will be visiting to consult on research into sugarcane yield decline and a post doctoral student from Professor Schroth's laboratory, Dr T Isakeit will be spending three months at Tully investigating the role of soil microorganisms in yield decline.

In 1986 Mr Magarey, Mr Hurney and Dr Ryan visited the CSIRO Division of Soils in Adelaide and the Waite Agricultural Institute to discuss poor root syndrome research and close contacts have been maintained with Dr Rovira and his group.

Mr B Croft was awarded a Queen Elizabeth II grant for young Australians in 1985 to spend 6 weeks at the USDA Biological Control and Root Disease Laboratory at Washington State University and the University of California, Riverside. Mr R Magarey visited research laboratories working on root disease in England, Netherlands and the United States during a study tour funded by SRDC in 1990.

Within BSES a poor root syndrome/yield decline group which involved all staff directly involved in the research, an extension officer, a senior plant breeder, a senior administrator and Mr Brian Roach, CSR plant breeder, met regularly from 1983 to assess current research and plan future programs. This group continued until 1988. In 1991 a much wider group was formed which involved representatives from all disciplines within BSES and two outside specialists. The outside specialists are Dr Wayne Strong, Queensland Wheat Research Institute and Dr Percy Wong, New South Wales Department of Agriculture and Fisheries. This group met for the first time in February, 1991 and developed a research plan for yield decline for the next three years. This group will meet 1-2 times per year to review and reassess the research plan.

Research into poor root syndrome has greatly advanced the knowledge of soil microbiology in sugarcane in Queensland and recent research has identified Zn deficiency in sugarcane in some northern soils. The results of this research have been published in international journals and at sugar industry and Australian conferences (see attached references). Canefarmers are adopting the use of resistant varieties to control *Pachymetra* root rot and the application of Zn to deficient sites.

1.3 Future research plan

The research plan developed by the BSES yield decline group in February will address the three major soil factors which may be restricting yield. These factors are soil-borne microorganisms, nutrition (with an emphasis on micronutrients), and soil physical properties. Techniques for studying root systems are also being developed. The emphasis of the work on soil microorganisms will be to identify deleterious microorganisms which may be responsible for the restricted root growth. *Pachymetra* root rot is an important disease in some areas and further research into the severity of the disease in different regions of the state, yield loss assessment experiments and breeding for resistance to the pathogen are part of the yield decline program. However, *Pachymetra* root rot is only one factor in the yield decline and evidence to date suggests that as yet unidentified microorganisms are largely responsible for the more general effects of the problem. Research into the role of nematodes and *Pythium* root rot in yield decline are not considered to be of high priority but will be monitored in conjunction with other experiments.

Micronutrient deficiencies have been identified recently in sugarcane in northern districts and this research will be extended to determine if micronutrient deficiencies are responsible for reduced yields in other districts. There is only limited understanding of the soil physical properties of sugarcane soils and the effect of new cultural practices such as minimum-tillage on these properties. BSES has recently appointed a research officer and a research assistant to investigate this area. Initial proposals are that the effects of compaction caused by harvesters and cane transporters running close to the stool on subsequent ratoon growth and the possibility of alleviating these effects through wider row spacing and controlled traffic paths will be studied. The changes in soil physical properties in soil recently brought under sugarcane production will also be investigated.

The research program is designed to identify the major factors in the soil restricting yield. Where possible research on biological, nutritional and physical factors will be conducted on common sites so that the interaction between these factors can be assessed.

2. EVIDENCE FOR SOIL BIOLOGICAL CONSTRAINTS TO SUGARCANE PRODUCTIVITY

2.1 Old - new land growth response

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].'

2.1.1 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.

In the field, the old-new land growth response varied considerably. Responses ranged from 3% to over 75%. These responses could not always be reproduced in pots. Physical, chemical, and biological analyses and assays failed to implicate a single factor causing the 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, and exchangeable aluminium than new land soils and more severe root disease, including *Pachymetra* root rot. 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 three year bare fallow increased cane yield spectacularly in an experiment at Babinda. *Pachymetra* numbers were one tenth of those in adjacent plots growing susceptible varieties.

2.1.2 Future research

Field experiments have been initiated, and further ones 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 warrants further investigation.

2.2 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. Sugarcane has been successfully grown on the same fields for many years but 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.

2.2.1 Field responses

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

Small-plot fumigation experiments were planted throughout Queensland sugarcane areas in 1988-89 as part of the yield decline research program. The results of the fumigation experiments are illustrated in Table 1. The results show that soil-borne factors are responsible for reducing yield by 20-40% in many soils in established cane growing areas of Queensland.

The monitoring of fumigated plots suggests that both *Pythium* and nematodes may recolonise plots during the plant crop. *Pachymetra*, which does not have mobile spores and which is not found below 45 cm depth, has not reinfested fumigated plots even two to three years after the treatment was applied.

2.2.2 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 nature of the fumigation response, are discussed below.

Table 1

1988/89 Yield decline fumigation trials

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

^a Tonnes cane per hectare

^b Tonnes sugar per hectare

2.2.3 General studies

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 doses 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 doses greater than those required to eliminate nematodes and *Pachymetra*. Below the dose 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 large release of nitrogen in this soil. Experiments comparing the fumigation response in 'old' canefields and adjacent 'new' canefields are planned.

2.2.4 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 \$1 500-2 000 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.

3. ORGANISMS INVOLVED IN YIELD DECLINE

3.1 *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.

3.1.1 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 there is resistance to the pathogen 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 incorporate varieties of differing varietal resistance, plot inoculum densities in the replanted crop vary considerably. Yield losses of 33% (plant crop) and 37% (first ratoon crop) have been attributed to *Pachymetra* root rot in a northern Queensland trial. Follow up experiments are currently in progress.

3.1.2 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 screen all varieties in the latter stages of the plant breeding program. Field experiments have validated the glasshouse assigned ratings and shown that susceptible varieties may greatly increase soil inoculum density while resistant varieties adequately control the disease.

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.

3.1.3 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 in the varieties Q117 and Q124 in the Mulgrave mill

area, failed to implicate *Pachymetra* root rot as the major factor governing stool tipping. It is likely that the result would have been different if varieties of greater susceptibility, such as Q90 could have been included in the study.

3.1.4 Future research

Yield loss assessment is continuing and has the following objectives:-

- (i) 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.

3.2 *Pythium* species

3.2.1 *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 a limited number of soils. It is devastating to plants in sterilised soils inoculated with the fungus, but appears to be of lesser importance in field soils.

3.2.2 *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. Propagules of the fungus decline in fields replanted with sugarcane.

3.2.3 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.

3.3 Other fungal pathogens

Historically very few fungal species have been identified as sugarcane root pathogens. Two *Rhizoctonia* spp. were found to be minor pathogens in Puerto Rico in the 1920's. *Rhizoctonia* spp. have been isolated from a yield decline affected root systems on a few occasions in Queensland and were found to be mildly pathogenic. In Taiwan, cultural filtrates from *Trichoderma* and *Fusarium* cultures have been shown to reduce the growth of glasshouse grown plants. Inoculation of soils with these species in Queensland had no effect on cane growth.

3.4 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.

3.4.1 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.

3.5 Soil fauna

There is a wide range of soil fauna which cause serious damage to sugarcane roots. The major pests include a number of whitegrub species, soldier flies, pink margarodids and symphyla. On most occasions these pests 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.

3.6 Unknown deleterious soil microorganisms

Fumigation experiments and general observations suggest that unknown soil organisms are very important in yield decline. Large growth responses have been obtained with methyl bromide at doses above that required to control *Pachymetra*, *Pythium*, nematodes and soil insects. Studies into replant diseases in other crops implicate rhizosphere bacteria and in some cases *Actinomycetes* as the causal agents. Other fungal rhizosphere inhabitants may also be involved. BSES research has attempted to determine the nature of unknown pathogens in sugarcane yield decline in several different ways in a co-ordinated program.

3.6.1 Root isolations

In preliminary studies, 100 bacterial isolates and 69 fungal isolates were obtained from the rhizosphere of yield decline affected roots. Pathogenicity tests were conducted in short term glasshouse experiments. A few bacteria restricted root growth, but in subsequent more detailed tests, failed to reproduce the deleterious effect. This program is being expanded, and a recently appointed soils microbiologist is researching the effect of different isolation techniques and cultural media on the ability to culture organisms from both the rhizosphere and within yield decline-affected roots.

3.6.2 Biocides

Biocides offer a unique way of investigating the effect of soil organisms on root growth and have been used extensively. Excellent control of nematodes and *Pythium* root rot (caused by *P. arrhenomanes*) has been achieved in the glasshouse through the use of Fenamiphos (Nemacur) and Metalaxyl (Ridomil) respectively. Their single and combined applications to many yield decline affected soils has elicited virtually no improvement in root health and little or no response in shoot growth. A significant number of fungicides

have given growth responses, and with two the response was nearly as great as obtained with methyl bromide fumigation. High doses of the fungicides Mancozeb and Benomyl have greatly improved root health in glasshouse experiments. Mancozeb has given a large field response in an experiment at El Arish in northern Queensland. Responses have also been obtained in a trial at Marian (central Queensland). PCNB (Quintozene), Anilazin (Dyrene), Dowco 444, Hymexazol (Tachigaren), and Propamocarb (Previcur) have all improved shoot and root growth to some extent. Current isolation studies are seeking to determine the organisms controlled by these chemicals and also the nature of the organisms controlled by fungicides giving no growth response.

3.6.3 Root observations

Isolation studies and biocide treatments are being combined with root observations to help determine the nature of the unknown pathogens. Specific root samples are being cleared and stained to highlight the presence of organisms around and within roots. Root sectioning equipment is being purchased to aid these studies.

3.6.4 Future research

Soil-borne organisms have been shown to substantially reduce the productivity of sugarcane in Queensland. The current BSES research program has the objectives of quantifying the importance of known pathogens and to implement satisfactory controls, and to determine the identity of unknown pathogens. The development of controls for these organisms would follow.

4. 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.

4.1 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 grower nitrogen rates 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 1967. 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.

FIGURE 1.
SUGAR YIELD RESPONSE TO NITROGEN

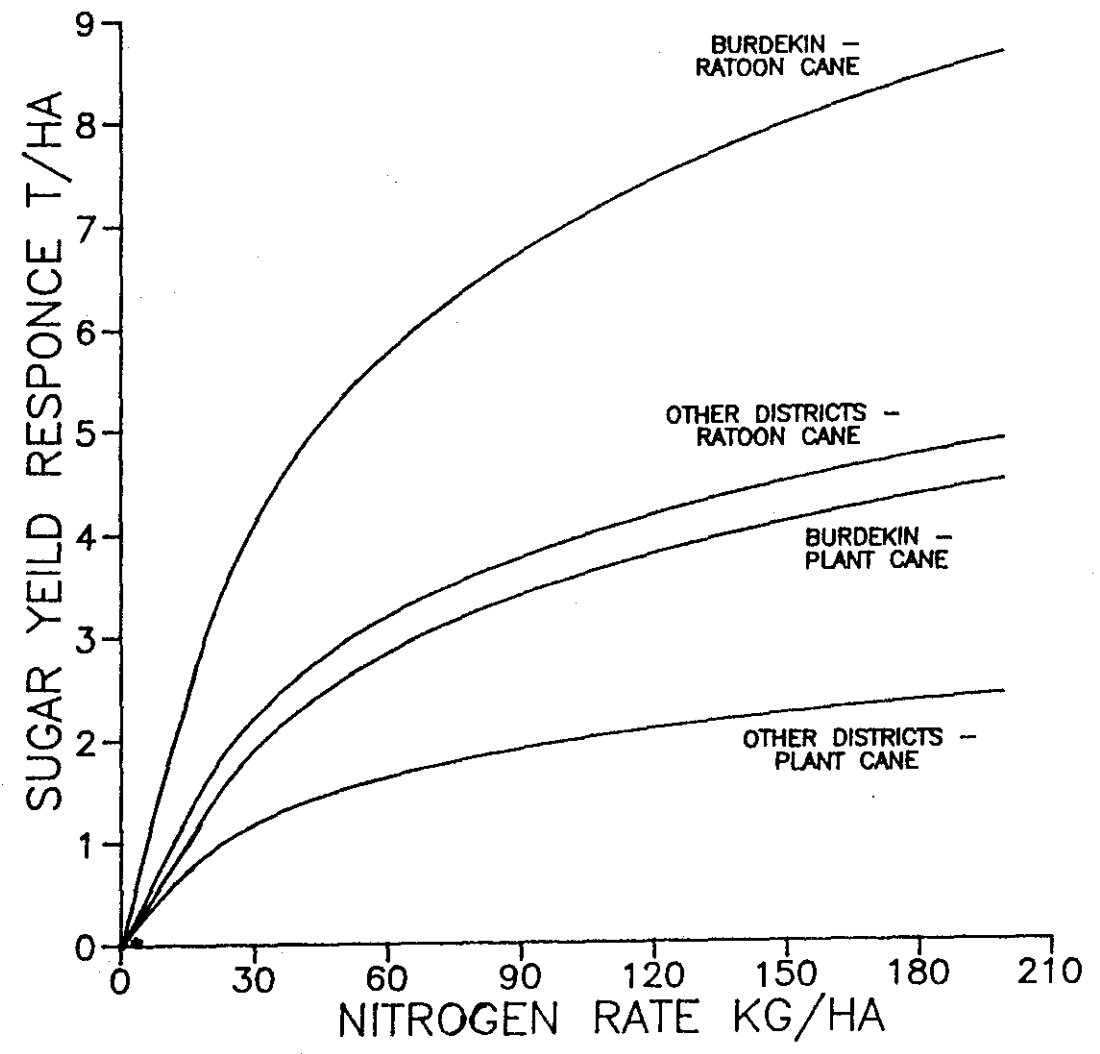
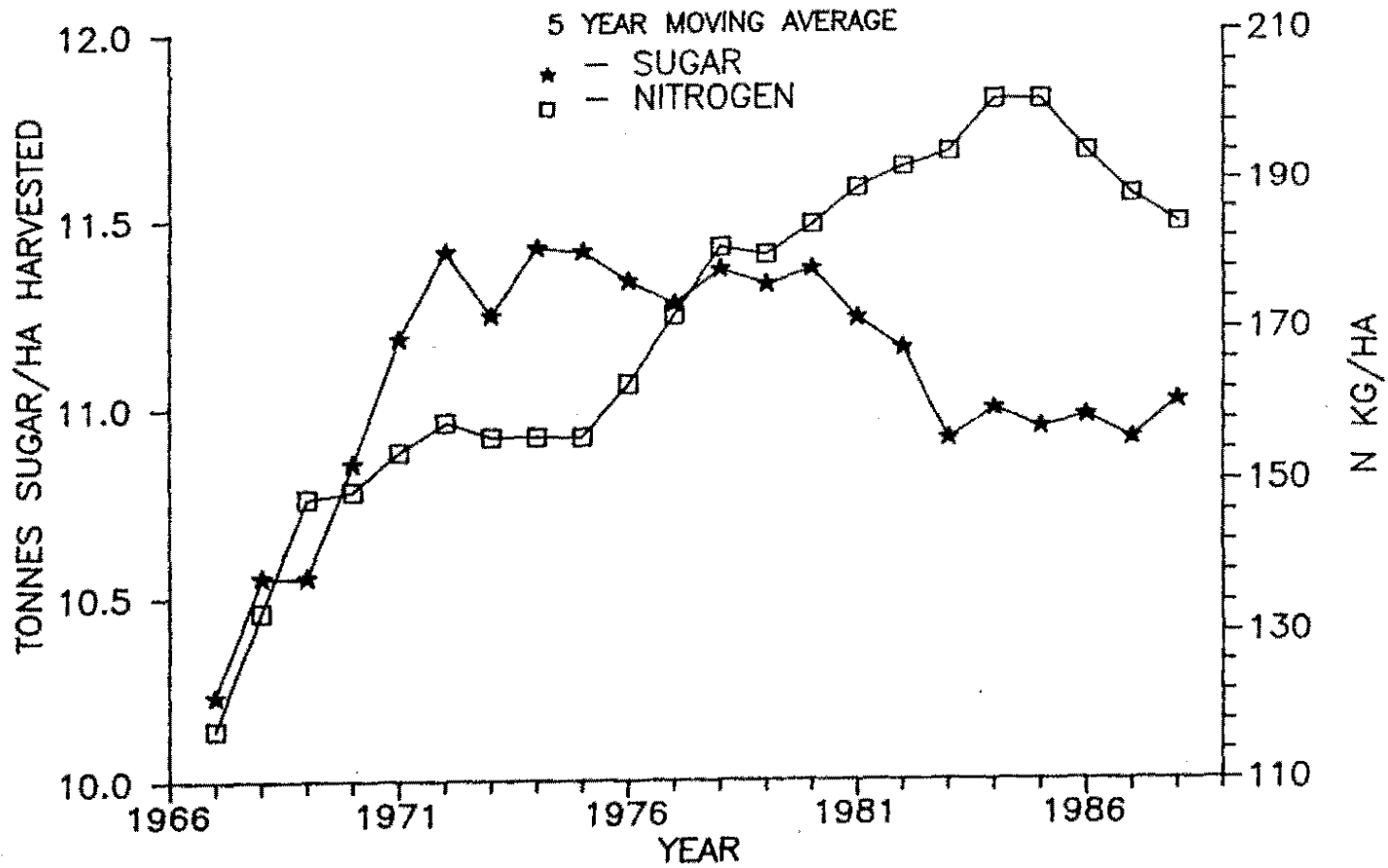


FIGURE 2.

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



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.

4.2 Phosphorus

Most sugar soils have a long history of phosphorus fertiliser application and reserves of phosphorus have built up in the soil. Depending on soil test values, recommended application rates vary from a maintenance application of 20 kg/ha in the plant crop only, to an annual application of 40 kg/ha. 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.

4.3 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.

4.4 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, and in lighter textured soils with low sulfur reserves.

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.

4.5 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. Calcium and magnesium nutrition is the subject of an ongoing extension campaign. Growers are encouraged to have their soils tested and if required, to apply liming agents on a routine basis. The recommended application is 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.

4.6 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 needs further investigation.

5. SOIL NUTRITION - MICRONUTRIENTS

5.1 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.

5.2 Zinc

Zinc deficiency has been identified in cane in certain areas of northern Queensland. As symptom expression differs with cane variety, foliar and soil tests are more reliable indicators of zinc deficiency. Typically there is interveinal yellowing of the leaves, reduced growth and thinner, more elastic stalks. Root growth was shown to be 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 and application technology are currently under investigation.

Recent research has shown that the DTPA extraction technique previously used for analysis of zinc was not reliable for most sugarcane soils and a hydrochloric acid extract was developed which allowed accurate diagnosis of deficient soils. The latter test is now commercially available to cane growers.

5.3 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 ratoon 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 plant uptake and availability of iron in the soil.

5.4 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. As other acid Australian soils have been shown to contain toxic concentrations of manganese particularly when waterlogged, this possibility should be monitored in cane growing areas.

5.5 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. In common with other grasses, sugarcane has a narrow window of tolerance to boron levels. Deficiency or sufficiency can easily be replaced by toxicity if excess boron is applied to the crop.

5.6 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 t/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.

5.7 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.

5.8 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 effects of symptomless deficiencies of micronutrients and interaction with soil-borne root pathogens requires further investigation. The extent and distribution of zinc deficiency and techniques for applying Zn are being investigated.

Correlation of soil and foliar test values with probability of plant responses remains poor for many micronutrients. Where deficiency or toxicity is identified there is a need to establish these relationships.

6. 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.

6.1 Varietal characteristics

6.1.1 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.

6.1.2 Lodging characteristics

Lodging is the catalyst for stool tipping. Vigorous varieties, such as Q124, with tall, thick barrelled 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.

6.2 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.

6.3 Cultural

6.3.1 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.

6.3.2 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.

6.3.3 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.

6.3.4 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 microorganisms 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.

7. SUMMARY

Evidence from investigations into fumigation, fungicide application, fallowing 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 microorganisms 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.

8. REFERENCES

- Allsopp, P G (1990). Sequential sampling plans for nematodes affecting sugar cane in Queensland. *Aust. J. Agric. Res.*, 41:351-358.
- Bull, R M (1979). New chemicals for nematode control in the Bundaberg district. *Proc. Aust. Soc. Sugar Cane Technol.*, 1:99-103.
- Chandler, K J (1984). Plant parasitic nematodes and other organisms as a contributing factor to poor sugarcane root development in north Queensland. *Proc. Aust. Soc. Sugar Cane Technol.*, 6:63-67.
- Chandler, K J (1987). Sugar cane grub control in Queensland. A.G.M. Australian Ento. Soc. abstract.
- Croft, B J (1988). Root rot of cowpeas caused by *Pythium myriotylum* in northern Queensland. *Australasian Plant Pathology*, 18:8-9.
- Croft, B J (1989). Effect of quintozone on *Pachymetra chaunorhiza* and poor root syndrome of sugarcane. 7th Conf. Australasian Pathology Society. Abstract.
- Croft, B J (1989). A technique for screening sugarcane cultivars for resistance to *Pachymetra* root rot. *Plant Disease*, 73:651-654.
- Croft, B J (1989). Etiology and control of poor root syndrome of sugarcane in Queensland. M.Agr.Sc. Thesis, University of Queensland.
- Croft, B J (1987). A bioassay to quantify *Pythium graminicola* in soil. *Australasian Plant Pathology*, 16:48-51.
- Croft, B J, Chandler, K J, Magarey, R C and Ryan, C C (1985). Northern Poor Root Syndrome of Sugarcane in Australia. In 'Ecology and Management of Soilborne

- Plant Pathogens' (Ed.) C A Parker, A D Rovira, K J Moore, P T W Wong, and J K Kollmorgen, p 17-19.
- Croft, B J and Magarey, R C (1989). A review of research into *Pachymetra* root rot, an important new fungal disease of sugarcane. Proc. International Society of Sugar Cane Technologists 20th Congress. Sao Paulo, Brazil.
- Croft, B J and Magarey, R C (1984). Pathogenic fungi associated with northern poor root syndrome of sugarcane. Proc. Aust. Soc. Sugar Cane Technol., 6:55-61.
- Dick, M W, Croft, B J, Magarey, R C, deCock, A W A M and Clark, G (1988). *Pachymetra*, a new genus of the Verrucalvaceae (Oomycetes). Botanical Journal of the Linnean Society, 99:97-113.
- Egan, B T, Hurney, A P, Ryan, C C and Matthews, A A (1984). A review of the northern poor root syndrome of sugarcane in north Queensland. Proc. Aust. Soc. Sugar Cane Technol., 6:1-9.
- Hurney, A P (1989). Stool tipping in north Queensland. BSES Internal report.
- Magarey, R C, Taylor, P W J and Ryan, C C (1987). Distribution of the root rot fungus involved in Poor Root Syndrome in cane fields from Ingham to Rocky Point, Proc. ASSCT 9: pp 105-108.
- Magarey, R C (1989). The spatial pattern of *Pachymetra chaunorhiza* and the effect of sugarcane varietal resistance on inoculum density. Australasian Plant Pathology Conference (Brisbane).
- Magarey, R C (1990). Quantitative assay of *Pachymetra chaunorhiza*, a root pathogen of sugarcane in Australia. Phytopathology, 79:1302-1305.
- Magarey, R C (1990). Development of sampling strategies for *Pachymetra chaunorhiza*, a sugarcane root pathogen. Phytopathology, 79:1306-1309.
- Reghenzani, J R (1988). Northern sugarcane response to soil solarization. Proc. Aust. Soc. Sugar Cane Technol., 10:163-169
- Reghenzani, J R (1988). Nutritional problems of northern sugarcane soils. ANZAAS Congress, Symposium on Chemistry in Agriculture, Townsville.
- Ridge, D R (1984). Review of research in sugarcane nutrition. BSES internal report.
- Ridge, D R, Hurney, A P, and Haysom, M B C (1980). Some aspects of calcium and magnesium nutrition in north Queensland. Proc. Aust. Soc. Sugar Cane Technol., 2:55-61.