SUGAR YIELD DECLINE JOINT VENTURE

Phase 1

(July 1993 — June 1999)

CSIRO

NATURAL RESOURCES

DPI QUEENSLAND DEPARTMENT OF PRIMARY INDUSTRIES

SUGAR YIELD DECLINE JOINT VENTURE

BSES Advancing Sugar

Sugar Research and Development Corporation

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Sugar Yield Decline Joint Venture Management Committee at the Tully rotation experiment.

The Sugar Yield Decline Joint Venture (SYDJV) was established for a six-year period from July 1993 to June 1999 with a charter to identify the reasons for, and develop solutions to, the problem of yield decline. Although some causes have been identified and solutions developed, the issue of yield decline has not been completely understood or resolved. Yield decline has turned out to be a more complex issue than imagined when the Joint Venture was established. As a consequence, the Joint Venture partners have supported a second phase of the program, which will run from July 1999 to June 2005. In this report, the research team will discuss the outcomes of 'Phase 1' and their relevance to sustainable sugar production.

Dr Alan Garside, SYDJV Leader

Sugar Yield Decline Joint Venture

The SYDJV was established between the Sugar Research and Development Corporation (SRDC), Bureau of Sugar Experiment Stations (BSES) and CSIRO in 1993. Two years later, in 1995, the Queensland Department of Primary Industries (QDPI) and Department of Natural Resources (QDNR) also became partners. The establishment of the Joint Venture was a very positive initiative that provided the resources to foster inter-organisational collaboration and a multidisciplinary approach – which was clearly the most likely way real progress would be made on such a complex issue.

The Joint Venture scientists were given a three faceted challenge to:

- **identify** causal factors and their contribution to yield decline in sugarcane;
- **develop** solutions to minimise or alleviate the impact of such causal factors on productivity in sugarcane; and
- **promote** the use of appropriate technologies developed by the Venture.

At the end of six years, the SYDJV team has made substantial progress towards achieving each of these objectives.

What is Yield Decline?

Yield decline means different things to different people. However, for the purposes of the Joint Venture it has been clearly defined as:

... the loss of productive capacity of sugarcane growing soils under long-term monoculture.

Yield decline has been a problem for the Australian sugar industry for most of its history and occurs in all sugarcane growing areas. It has variously been estimated to cost the Australian sugar industry between $200-400 m each year.

Although yield decline has often been confused with the productivity plateau that was evident in the industry from 1970 to 1990, it is now known that the productivity plateau was caused by a combination of many factors (yield decline was only one).

... the loss of productive capacity of sugarcane growing soils under long-term monoculture.

At the outset of the SYDJV, it was thought that root pathogens (ie root diseases) were the main cause of the problem, since "poor root syndrome" had been a precursor to yield decline. It was, therefore, initially believed that the main task was to identify the pathogen/s and develop means to control it/them. However, the research team quickly realised that, although root pathogens were an important component, there were other biological, chemical and physical properties involved. To fully understand the causes of yield decline, it was decided that an in-depth examination of soil properties associated with "long-term monoculture" was a necessary starting point for SYDJV research.

SYDJV Focus

The majority of SYDJV activities have concentrated on paired old land sites (that have grown sugarcane for at least 20 years) and new land sites (that have either never grown sugarcane or are in their first year of production) in conjunction with rotation experiments. In the rotation experiments, land that had grown sugarcane for at least 20 years with minimal break, was rotated to other crop species (soybean, peanut, maize), pasture (grass, legume) or bare fallow for different periods of time.

Other studies initiated by the group have focused on sugarcane root systems, soil biology, nematodes, soil organic carbon, silicon nutrition, strategic tillage, and legume agronomy.

Key Findings

Paired old and new land sites

Paired sites established in the Tully, Herbert and Burdekin districts were intensively monitored for a range of soil chemical, physical and biological properties, as well as for growth and yield. This research showed that growth and yield were likely to be lower on old land due to greater soil degradation.

In general, the results indicated that old land was likely to:

- be more acidic;
- have lower cation exchange capacity (ability to hold nutrients);
- have more exchangeable aluminium and manganese (undesirable at high levels);
- have less copper and zinc (essential minor elements);
- have less microbial biomass (less soil biological activity);
- have greater soil strength (more compacted);
- have lower infiltration and water holding capacity; and
- have more root pathogens.

However, it clearly emerged that changes in soil properties were not constant across sites. There was strong dependence on soil type, environment, and crop management. It appears that a wide range of soil properties is likely to be implicated in yield decline and that there are interactions between these properties that will have an effect on ultimate productivity. Improved farming systems, rather than single factor remedies, will be more likely to minimise the impact of these deficiencies.

Rotation Experiments

Long and short-term rotation experiments have been conducted by the Joint Venture. In every instance a break from sugarcane has resulted in improved productivity. Major rotation experiments were conducted at Bundaberg, Mackay, Burdekin, Ingham and Tully. All of these have now had their plant crops harvested, with the first ratoon also being harvested at Bundaberg. In general, the best breaks out yielded plough-out/replant by:

14% in Bundaberg plant crop[(1)]	(112 to 128 t/ha)
21% in Bundaberg first ratoon	(121 to 146 t/ha)
84% in Mackay [aaaa]	(60 to 114 t/ha)
27% in Burdekin[***]	(110 to 140 t/ha)
51% in Ingham	(48 to 71 t/ha)
58% in Tully	(44 to 75 t/ha)

*** *Burdekin yields are for an 8 month crop. All other yields are for 12 months.*

aaaa *Late application of nitrogen may have biased against plough-out/replant at Mackay.*
Both Tully and Ingham sites were very wet.
Bundaberg and Burdekin crops were both fully irrigated.

(1) *Bundaberg variety Q124, all others Q117.*

- In all experiments plough-out/replant provided the lowest yield in the plant crop and in the first ratoon at Bundaberg. Observations suggest similar responses at other sites when the first ratoon is harvested.

Burdekin rotation experiment. Plough-out/replant (left), Cane following a pasture break (right).

- At Bundaberg the cumulative sugar yield (plant plus first ratoon) from the best break was 6 t/ha more than for plough-out/replant.
- Yield increases following breaks were recorded regardless of type of break – other crop, pasture or bare fallow.

The basis of the yield response to breaks is established very early in crop growth through better shoot development (Figure 1). However, the ultimate yield response is also dependent on subsequent crop management.

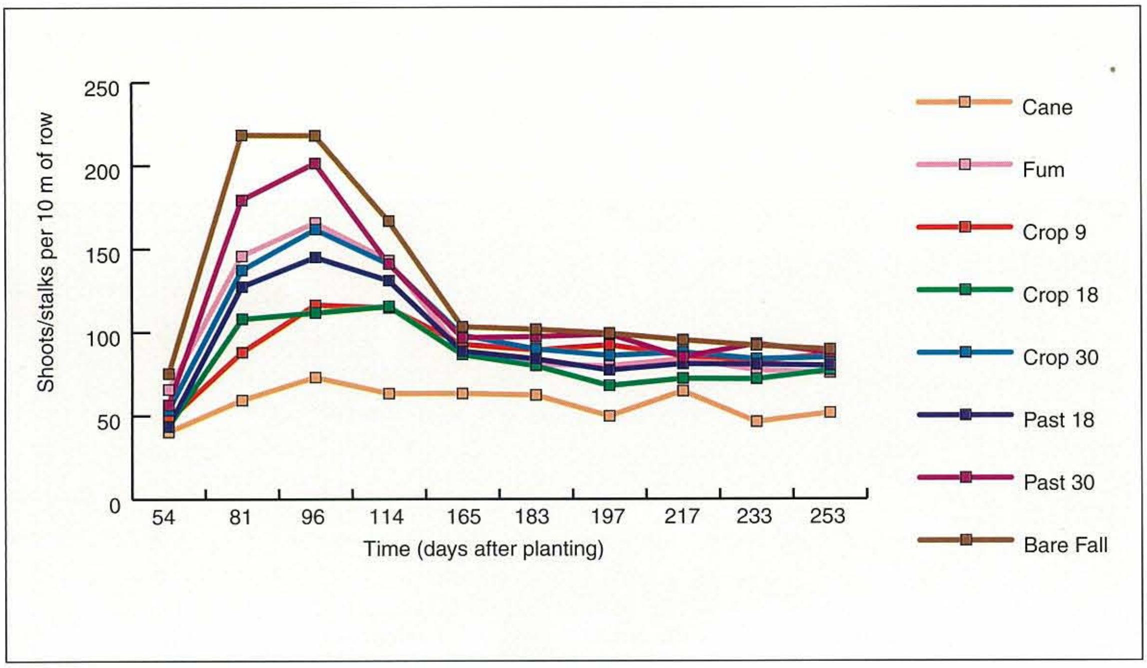


Figure 1. Changes in shoot/stalk number with time for the Mackay rotation experiment after re-planting various breaks to sugarcane. Crop 9 refers to land being out of cane and in another crop for 9 months. Past 30 refers to break of 30 months in pasture. Similar patterns of shoot/stalk development occurred at all sites.

Sugarcane Root Systems

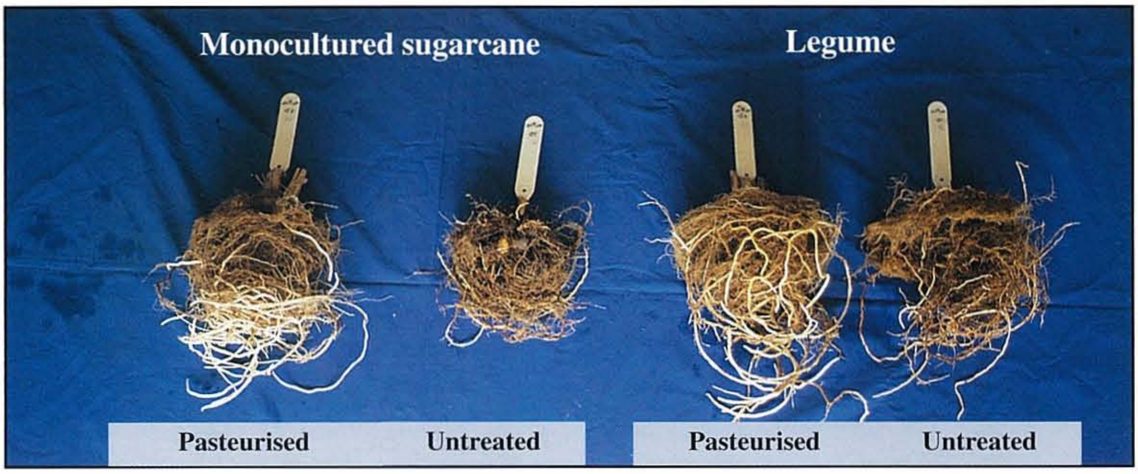
With yield decline being a soil related problem that influences sugarcane productivity, a good understanding of sugarcane root systems was identified as a necessary tool to research the problem. The root system is the link between the source of the problem (the soil) and the expression of yield decline (crop growth). In the early life of the Joint Venture, little was known about the capacity and functioning of sugarcane root systems and how that influenced crop growth. In accordance, the root growth and development studies carried out by the Joint Venture, in conjunction with the Cooperative Research Centre for Sustainable Sugar Production, have focused on understanding the growth and function of sugarcane root systems, developing means by which root systems could be easily measured, and exploring the relationship between root and shoot growth.

Results that have emerged

- Under controlled optimum conditions (aeroponic system) a very small root system can support maximum shoot growth.
- The sugarcane root system appears to have spare capacity under optimal soil conditions.
- A loss of functional roots may not necessarily cause a reduction in growth if conditions are sufficiently favourable. For example, relatively poor root systems may be able to support maximum growth under well irrigated conditions, but not under rainfed conditions.
- The root/shoot ratio for sugarcane, as defined by environmental conditions and development stage, is relatively stable.
- Soil conditions that reduce the physical size of the root system will cause a proportional reduction in above ground growth.
- In terms of root length, the proportion of the root system that can be classified as primary, secondary and tertiary roots is also very stable in both glasshouse and field conditions. It comprises 80% tertiary, 12% secondary and 6% primary. This finding provides an important research tool for measuring the capacity of the root system without removing and measuring the whole system.
- Sugarcane shoot growth and transpiration is extremely sensitive to soil drying, considerably more sensitive than sorghum.

Soil Biology

A significant component of the sugar yield decline problem is the build up of harmful soil organisms which attack and feed on sugarcane roots. The presence of these organisms is demonstrated by the large (20-30%) increase in cane growth that is achieved when the soil is fumigated. The build up of these harmful organisms is a natural process associated with the long-term growth of sugarcane as a monoculture. Some of these harmful organisms have been identified and include pathogenic fungi (eg *Pachymetra*) and root-infecting nematodes (eg the lesion nematode,



A glasshouse experiment comparing sugarcane root growth and responses to soil pasteurisation in soil from monocultured sugarcane (left two root systems) and legume rotation (right two root systems). Within each pair the root system on the left is from soil that has been pasteurised. Note the better growth where the cane monoculture has been broken, and when the soil has been pasteurised.

Table 1. The effect of the rotation breaks (30 months duration) on measured components of the soil biota.

Measurement	Pasture	Crop	Bare fallow
Microbial biomass	increase	no change	decrease
Functional diversity	increase	no change	decrease
Bacteria	no change	no change	no change
Pseudomonads	increase	increase	decrease
Bacilli	no change	no change	no change
Actinomycetes	no change	no change	decrease
Fungi	increase	increase	decrease
Mycorrhizal fungi	increase	increase	decrease
Pachymetra	decrease	decrease	decrease
Lesion nematodes	decrease	decrease	decrease
Free-living nematode	increase	increase	no change
Earthworms	increase	no change	decrease
Other herbivores	no change	no change	decrease
Ground pearls	decrease	decrease	decrease

Changes relative to continuous cane	increase	no change	decrease

Pratylenchus zeae). However, the fact that yield decline persists even when populations of these identified organisms are reduced or absent confirms our belief that there are potentially many other harmful soil organisms involved in yield decline.

Part of the strategy behind the rotation trials set up in Phase 1 of the Joint Venture was to cause major changes in soil properties to see how these changes affected the yield decline status of the soil. In addition to monitoring changes to populations of nematodes, changes were also monitored in:

- the amount of soil microbial biomass;
- the structure and functioning of the whole soil microbial community;
- populations of different functional groups of soil microorganisms (total bacteria, pseudomonads, bacilli, actinomycetes and fungi);
- root colonisation by mycorrhizal fungi;
- number of *Pachymetra* spores; and
- soil invertebrates (earthworms, other herbivores and ground pearls).

Each of the breaks had a major effect on the soil biota (Table 1).

The pasture break generally had a beneficial effect, causing an increase in microbial biomass and the functional diversity of the microbial community, and increases in populations of pseudomonads, fungi, mycorrhizal fungi, free-living nematodes and earthworms – all signs of a more healthy biota. The beneficial effect of the pasture was believed to be associated with lack of soil disturbance and increased inputs of organic matter into the soil through a large fine root biomass and returning the tops.

The alternate crop break also had a beneficial effect – it caused increases in some functional groups of the soil biota, but it did not cause the same increases in microbial biomass and functional diversity seen under the pasture break. In contrast, the bare fallow break caused a decline or no change in all measured components of the biota (which could be a due to the lack of organic inputs into the soil under a bare fallow).

All three breaks were effective in reducing numbers of *Pachymetra* spores and lesion nematodes, organisms associated with yield decline.

Fumigation (methyl bromide) growth response in sugarcane growing in soil that has been under a sugarcane monoculture.

The breaks were also found to be effective in reducing the numbers of ground pearls (*Magarodidae*) in the soil. Ground pearls are a soil invertebrate known to feed on cane roots.

Did these changes alter the yield decline status of the soil?

Glasshouse experiments where cane growth was compared in fumigated and unfumigated soil from each of the rotation breaks indicated that yield decline pathogens were still present in the pasture and alternate crop soils, but absent from bare fallow soil after a 30 month break. While pasture and alternate crop breaks reduced populations of known yield decline pathogens (*Pachymetra*, lesion nematode) and generally improved the biology of the cane soils, these breaks were not as effective as bare fallow in removing the biota associated with yield decline from the soil. This indicates that there are other unidentified biota associated with yield decline. However, the plant cane yields following the pasture and crop breaks were as high as those following the bare fallow indicating that, if the unidentified biotic factors can be managed, yields may be further increased.

Nematodes

Nematodes are one of the biological factors associated with 'yield decline' under investigation. Nematodes are worm-like parasites, about 0.5-1.0 mm in length, that feed on and burrow into roots, causing lesions, malformations and stunting of the root system. Our research is showing that nematodes are an important component of the biological complex that limits sugarcane productivity in Queensland.

Surveys of more than 700 fields in all mill districts found as many as eight different nematode species feeding on sugarcane roots in most fields. In sandy soils, the dominant species was root-knot nematode, which forms terminal root galls that hinder root elongation and function. However, root-lesion nematode was the most widespread and important nematode associated with 'yield decline'. This species is found in high numbers in all soil types and densities of more than five nematodes per gram of soil are common. This nematode destroys feeder roots and causes lesions and blackening of the root system. These symptoms are consistent with

(Below background) Yield losses from nematodes are assessed by comparing crop growth in untreated plots (left) with growth in plots where nematodes have been selectively eliminated (right).
(Inset) Root-lesion nematodes inside a sugarcane root-tip.

premature root aging and impaired root function, and are typical of the poor root systems that sugarcane develops when growing in 'yield decline' soils.

Field trials have shown that large increases in yield are obtained when continuously-cropped sugarcane soils are fumigated, bare fallowed or planted to another crop or pasture. These treatments typically reduce nematode populations, providing further evidence of their involvement in yield decline. To estimate crop losses in the field, nematicides were applied as a research tool to selectively control nematodes. Results of this work showed that nematodes reduce yields by 20-40% in sandy soils and 5-15% in heavier soils. Because the trials were carried out in soils that are representative of large areas under sugarcane production, we estimate that nematodes may be costing the sugar industry as much as $100 million each year in lost production. Nematode research will be developed further in Phase 2.

Soil Organic Carbon

Paired site and rotation experiments provided opportunities to measure changes in soil chemical properties, soil organic carbon levels, and to investigate the relationships between soil organic carbon and other soil properties. Soil organic carbon is made up of a number of fractions from the labile or active fraction to inert or unavailable fractions such as charcoal. Studies in the paired sites and rotation experiments have shown little change in total organic carbon. However, the fractional composition of the total organic carbon has varied considerably in both. Basically, there is evidence of an increasing percentage of the inert charcoal fraction in old land and in burnt cane systems. Conversely, there were substantial changes in the labile fraction following the various breaks in the rotation experiments, it being highest following pasture breaks and lowest following burnt cane.

Further, the results demonstrate clear links between soil organic carbon, particularly the labile fraction, and the key soil properties of cation exchange capacity (a measure of the nutrient holding capacity of the soil), aggregate stability (a measure of soil physical properties) and size of the soil microbial population. This indicates that the labile fraction may be a primary determinant of key soil properties. Management strategies that enhance it are likely to promote a more sustainable cane farming system through increased diversity of the soil microbial population and, possibly, improved soil suppressiveness to root pathogens. Improvements in labile carbon have also been measured with green cane trash blanket compared with burnt cane systems.

Lesions on primary roots of sugarcane caused by lesion nematode.

Silicon Nutrition

The Joint Venture has focused some of its activities on studies of soil silicon because it is well established that sub-optimal levels can result in decreased cane and sugar yields. Sugarcane responses to silicon can be attributed to a number of factors, including protection from insect and fungal disease damage and improved structural strength (ie more lodging resistance) of the sugarcane plant.

Soil maps developed for virgin soils on the wet coast (Figure 2) show that out of some 34,000 ha of land rated suitable for sugarcane production in the area between Tully and Innisfail, 67% is low to very low in soil silicon and a further 28% is marginal. To make matters worse, paired site analysis shows that many of these soils are

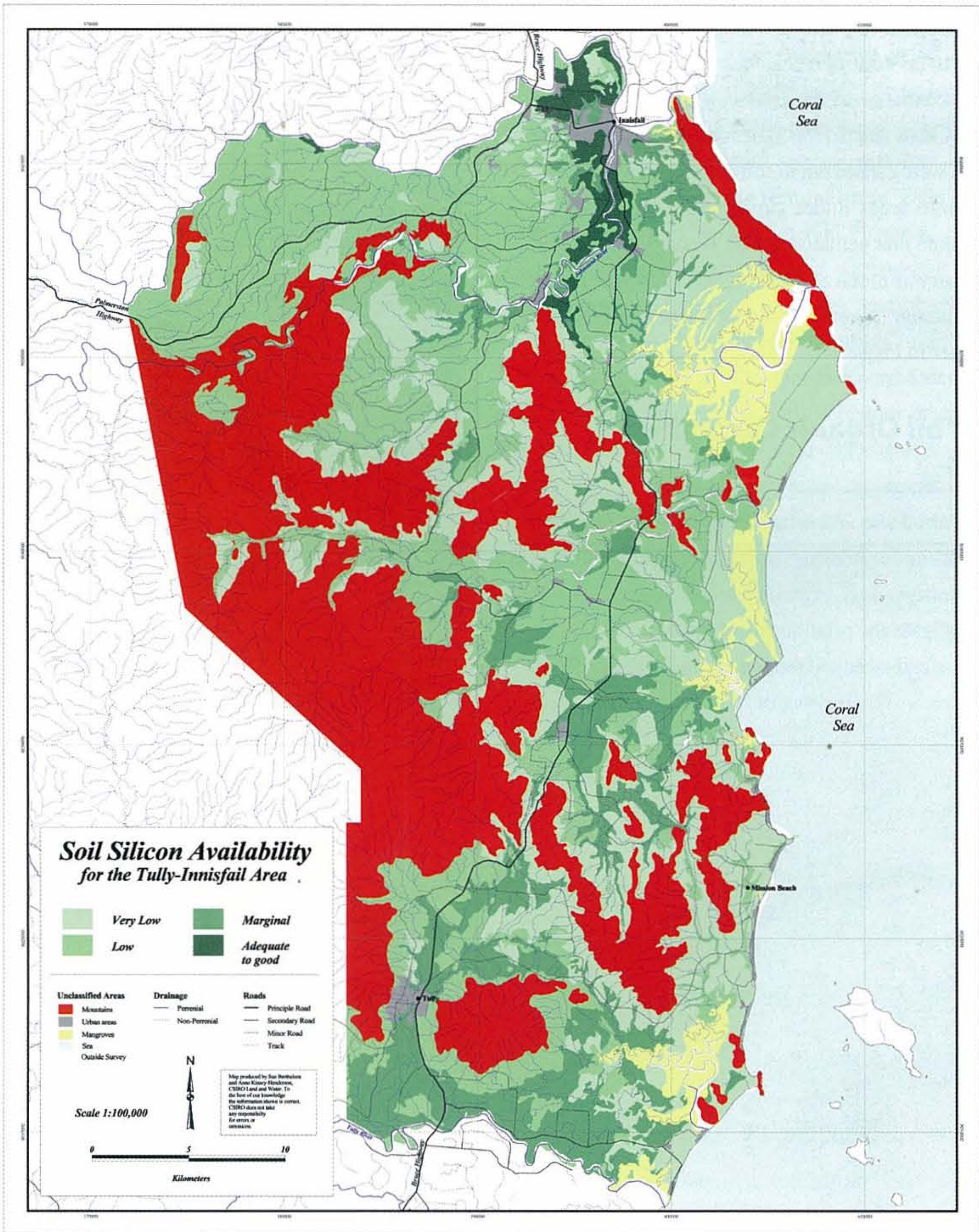


Figure 2. Availability of soil silicon for the Tully/Innisfail area.

becoming more deficient under the long-term sugarcane monoculture system. Conversely, analysis of the rotation sites has shown that breaking the monoculture with rotations can increase the availability of silicon. It appears that varieties can also play a part, with the more recently released varieties having lower stalk silicon levels than historical varieties. This probably has important implications for crop lodging.

As a result of this exploratory SYDJV work, SRDC has funded a specific project to further research silicon in the sugarcane system, with particular emphasis on the application of silicon products.

Strategic Tillage

The SYDJV strategic tillage studies have been based around the concept that excessive tillage for plant cane establishment and uncontrolled haulout traffic are causing soil structural decline and soil compaction and that these in turn are reducing yield potential. Strategic tillage only cultivates the row and leaves the inter-row intact. The results from experiments at Bundaberg and Tully are clearly showing that, when compared with conventional cultivation, strategic tillage will produce:

- similar seedbed conditions demonstrating that repeated cultivations are unnecessary;
- substantial cost savings in terms of labour, fuel and machinery wear (Figure 3);
- improvement in soil structure – the poor structure of the old inter-rows in conventional cultivation is still evident; and
- similar yields to conventional cultivation (Table 2).

Table 2. Plant Crop Yield (tonnes cane/ha) for the Strategic Tillage Experiments at Bundaberg and Tully.

Site	Variety	Conventional	Stool plough out	Stool spray out	Ploughout-replant
Bundaberg	Q155	107	96	99	85
	Q138	103	106	119	110
Tully	Q115	79	71	71	65
	Q117	84	81	82	74

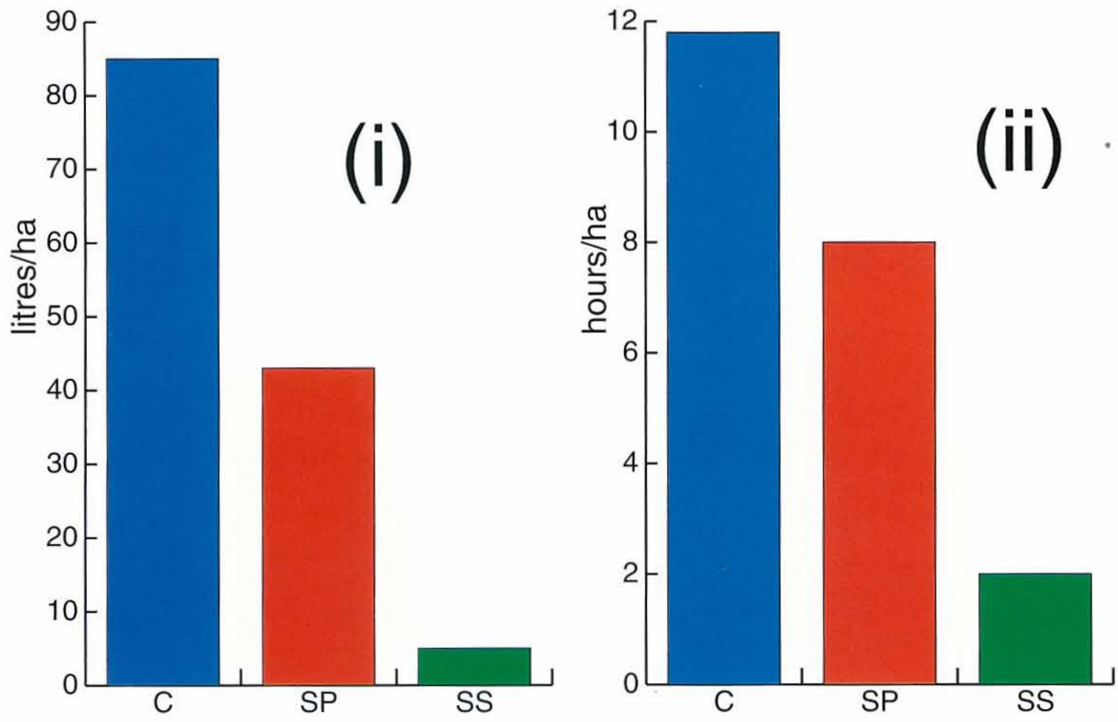
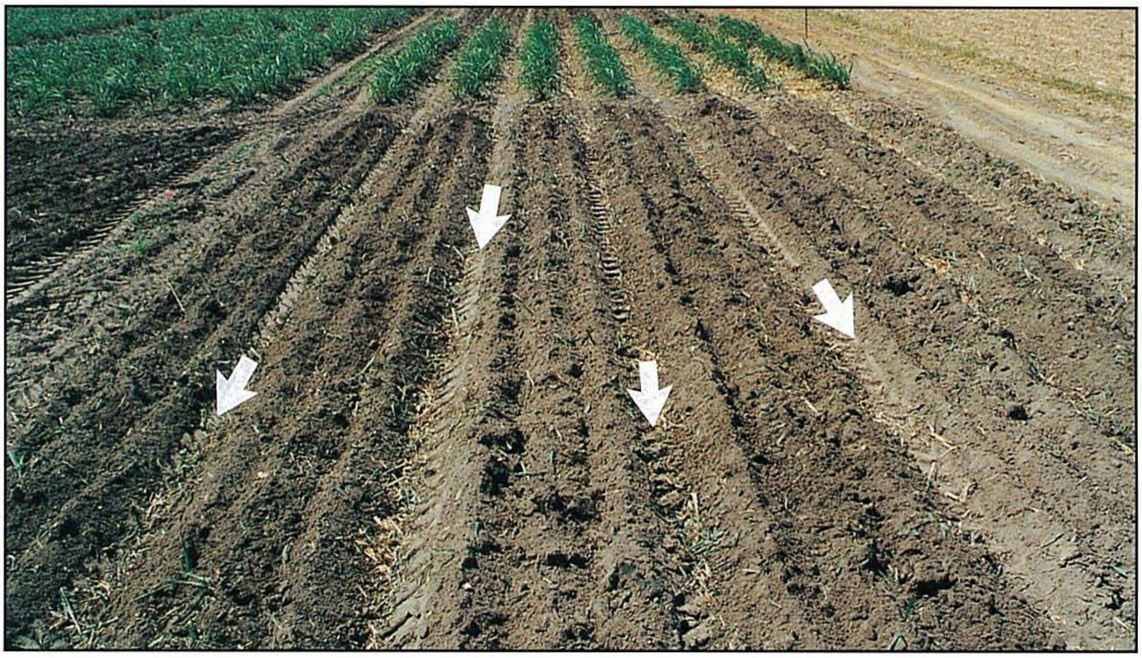


Figure 3. Tractor efficiency data from the three treatments - conventional cultivation (C), stool plough-out (SP) and stool spray-out (SS) at the Bundaberg site: (i) litres/ha of fuel, (ii) hours to preapre a hectare.

Top : A stool ploughout block after rotary hoeing and ripping of the beds. The hills are disturbed and the inter-rows (arrows) left undisturbed.

Bottom: A conventionally cultivated block after rotary hoeing and cross ripping (45 degrees). The old inter-rows are still visible.



...excessive tillage for plant cane establishment and uncontrolled haulout traffic are causing soil structural decline and soil compaction therefore reducing yield potential.

Legume Agronomy

Although legumes, particularly cowpea, for green manure fallows have always been a part of sugarcane cropping systems, little attention has been paid to selecting the most suitable species or developing the best management strategies to maximise the benefits of legumes. Given that the SYDJV team was using rotation experiments involving legumes as research tools, it was important to grow the legumes as well as possible. Hence, research into the agronomy of legumes and their potential as complimentary crops in sugarcane cropping systems has been an important part of the Joint Venture research.

What has legume research demonstrated?

- Maximum benefits from legume fallows will only be realised if good agronomy practices are applied.
- Good agronomy involves planting with a seeder, planting onto raised beds (particularly on the wet coast), and applying a pre-emergent herbicicde.

- Soybean is a more suitable species than cowpea as a fallow legume for sugarcane cropping systems. It produces more dry matter, more nitrogen and is better adapted to wet conditions.
- Well grown fallow legumes will provide benefits to the following plant cane crop (Table 3) in terms of both nitrogen nutrition and reducing the impact of yield decline (Table 4).
- There is considerable potential for legumes such as peanut and soybean to be grown as grain crops in sugarcane cropping systems, particularly in areas outside the wet tropical coast (Table 5).

Table 3. Effect on Cane Yield (t/ha) of a Legume Break

	Re-plant	Poor fallow	Soybean/peanut fallow
Tully	88	85	102
Ingham	48	—	61
Mackay	63	—	90
Bundaberg	107	—	124**

***peanut fallow, rest were soybean.*

Table 4. Effect of a Soybean Break on Yield Decline as Expressed by Sugar Yield (t/ha)

	Re-plant	Soybean fallow
0 kg/ha N	9.75	11.50
140 kg/ha N	9.87	11.23

Table 5. Indicative Gross Margins for Soybean and Peanuts. Based on Yield Data from Joint Venture Rotation Experiments

	Soybean			Peanut		
	Yield (t/ha)	Crop value ($/t)	Gross margin ($/ha)	Yield (t/ha)	Crop value ($/t)	Gross margin ($/ha)
Tully	2.0-4.0	$420	$500-1370	1.8-3.9	$675-746	$200-1780
Ingham	2.3-2.5	$420	$700-710	2.3-3.5	$577-625	$440-1020
Burdekin	2.4-3.9	$420	$645-1275	2.6-2.9	$750-795	$1050-1410
Mackay	3.2-3.6	$420	$975-1130	3.1-4.1	$785-775	$1570-2300
Bundaberg	3.5-5.0	$420	$1110-1740	5.1-6.9	$755-826	$3090-3880

Comparison between a cowpea fallow (left) and a soybean fallow (right). The cowpea was severely affected by waterlogging. The amount of nitrogen returned to the soil by these fallows was 40 kg/ha (cowpea) and 250 kg/ha (soybean).

How can we incorporate these findings into a sugarcane cropping system?

The SYDJV team has delved into many components of the sugarcane farming system and, in almost every case, has identified deficiencies in most of these components. Improving any one of these deficiencies is likely to enhance productivity. However, to fully capitalise on such improvements they must fit into the farming system in such a way that improvements to one component don't have adverse effects on another. An improved system can be envisaged from the results emerging from Phase 1.

Benefits can be realised by breaking the monoculture, reducing tillage and traffic, and improving the organic carbon status of the soil. All of these factors operate to promote healthier soil in terms of soil biota, improved physical structure, and improved soil chemical properties. Research suggests that an improved system can be based on strategic tillage, where traffic lanes are maintained, and stools are removed by herbicides or a narrow line of cultivation. Legumes could be directly seeded into the old sugarcane line and, not incorporated

Tully rotation experiment with bare fallow, pasture and soybean.

but, allowed to mulch down at an appropriate time or incorporated only into the crop line – the next plant cane crop can be directly planted into the same area. Green cane trash blanketing would be an important part of such a system to further boost organic carbon levels. Strategies to manage root diseases would also be needed. The development of such a system will form a significant component of the Sugar Yield Decline Joint Venture's Phase 2.

Acknowledgements

The SYDJV team acknowledges the contribution of the Management Committee to the outcomes of Phase 1 and is also indebted to the support provided by senior management from the partner organisations. The visitor to the Joint Venture, Dr J.K. Leslie, has provided invaluable support in focussing the program.

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TECHNICAL SUMMARY REPORT PHASE 1

JULY 1993 - JUNE 1999

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SUMMARY AND CONCLUSIONS

The Sugar Yield Decline Joint Venture (SYDJV) defined yield decline as ..... *the loss of productive capacity of sugarcane growing soils under long-term monoculture.* Phase 1 of the SYDJV commenced in July 1993 and ran for a 6 year period until June 1999. During Phase 1 the primary focus of the SYDJV was directed at measuring the effect of the long-term monoculture of sugarcane on chemical, physical and biological properties of the soil and crop growth and yield. In large part, this was approached by a multi-disciplinary team utilising paired old and new land sites and rotation experiments as research tools. An initiative to develop a rundown experiment, where changes in soil properties were measured as new land was first planted to and continued to grow sugarcane, was abandoned because of site unsuitability. In addition to this major multi-disciplinary thrust, studies commenced prior to the SYDJV being established (some soil biological aspects) and some specific new initiatives (root system studies, legume agronomy, strategic tillage and silicon nutrition) were incorporated in SYDJV Phase 1. The new initiatives were largely developed to fill voids in current knowledge.

Studies conducted by BSES prior to the establishment of the SYDJV had shown that yield decline was an industry wide problem and that soil biotic factors were certainly involved. Further, when Phase 1 commenced there was a strong view within the research community that the yield decline problem was largely biotic and that the identification of the specific organisms involved and the development of control mechanisms would overcome the problem. However, early in the life of Phase 1 the scientists involved developed a belief that yield decline would not be overcome by a single or discreet factor approach. The initial paired sites studies convinced us that a whole range of chemical, physical and biological factors could be involved and that the importance of any specific factor would vary with soil, climate and crop management. Hence, although yield decline was an industry wide problem the major causal factors were likely to vary between regions. It became clear that the answer to yield decline would lie in understanding how the numerous factors interacted with each other and then developing a farming system that would minimise the impact of these various factors.

Consequently, the approach taken delved into numerous components of the sugarcane farming system to allow indentification of limitations. In almost every component of the farming system deficiencies have been identified. Improving any one of these deficiencies is likely to enhance productivity. However, to fully capitalise on such improvements they must fit into the farming system in such a way that improvements to one component don't have adverse effects on another.

The results of Phase 1 clearly indicate that the monoculture is having an adverse effect on productivty. In every rotation experiment conducted in Phase 1 the breaking of the monoculture has resulted in enhanced cane and sugar yields in at least the plant crop. The average plant cane yield increase from a break compared with plough-out/re-plant has been of the order of 20 – 30%. Further, in the absence of other known overriding factors (waterlogging, harvester damage etc.) the improved yields have been maintained in the ratoon crops. For example, at Bundaberg where the second ratoon has been harvested, the yields following a one year legume crop break have been 16, 25 and 17% higher than for plough-out/re-plant in the plant, first and second ratoon, respectively. However, the results are also suggesting that in high (luxury) input situations the adverse effects of the long-term monoculture are not likely to be as significant as they are in lower input environments. Regardless, the latter represents a substantial area of the Australian sugar industry.

The basis of the yield response to breaks is established very early in the life of the cane crop through large differences in shoot establishment, in terms of both rate and ultimate number. Although the precise reasons for this differential establishment have not been clearly identified, it certainly appears that a complex of biotic factors, including nematodes, are involved. We believe that it is worth looking closer at this complex in order to more clearly understand the mode of operation of these biotic factors. However, we don't think it wise to focus solely in this area. Although early shoot establishment may be the basis of the response to breaks, actually realising improved yields is clearly dependent on subsequent management.

The various soil treatments used in these studies (breaks of other crop, pasture and bare fallow and fumigation) all improved sugarcane yield. Further, in large part, there was little difference in yield in most of the rotation experiments between pasture, bare fallow and field fumigation of continual sugarcane treatments. The cropping plots generally yielded slightly less. This clearly suggests that biotic factors are the main problem and are similarly controlled by field fumigation, pasture and bare fallow. However, when soil from pasture treatments in most of the rotation experiments was fumigated in pot experiments there was a further increase in growth due to fumigation. This suggests that the mechanisms of yield accumulation in sugarcane following field fumigation and pasture may well be different. Further yield increases may accrue with improved management of soil biota following a break.

In these rotation experiments growing a pasture or bare fallow has been achieved with no tillage once the pasture or bare fallow has been established. Further, the pasture has been managed in such a way that almost 20 t/ha/year organic matter has been returned to the plots. Certainly, under the pasture, improvements in soil physical properties through increased pore size have been measured in addition to a much better balanced biology. Thus the indications are that the yield enhancement following a break may not simply be of a biotic nature but may well have chemical and physical components. The other possibility is, that degraded soil chemical (e.g. increasing acidity) and physical (e.g. increased compaction) properties developed under the monoculture, may be pre-disposing the system to the development of more detrimental biota. Thus is the phenomenon of yield decline due to: a single dominant species (sugar cane) being grown, the way that species is grown, or a combination of the two?. The evidence from Phase 1 suggests that both the species and the way it is grown are involved.

The species can be modified through resistance/tolerance breeding and possibly, in the future, though genetic engineering. However, to follow such a direction without questioning the way the farming system is currently prosecuted would appear to be a restrictive approach. The evidence from Phase 1 suggests that rotations, improved organic matter status, minimum tillage and managing acidity are all likely to enhance productivity. The development of a farming system that encompasses these practices should be a high priority.

In moving into Phase 2 of the SYDJV the approach we are taking is four fold. First, resources are being devoted to further understand the early establishment problems in the sugarcane monoculture. Second, studies are investigating the relationship between the component of the problem caused by the species *per se* and that attributable to the manner in which the farming system is prosecuted. Third, the interactions between chemical, physical and biological properties and their effect on yield decline will be further investigated. Finally, a major effort will be applied to the development of a practical sugarcane farming system that will incorporate rotations/breaks, organic matter inputs and strategic tillage.

The SYDJV was started with considerable trepidation. The development of a multi-discipline, multi-organisational programme such as the SYDJV was new to the sugar research and development agenda. Further, the development and implementation of such a programme is undoubtedly costly. However, the SYDJV has made a significant contribution to our general understanding of sugarcane farming systems and the phenomenon of yield decline, in particular. Further, from the results of Phase 1 a clear direction has been defined to further progress the issue. These achievements would not have been possible without a Joint Venture.

A.L. Garside
Research Leader
4/4/2000

ABOUT THIS REPORT

This report is a technical summary of the research carried out in Phase 1 of the Sugar Yield Decline Joint Venture (SYDJV) which ran from July 1993 to June 1999. Initially, the resources/funds for Phase 1 were provided by SRDC, BSES and CSIRO Division of Soils (now Land and Water) as core contributions to the Joint Venture. Much of the research carried out in Phase 1 was funded by these core contributions.

In 1995 the Queensland Government Departments of Primary Industries and Natural Resources joined the SYDJV with funding provided by the Sugar Industry Reference Panel (SIRP). Research carried out with this funding included the southern rotation experiment and southern component of the strategic tillage work at Bundaberg and all of the nematode studies. Other research, not part of SYDJV, was also funded by SIRP.

In addition, SRDC funded some specific projects within the Joint Venture. These included:

BSS121 – Cane based farming systems for the amelioration of yield decline.

CLW 002 – The role of root growth and activity in determining sugarcane productivity

BSS 211 - Increasing farmer participation in the yield decline joint venture

BSS 143 – Strategic tillage to reduce soil structural degradation and improve productivity

CSS4S - Breakdown in soil productive capacity under sugarcane monoculture.

In this report the results of BSS121, CSS4S and BSS143 are presented in some detail. However, CLW 002 is only summarised as it was the subject of a full detailed report in 1999 when the project terminated. Likewise only a summary is provided of BSS211 as this project only commenced in July 1998 and was subsequently terminated as a separate project in June 1999 when it was included in Phase 2 core funding. Similarly BSS121, which included most of the rotation experiments, has been rolled into Phase 2. However, a substantial summary is provided in this document as it had been operating since 1994. Project BSS143 is continuing as a separate project but as an integral part of the SYDJV until June 2003. A detailed final report will be provided then.

As the name suggests this is a technical summary report, not a full detailed report on all the data collected in Phase 1. The degree to which various projects are discussed is dependent on previous publications. In those areas where much of the work has been published only summaries are provided and vice versa. A list of publications associated with each work area is provided at the end of each work area. Those highlighted are provided as reprints in Appendix 2.

This report consists of two bound volumes. The first is the Technical Summary Report while the second contains two appendices. Appendix 1 contains reprints of some of the publications from the SYDJV. Appendix 2 is a report prepared following a review of the SYDJV in 1996. In addition, a topical summary report published in 1999 is attachted.

Finally, at least some of the research carried out in Phase 1 is continuing into Phase 2, for example, the rotation experiments. In these instances it is inappropriate to attempt to provide a final report as many of the outcomes will only be measured in the future. We trust readers will appreciate the lack of finality in these instances.

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INTRODUCTION AND BACKGROUND

INTRODUCTION

Yield decline is defined as - *the loss of productive capacity of sugarcane growing under long-term monoculture.* The Sugar Yield Decline Joint Venture (SYDJV) was established between the Sugar Research and Development Corporation (SRDC), Bureau of Sugar Experiment Stations (BSES) and CSIRO in 1993. Two years later, in 1995, the Queensland Department of Primary Industries (QDPI) and Department of Natural Resources (QDNR) also became partners. The Joint Venture was established to identify the causes of, and develop solutions to, a phenomenon that was thought to be the cause of a productivity (sugar yield / harvested hectare) plateau that existed in the Australian sugar industry between 1970 – 1990. Yield decline was believed to be costing the Australian sugar industry between $200 – 400 M per year.

After the establishment of the Joint Venture it became clear, from several studies, that yield decline was not the cause of the productivity plateau but was one of a number of factors that combined to cause the productivity plateau (Smith, 1991; Leslie and Wilson, 1996; Garside *et al.* 1997). Other notable factors include; more ratoons, use of chopper harvesters, green cane harvesting and nutrient excesses and deficiencies (Garside *et al.,* 1997). Regardless, numerous studies over a considerable period of time, have demonstrated that the productive capacity of the soil is reduced by sugarcane monoculture. This is evidenced by yield responses to; fumigation of the order of 20% (Bell, 1935; Egan *et al.,* 1984; Muchow *et al.,* 1994; Magarey and Croft, 1995; Garside *et al.,* 1995); on new land compared to old land (Anon., 1935; Garside and Nable, 1996); and following breaking of the monoculture with rotation species (Beiske, 1965; Chinloy and Hogg, 1968). Hence, although studies into the cause of yield decline were unlikely to solve the whole problem of plateauing productivity, overcoming yield decline would make a significant contribution.

When the SYDJV was established the scientists were given a three fold challenge:

- ***Identify*** *causal factors and their contribution to yield decline in sugarcane;*
- ***Develop*** *solutions to minimise or alleviate the impact of such causal factors on productivity in sugarcane; and*
- ***Promote*** *the use of appropriate technologies developed by the Venture.*

The initial 6 year period of the Joint Venture finished in June 1999. This report discusses the major outcomes of this 6 year research and development project. The SYDJV did not fully achieve any of its stated objectives but, as the following report shows, made considerable progress in all areas.

HISTORICAL ASPECTS OF YIELD DECLINE

Yield Decline is not new to the Australian sugar industry. It is an issue that has vexed the industry almost since it's establishment in Australia (Maxwell 1900), although the term itself has only been invoked in more recent times. However, what we now know as a productivity plateau was apparent in some sugar cane growing areas as early as the turn of the century (Bell 1935, 1938). For example, during the 40 year period from 1898 to 1937 the average yield of sugar cane in the Bundaberg - Gin Gin district was around 37 t/ha with 10 year averages being 36.5, 38.3, 36, and 39.7 t/ha (Bell 1938). In discussing this data Bell observed .... "During this period much new land has been brought under cultivation, the use of artificial fertilizers has developed from nothing to a highly important farm practice, while new and better varieties have been grown. Yet the yield of cane has barely held it's own, and one might well ask why it has not progressed"........ and further........ "In short, the native fertility is being rapidly lost as a result of growing continuously a crop which is a gross feeder and which requires that constant cultivation which brings about fertility depletion and soil erosion; the soil is becoming "*dead*".

The recent history of yield decline dates back to 1967 when northern poor root syndrome (NPRS) was recognised as a problem in sugarcane on Queensland's wet tropical coast (Egan *et al.* 1984). The BSES has had a dedicated program to research yield decline since this time. This program initially investigated a whole range of agronomic, nutritional, entomological, and pathological issues as possible causes and eventually isolated the root pathogen *Pachymetra chaunorhiza*, which, when controlled by the use of resistant sugarcane varieties, led to yield increases of up to 40% (Magarey 1994). However, even greater responses (>100%) were obtained when soil from the same site was fumigated with methyl bromide, suggesting that factors other than Pachymetra root rot were involved (Croft *et al.* 1984). Further, when Pachymetra susceptible and resistant sugarcane varieties were grown on fumigated and unfumigated soil at the same site, the resistant variety outyielded the susceptible variety but still showed a 36% yield response to fumigation (A.P.Hurney, unpublished data). More recently it has been established that substantial sugarcane yield responses to fumigation can be measured in all sugar growing areas of Queensland, whether Pachymetra is present or not (Magarey and Croft 1995). However, the discovery of *Pachymetra chaunorhiza* (Croft and Magarey 1984) along with major responses to fumigation clearly indicated that root pathogens were involved and that the severity of their effect was favoured by the long term monoculture (Croft *et al.* 1984).

Subsequent research by BSES concentrated on isolating other pathogenic fungi with limited success (Magarey *et al.* 1995). Consequently, the approach that assumes root pathogens are the primary cause of yield decline has been questioned. Indeed it has been suggested that a build up of root pathogens may simply be the ultimate expression of other factors being out of balance in the farming system (Garside 1996). This concern led to the establishment of the Sugar Yield Decline Joint Venture in order to provide a suite of expertise to research the issue.

RESEARCH APPROACH TAKEN BY THE SYDJV

The SYDJV started with the premise that yield decline was a complex issue associated with a number of factors being out of balance in the farming system and that these factors and their relative importance were likely to vary in response to soil and environment. Further, only two pieces of previous evidence were fully accepted - yield decline was associated with the long term monoculture and root pathogens were certainly involved. Consequently, the SYDJV attempted to consider all aspects of the farming system in approaching the yield decline problem. A three phase approach was implemented based around ***identifying, understanding*** and ***overcoming/managing*** the problem. Progress has been made in each of these areas.

The research has largely been based around studying differences in soil chemical, physical, and biological properties and their effect on sugar cane growth in; paired old and new land sites, and old land after it had breaks from sugarcane monoculture for different periods of time. The breaks have included other crops, pasture or bare fallow. These rotation experiments have been conducted in a number of areas throughout Queensland. Within the broad area of soil biology; root pathogens, nematodes, soil invertebrates, soil microbial biomass and microflora and fauna dynamics have been studied. Within soil chemistry general nutrient levels have been monitored in addition to some specific studies on soil organic carbon.

In addition, four specific areas of research were carried out in Phase 1 of the SYDJV. First, a project on root growth and development was carried out to understand the critical linkage function of the root system between the source of yield decline (soil) and the effect (top production). The results of this project have been reported separately (Final Report SRDC Project CLW002 – The role of root growth and activity in determining sugarcane productivity). Second, studies into the need for silicon in sugarcane production were carried out and this work is summarised. Third, legume agronomy was an integral part of the program and although closely related to the rotation studies is considered separately in this report. Finally, the strategic tillage studies were incorporated into the SYDJV early in Phase 1 and have formed an integral part of the program. This aspect is covered in some detail in this report.

A brief outline of the paired sites, legume agronomy, and rotation experiments is provided in the agronomy section with references and/or copies of papers supplied to allow readers to access more detail. However, it should be noted that the paired sites and rotation experiments were utilised for considerably more than agronomic measurements and are referred to in other sections of this report.

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AGRONOMY

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PAIRED OLD AND NEW LAND SITES

Paired old and new land sites were studied in the first year of the SYDJV in 1993/94. These were aimed at identifying differences in soil chemical, physical and biological properties, and crop growth and yield between old and new land sites in three areas of north Queensland which experience a diversity of soils and climate, namely the Burdekin, Herbert and Tully areas. Yield decline has been recorded in each of these areas. Seven paired sites were selected. Three of the sites were in the Tully area (BSES, Costanzo, Harney), two in the Herbert area (Fortini, Marbelli/BSES), and two in the Burdekin area (Pegoraro, Kalamia) (Table I). In broad terms the climates can be described as wet tropics (Tully - 4000 mm mean annual rainfall), humid tropics (Herbert - 2000 mm annual rainfall) and dry tropics (Burdekin - 1000 mm annual rainfall). A range of soil types was included, mainly sandy or clay loams.

Table 1. Site and Land Use History Details for Seven Paired Sites

SITE	LAND USE HISTORY	
	OLD LAND	NEW LAND
BSES, Tully	Continuous Cane >30 years	Uncultivated grass pasture and rainforest
Costanzo, Tully	Continuous Cane >30 years	First ratoon cane, previously house site
Harney, Tully	Continuous cane >30 years	First ratoon cane, previously uncultivated grass headland
Fortini, Herbert	Continuous cane, 19 years	Plant cane, previously native scrub
Marbelli & BSES, Herbert	Continuous cane >50 years	Cultivated but not planted to cane, previously native pasture
Kalamia, Burdekin	Continuous cane >50 years	Plant cane, previously mango orchard
Pegoraro, Burdekin	Continuous cane >30 years	Pumpkins in 1992 and 1993, previously continuous cane > 30years

The measurements made on these paired sites included: crop growth and yield, soil chemical, physical and biological properties, and soil organic matter. An overall results summary is provided in this section while more specific details are provided in individual discipline areas later in this report.

The general pattern that emerged from the paired sites was that soil properties were more degraded on old than new sugarcane land. However, the same factors were not important at all sites. Further, it was apparent that the importance of a particular factor varied with soil type and environment and was likely to be influenced by crop management. For example, in the Burdekin, compaction, as measured by soil strength, was considerably higher on old land than new land whereas most soil chemical properties were quite adequate on old land. By contrast, on the wet coast, compaction was rarely an issue but old land was characterised by declining pH and CEC and increasing levels of Al saturation.

Overall, the following soil properties, indicative of the adverse effect of long term monoculture, were identified in at least one pair. Old land was shown to be more acid; have lower cation exchange capacity; have more exchangeable aluminium and manganese; have less copper and zinc; have less microbial biomass; have greater soil strength; have lower infiltration and water holding capacity; and have more root pathogens.

Generally, all sites measured showed a potential for yield decline in old sugarcane land. However, crop yields were either the same on old and new land or lower on old land. A number of reasons could be put forward for this ultimate effect on crop yield. Of three sites where yield comparisons were recorded one yielded higher on new land (Harney), there was no yield difference at another (Pegoraro), while at the third (Costanzo), the old land yielded higher (Table 2). At this third site, growth was considerably better on new land, so much so that the crop lodged very badly early in the growing period and this resulted in substantial crop loss on the new land. The site where yield differences weren't recorded (Pegoraro) was in the Burdekin where high input of radiation, water and nutrients were available. The indications from this site were that the adverse effects of degraded soil properties on crop growth may be able to be masked in high input situations.

Table 2. Cane and sugar yield from three paired sites in north

Site	Cane Yield (t/ha)		Sugar Yield (t/ha)	
	Old	New	Qld	New
Harney	76	98	12.1	13.7
Costanzo	104	98	15.6	14.3
Pegoraro	179	176	30.0	19.4

Notes – Pegoraro – new land actually old land which had two years of pumpkins. Cane and sugar yield not what expected on basis of early growth and stalk numbers. High input site (water, fertiliser, radiation). Expression of yield decline minimised under high inputs.

Harney – cane and sugar yields as would have been expected

Costanzo – cane and sugar yields reverse of what expected and reverse of actual biological yield. Severe early (February) lodging on new land at this site.

Biological factors appeared the most responsive to conditions imposed by the sugarcane cropping system. There was a general decline in microbial activity and an increase of the more deleterious fungal pathogens with duration of sugarcane cropping in these studies.

Probably the most important finding to come from these paired site studies was that no one factor can be clearly identified as being the cause of yield decline. Clearly, a range of soil properties (chemical, physical and biological) are adversely affected by sugarcane monoculture and the relative importance of each is dependent on soil, environment, and farming practice. In all probability any degraded soil property contributes in some way to the loss of a soils productive capacity (yield decline), and the repair of a specific degraded soil property is likely to enhance productivity. However, a single factor approach ignores the fact that many soil properties interact, and that major productivity improvements will be dependent on ameliorating the suite of factors contributing to poor soil health. The paired sites studies clearly demonstrated the complexity of the yield decline phenomenon.

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LEGUME AGRONOMY

Although legumes, particularly cowpea for green manure fallows, have always been a part of sugarcane cropping systems, little attention has been paid to selecting the most suitable species or developing the best management strategies to maximise their benefits. Given that the Sugar Yield Decline Joint Venture was using rotation experiments involving legumes as research tools it was important to grow the legumes as well as possible. Hence, research into the agronomy of legumes and their potential as complimentary crops in sugarcane cropping systems has been an important part of the Joint Venture.

Much of the legume work has revolved around soybean and peanut, but other species tested include cowpea, lablab, mungbean and navy bean. This research commenced in 1993, with a total of 13 experiments involving legumes having been conducted up to the end of Phase 1. Included in these are five long-term rotation experiments discussed below.

The other eight experiments have concentrated on short term (6 months) legume breaks where sugarcane has been re-established and productivity measured. Most of these experiments were conducted in tropical north Queensland, where average annual rainfall ranges from 2000 – 4000 mm. They involved studies with different legume species and agronomic management, assessments of the contribution made by biological nitrogen fixation, the impact on subsequent cane productivity and effects on yield decline. Full experimental details are provided in Garside et al.1996, 1997 and 1998; Bell et al. 1998.

The main findings to emerge from the legume agronomy program were:

- Maximum benefits from legume fallows will only be realised if good agronomy is applied to the legumes.
- Good agronomy involves planting with a seeder, planting onto raised beds (particularly on the wet coast), and applying a pre-emergent herbicicde.
- Soybean is a more suitable species than cowpea as a fallow legume for sugarcane cropping systems. It produces more dry matter, more nitrogen and is better adapted to wet conditions.
- Well grown fallow legumes will provide benefits to the following plant cane crop (Table 3) in terms of both nitrogen nutrition and reducing the impact of yield decline.
- There is considerable potential for legumes such as peanut and soybean to be grown as grain crops in sugarcane cropping systems, particularly in areas outside the wet tropical coast

Table 3. Effect on Cane Yield (t/ha) of a Legume Break

Site	Plough-Out/ Re-Plant	Traditional Broadcast Cowpea Fallow	Well Managed Soybean/Peanut Fallow
Tully	88	85	102
Ingham	48	__	61
Mackay	63	__	90
Bundaberg	107	__	124**

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ROTATION EXPERIMENTS

Five rotation experiments were established in major sugarcane growing areas of Queensland - Tully, Herbert, Burdekin, Mackay and Bundaberg. In most instances breaks of, bare fallow, alternative crop, and pasture, along with continual sugarcane were established for periods of 6, 18, 30, and 42 months. These basic break treatments were designed to provide diverse soil management viz. no plant growth and no soil disturbance (bare fallow), plant growth and no soil disturbance (pasture), plant growth and soil disturbance (alternative crop). When the experiments were returned to sugarcane continual cane plots were split between fumigation and no fumigation. These experiments were returned to sugarcane in 1996 (part of Bundaberg), 1997 (Mackay, Ingham and part of Tully) and 1998 (part of Burdekin). Site and treatment details are provided in Table 4 and in Garside et al. (1999, 2000). The second parts of the Tully, Burdekin and Bundaberg experiments will be returned to cane in 2000, 2001 and 2001, respectively. As well as growth and development of sugarcane, which is discussed here, a whole range of chemical, physical and biological properties were monitored to measure the effects of different breaks on soil properties. These are discussed in the relevant discipline sections of this report. In all the rotation experiments cane yield was measured at 8 (interim) and 12 (final) months.

Table 4. Cultural details for the histories at each rotation experiment.

	Tully	Ingham	Mackay	Bundaberg	Burdekin
Date acquired	Sep-93	Sep-94	Sep-94	Oct-95	Oct-94
Original cane variety	Q115	Q124	CP 44 - 101	CP51 21 and Q144	Q117
Soil Type	Yellow Kandosol	Chromosol	Red Chromosol	Yellow Chromosol	Melanic Tenosol
Break duration	42 month	9, 18 & 30 month	9, 18 & 30 month	12 month	42 month
Date breaks removed	15/07/1997	27/07/1997	26/07/1997	23/08/1996	24/07/1998
Fumigation date and rate	26/9-6/10/97 900 kg methyl bromide/ha	19/09/1997 900 kg methyl bromide/ha	19/08/1997 900 kg methyl bromide/ha	4/09/1996 1000 kg methyl bromide/ha	24/08/1998 1500 kg methyl bromide/ha
Plot size	24m * 30m	16.5m * 25m	15.6m * 25m	10.5m * 30m	9m * 19m
Cane planting date	14/10/1997	29/09/1997	28/08/1997	14/10/1996	21/08/1998
Cane variety	Q117	Q117	Q117	Q124	Q117
Basal fertiliser	20P, 100K	20P, 100K	20P, 100K	44N, 5P, 28K, 6S	10 P, 0 or 50N
Side dressing/ N rates	0 or 140 N @ 63 dap	0, 70, 140 or 280N @ 66 dap	0, 70, 140 or 280N @ 102 dap	100N, 12P, 63K, 13S	0, 130 or 180N @ 90 ap

The rotation experiments are being carried through to Phase 2 of the SYDJV. Of the five originally established, only the Ingham experiment has been terminated as an extremely wet 1998 harvest season resulted in very poor ratooning. At the end of 1999 the status was as followed:

Bundaberg – harvested plant, first and second ratoon.
Mackay – harvested plant and first ratoon.
Burdekin – harvested plant
Ingham – harvested plant
Tully – harvested plant and first ratoon.

Overall Outcomes:

- In all rotation experiments there has been a yield increase following a monoculture break in the plant crop and at two of the three sites where the first ratoon has been harvested. At Bundaberg the yield response has carried through to the second ratoon.

- Fumigation generally produced higher or similar yields to the best breaks in plant crops, although the differences were not always significant and there were exceptions to this general trend.

- The fumigation response was considerably reduced in the first ratoon, such that in most instances the yield was no better than plough-out/re-plant and generally inferior to the better breaks.

- Yield responses to breaks were recorded regardless of the type of break – other crop, pasture or bare fallow.

- Yield responses to breaks were recorded regardless of the duration of break – 9, 18, 30 or 42 months.

- Cane yield response to breaks tended to be higher following bare fallow or pasture breaks than other crop breaks. This may be associated with the pasture and bare fallow breaks not being tilled during the break period while the crop breaks were tilled at least annually. Further the pasture breaks produced 20 t/ha/year dry matter that was retuned to the soil.

- With legume cropping breaks (soybean, peanut) a large percentage of the yield response can be achieved with a short break period (6 – 12 months).

- The basis of the yield response to breaks is established very early in the following cane crop through better early shoot development.

- However, the realisation of the potential yield will be dependent on following crop management.

- In nearly all experiments treatments that promoted good early growth tended to grow slower later in the growing period and vice versa.

- Thus the indications were that when strong early growth occurred there was a later limitation of assimilates that restricted the realisation of yield potential.

- The results also indicate that early shoot development is independent of soil type and climatic conditions and is most likely biotic.

- Nitrogen nutrition has little influence on early shoot development but can have a substantial effect on secondary and tertiary shoot development and through them on ultimate yield.

- There were indications that the magnitude of the break effect over plough-out/re-plant is likely to be relatively small in high input environments (high radiation, water and nutrients), such as the Burdekin, but relatively large where inputs are more limited.

- This is not to say that soils are less degraded in high input enviroments, but that the high inputs mask the effects of poor soil health.

Individual Experiment Outcomes

Bundaberg

In all three cane crops (plant, R1, R2) harvested from the Bundaberg experiment plough-out/re-plant has produced the poorest yield. The ranking of the breaks in producing higher yields than plough-out/re-plant has varied between years. However, the best breaks in each year outyielded plough-out/re-plant by 14% (plant), 21% (R1), and 21% (R2). With the second ratoon, the 12 month legume crop break (certainly a practical option) produced the highest cane yield (125 t/ha vs 103 t/ha for plough-out/re-plant). Overall, for the plant, first, and second ratoon crops the increase in yield with a 12 month break of a legume crop compared with a continual cane system has been 10, 14, and 21%, respectively. In terms of cumulative yield, the difference across the three crops has been 387 vs. 324 t/ha cane and 58.8 vs 51.1 t/ha sugar (Table 5).

Mackay

The yield differences with the two crops harvested at Mackay (Table 6) have followed a similar trend to Bundaberg but the differences between the breaks and plough-out/re-plant have been greater than in Bundaberg. In the plant crop, the best break (bare fallow) outyielded plough-out/re-plant by 84% while in the first ratoon the best break (9 months legume crop) outyielded plough-out/re-plant by 26%. The continual cane and the nine month crop treatment are the appropriate data to consider when making a comparison with Bundaberg. However, in this case most of the crop was returned with only small sections being removed for grain yield estimation. In the Bundaberg experiment all of the legume grain was removed. In the plant and first ratoon crops the yield increase for nine month crop break vs continual cane was 40 and 26%, respectively. It is interesting to note that some of the highest yields in the plant crop were following bare fallow and fumigation whereas in the first ratoon these treatments did not yield significantly more than plough-out/re-plant. We suspect this to be due to biological causes, as will be discussed later.

Ingham

The Ingham experiment was only taken to the plant crop stage (Table 7). Severe waterlogging during growth of the plant crop and immediately after harvest seriously impeded ratooning. Hence, the Ingham experiment was abandoned after the plant crop. Regardless a similar trend emerged to that recorded at Bundaberg and Mackay. The best break (30 month grass/legume pasture) produced a 51% yield increase over plough-out/re-plant. The 9 month legume crop break (which was managed the same way as Mackay) outyielded plough-out/re-plant by 21%. Further, it should be noted that in this experiment there was virtually no increase in cane yield between the interim (harvest at 8 months) and final harvest (harvest at 12 months) and for some treatments there was an apparent decrease in yield (Table 7). This was due to adverse effects of late waterlogging causing stalk death. There was also substantial late sucker development in this experiment.

Tully

In the Tully experiment all of the breaks were of 42 month duration (Table 8). The best breaks (legume/maize crop and legume grass pasture) outyielded plough-out/re-plant by 58% in the plant crop. However, there were no treatment effects in the first ratoon crop. It is suspected that wet conditions causing waterlogging, radiation limitation, and harvester damage when harvesting the plant crop may all have helped to mask potential responses.

Burdekin

Like Tully, the breaks in the Burdekin experiment were of 42 month duration (Table 9). In the plant crop there was no yield difference between any of the breaks and fumigated cane but the average yield increase over plough-out/re-plant was 28%. The first ratoon will be harvested in 2000.

Basis of the Yield Response

In all of the rotation experiments the basic difference between breaks and plough-out/re-plant has been early shoot/stalk development, it being much better following breaks (Figure 1 – Burdekin data). Hence this forms the basis for improved yields following breaks. However, whether yield improvements are realised, and what their magnitude will be, is likely to be closely associated with subsequent management.

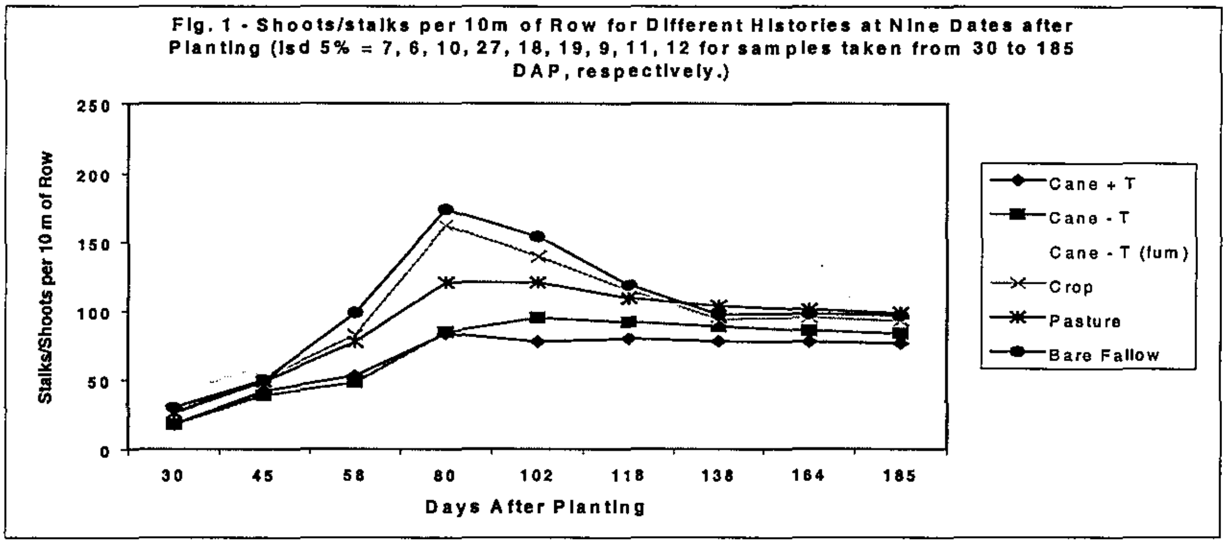

Figure 1. Stalks per 10m of row for different histories at nine dates after re-planting the Burdekin rotation experiment.

In almost all of the rotation experiments there was a general trend for those treatments that showed very good early shoot development and growth to grow more slowly later in the growing period and vice versa. This can be seen from the data in Figure 2 for 8 month and 12 month harvests of the Mackay rotation experiment. For example, relatively poor early growth following the 9 month cropping treatment was replaced by substantial cane yield accumulation in the last 4 months. The reverse was true for the 18 month crop. The general pattern that emerges is that those treatments that produced good early growth appear to have run short of some essential growth factor later in the growing period. We suspect that nitrogen may be implicated (see below).

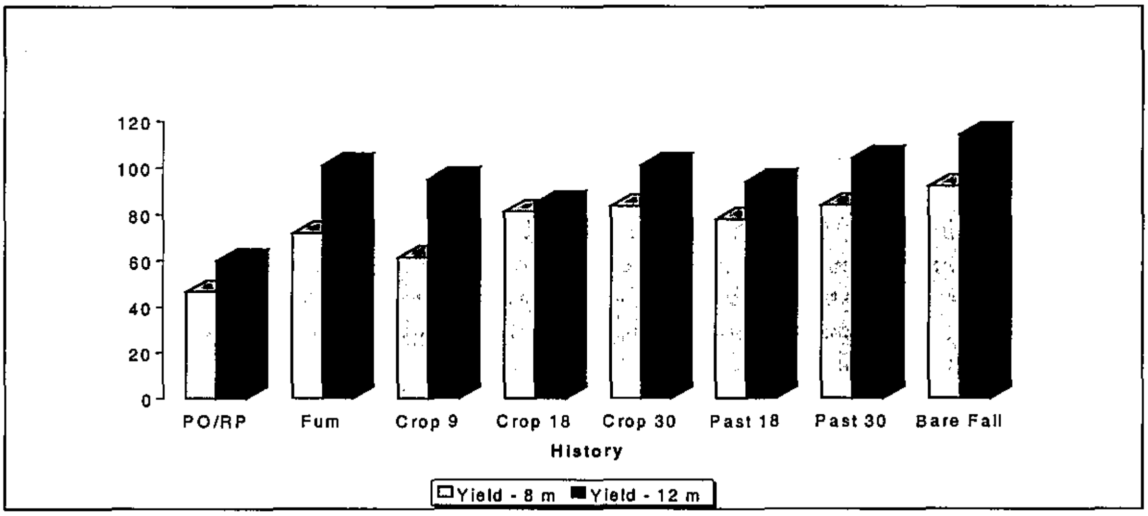

Figure 2. Cane yield (t/ha) for harvests at 8 and 12 months in Mackay Rotation Experiment. Lsd 5% = 15 (8 months), 18 (12 months).

Influence of Nitrogen Fertiliser

We were concerned after harvesting the plant crops in the experiments at Mackay, Tully and Ingham that because we had used largely legume breaks (soybean, peanuts, legume based pasture) and there was a minimum period in which to break down remaining sugarcane root systems in plough-out/re-plant, the subsequent cane yields may have been biased in favour of the breaks through differential nitrogen availability. Consequently when the Burdekin experiment was returned to sugarcane all of the breaks and continual sugarcane were split to 4 rates of nitrogen fertiliser. These were 0, 0 at planting + 180 kg/ha at 90 days, 50 kg/ha at planting, and 50 kg/ha at planting plus 130 kg/ha at 90 days. There was no response to nitrogen fertiliser following crop, bare fallow or fumigated sugarcane pre-histories, but a significant response following continual sugarcane and pasture pre-histories. Initial primary shoot development was independent of available nitrogen (soil + fertiliser) but secondary tillering was strongly influenced by available nitrogen. In addition, shoot retention was improved with enhanced nitrogen status. The yield differential between break pre-histories and continual sugarcane ranged from 48 % when no nitrogen was applied to 13 % at the maximum nitrogen rate of 180 kg/ha. These results are suggesting (like the paired sites) that in a system with high inputs of radiation, water and nitrogen (such as the Burdekin), the effect of poor soil health (yield decline) may be able to be masked to some extent. The indication from these results is that rates of nitrogen, higher than the 180 kg/ha used here, may have further reduced the yield difference between the breaks and plough-out/re-plant. However, the capability of providing optimum conditions of radiation, nitrogen and water does not apply industry wide. In lower input environments (Mackay, Ingham, Tully) the adverse effects of the long term monoculture are likely to be more pronounced. It is in these environments that soil health will be critical to long-term productivity.

Relationship Between Field and Glasshouse Effects on Shoot/Stalk Development

When each of the rotation experiments was returned to sugarcane glasshouse biosassays were carried out by R. Magarey on soil from each of the histories. These studies showed significant ($p<0.05$) effects of break on early shoot growth (35-45 days) at four of the five sites. Positive responses to soil fumigation were also recorded at three of the five sites. Fumigation produced minimal effects on early growth in soil that had been bare fallowed (-15% to 2%), or soil that had been fumigated in the field (-4% to 29%). Fumigation of soil from continuous cane treatments typically increased early cane growth by 25-30%. Most breaks had effects intermediate between the control and the bare fallow – both in early growth and response to fumigation. Shoot dry matter in unfumigated soil in the short-term glasshouse studies was strongly correlated with field shoot numbers at 70-90 days after planting and with dry matter production after 8 months. Correlations were either much weaker, or had disappeared entirely, by final harvest due to unexplained differences in growth rates among treatments during the final 4 months. Growth in fumigated break soil in the glasshouse was not correlated significantly with growth in the field, indicating that biotic factors were associated with these early growth differences in the field.

Table 5. Cane and Sugar Yield (t/ha) for Bundaberg Rotation Experiment

History	Plant Crop		First Ratoon		Second Ratoon		Cumulative		Return per ha at $300/t of Sugar
	Cane	*Sugar*	*Cane*	*Sugar*	*Cane*	*Sugar*	*Cane*	*Sugar*	
Cane (Burnt)	107	16.5	110	17.2	107	17.4	324	51.1	15330
Cane (Burnt) Fum	146	22.1	124	18.5	102	15.8	372	56.4	16920
Cane (GCTB)	118	18.2	131	20.0	99	15.7	348	54.0	16200
Cane (GCTB) Fum	141	22.3	150	21.0	124	19.7	415	63.0	18900
Legume Crop (12 M)	124	18.6	138	21.1	125	19.1	387	58.8	17640
Grass Crop (12 M)	128	19.3	145	22.0	105	16.8	378	58.1	17430
Legume Past (12 M)	116	17.9	115	18.2	112	18.2	343	54.3	16290
Grass Past (12 M)	121	18.3	136	21.4	116	18.5	373	58.2	17460
Bare Fallow (12 M)	120	18.6	135	20.6	115	17.9	370	57.1	17130
lsd 5%	*12.8*	*2.2*	*18.2*	*3.0*	*13.8*	*2.6*			

Table 6. Cane and Sugar Yield (t/ha) for Mackay Rotation Experiment

History	Plant Crop		First Ratoon		Cumulative		Return per ha at $300/t of Sugar
	Cane	*Sugar*	*Cane*	*Sugar*	*Cane*	*Sugar*	
Cane	63	9.8	92	16.3	155	26.1	7830
Cane Fum	104	15.9	93	16.0	197	31.9	9570
Crop 9 M	88	13.1	116	20.5	204	33.6	10080
Crop 18 M	86	12.1	109	18.2	195	30.3	9090
Crop 30 M	98	14.5	104	18.0	202	32.5	9750
Pasture 18 M	99	15.1	112	18.8	211	33.9	10170
Pasture 30 M	106	16.3	100	17.4	206	33.7	10110
Bare Fallow 30 M	116	17.4	102	17.0	218	34.4	10320
lsd 5%	*15.3*	*2.5*	*13.7*	*2.5*			

Table 7. Cane and Sugar Yield (t/ha) for the Ingham Rotation Experiment

History	Cane Yield (t/ha)		CCS		Sugar Yield (t/ha)	
	Int	Final	Int	Final	Int	Final
Cane - Trash	40	51	14.7	17.3	5.9	8.8
Cane + Trash	49	46	15.2	17.4	7.4	8.1
Cane + Trash Fum	55	81	14.4	17.9	7.9	14.6
Crop 9M	58	59	14.6	17.8	8.3	10.6
Crop 18 M	67	72	14.2	17.3	9.5	12.5
Crop 30 M	71	59	14.4	17.2	9.0	10.1
Pasture 18 M	60	61	14.3	17.3	8.4	10.6
Pasture 30 M	71	73	13.1	17.5	9.3	12.8
Bare Fallow 30 M	70	53	14.8	18.1	10.4	11.4
lsd 5%	*13*	*12*	*1.2*	*0.8*	*1.8*	*2.9*

Table 8. Cane and Sugar Yield (t/ha) for Tully Rotation Experiment

History	Plant Crop		First Ratoon		Cumulative		Return per ha at $300/t of Sugar
	Cane	*Sugar*	*Cane*	*Sugar*	*Cane*	*Sugar*	
Cane	52	8.1	76	11.97	128	20.07	6021
Cane Fum	86	13.4	72	11.36	158	24.76	7428
Crop 42 M	73	10.7	74	11.26	147	21.96	6588
Pasture 42 M	78	11.8	79	12.33	157	24.13	7239
Bare Fallow 30 M	76	12.2	68	10.94	144	23.14	6942
lsd 5%	*16.8*	*2.4*	*nsd*	*nsd*			

Table 9. Cane and Sugar Yield (t/ha) for the Burdekin Rotation Experiment

History	Cane Yield (t/ha)		CCS		Sugar Yield (t/ha)	
	Int	Final	Int	Final		
Cane - Trash	112	118	12.6	17.6	14	21
Cane + Trash	106	120	12.4	17.7	13	21
Cane + Trash (Fum)	143	152	11.7	17.2	17	26
Crop 42 M	144	147	12.6	16.8	18	25
Pasture 42 M	143	153	11.9	17.2	17	26
Bare Fallow 42 M	145	154	12.5	17.4	18	27
lsd 5%	*13*	*12*	*nsd*	*nsd*	*1.8*	*2.9*

Publications from Rotation Experiment Agronomy Research

Bell, M.J., Garside, A.L., and Magarey, R.C. (2000). Effects of breaks on sugarcane growth: relations between glasshouse and field studies. *Proc. Aust. Soc. Sugar Cane Technol.,* 22, 68-76. **(Copy in Appendix)**

Garside, A.L., Bell, M.J., Cunningham, G., Berthelsen, J., and Halpin, N. (1999). Rotation and fumigation effects on the growth and yield of sugarcane. *Proc. Aust. Soc. Sugar Cane Technol.* , 21, 69-78. **(Copy in Appendix)**

Garside, A.L., Bell, M.J., Berthelsen, J.E., and Halpin, N.V. (2000). Effect of breaks and nitrogen fertiliser on shoot development, maintenance, and cane yield in an irrigated plant crop of Q117. *Proc. Aust. Soc. Sugar Cane Technol.,* 22, 61-67. **(Copy in Appendix)**

Magarey, R.C., Garside, A.L. and Bull, T.A. (1999). Opportunities for improved productivity in high input farming systems. *Int. Soc. Sugarcane Technol., 23* (in press).

Note: There are a substantial number of other publications that have come out of the rotation experiments. These are mentioned in later sections of this report.

INCREASING FARMER PARTICIPATION IN THE YIELD DECLINE JOINT VENTURE (BSS211)

M. Hanks, R. Kelly, G. Shannon, I. Christiansen, C. Jones
BSES

This project involved the bulk of the direct extension work carried out in Phase 1 of the Joint Venture, although a considerable amount of promotion was also carried out by the research personnel. One BSES extension officer was given responsibility for the extension part of the Joint Venture in each of the regions where long term rotation experiments had been established. These were Tully, Ingham, Burdekin, Mackay and Bundaberg. The following report covers each area individually. It should be remembered that the extension program only commenced in July 1998 and so only one years activities are discussed here and these largely focus on fallow legume extension.

BURDEKIN

Much of the work in the first year was based around organising grower meetings to explain the work being carried out by the Joint Venture and providing an extension program on fallow legumes, particularly soybean. Advice was given on weeds, diseases, irrigation and pests; and appropriate control measures have been explored. Crops were consistently monitored until maturity. Contacts were made with grain buyers and harvesting, transport and marketing options were explored.

Information about the SYDJV and particularly the benefit of legume fallows (vis Leichardt soybean) were heavily promoted through shed meetings in all mill districts to approximately 300 farmers. Additionally the SYDJV was discussed in an article in BSES Newsletters (to all Burdekin canegrowers), and through three newspaper articles in the grower section of the Burdekin Advocate. SYDJV was also presented at the Burdekin BSES Field Day (May 13, 1999) through a poster display and an article in the program. Visits by growers to the Burdekin rotation experiment were also arranged at various times.

HERBERT

An initial focus group was established for growers interested in strategic/minimum tillage. The focus group was run by Dr Mike Braunack with good interaction from the growers. Great interest was shown in minimum tillage linking in with the close row planting. Several of the participants were contractors and made the point that they will be willing to invest in machinery for minimum tillage once research has proved the dollar return is there. All agreed with minimum tillage in principle and one Herbert grower planted his 1998 plant crop under minimum tillage using conventional 1.5m spacings.

Trials of soybeans were planned with several growers showing interest. However, a very wet summer period operated against any areas being planted.

TULLY

Very wet summer conditions truncated much of the extension work planned in the Tully area. A meeting of interested growers scheduled for February at the yield decline rotation site at Feluga had to be cancelled. A lot of interest has been shown in strategic tillage and several shed meeting of interested growers have been held. Many growers expressed interest in fallow legumes, particularly soybean, and substantial areas can be expected to be sown in future years.

BUNDABERG AND SOUTHERN AREAS

There was a lot of activity with soybean in southern areas during 1998/99. In all mill areas at least some soybean were grown and in most cases extension officers attached to the Joint Venture were heavily involved with newsletters, field days, direct extension and general publicity through the mass media.

In particular the Bundaberg area has shown substantial interest. QDPI's involvement has fostered this interest. Soybean as a fallow crop seems assured of a long term place in sugarcane cropping systems in the Bundaberg area. A bus tour of soybean and peanut crops and experiments in early 1999 attracted 50 canegrowers. A very successful bus tour to Northern NSW to inspect soybean in cane cropping systems was also well attended. The interest has resulted in the development of research programs into soybean varieties and management from QDPI staff based in Bundaberg and Kingaroy. This research is being carried out under the banner of the SYDJV.

Nematodes – some interest has also been shown in the possible problem that nematodes are likely to be in sugarcane farming systems. A fact sheet was developed and information was dispersed by newsletters and field days.

MACKAY

Interest in soybeans in the central district continued to grow. There has been considerable interest in commercial production of soybean with a number of growers participating in a CPPB bus tour to NSW to inspect soybean production and visit Cargill seeds.

The key messages from the SYDJV that were promoted were 1) value of fallow – minimum six months for nematode control, yields and microbial populations; 2) strategic tillage; and 3) soybean fallows

A focus group on strategic tillage was conducted with Dr. Mike Braunack. There was considerable interest in the topic. All growers attending indicated that they have significantly reduced their cultivations over the past few years. Generally, growers did believe that there was a need to prepare a good seed bed. Strategic tillage was regarded as a good option for times where there is a narrow window of opportunity for planting – eg in a very wet season. Comment was made that the meeting had seeded a number of new ideas in their minds.

THE ROLE OF ROOT GROWTH AND ACTIVITY IN SUGARCANE PRODUCTIVITY (CLW002)

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SUMMARY

Research conducted in this project aimed to better understand the relationship between root and shoot growth, in areas such as how the size of the root system affects shoot growth, do particular root parameters have a controlling influence on shoot growth, how do soil characteristics affect root penetration rates, and how the root system develops through the life of a sugarcane crop. This was achieved through the application of a wide range of experimental techniques in both the glasshouse and field situation. The study of root systems in sugarcane is difficult - due to the size of the crop and the length of the cropping period. As a result there have been few previous studies on sugarcane root systems in Australia, and indeed around the world.

A number of techniques were either developed, or adapted, in this project research. A soil-less aeroponic culture technique was installed and refined at Tully Sugar Experiment Station. This allowed sugarcane roots to be examined on a daily basis and root measurements made, or root pruning to occur. This overcame the difficulty of dealing with the bulky, opaque soil medium. A tall pot system was adapted for sugarcane where sugarcane could be grown for an extended period in controlled conditions. This enabled plant water relations to be studied in association with modification to root growing conditions. Root image analysis techniques were further refined for sugarcane, allowing measurement of both whole glasshouse-grown root systems, or the quantification of root lengths in material from soil cores obtained in the field. A technique for growing sugarcane with a split root system was also adapted enabling the direct and indirect effects of water stress and root pruning in a soil culture to be examined, and the likely presence of root signals as a mechanism for control of shoot growth.

Studies using these techniques facilitated an examination of the relationship between roots and shoots under various experimental conditions - ranging from controlled conditions with no soil in the glasshouse, through other soil-based glasshouse trials, to the field situation. This gave depth to project results and a broader understanding of root-shoot relationships using a range of experimental observations.

Aeroponic and split root experiments suggested that a healthy root system normally functions at less than full capacity. Pruning root systems to 5% of their original size failed to reduce shoot growth under ideal growth conditions. This extra root capacity may allow the plant to cope with adverse environmental conditions, with the loss of some roots having minimal impact on shoot growth. The result suggests that if restrictions on root growth in normal cropping situations is reducing shoot growth, the efficiency of the field-grown root system must be very poor.

On the other hand, experiments also showed that root : shoot bio-mass ratios are strongly conserved in sugarcane. Pruning of either the shoot or roots led to a cessation in the growth of either the roots or shoot respectively, until the former ratio was again established. Research also showed that the value of the ratio varied between variety; some varieties developed a relatively bigger root mass than others.

Studies with soil treatments known to affect shoot growth, such as soil fumigation with methyl bromide and fertilisation with nitrogen, had a large effect on root system parameters. Fumigation almost doubled root length densities in both the glasshouse and field. The fumigant also appeared (by visual assessment) to improve root health. This suggests that growth responses to soil fumigation result at least in part from the greater utilisation of soil resources. Nitrogen reduced primary root extension but increased primary root number, diameter and total root length. This response may allow the sugarcane plant to concentrate

the root system in soil with high concentrations of nutrients (in this case nitrogen). Pachymetra root rot had a big effect on root systems, principally reducing primary root length.

Root measurements showed that the ratio of primary : secondary : tertiary root lengths was strongly conserved in sugarcane. This characteristic may simplify field root system sampling using soil cores – only the larger roots need be measured and extrapolation of total root length made using the consistency of root length ratios. A modified strategy based on this observation would greatly reduce costs, particularly as the separation and identification of the origin of fine roots in cores, whether they are from weeds or sugarcane, is laborious and very time consuming.

Sequential sampling of the root system of a plant crop over a 12 month period established that root system development varies according to such characteristics as soil type and physical conditions. In the wet tropics, the root system had evenly developed through the row-interrow area days after planting. Upto 90 % of roots were above 90 cm depth 192 days after planting. In an irrigated situation in the dry tropics, close to 90 % of roots were above 60 cm depth due to the duplex soil profile. Soil compaction at the plough pan (30 cm) restricted early development but did not prevent colonisation of lower soil levels. Root length densities were found to be low in sugarcane relative to figures reported in the literature for other crops.

Tall pot studies showed that sugarcane leaf extension and transpiration is very sensitive to water stress, much more so than sorghum. This suggests that irrigation scheduling needs to ensure water stress is kept to a minimum to avoid restriction on shoot growth. The concept of plant available water could be used in further studies of root system efficiency.

Further sugarcane root research is needed. A method to quantify root health would enable better estimation of the effects of soil constraints on root function. Techniques developed in the research reported here may aid the study of root health and root functioning. Remote measures of root functioning would be ideal to avoid the expenditure required to sample root systems in the field and the associated difficulties. Further research on the factors governing the shoot-root relationship would be useful, particularly if the relationship could be modified to take advantage of the spare root capacity which appears to operate under ideal growth conditions. Before this can happen, better knowledge on the functioning ability of root systems under normal field conditions, and ways to improve this functioning ability, are needed. This is where the study of root systems complements the research currently being conducted in the Yield Decline Joint Venture, where the improvement of root growing conditions and root health are two major program emphases.

Publications from Root Growth and Activity Research

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IDENTIFICATION OF BIOLOGICAL FACTORS ASSOCIATED WITH THE EXPRESSION AND ALLEVIATION OF YIELD DECLINE IN SUGARCANE

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BSES

SUMMARY

Old / new land

- Old / new land growth differences were generally reproduced in pot trials
- Old land had higher pathogen populations
- A greater fumigation response occurred in old land
- Pachymetra root rot was only found in land which had grown cane
- Excellent root health (visual appearance) was only seen in rainforest soil; new land previously supporting grasses grew root systems with mediocre root health
- Old land root systems were typically very poor

Yield decline in other crops

- A similar constraint is seen in a number of other monocultured crops
- Experiments with apple replant disease conducted in Tully suggest root systems are similarly affected as cane is with yield decline.
- Attendance at two replant disease conferences suggests similar yield decline-type research is occurring in other crops – cooperation with researchers in other crops could be invaluable.

Transmission of the biological components of the yield decline constraint

- Washed field-grown roots affected by yield decline reduced shoot and root growth by 30% when introduced into pasteurised soil in glasshouse trials (including rainforest soil)
- Poor root health associated with inoculated soil suggests deleterious biological components of yield decline could be transferred.

Biocide research

- Fungicides from two chemical groups (possessing very general fungicidal properties) led to much improved root health and shoot and root growth in a range of yield decline soils (averaging 50-70% of the fumigation response)
- Not all the fumigation response was reproduced with these fungicides – nematodes and Pachymetra may have contributed to the remainder of the constraint
- These results suggest significant components of the biological constraint are not accounted for by known cane pathogens.

VAM

- Mycorrhizae were investigated as potential pathogens or beneficial organisms
- Field trials suggested that *Glomus clarum* improved cane growth in low P soils, and reduced drought stress
- Potential cane yields were seen to be well above fumigation of old cane land alone – the greatest yields were obtained where beneficial organisms were re-added to fumigated soil.

Rotation trials

- Short-term growth responses in glasshouse trials were found to correlate (in most cases) with early growth responses in the same treatments in the field (see Bell et al, ASSCT 2000). The glasshouse assay is generally a useful tool for assessing constraints on early growth in the field
- Pachymetra populations declined with all rotation treatments besides cane
- Large fumigation responses were obtained in continuous cane soils
- Bare fallow led to a zero, or slightly negative, fumigation response in all trials – suggesting that pathogen populations had declined to near zero, and that some remaining beneficial organisms could have been eliminated by this treatment
- Some fumigation response was still obtained in pasture and alternative crop soils, suggesting that deleterious biological properties persisted in these soils.
- The large field responses obtained with pasture and crop (equivalent to bare fallow) suggest that other soil parameters were improved by these treatments. The potential for improving cane yield may be well above any of the rotation treatment yields obtained in the field.

Suppression of pathogens

- A glasshouse test for suppression of Pachymetra root rot was developed
- Initial results suggest there is very little non-biological suppression of Pachymetra in cane, pasture and bare fallow soils
- Significant biological suppression was suggested in pasture and cane soils.

INTRODUCTION

Long term monoculture of a range of crops almost invariably leads to poor root growth and a growth depression. This is evidenced by responses to partial soil sterilisation treatments (such as soil fumigation, pasteurisation and biocides), to growing crops on new land, to rotating crops, and in the growth of resistant varieties (previous variety effect). The research undertaken by BSES at Tully Sugar Experiment Station investigated most of these aspects in relation to sugarcane yield decline. Each area of research is reported below.

RESEARCH AREAS

Old / New Land

Research into old and new land has been undertaken in Tully since 1984. Further emphasis was placed on this research in Phase 1 of the Joint Venture, in 1994. A summary of this research is contained here. Research investigated the glasshouse reproduction of the old / new land responses and responses to soil fumigation / pasteurisation / biocides. This was undertaken to determine more about the nature of the causal agents involved.

Method

Fourteen sites were selected in the mid-1980s, while a further four sites were included with Joint Venture core sites in the mid-1990s. Shoot and root growth, responses to soil pasteurisation, the presence of root pathogens and some general soil biological groups were monitored. Root pathogens included *Pachymetra chaunorhiza* (the causal agent of Pachymetra root rot), *Pythium arrhenomanes*, and various nematodes, while some general biological groups were assayed including total fungi, total bacteria, actinomycetes, fluorescent Pseudomonads and VAM (vesicular arbuscular mycorrhizae). The sites selected and details of the land use prior to planting with sugarcane are included in Table 10.

Table 10. Location and site description of paired sugarcane old and new land sites from which soil was obtained for glasshouse experiments

Site	Region	Location	Annual rainfall (mm)	New land vegetation	Site planted to sugarcane (and in first crop cycle)
BSES, Tully	Northern Queensland	17°9'S, 145°9'E	3000-3500	Rainforest	No
Cristiano	Northern Queensland	17°4'S, 145°9'E	3500-4000	Grassed headland	Yes
Edwards	Northern Queensland	17°5'S, 146°E	3500-4000	Rainforest	Yes
Ghidella	Northern Queensland	17°4'S, 146°E	3500-4000	Grassed headland	Yes
Grasso	Northern Queensland	17°5'S, 146°E	3500-4000	Grassed headland	Yes
LoMonaco	Northern Queensland	17°8'S, 146°E	3000-3500	Grassed headland	Yes
Mizzi	Northern Queensland	17°5'S, 146°E	3500-4000	Grassed headland	Yes
Toigo	Northern Queensland	17°5'S, 146°E	3500-4000	Grassed headland	Yes
Turnbull	Northern Queensland	17°5'S, 146°E	3500-4000	Grassed headland	Yes
Fortini	Herbert River	18°6'S, 146°E	1500	Savannah woodland	No
Kangas	Herbert River	18°5'S, 145°8'E	1500-2000	Grassed headland	Yes
Kalamia Estate	Burdekin	19°6'S, 147°4'E	1100	Grassed headland	Yes
Pegoraro	Burdekin	19°6'S, 147°1'E	750-1000	Pumpkin rotation	No
Valmadre	Proserpine	20°4'S, 148°5'E	750-1000	Grassed headland	Yes
Fordyce	Mackay	21°2'S, 148°9'E	1000-1500	Grassed headland	Yes
Vella	Mackay	21°2'S, 149°E	1000-1500	Grassed headland	No
Heck	Southern Queensland	27°8'S, 154°3'E	1000-1500	Grassed headland	Yes

Some other new land sites in a district where Pachymetra root rot is widely distributed, and at a high level (Babinda), were selected for a biological assay for Pachymetra root rot, to see if the disease is present in fields which had never grown cane.

Results

The biological assay of non-cane growing soils showed that Pachymetra root rot was not present in any new land soils. Where the pathogen originated is unknown, but it is clear that continuous sugarcane culture favours its rapid build up in particular districts. In other new land studies (where cane had been growing for a few years), some Pachymetra root rot was present in what was new land (see Table 11). It was clear that high levels of the disease were present in a number of old land sites, and that this disease would have contributed to some of the old/new land effect.

Pythium root rot symptoms were present in only a few sites and this root disease was unlikely to have influenced the crop response. (see Table 11). Nematodes were present in all sites, with *Pratylenchus zeae* detected at each site. This is consistent with other nematode assays conducted by Stirling, Blair and Whittle which suggests all sites assayed around Queensland supported populations of *Pratylenchus zeae* (Table 12).

Glasshouse experiments revealed that in general the old/new land growth responses could be reproduced in the glasshouse, that responses to soil pasteurisation were greatest in old land (though some response was also obtained in new land Table 13), and that very good root health was only observed in untreated rainforest soil (as compared to untreated soils from the other sites). In rainforest soils, young roots were always white and apparently uninjured; in all other new land sites root health was at best mediocre. These other sites contained grasses which are likely hosts for some of the same pathogens which attack sugarcane root systems. In the Tully Sugar Experiment Station old / new land site, very marked differences in root health were seen between old land, grassed headland and virgin rainforest. Soil pasteurisation removed most of the growth limitation imposed by the old land soil, and restored root health (as judged by root colour and vigour).

Table 11. Assay data for the sugarcane root pathogens *Pachymetra chaunorhiza* (as percentage rotted primary shoot roots) and *Pythium arrhenomanes* [as present (+) or absent (-)] in root systems at harvest in experiments 1-3. Likelihood ratio (*P.chaunorhiza*) = 87.4 ($P<0.001$, df = 13); Analysis of variance: site ($P<0.001$, df = 27, $F = 11.65$); old/new land status ($P<0.05$, df = 27, $F = 4.09$).

Site	*P.chaunorhiza*		*P.arrhenomanes*	
	Old	**New**	**Old**	**New**
	Experiment 1			
Edwards	74.1	43.1	-	-
LoMonaco	0	0	-	-
Toigo	76.1	77.8	-	+
Turnbull	3.7	0	-	+
Vella	19.0	0		
	Experiment 2			
Fordyce	57.7	13.2	-	-
Heck	0	0	+	+
	Experiment 3			
Cristiano	74.0	68.7	-	-
Ghidella	80.4	57.1	-	-
Grasso	18.3	54.3	+	+
Kangas	26.2	1.6	-	-
Mizzi	60.7	25.9	-	-
Turnbull	4.9	0	-	-
Valmadre	0	0	-	-
Mean (all experiments)	35.4	24.4	14.3[A]	28.6[A]

[A] Percentage of samples with *P.arrhenomanes*

Table 12. Nematode populations in soil and sugarcane root systems from some sites in experiments 1-3 Nematode assays on soil were conducted at harvest. Likelihood ratio (*Pratylenchus* in roots) = 3764.1 ($P<0.001$); Analysis of variance; site ($P<0.05$, df = 9).

Site	**Soil**	**Nematode species**			
		Pratylenchus	*Criconemoides*	*Helicotylenchus*	*Rotylenchus*
		Soil (no. of nematodes/kg soil)			
Edwards	Old	-	-	-	-
	New	-	-	-	-
LoMonaco	Old	-	1460	-	-
	New	800	-	-	-
Toigo	Old	-	-	117	117
	New	-	-	-	-
Turnbull	Old	350	-	-	-
	New	1625	-	-	-
Vella	Old	-	-	-	-
	New	-	-	-	-
		Roots (no. of nematodes/100 g root fresh weight)			
Edwards	Old	8550	-	225	-
	New	10525	-	850	-
LoMonaco	Old	500	-	-	-
	New	2100	-	-	-
Toigo	Old	1400	-	-	50
	New	6100	-	-	-
Turnbull	Old	12425	-	75	-
	New	11250	-	-	-
Vella	Old	8250	-	-	-
	New	13800	-	150	-

Monitoring of other biological groups suggested that actinomycetes were lower in old cane land, while fluorescent Pseudomonads (which often possess biological control properties) were higher in rainforest soil than old land (Table 14).

Table 13. Harvest measurements for glasshouse experiments conducted with old and new land soils from sites at Fortini, Kalamia Estate, and Pegoraro, and with old, grassed headland and undisturbed rainforest soils from the BSES Tully site. Response is defined as yield in (pasteurised soil-untreated soil)/untreated soil x 100

Soil	Shoot DW (g)		Response (%)	Root DW (g)		Response (%)
	Untreated soil	Pasteurised soil		Untreated soil	Pasteurised soil	
			Experiment 4 (Fortini)			
18 years cane	15.62	27.81	78	8.14	18.79	131
5 years cane	13.08	18.11	38	8.21	14.10	72
<1 years cane	14.44	23.05	60	9.92	13.90	40
New land	14.51	17.63	22	8.60	12.33	43
	L.s.d (P=0.05): soil=3.12, treatment = 2.25			L.s.d (P=0.05): soil=2.43, treatment = 1.72		
			Experiment 5 (Pegoraro)			
Pumpkin rotation soil	19.89	29.21	47	6.52	14.57	123
>20 years cane	16.30	20.74	27	7.07	11.05	56
	L.s.d (P=0.05): =3.14			L.s.d (P=0.05): =1.67		
			Experiment 6 (Kalamia Estate)			
Old land	9.79	19.56	100	3.63	9.55	164
New land	8.73	14.19	63	3.83	8.00	109
	L.s.d (P=0.05): =3.84			L.s.d (P=0.05): =1.77		
			Experiment 7 (BSES Tully)			
Old land	10.70	15.53	45	2.81	12.25	336
Headland	9.79	14.71	50	6.24	10.99	76
Rainforest	13.23	20.54	55	9.51	13.45	41
	L.s.d (P=0.05): soil=1.59, treatment = 1.30			L.s.d (P=0.05): soil=1.58, treatment = 1.29		

Table 14. Fungal, bacterial, fluorescent pseudomonad, actinomycete, *Pachymetra chaunorhiza*, *Pythium* spp. and nematode populations in old and new land (non-rhizosphere) soils from BSES Tully. Likelihood ratio = 471.8 (P<0.001, df = 12); Analysis of variance: old/new land status (n.s.).

Organism	Old land	Headland	Rainforest
Total fungi (x 10^6/g)	4.2	2.2	3.4
Total bacteria (x 10^8/g)	4.1	3.7	4.1
Total actinomycetes (x 10^6/g)	5.4	48.0	21.8
Fluorescent *Pseudomonas* spp. (x 10^4/g)	2.0	0	14.0
Fungal pathogens			
Pachymetra chaunorhiza [spores/g soil (DW)]	36	0	0
Pythium spp. (% baits colonised)[A]	17	33	17
Nematodes			
Pratylenchus zeae (nematodes/kg)	273	0	0[B]
Helicotylenchus spp. (nematodes/kg)	273	0	0

[A] *Pythium arrhenomanes* present only in headland soil.
[B] Unrecognised plant parasitic species present.

Substantial suppression of *Pythium arrhenomanes* has been demonstrated in trials using untreated rainforest soil – suppression was eliminated by pasteurising the same soil. VAM were also monitored in old and new land soils and were common in each. Sugarcane is a good host for some VAM species; the effect of cane on species composition of VAM was not included in these studies but has been reported elsewhere. Sugarcane influences the species proliferating and changes the VAM ecosystem.

SRDC Project BS73S was included in the early stages of the Joint Venture. Rather than providing all the details here, only a brief summary of the findings will be presented.

OTHER EXAMPLES OF YIELD DECLINE

Apple-replant disease is also a growth limitation resulting from crop monoculture. Apple trees are usually grown for 50-60 years before the trees are pushed out and new trees planted. Growth stunting can be dramatic in replanted orchards. There is strong evidence (responses to soil fumigation, growth of trees on new land, responses to biocides, the effect of fallowing) that sugarcane yield decline and apple replant disease are similar in nature. The literature suggests there are other crops similarly affected, including asparagus, corn, grapes, pears, cherries, potatoes, tobacco and even some natural ecosystems - where one species predominates in the early stages of species succession. This similarity was examined by growing apple trees in apple replant disease soil and sugarcane in yield decline affected soil in a glasshouse in Tully. Temperatures were optimised for each species via temperature-controlled chambers. Root systems were compared, as were responses to pasteurisation and biocides. With both conditions, poor root health and the loss of root hairs were characteristic. Growth of both species was markedly improved by soil pasteurisation and application of particular biocides (mancozeb) (variation in the apple tree growth resulting from the propagation of trees from seed hindered statistical significance). The conditions showed much similarity. It is likely that research conducted with other crops will be highly relevant to sugarcane research. Attendance at two International Replant Disease Conferences (Vancouver 1993, and Budapest 1996) illustrated this with similar areas of research reported. Further on-going contact with researchers in other cropping systems should be encouraged.

BIOCIDE STUDIES

A range of biocides was screened for ability to improve root health (judged by visual symptoms) and shoot and root growth. Soil fumigation with methyl bromide or metham sodium (Vapam) had a large effect on both components and has lead to large growth responses in the field. Responses to soil fumigation will be discussed in more detail in a section on core rotation trials.

As Pachymetra root rot could not explain all the detrimental effects of the poor biological status of yield decline soils, other biocides were screened for phytotoxicity, and then for activity, against unknown detrimental organisms associated with the problem.

Many fungicides were tested, with representatives having either specific or very general fungicidal activity. Of those tested (over 25), only general fungicides from two groups substantially affected plant growth and root health. These included the dithiocarbamates mancozeb, zineb and maneb, and the bezimidazole, benomyl. All four fungicides greatly improved root health, judging by root symptoms. Field trials conducted just before, or at the initiation of the JV showed that in Tully, mancozeb elicited a response almost as great as methyl bromide fumigation. Glasshouse trials with soils from other places suggested that responses were 50-80% of the fumigation response. It is thought that other biological components, such as nematodes, were responsible for the rest of the growth constraint (mancozeb generally doesn't control nematodes or Pachymetra).

Some fungicides were also identified which had no effect on shoot and root growth; these are seen as potential tools for eliminating parts of the microflora which apparently are not directly involved in controlling growth or affecting root health.

NATURE OF THE DETRIMENTAL BIOLOGICAL COMPONENTS IN YIELD DECLINE SOILS

In order to find out more about the nature of the deleterious organisms associated with YD, glasshouse transmission studies were conducted. It was found that roots collected from YD-affected field-grown root systems, when added to pasteurised soil, could lead to poor root health, a reproduction of YD-type symptoms and growth reductions of up to 30%. This was repeated four times with similar results, including rainforest soil. The addition of 10% by weight of untreated soil to pasteurised soil is also known to induce poor root health and reduced growth.

Heat treatment of a range of soils at 70^{0}C for 90 minutes (soil pasteurisation) is known to lead to a large improvement in root and shoot growth, and improved root health (visual symptoms). The effect of graded heat treatments was tested, with sequential increments of 2.5°C or 5°C applied from 40°C and above. Root symptoms were visually assessed and plant growth responses measured; soils were assayed for root pathogens. It was found that nematodes were eliminated between 45 and 47.5°C while Pachymetra root rot was eliminated between 50 and 55°C. Shoot and root growth increased above 42.5°C (where it was lower than the untreated soil, perhaps because of a disruption to biological control mechanisms) with improvements in shoot and root dry weights up to 70°C. The results confirm the effect of the known pathogens in affecting growth, but suggest some unknown mechanisms (and pathogens) may explain the rest of the response.

VAM (VESICULAR ARBUSCULAR MYCORRHIZAE)

This group of soil fungi are very common and infect the root systems of almost all species, forming a symbiotic relationship with their host plant. The extension of hyphae from the infected root into the surrounding soil aids plant uptake of P in low P soils; trace element uptake may also be improved (Zn, Cu). In tobacco in Kentucky, a pathogenic species was recognised and the question arose as to whether VAM could be pathogenic in cane. Open pot cultures of several species were established and field and glasshouse work conducted. In short term glasshouse trials, some growth retardation was found, but this is not unexpected; early in VAM colonisation there is a plant cost as VAM fungi establish their hyphal network. In a field trial on a very low P soil (4mg/kg), VAM fungi were beneficial at all P levels applied (4-200 mg/kg equivalent). Responses to VAM were greater at low P. In this, and in other trial(s), VAM appeared to alleviate drought stress with improved sugarcane growth immediately after transplant of the pre-germinated plants (compared to no-VAM plants). This has been recognised before in other crops. A finding of note was that fumigated yield decline soils without VAM grew less than fumigated soils with VAM – suggesting that the fumigation treatment alone does not provide the growth benchmark for sugarcane. The addition of beneficial organisms is needed to optimise yield. A thorough study of benefical organisms has not been attempted in sugarcane.

ROTATION TRIALS

The biology of core rotation trials was studied in both the glasshouse and laboratory at Tully Sugar Experiment Station. Rotation trial site selection was aided by a preliminary glasshouse fumigation trial to assess the potential for growth improvement and to provide an opportunity to examine root health. Trials were conducted from 1993 (Tully) onwards with calculation of responses to rotation and soil fumigation. Later, suppression of Pachymetra root rot was examined in soils from long-term rotation treatments.

Relating glasshouse and field data

The harvest of the rotation trials, in their first year in cane following the long term rotation treatments, allowed a comparison of glasshouse and field results. A 2000 ASSCT paper (by Mike Bell *et al*) indicates that the short-term glasshouse trial response with different rotation treatments correlated in most of the rotation trials to short term field responses with the same treatments. It was considered that these responses were likely to be mostly biological. In a couple of trials and some treatments, a late season growth response occurred, with unknown cause, leading to a lower correlation of glasshouse and final yield. Alternative management of the crops growing after the different rotations may have improved late season growth in treatments with poorer late season growth. The short term glasshouse trials may therefore prove a rapid, quick way of examining some of the effects of treatments on YD soils. Field verification of responses will always be needed however.

Responses to rotation

Growth responses to rotation also occurred in glasshouse trials. Almost invariably, shoot and root growth were lowest in soil from the continuous cane treatment. Greatest rotation treatment responses were generally obtained in pasture or bare fallow soils. This would not be unexpected, given that most biological components would have declined in the bare fallow soil (including pathogens), while the increase in microbial biomass in pasture (see Pankhurst report) could have lead to among other things, the suppression of root pathogens. These responses are summarised in Table 15.

Table 15. Average growth responses to rotation and fumigation in soils from rotation trials (average results – all trials 1996)

Treatment	Fumigation %	Rotation %
Pasture	31	23
Crop	16	26
Fallow	9	36
Cane	43	0

Responses varied year by year (from 1993-5 to the year of field replanting – 1997). Root pathogens were affected by rotation, with Pachymetra root rot declining with time in some treatments (see Table 15). This would have had a small effect on growth as a resistant variety was grown in both glasshouse and field trials (with a susceptible a bigger response would have resulted). Research by Stirling et al indicates that nematode numbers also declined in rotations other than cane; this is most likely indicative of the trend in populations of other unrecognised deleterious biological components.

Responses to fumigation

Not unexpectedly, the greatest responses to methyl bromide soil fumigation occurred in continuous cane soils; this is where the highest populations of soil pathogens were recorded. Near zero (slightly positive or negative) responses were obtained in long term bare fallow soils. This near zero response is not usually observed in cane growing soils, and has only been seen in rainforest soils where impeccable root health occurs. The bare fallow response could be expected because of a decline in soil pathogens in these soils and a general decline in microbial biomass. Both responses (cane and bare fallow soils) were consistent across rotation sites.

The magnitude of responses to fumigation of pasture and alternative crop soils was in-between those of the continuous cane and bare fallow. This suggests that some deleterious biological components may have still been present in these soils. The implications of this are quite significant – though further field work is needed to validate hypotheses. With pasture leading to growth responses nearly as great as bare fallow in the field, glasshouse research suggests that some general soil characteristics have been improved by pasture breaks but yields are still limited by aspects of the soil biology. If these other elements could be eliminated, the potential growth in pasture soils would be well above that in bare fallow soil (and well above fumigation yields). The nature of the improvements gained by pasture treatments (likely to be a more balanced soil biology, the presence of beneficial organisms and greater nutrient cycling etc) should be investigated and methods for establishing these soil conditions examined..

A pot trial conducted nine months into the plant cane crop (planted on to previous rotation treatments) suggested that the response to bare fallow had already decreased, and that plant growth in this soil was responding to fumigation. With low levels of microbiological activity, pathogen populations were most likely being exposed to less biological suppression (Table 16).

Table 16. Responses to rotation and fumigation in cane growing in soils from the Mackay rotation trial nine months after replanting with sugarcane

Treatment	Fumigation %	Rotation %
Pasture	51	17
Crop	42	24
Fallow	28	19
Cane	76	0
After a short period back in cane. Trend: fallow: fumigation response increasing rotation response decreasing		

Pathogen suppression

In order to pursue the nature of some of the biological components of the rotation soils, suppression of Pachymetra root rot in the bare fallow, cane and pasture soils was tested. This was done by adding small quantities of untreated soils from each treatment to pasteurised YD soil, with and without inoculation with *Pachymetra chaunorhiza*. Control treatments included pasteurisation of the added rotation soils. Several doses of *P. chaunorhiza* were included to aid statistical interpretation of the data. In treatments with pasteurised soils from each rotation (no added untreated soil), Pachymetra root rot increased to the same level in each soil. This indicates minimal non-biological suppression. With added untreated soil from each treatment, substantial suppression occurred with the greatest amount in pasture and cane soils. (see Figures 3-5). Biological suppression is most likely the reason for this response.

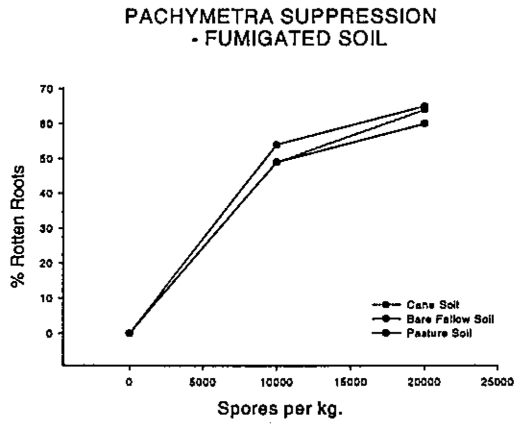

Figure 3. The relationship between *P.chaunorhiza* inoculum level and the expression of disease in fumigated soils from cane, bare fallow and pasture treatments.

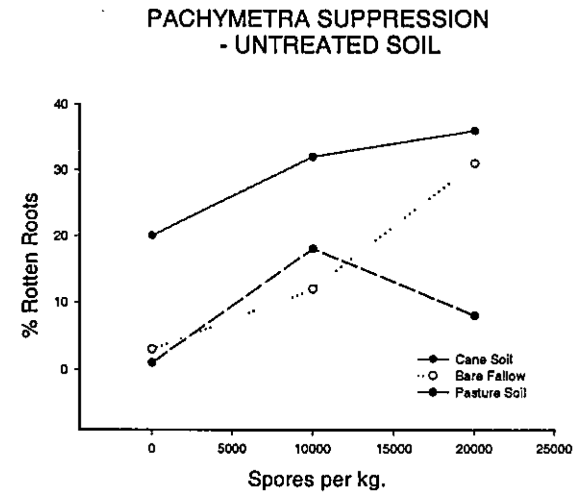

Figure 4. The relationship between added *P.chaunorhiza* inoculum and disease expression in untreated soils from cane, bare fallow and pasture treatments. Cane soil had a background level of P.chaunorhiza inoculum.

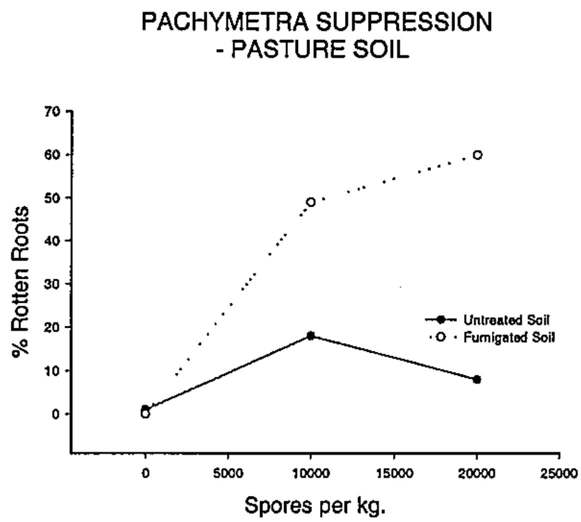

Figure 5. The effect of soil fumigation in alleviating *P.chaunorhiza* suppression is clear in a graph of the results from pasture soil.

Data from the work by Pankhurst would suggest that suppression of Pachymetra root rot in pasture treatments could be expected. The presence of a moderate microbial biomass in the cane soil would also be expected to suppress Pachymetra to some degree (compared to the bare fallow soil). It is also known that *Pythium arrhenomanes* is antagonistic to Pachymetra, and may also exert some suppressiveness in untreated cane soil.

This research should be pursued, as a soil suppressive to the major pathogens associated with continuous sugarcane is what altered management strategies should achieve (amongst other things); this is a major aim of the YD JV.

DISCUSSION

Results obtained previous to, and in the first phase of the Joint Venture, have provided some significant information. The involvement of soil biology in the growth constraint has been demonstrated, though much is still unknown of the organisms contributing to poor root health and of the organisms which are / would be beneficial in the sugarcane cropping system. With the soil being a complex environment - with many interactions between biological and non-biological parameters - it is difficult to obtain a clear picture of the mechanisms which enhance or restrict plant growth.

Results suggest involvement of biological parameters in both old / new land, and rotation growth responses. Differences in growth could generally be reproduced in short term glasshouse trials, and such trials provide a useful tool in further understanding the system. This is especially so for undertaking certain assays, for determining possible responses from selected treatments and for undertaking experimental treatments which would not be logistically possible in the field (eg fumigation of soils from a range of treatments). Results from these trials should always be verified in the field however (if possible). Some further research may be needed to reduce glasshouse trial variation.

Biocide experiments suggest that unknown components of the deleterious organisms in yield decline soil are having a significant constraining effect on cane growth. Further field experimentation should be undertaken to confirm this and to compare the magnitude of the constraint imposed by this group of organisms with that posed by known pathogens (nematodes and Pachymetra).

Beneficial organisms may be enhanced or reduced by cropping systems. Not enough is understood about these organisms, for both those that interact with root pathogens (in biological control or disease suppression) and those that enhance other growth promoting effects (nutrient cycling or availability eg mycorrhizae). An assay for disease suppression has been trialed with positive results and this will be a useful tool for assessing the ability of cropping systems to enhance soil health. Significant emphasis should be given to disease suppression in the next phase of the JV, since the development of cropping systems which minimise deleterious biological groups would appear to be a central objective. The addition of organic matter to soils has strong potential to improve soil health and increase disease suppression.

A large field of study is posed by beneficial organisms alone. Tools that allow characterisation of the general soil biology have been useful in phase 1 of the Joint Venture and may allow more of these details to be established. Mycorrhizae should not be forgotten nor other types of beneficial organisms involved in making nutrients available for plant growth.

Close cooperation between scientists, and familiarisation with other crop constraints, should be fostered. The subject of soil health is not limited to Australian research, nor with sugarcane or cereals. Links, or travel, to exploit the research of other groups could be most valuable.

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CHANGES IN FUNCTIONAL GROUPS OF SOIL MICROORGANISMS ASSOCIATED WITH THE DEVELOPMENT AND AMELIORATION OF SUGARCANE YIELD DECLINE

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CSIRO Land and Water

The objective of our research was to identify and monitor changes in the abundance of selected functional groups of microorganisms in the rotation and rundown field trials. This information will complement other studies in the joint venture that have monitored changes in soil physical / chemical properties, nematodes, microbial biomass, root pathogens and crop production in these trials. Shifts in microbial populations may be a sensitive indicator of changes in soil health and may be a contributory factor to changes in sugarcane yield decline brought about by crop rotations and soil management.

APPROACH

We have used soil samples, collected at regular intervals, from the rotation trials at Tully, Ingham, Burdekin, Mackay and Bundaberg and from the rundown trial at Tully, for all of our microbiological measurements. The soil samples were subsamples of those used for microbial biomass determinations and estimation of nematode populations. The microbiological measurements we made included:

1. Enumeration of total bacteria, *Pseudomonas* spp., *Bacillus* spp., actinomycetes and fungi, using selective culturing techniques (Pankhurst *et al.* 1995).
2. Estimation of the composition of the microbial community based on analysis of fatty acid methyl esters (FAMEs) extracted from the soil samples (Cavigelli *et al.* 1995; Ibekwe and Kennedy, 1999). This technique does not rely on the culturing of soil microorganisms and was thus able to provide an objective picture (fingerprint) of changes occurring to the microbial community in response to changes in soil conditions. The technique also provided an opportunity to follow changes to selected groups of microorganisms using signature fatty acids (Frostegard and Baath, 1996).
3. Estimation of the metabolic activity and functional diversity of the bacterial component of the microbial community using the Biolog technique (Garland and Mills, 1991).
4. Identification of bacterial isolates from the rhizosphere of sugarcane plants using the MIDI FAME identification system (Welch, 1991).
5. An in vitro "growth inhibition" assay for testing bacterial isolates for production of antibiotics inhibitory to the growth of *Pachymetra* and *Pythium*.

EFFECT OF ROTATION BREAKS ON THE COMPOSITION OF THE SOIL MICROBIAL COMMUNITY

Populations of culturable microorganisms

Populations of culturable microorganisms (total bacteria, *Pseudomonas* spp., *Bacillus* spp., actinomycetes and fungi) were monitored annually at each trial site (5 occasions at Tully, and 4 occasions at Ingham, Burdekin and Mackay). Results for the spring 1997 sampling are shown in Table 17. A general trend across all four sites was for populations of all functional groups to increase under the pasture and alternate crop treatments and to decline under the bare fallow treatment. The most responsive groups were the *Pseudomonas* spp (gram –ve bacteria), which increased markedly under the pasture and declined markedly under the bare fallow, and fungi, which showed a marked decline under bare fallow (Table 17).

Table 17. Impact of rotation breaks on populations of culturable microorganisms (Log cfu / g soil)

Site	Pasture	Crop	Bare fallow	Contin. cane
Tully				
Bacteria	6.9ab	6.6b	n.d	7.1a
Pseudomonas spp.	5.0a	3.7b	n.d	3.8b
Bacillus spp.	5.8b	6.2a	n.d	6.2a
Actinomycetes	6.1a	5.9a	n.d	6.2a
Fungi	4.8a	4.8a	n.d	3.6b
Ingham				
Bacteria	7.5a	7.3a	6.7b	7.2ab
Pseudomonas spp.	4.8a	4.5a	3.7c	4.1b
Bacillus spp.	5.9ab	5.7bc	5.6c	6.1a
Actinomycetes	6.4bc	6.1c	6.4bc	6.8a
Fungi	6.5ab	6.8a	5.6c	6.2b
Burdekin				
Bacteria	7.8a	7.2b	6.9b	7.5ab
Pseudomonas spp.	5.1a	5.0a	4.0b	4.1b
Bacillus spp.	6.3b	6.8a	6.2b	6.8a
Actinomycetes	6.2b	5.8b	6.7a	6.8a
Fungi	6.3a	6.2ab	5.7c	6.0b
Mackay				
Bacteria	7.3a	7.4a	6.7b	7.1ab
Pseudomonas spp.	4.3a	4.2a	3.5b	3.7b
Bacillus spp.	6.2a	6.2a	6.0a	6.2a
Actinomycetes	6.0a	5.6 a	5.1b	5.7a
Fungi	4.9a	4.4a	3.4b	4.8a

n.d., not determined. Values within rows followed by the same letter are not significantly different (P=0.05)

Fatty acid analysis

Throughout the project we performed a routine GC-FAME analysis of all soil samples obtained from the rotation trials, including soil samples from the Bundaberg rotation and trash management trials. This analysis enabled us to identify (1) changes in the overall composition of the microbial community by comparing soil FAME profiles (based on principal component analysis, PCA), and (2) changes in the relative amounts of specific microbial groups based on changes in the concentration of selected "signature" fatty acids.

The output from these analyses was consistent across all trial sites. Between 35 and 50 fatty acids were detected in the soil FAME profiles from each of the sites. Examples of PCA diagrams of the soil FAME profiles for the Burdekin, Mackay and Ingham sites, 2.5 years after establishing the rotation breaks, and at Tully (6.5 yr pasture, 3.5 yr crop) is shown in Figure 6. Across all the sites the pasture break was shown to have the greatest impact on the composition of the microbial community. This can be seen clearly in the PCA diagrams for the Tully, Burdekin and Mackay sites where the points depicting the pasture FAME profiles cluster separately and at some distance from the points depicting the FAME profiles from the other soils. At the Ingham site there was less distinction between the pasture and alternate crop breaks. It is noteworthy that the PCA diagrams did not differentiate between the continuous cane soil and the bare fallow soil despite the significant differences between these soils found for some groups of culturable microorganisms. This may be due to the fact that the FAMEs extracted from the soil come from living as well as dead microbial biomass. Hence, whilst an increase in microbial biomass (as occurs under the pasture treatment) may be detected, a decline in biomass (as under the bare fallow treatment) or only a small change in biomass (as under the alternate crop treatment) (Pankhurst *et al.* 1999) may be less easily detected. Also, whilst the FAME profiles used in the PCA diagrams contain all fatty acids detected, certain fatty acids that are present in large amounts in one treatment eg. fatty acid 16:1 w5c in the pasture soil, may have a dominating influence on the PCA diagrams. The importance of this factor may be seen in

Table 18 which gives the concentration of four fatty acids, 15:0 iso, 16:1w7c, 16:1w5c and 18:2w6c used as signatures for gram +ve bacteria, gram-ve bacteria, mycorrhizal fungi and fungi respectively.

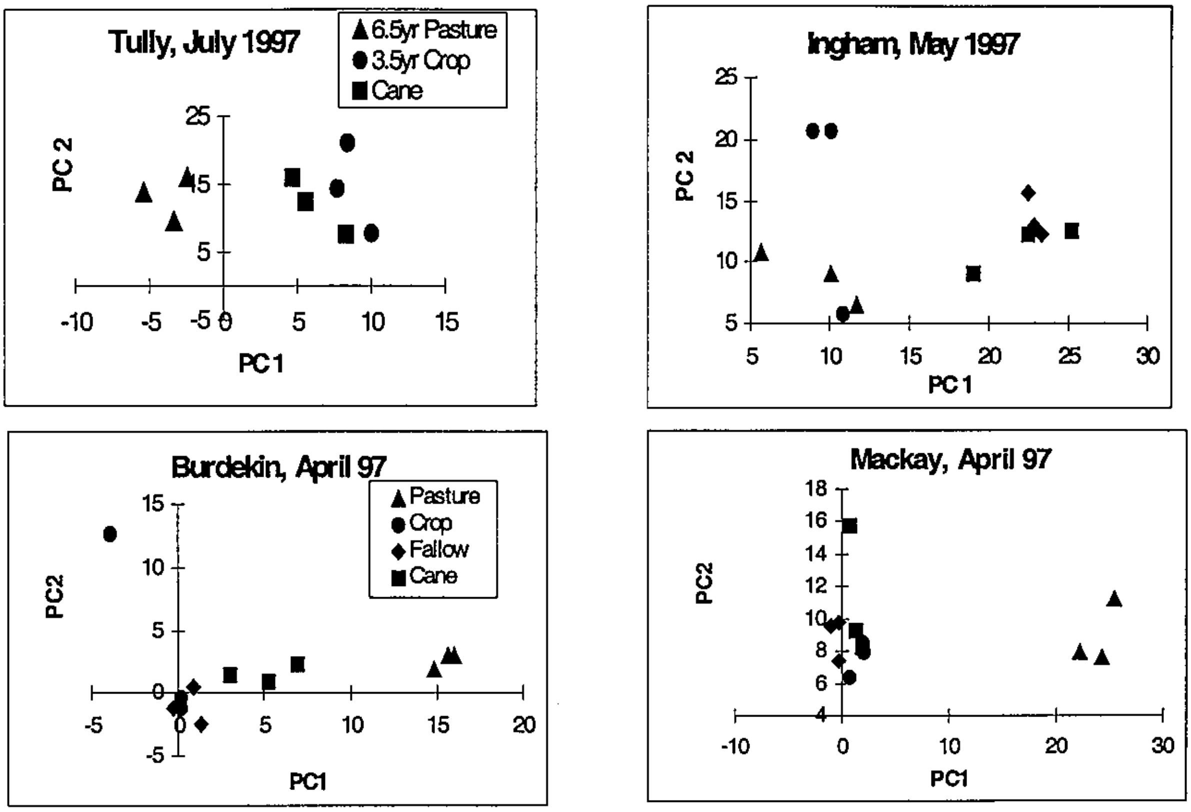

Figure 6. PCA diagrams of soil FAME profiles of the rotation and sugarcane soils from Tully, Ingham, Burdekin and Mackay.

The concentration of each of these fatty acids was significantly higher in the pasture soil compared to the continuous cane and bare fallow soil at all four sites. Though not shown in Table 18, results from the Tully site obtained in 1998 also showed the bare fallow soil at this site to contain significantly lower concentrations of these fatty acids compared to that in the pasture soil. The concentration of the gram +ve, gram –ve and mycorrhizal fungi signature fatty acids in the alternate crop soils at each site was generally lower than the concentrations in the pasture soil whereas the concentration of the fatty acid signature for fungi was higher in the crop soil compared to the pasture soil at Ingham, Burdekin and Mackay.

The most interesting feature of the signature fatty acid analysis was the marked increase (4-6 fold) in the fatty acid 16:1w5c under pasture. This fatty acid has been used as a signature for mycorrhizal fungi, notably *Glomus* spp. (Graham *et al.* 1995). *Glomus clarum* has been reported to be the most common species of mycorrhizal fungi in sugarcane soils (Kelly *et al.* 1997). Also, an independent test based on colonisation of sugarcane roots, showed that the amount of mycorrhizal fungi in the rotation break soils at Tully, Ingham and Mackay, was highest in the pasture soil and lowest in the bare fallow soil (Pankhurst *et al.* 1999).

Table 18. Impact of rotation breaks on the concentration of fatty acids (g/g soil) used as signatures for gram +ve bacteria (i15:00, gram –ve bacteria (16:1 w7c), mycorrhizal fungi (16:1 w5c) and fungi (18:2 w6c).

Site	Pasture	Crop	Bare fallow	Contin. cane
Tully				
Gram +ve bacteria	1.35a	1.06b	n.d.	1.01b
Gram –ve bacteria	2.46a	0.53b	n.d.	0.66b
Mycorrhizal fungi	3.19a	0.62b	n.d.	0.66b
Fungi	1.80a	1.34b	n.d.	0.83c
Ingham				
Gram +ve bacteria	1.23a	1.14ab	0.83c	1.06b
Gram –ve bacteria	2.76a	2.78a	0.87b	0.95b
Mycorrhizal fungi	4.01a	1.05b	0.47d	0.68c
Fungi	2.86a	3.10a	0.98b	1.01b
Burdekin				
Gram +ve bacteria	1.72a	1.25b	1.15b	1.28b
Gram –ve bacteria	2.87a	1.65b	1.12c	1.78b
Mycorrhizal fungi	6.81a	2.15b	1.56c	2.45b
Fungi	2.58b	3.12a	2.01d	2.22c
Mackay				
Gram +ve bacteria	1.54a	1.36b	0.90c	1.42ab
Gram –ve bacteria	2.43a	0.90b	0.45c	1.03b
Mycorrhizal fungi	4.19a	1.29b	0.32d	0.78c
Fungi	2.24b	3.29a	0.46d	1.84c

n.d., not determined. Values within rows followed by the same letter are not significantly different (P=0.05)

Biolog analysis

Biolog analysis was carried out to determine the effect of the rotation breaks on the metabolic activity (capacity to use 128 different carbon substrates) and functional diversity (diversity of substrates used) of the bacterial component of the microbial community.

As with the GC-FAME analysis, the output from this form of analysis was consistent across the rotation sites. An example of the data obtained is given for soils obtained from the Tully site in May 1998 (Figure 7). This PCA diagram indicates that the bacterial community in the pasture soil is quite different to the community in the crop, bare fallow and cane soils. The sugarcane community appeared to be variable but showed more similarity with the crop treatment than the bare fallow treatment (Figure 7).

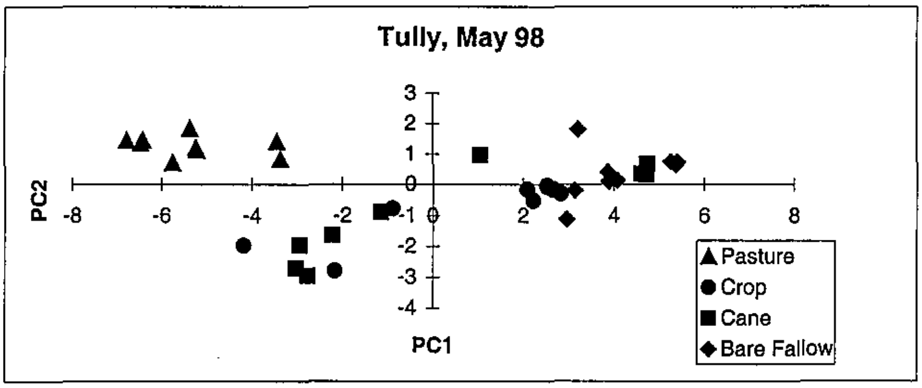

Figure 7. PCA diagram of Biolog utilisation patterns from rotation and sugarcane soils at Tully.

The bacterial community in the pasture soil also utilised significantly more substrates and had significantly higher metabolic acitivity than in any of the other soils. Similarly, calculation of the Shannon diversity index and the Gini coefficient from the Biolog data (Harch *et al.* 1997) indicated that the pasture soil community had higher functional diversity than the crop, bare fallow or cane soil communities (Table 19).

Table 19. The effect of rotation breaks on the bioactivity and functional diversity of bacterial communities in soils at Tully.

Soil	No. substrates used (out of 128)	Metabolic activity	Shannon index	Gini coefficient
Pasture	120	1.31	4.46	0.40
Crop	100	0.91	4.44	0.47
Bare fallow	67	0.31	3.81	0.62
Cont. cane	96	0.81	4.40	0.48
Lsd (P= 0.05)	12	0.15	0.24	0.04

Return of rotation breaks to cane

Utilising both selective culturing and GC-FAME techniques, it was found that within 12 months of re-planting the rotation soils to cane (at Tully, Mackay and Burdekin) the rotation-induced changes in the composition of the microbial community showed signs of reverting back to the community profile typical of a continuous cane soil. Results from the Mackay site comparing populations of culturable microorganisms and concentrations of signature fatty acids at the time of re-plant of the rotation soils to cane, and 7 months later, are given in Table 20. As found previously, the most responsive group of microorganisms were the *Pseudomonas* spp. which showed a significant decline in the pasture and cropped soils following their return to cane. There was an increase (not significant) in *Pseudomonas* spp. and a significant increase in fungi in the bare fallow soil following its return to cane. The fumigated soil showed a large decrease in populations of all functional groups measured but these had all recovered significantly after 7 months (Table 20). Although the GC-FAME analysis was less effective in detecting changes over this time-frame, it did detect a significant change in the fatty acids used as signatures for gram –ve bacteria and mycorrhizal fungi. In both cases concentrations of these fatty acids had decreased following the re-planting of the pasture soil to cane. There were also measurable differences (not significant) in these two fatty acids and the fatty acid signature for fungi in the fumigated soil pre- and post planting.

Analysis of soil samples obtained in 1999 following the harvest of the first ratoon crop at Mackay and Tully and after the plant crop at Burdekin confirmed the progressive reversion of the microbial community composition in the break soils to the community profile of the continuous cane soil. This can be seen by the absence of differentiation between the soils in the PCA diagram of the FAME profiles of the soils at Tully and Mackay (Figure 8, compared to Figure 6). Furthermore, there were now no longer any significant differences between populations of culturable microorganisms, signature fatty acids or microbial biomass across all the plots at both of these sites.

EFFECT OF ROTATION BREAKS ON THE DIVERSITY OF BACTERIA IN THE RHIZOSPHERE

Results from the rotation trials at Tully, Ingham and Mackay, showed that all 3 rotation breaks significantly increased the yield of cane in the plant crop (Garside *et al.* 1999). It was hypothesised that if the changes to the soil microbial community resulting from these rotation breaks were a contributory factor to the increased cane yield, then these changes might be reflected in the composition of the rhizosphere microbial community. For example, one might expect to find a higher proportion of "beneficial" gram-ve bacteria in the rhizosphere of cane plants growing in the pasture and bare fallow soil compared to the rhizosphere of cane plants growing in continuous cane soil. As the Burdekin site was just in the process of being returned to cane at this time, we examined the diversity of bacteria colonising the rhizosphere of cane plants 6 weeks after their establishment into the pasture, bare fallow and continuous cane soils.

A total of 120 bacterial isolates were obtained from the rhizosphere of cane 6 weeks after planting into soil that was previously under pasture, bare fallow or continuous cane. Species from 25 different bacterial genera were identified (Table 21). The frequency of isolation of bacteria from the different genera showed two important differences between the rhizosphere populations of cane growing in the continuous cane soil and cane growing in the pasture or bare fallow soil. Firstly, there was a greater diversity of bacterial genera in the rhizosphere of cane growing in the continuous cane soil than in the rhizosphere of cane in either the pasture or bare fallow soils. Those bacterial genera found only in the former included *Acidovorax*, *Clavibacter*, *Klebsiella*, *Kluyvera*, *Lactobacillus*, *Nocardiodes*, *Salmonella*, *Sphingomonas* and *Sphingobacterium* (Table 20). Secondly, the rhizosphere of cane growing in the pasture and bare fallow soils contained a much higher proportion of *Pseudomonas* spp.; 23 and 35% respectively, compared to only 5% in the rhizosphere of cane growing in the continuous cane soil.

Table 20. Effect of returning rotation breaks to sugarcane at Mackay on populations of functional groups of microorganisms and concentrations of signature fatty acids.

	Functional groups (Log cfu / g soil)					**Signature fatty acids**			
	Bacteria	**Pseudo.**	***Bacillus***	**Actino.**	**Fungi**	**Gram +ve**	**Gram -ve**	**Mycorrh**	**Fungi**
Aug. 97									
Before replant									
Past.	7.3	4.3	6.2	6.0	4.9	1.57	2.43	4.19	2.24
Crop	7.4	4.2	6.2	5.6	4.4	1.36	0.90	1.29	3.29
BF	6.7	3.5	6.0	5.1	3.4	0.90	0.45	0.32	0.46
Cane UF	7.1	4.2	6.2	5.7	4.8	1.42	1.03	0.78	1.84
Cane F	5.5	2.7	5.3	4.8	4.1	1.44	0.82	0.67	1.41
March 98									
After replant									
Past. /Cane	7.0	3.8	6.2	5.2	4.5	1.75	1.54	2.78	1.34
Crop / Cane	6.9	3.4	6.2	5.2	4.5	1.38	0.77	1.64	2.59
BF / Cane	6.4	3.6	6.1	5.0	4.3	0.98	0.63	0.63	0.80
Cane UF / Cane	6.7	2.9	6.2	5.8	4.5	1.67	0.84	1.06	1.37
Cane F / Cane	7.0	3.2	6.1	5.5	5.1	1.54	0.70	1.33	1.33
Lsd (P=0.05)	0.5	0.6	0.2	0.5	0.6	0.52	0.59	0.67	0.94
Time* treatment	***	***	***	***	***	n.s.	**	***	n.s

n.s., not significant; ** P<0.01, *** P<0.001. UF, unfumigated, F, fumigated.

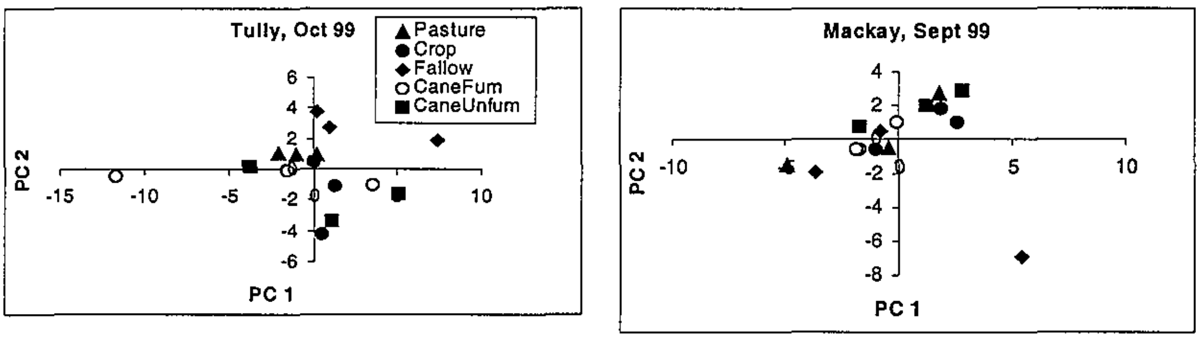

Figure 8. PCA diagrams of soil FAME profiles of the rotation and continuous cane soils following the harvest of the first ratoon crop in at Tully and Mackay.

Table 21. Isolation frequency (%) of bacteria from the rhizosphere of cane 6 weeks after planting into soil previously under pasture, bare fallow and continuous cane. The number of isolates identified to genus level were pooled over 3 replications. Observations of whether a genus contains species known to be detrimental or beneficial to plant growth is based on a literature survey of the genus in question.

Genus	**Previous soil history**			**Genus contains species known to be**	
	Pasture	***Bare Fallow***	***Continuous cane***	***Detrimental to plant growth***	***Beneficial to plant growth***
Agrobacterium	2		1	Yes	Yes
Acidovorax			4	Yes	
Arthrobacter	6	25	30		
Aureobacterium		1			
Bacillus	16	9	5		Yes
Burkolderia		4	1		Yes
Cellulomonas	4	1	3		
Chryseobacterium	8		1		Yes
Clavibacter			6	Yes	
Cornynebacterium	4			Yes	
Curtobacterium		4			Yes
Enterobacter	2				Yes
Klebsiella			1		Yes
Kluyvera			1		
Lactobacillus			1		
Methylobacterium		1			
Micrococcus	10	6	8		
Nocardioides			1		
Panotea	2				
Pseudomonas	23	35	5	Yes	Yes
Salmonella			2		
Sphingomonas			1		
Sphingobacterium			5		Yes
Xanthobacter	2		3		Yes
Variovorax	2				Yes
Unidentified	19	14	21		

The apparent reduction in the diversity of bacterial genera in the rhizosphere of cane in the pasture and bare fallows soils compared to that in the rhizosphere of cane in the continuous cane soil could be due to a number of factors. For example, the disproportionate increase in *Pseudomonas* spp. in the rhizosphere of cane in the pasture and bare fallow soil would have reduced the probability of isolating species present in low numbers. Also there could have been loss of some species in the bare fallow soil due to the lack of organic inputs and the selective stimulation of some species (eg. *Bacillus* spp.) in the pasture soil due to a different array or organic inputs. It was of interest to note the number of genera that were present in the rhizosphere of cane in the continuous cane soil that were absent in the rhizosphere of cane in the pasture and bare fallow soils (Table 21). Whilst none of these genera were present in disproportionatly high numbers which might suggest they had some role in yield decline, two genera, *Acidovorax* and *Clavibacter* contain species that have been reported to be pathogenic towards plants. The *Acidovorax* isolates obtained were identified as *A. avenae* subsp. *avenae,* reported to be pathogenic towards a number of crop plants including sugarcane (Hu *et al.*, 1997). The *Clavibacter* isolates were identified as *C. michiganensis* subsp. *insidiosus*, which has been reported as the casual agent of alfalfa bacterial, wilt (Samac *et al.*, 1998). Its pathogenicity towards sugarcane is unknown. However, a closely related *Clavibacter* species, *Clavibacter xyli* subsp. *xyli* is the casual agent of ratoon stunting disease (RSD) (Croft, 1996). Further investigations of the *Clavibacter* group in relation to yield decline are therefore required.

All the bacterial isolates were tested for their capacity to inhibit the growth of *Pachymetra* and *Pythium* in a laboratory assay. Isolates showing inhibitory activity included isolates of *Bacillus, Burkolderia, Chryseobacterium* and *Pseudomonas* (Table 22). In addition, a large proportion of the isolates from the rhizosphere of cane in the pasture and continuous cane soil that were unidentified, were shown to be inhibitory towards both fungi. Isolates showing the strongest growth inhibition included *P. syringe* from the pasture soil, *P. pudita* and *Burkolderia gladioli* from the bare fallow soil and *P. pudita, P. syringe* and the unidentified isolates from the continuous cane soil (Table 22). In general *Pachymetra* was more sensitive to growth inhibition than *Pythium.*

Table 22. Bacterial isolates showing in vitro inhibition of the growth of *Pachymetra chaunorhiza* and *Pythium graminicola.* Level of inhibition is classified as follows: strong (15-30 mm inhibition zone), moderate (5-15 mm inhibition zone), weak (2-5 mm inhibition zone).

Source	Bacterial species	No. isolates	No. of isolates showing in vitro inhibition of *Pachymetra* and *Pythium*			
			Strong	Moderate	Weak	None
Pasture	***Bacillus megaterium***	4		1	1	2
	B. pumilus	1		1		
	Chryseobacterium indologenes	4			2	2
	Pseudomonas putida	12	1	2	9	
	P. syringe	4	4			
	Unidentified	12		12		
Bare Fallow	***Burkolderia gladioli***	4	4			
	P. chlororaphis	3			1	2
	P. putida	21	15		5	1
	P. fluorescens	3			3	
	Unidentified	3			3	
Continuous cane	***P. fluorescens***	1	1			
	P. putida	4	4			
	P. syringe	1	1			
	Unidentified	19	15	1	3	

Pseudomonas spp. are well known for their capacity to produce substances that are antagonistic towards fungal plant pathogens (Bowen and Rovira, 1999). Overall, and including isolates that were not identified by the MIDI FAME procedure, there were more bacterial isolates showing inhibitory activity towards *Pachymetra* and *Pythium* in the rhizosphere of cane in the pasture and bare fallow soils (32% and 26% of isolates respectively) than in the rhizosphere of cane in the continuous cane soil (20% of isolates). Based on this criterion, the data suggests that both the pasture and bare fallow breaks have had a favourable impact on the composition of the bacterial flora in the rhizosphere. However, it is likely that the increase in *Pseudomonas* spp. per se in these rhizospheres is of greater significance as this may be indicative of an improvement in soil and root health.

RUNDOWN FIELD TRIAL

Populations of culturable microorganisms were determined and GC-FAME analyses were carried out on soil samples from the Rundown field trial from 1995 (establishment) until 1998. The trend that emerged over this period was for a marked decline in populations of all functional groups measured (particularly *Pseudomonas* spp.) in the bare fallow treatment and in the cane treatments where there was no inputs and where trash was removed. This decline is not as great where trash was retained. The GC-FAME analysis showed good separation between the new land plots (still under pasture) and all the other treatments (Figure 9). The cane treatment where trash was incorporated grouped closer to the new land than the other cane treatments, whilst the bare fallow treatment was also clearly different from all the other treatments. The fatty acid signature for gram-ve bacteria was lower in the cane and bare fallow treatments compared to the new land.

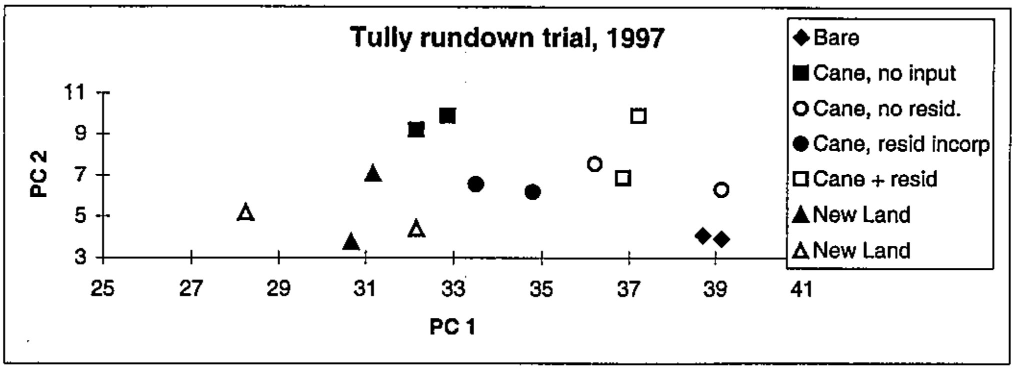

Figure 9. PCA diagram of soil FAME profiles from the Tully rundown trial.

CONCLUSIONS

1. Each of the rotation breaks had a demonstrable effect on the composition of the soil microbiota. Pasture had a positive impact, increasing populations of beneficial microorganisms such as gram-ve bacteria and fungi. Bare fallow had a negative effect, with a decline in all functional groups of microorganisms. Alternate cropping had the least effect, although there was a small increase in gram-ve bacteria. These effects were consistent across all the trial sites.
2. Shifts in the composition of the soil biota (notably under the pasture break) took 12 months to develop.
3. Changes in the composition of the soil microbiota under the 3 different breaks could be measured quantitatively and objectively using GC-FAME analysis and fatty acid signatures for selected microbial groups. Where applicable changes in the composition of the microbiota predicted by FAME analysis agreed with results of the selective culturing of microorganisms and compositional changes (eg. in mycorrhizal fungi) detected by complementary bioassays.
4. The fatty acid 16:1w5c (used as signature for mycorrhizal fungi in this work) increased significantly in soil under pasture at all sites. This fatty acid may have potential as a bioindicator of a more healthy / balanced soil microbiota.
5. The Biolog technique was effective in showing that the bacterial community that developed under the pasture was more metabolically active and had more functional diversity than the communities under alternate crop, bare fallow or continuous cane treatments.
6. Shifts in the composition of the microbiota induced by the rotation breaks showed signs of reverting back to the sugarcane "microbiota profile" within 7 months of re-planting the rotation soils to cane. At the end of the first ratoon crop there were no longer any significant differences between the composition of the microbial community in soils that were previously under rotation breaks or continuous cane.
7. A study of the composition of the rhizosphere bacterial community of cane 6 weeks after planting into the pasture and bare-fallow soil at the Burdekin site showed that the diversity of bacteria in the rhizosphere of cane growing in the continuous cane soil was greater than that in the rhizosphere of cane growing in soil that had been under pasture or bare fallow. Several bacterial genera including two, *Acidovorax* and *Clavibacter* which contain known plant pathognes, were present in the continuous cane rhizosphere but absent from the rhizosphere of cane growing in the pasture and bare fallow soils. Compared to the rhizosphere of cane in the continuous cane soil, the rhizosphere of cane growing in the pasture and bare fallow soils contained higher numbers of bacteria (notably *Pseudomonas* spp.) that were inhibitory to the growth of *Pachymetra chaunorhiza* and *Pythium graminicola* in a laboratory bioassay. The results suggest that one possible mechanism by which rotation breaks reduce the impact of yield decline is by encouraging an increase in potentially beneficial bacteria in the rhizosphere.

8. The rundown experiment showed rapid decline in all functional groups of microorganism measured in treatments where the land received no organic inputs (bare fallow, cane with no inputs and trash removed).

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CHANGES IN MICROBIAL BIOMASS ASSOCIATED WITH THE DEVELOPMENT AND AMELIORATION OF SUGARCANE YIELD DECLINE

John Holt and Malcolm Hodgen
CSIRO Land and Water

The soil microbial biomass (MB) is the combined biomass of all the bacteria, actinomycetes, fungi and small protozoans present in the soil. The most important function of the MB in soils is the mineralisation of organic matter and the subsequent release of plant nutrients. This function is vital for plant production in both undisturbed and agro-ecosystems. In general, MB tends to be higher in undisturbed systems where there is usually efficient capture of the mineralised nutrients by the plant community. In agro-ecosystems, the MB is often low and capture of mineralised nutrients by the cropped plants tends to be less efficient.

In the Sugar Yield Decline Joint Venture MB was determined in the initial paired sites experiment, in the rotation breaks experiments and in the rundown experiment.

METHODOLOGY

Soil sampling

On each sampling occasion, 10 soil cores, 50 mm diameter x 150 mm deep were collected from each treatment and bulked to form a composite sample. Samples were collected from a point approximately 300 mm from the base of plants in the cane and crop treatments, and from random locations within pasture and bare fallow treatments.

MB carbon

All soil samples were passed through a 2-mm sieve, adjusted to 40% water holding capacity and incubated at 4°C for 7 days prior to analysis. MB carbon was measured using the method of Amato and Ladd (1988), whereby a soil sample is fumigated under an atmosphere of chloroform for 10 days, followed by extraction of the fumigated soil with 2 M KCl and reaction of the extract with ninhydrin. A factor of 21 was used to convert the ninhydrin-reactive N (biomass N) to biomass carbon.

PAIRED SITES STUDY

The objective of this study was to compare MB in soil that had been under continuous cane with minimum breaks for >20 years (old cane land) with the MB in soil in an adjacent area of land that had not previously been used for cane production (new cane land). The definition of new land was sufficiently broad to include sites covering a range of treatments including pastures, plant cane (1st year under cane and previously scrub), first ratoon cane (previously uncultivated grassed headland) and a pumpkin paddock (previously under continuous cane). The results of the MB measurements are shown in Figure 10. There were significant effects ($P<0.05$) of sites and treatments. At 5 of the 7 sites (Tully, Fortini, Ingham, Kalamia and Pegararo) the MB of the new land was 34-60% higher than that of the old land. These sites had new land treatments where cane had yet to be planted (Tully, Ingham) or had been growing for less than 6 months (Fortini, Kalamia, Pegararo). At two of the sites the MB levels of the old land and new land were similar (Costanzo and Harney) (Figure 10). However, the new land treatments at these sites had already produced one crop of sugar cane and was supporting the first ratoon crop at the time of sampling. Averaged over all sites, the MB values were 411 μg C g soil^{-1} for new cane land and 246 μg C g soil^{-1} for old cane land.

The results demonstrated large difference between MB levels in old cane land and new land that has not previously grown cane (Tully and Ingham sites). They also demonstrated that following the introduction of cane to new land, MB levels dropped rapidly and that within 12-18 months, MB levels were similar to that in old cane land (Costanzo and Harney sites).

It was of interest to note that at the Kalamia site, where the new land site had been used previously for other horticultural activities, the MB was still higher than in the old cane land, and that the soils of a 2-year pumpkin rotation at Pegararo, following more than 30 years of cane production, also had higher MB levels than old cane land.

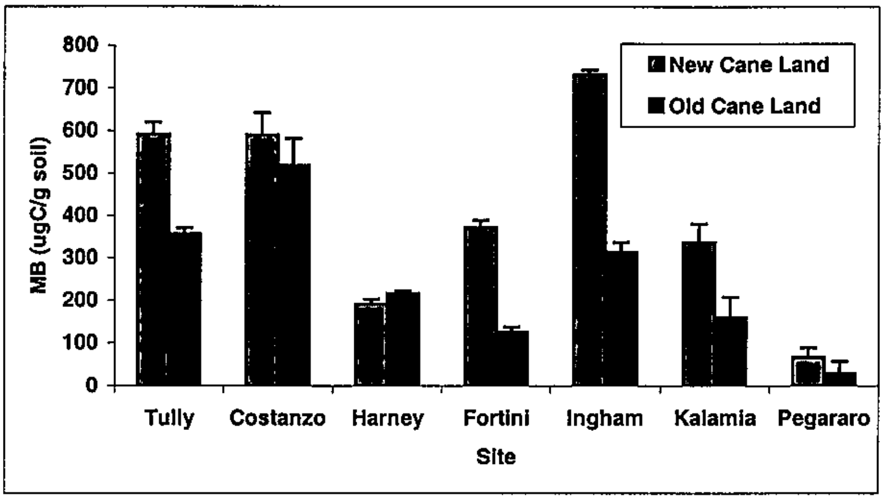

Figure 10. Microbial biomass at the paired sites.

ROTATION EXPERIMENTS

MB was monitored at regular intervals (at least twice a year) at each trial of the 4 experimental sites (Tully, Ingham, Burdekin and Mackay) from June 1994 until October 1998. Additional measurements were made in October 1999 by Pankhurst and Hawke.

At three of the sites (Ingham, Burdekin and Mackay) changes in MB were followed with all three rotation break treatments, ie. pasture, alternate crop and bare fallow in addition to a continuous cane control. The duration of the breaks were 30 months at Ingham and Mackay and 42 months at Burdekin. At this time the breaks and the continuous cane treatments were planted back to cane. A fumigation treatment was applied to the continuous cane block to provide a reference point for the "amount" of yield decline in the soil. At the Tully site, samples were collected from a wider range of treatments including long-term pasture, 42 month crop and pasture and 30 month crop and pasture plus 12 month bare fallow. The rotation breaks were returned to cane after 42 months at Tully.

Overall, the effect of the rotation breaks on MB was similar at each of the sites. An example of the trends observed is shown in Figure 11 for the Burdekin site. Relative to MB levels in the continuous cane treatment, MB was seen to decrease significantly under the bare fallow treatment at Ingham, Burdekin and Mackay (not measured at Tully) and to increase under the pasture treatment. The increase under pasture was least at Mackay, possibly because of the lower rainfall at this site compared to the other sites. MB under the alternate crop treatment was generally little different to that under continuous cane.

The effect of returning the breaks to cane on MB levels was seen mostly in the soil that had been under pasture. Here the MB that had increased under the pasture declined rapidly following the return of the soil to cane (Figures 11, 12). Twelve months after the return of the breaks to cane the level of MB in soil that had been under the pasture break was similar to that in soil that had been under continuous cane. In contrast, 12 months after the return of the bare fallow soil to cane the level of MB was still lower than that under the continuous cane treatment (Figure 11).

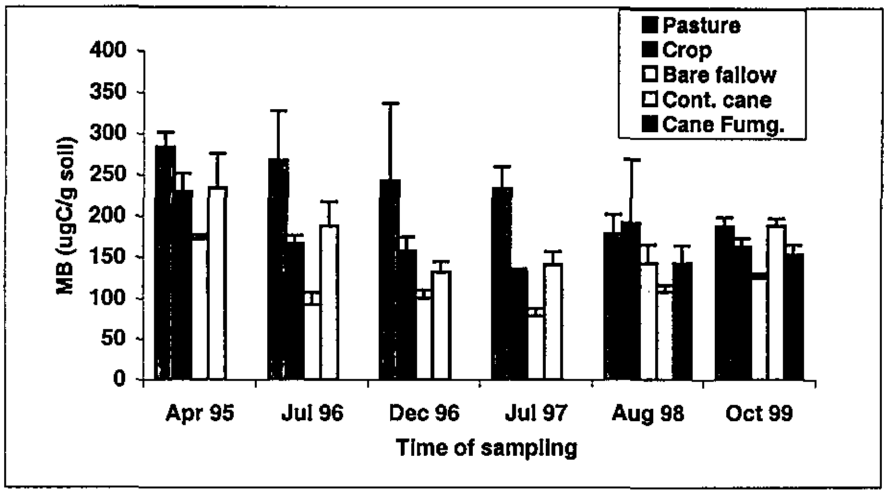

Figure 11. Effect of rotation breaks on MB at the Burdekin site. The breaks and continuous cane treatment were re-planted to cane in August 1998.

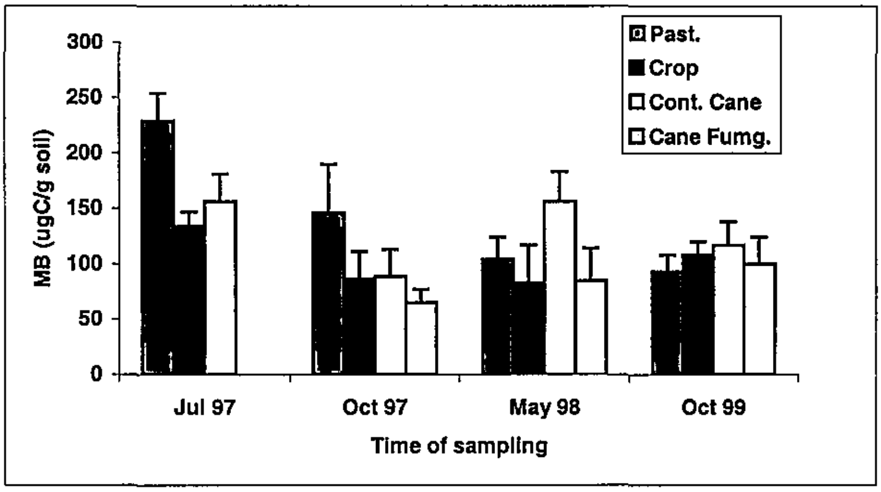

Figure 12. The effect on MB of returning pasture and alternate crop breaks to cane at Tully. The breaks and continuous cane treatments were re-planted to cane in October 1997.

Fumigation of continuous cane plots generally had a negative effect on MB which persisted for about 12 months before the MB levels returned to levels normally present in the continuous cane soil (Figure 12).

RUNDOWN EXPERIMENT

The objective of this research was to monitor (over a number of years) changes in MB following the planting of new land to cane. The experiment was established in 1995 on land that was under pasture and which had never previously grown sugarcane. Treatments plots were established in July 1996 and included four cane treatments; one treatment where the cane was planted with no chemical or fertiliser inputs and where trash was subsequently to be removed, and 3 cane treatments established with chemical and fertiliser inputs but where variations in the treatment of trash after harvest were to be imposed. These trash treatments were (1) trash burnt, (2) trash retained, and (3) trash retained and incorporated. Other treatments included bare fallow, alternate crops and plots that remained under pasture to be planted to cane at different future intervals. The experiment was terminated in 1998 because of difficulties with the hydrology of the site.

MB measurements were made on a selection of the treatments beginning with samples obtained in April 1996 following the first working of the experimental plots. This second lot of samples was obtained in September 1996, two months after the planting of cane in the cane plots. The cane was planted following two further workings of the soil in June. This additional working of the soil was of significance because the MB in each of the cane plots in September had declined significantly from the levels present in April (following the initial working of the new land) (Figure 13). The MB in the cane plots remained at this low level (compared to the MB in the pasture plots) throughout course of the experiment and re-affirmed the rapid loss of MB following intensive cultivation of previously undisturbed pasture soil. The MB in the bare fallow also declined rapidly and was similar to that in cane plots at the November 1996 sampling (Figure 13).

The dramatic decline in MB following cultivation and establishment of cane was again shown in plots of pasture that were cultivated and planted to cane in August 1997; here the MB level in the soil dropped to be similar to that in the other cane plots within 6 months (Figure 13).

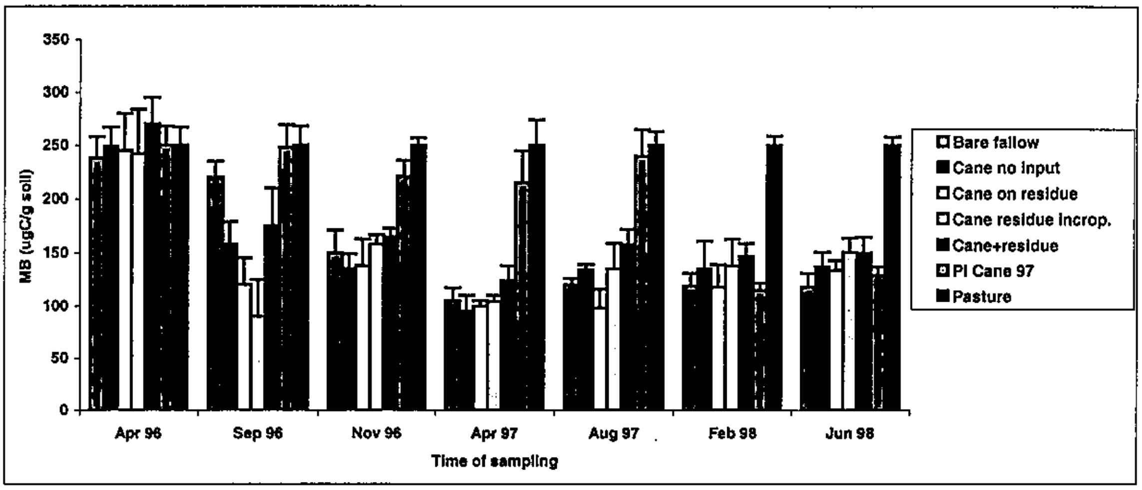

Figure 13. Effect of different cane management treatments on MB at the rundown site.

Within the four cane treatments there was evidence for an increase in MB in the two treatments where the cane trash was retained (on the soil surface, or incorporated) compared to the two treatments where the trash was removed.

CONCLUSIONS

1. The paired site study showed that MB in new cane land was substantially higher than that in old cane land.
2. MB declined rapidly (within 6-18 months) following the cultivation and establishment of cane on new land.
3. Rotation breaks imposed on land under continuous cane monoculture had different effects on MB. Compared to MB levels in the continuous cane treatment, MB increased under a pasture break, showed little or change under and alternate crop break and declined under a bare fallow break.
4. MB built up under a pasture break rapidly declined following cultivation and the re-planting of the soil to cane.
5. Retention of trash (including its incorporation) appears to favour the build up of MB.

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NEMATODE STUDIES IN THE SUGAR YIELD DECLINE JOINT VENTURE

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Several approaches were used to determine whether nematodes are important in the Queensland sugar industry.

SURVEYS OF NEMATODE DISTRIBUTION

Surveys of 548 fields in all mill districts south of Townsville, and data obtained previously from 155 fields in north Queensland are summarised in Table 23. Thirty five species of plant-parasitic nematodes were associated with roots of sugarcane, with more than a third being new records for sugarcane in Australia, namely *Pratylenchus teres, P. penetrans, P. coffeae, Macroposthonia xenoplax, M. caelata, Criconema talanum, Criconemella curvata, Ogma imbricatum, Paratylenchus colbrani, Helicotylenchus multicinctus, Hoplolaimus seinhorsti, Xiphinema radicicola* and *Rotylenchulus reniformis.*

Table 23. Distribution and population densities of plant-parasitic nematodes in various sugarcane regions of Queensland.

		% occurrence				
Common name	**Predominant genera and species**	**Southern**	**Mackay/ Proserpine**	**Burdekin**	**Northern**	**Mean population density (nematodes /200ml soil)***
Lesion	*Pratylenchus zeae*	100	100	100	100	929
Root-knot	*Meloidogyne javanica*	68	71	47	29	604
Stubby root	*Paratrichodorus minor*	83	95	68	24	128
Stunt	*Tylenchorhynchus annulatus*	68	81	96	30	248
	Rotylenchulus parvus	59	1	1	10	967
Reniform	*Helicotylenchus dihystera*	87	85	56	78	191
Spiral	*Criconema, Criconemella*					
Ring	and *Ogma* spp.	25	17	53	63	61
	Xiphinema spp.	28	66	20	35	47
Dagger	*Radopholus* and *Achlysiella*					
Burrowing	spp.	0	2	25	46	96

*** Mean population density at sites where the nematode was present.**

Lesion nematode *(Pratylenchus zeae)* was found in every field. Root-knot nematodes (predominantly *Meloidogyne javanica* but also *M. arenaria* and *M. incognita)* and stubby root nematode *(Paratrichodorus minor)* were present in 53% and 68% of fields respectively. On the basis of published information on their pathogenicity, these nematodes are considered the most important nematode pests of sugarcane in Queensland. Mean mid-season population densities were 929, 604 and 128 nematodes/200 mL soil, respectively. High numbers of lesion nematodes were commonly present in roots, with 28% of sites having population densities of more than 1000 nematodes/g dry weight of root.

A number of moderately pathogenic nematodes were found in most fields. Stunt nematode (*Tylenchorhynchus annulatus*) and spiral nematode (*Helicotylenchus dihystera*) were the most common species. Another spiral nematode (*Rotylenchus* sp.), reniform nematode (*Rotylenchulus parvus*) and several ring nematodes in the genera *Criconemella*, *Criconema*, *Macroposthonia* and *Ogma* were also relatively common.

Some nematodes of unknown pathogenicity were distributed widely enough to suggest that their importance on sugarcane should be determined. These included dagger nematodes (*Xiphinema* spp.), which feed ectoparasitically on root tips and cause damage to other crops at relatively low population densities, and *Achlysiella williamsi*, an endoparasitic species with a close taxonomic relationship to *Radopholus similis*, a serious pest of banana.

Nematode incidence was largely independent of soil type. However, root-knot and stubby root nematodes tended to occur more commonly and at higher population densities in sands and sandy loams. Highest densities of lesion nematode were recorded in the sandy loam, clay loam and clay soils of the Plane Creek mill area, and in the fine sandy loams of the Burdekin Irrigation Area.

High nematode densities were associated with plant crops, suggesting that the current fallow system has no more than a short-term effect in reducing nematode populations. Presumably many fallows are weed-infested and the length of the fallow (2-10 months) is too short for nematode populations to decline.

Plant-parasitic nematodes were not restricted to soils under long-term sugar production. In the Burdekin region, *P. zeae* was well established in 'new land' that had been recently planted to sugarcane, presumably because the nematode was present on the native grasses that existed prior to agricultural development.

Similar nematodes were generally found in all sugarcane-growing regions, but there were some regional differences. For example, there was more species diversity in the Burdekin than in other regions and *Achlysiella williamsi* was largely restricted to north Queensland and the Burdekin.

PATHOGENICITY STUDIES

The effects of *P. zeae* on sugarcane were examined by inoculating the nematode into methyl bromide-fumigated soil in 50 L microplots at initial densities (Pi) of 0, 9, 37, 250 and 350 nematodes/200 mL soil. Differences in initial nematode densities were maintained for 6 weeks, but at 12 weeks densities in all treatments were similar and populations peaked at about 2,700 nematodes/200 ml soil (Figure 14a). After 16 weeks, population densities in inoculated microplots were about 2,500 nematodes/g root, and did not differ significantly between treatments. When plants were harvested at 20 weeks, root weights were not affected by treatment. However all inoculated plants had darker root systems, with discrete dark red lesions on newly formed primary roots. Nematode infestation reduced the length and surface area of tertiary roots by 55 and 41 % respectively compared with the uninoculated control.

Three weeks after planting, progressively fewer shoots were initiated in microplots as numbers of *P. zeae* increased, but the large differences (25-129 %) were not significant ($P>0.05$). This pattern continued at 5 weeks, but the three highest inoculation densities had significantly fewer shoots. After 8 weeks, these differences were no longer apparent (Figure 14b). For the duration of the experiment, uninoculated plants and plants inoculated with low densities of nematodes (Pi = 9 and 37) tended to have a longer primary shoot than plants inoculated with high nematode densites (Pi = 250 and 350). Sometimes these differences were significant at either $P<0.05$ or $P<0.1$ (Figure 14c). Uninoculated plants and the low inoculum density treatment (Pi= 9) had significantly more leaves than the high inoculum density treatment after 5 and 8 weeks, but these differences were not observed at 12 weeks (Figure 14d). Shoot biomass was the highest in uninoculated (Pi = 0) and low inoculum denstity treatments (Pi = 9), but only the latter treatment was significantly greater ($P<0.05$) than plants inoculated with the highest nematode density.

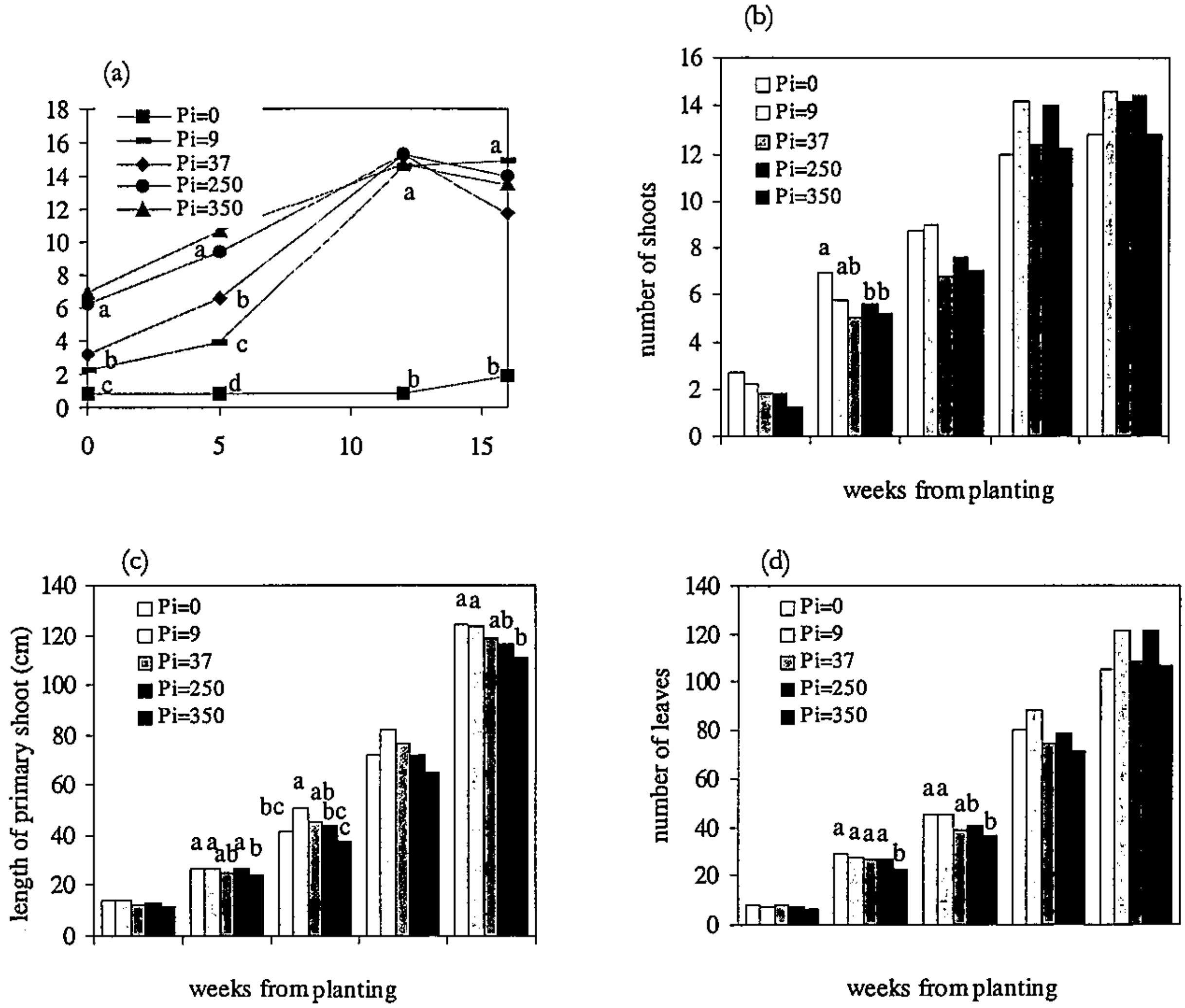

Figure 14. Multiplication of *Pratylenchus zeae* at five inoculum densities (a) and effect on number of shoots (b), length of the primary shoot (c) and number of leaves (d). Note: at each date, columns with the same letter are not significantly different at P=0.05.

The effects of root-knot nematode were examined in microplots using similar procedures to those used for *P. zeae*. Five initial densities of *M. javanica* (0, 7, 9, 153 and 786 nematodes/200 ml soil) were established and initial differences between treatments were maintained for 5 weeks after planting. However, after 12 weeks, nematode densities were similar in all except uninoculated microplots (Figure 15a). At harvest, nematode populations were highest in treatments inoculated with low densities (Pi = 7 and 9). Some uninoculated microplots were infested with nematodes but the population density was very low (Figure 15a). Nematode populations in roots at harvest were related to numbers in soil, with about 9, 18,700 and 9,500 nematodes/g root in uninoculated (Pi = 0), low inoculum densities (Pi = 7 and 9), and high inoculum desnities (Pi = 153 and 786) respectively.

Three weeks after planting, uninoculated (Pi = 0) and plants inoculated with a low nematode density (Pi = 7) had more shoots than treatments where Pi was 153 or 786. At later sampling times this difference was no longer apparent (Figure 15b). Length of the primary shoot and number of leaves were not affected by inoculation (Figure 15c,d).

At harvest, terminal galls were evident on primary roots and root length of inoculated plants was reduced by about 50%. Some discrete galling was evident on fine roots and the root biomass of all inoculated plants was reduced. However, this effect was significant in only two treatments (Pi = 7 and 9).

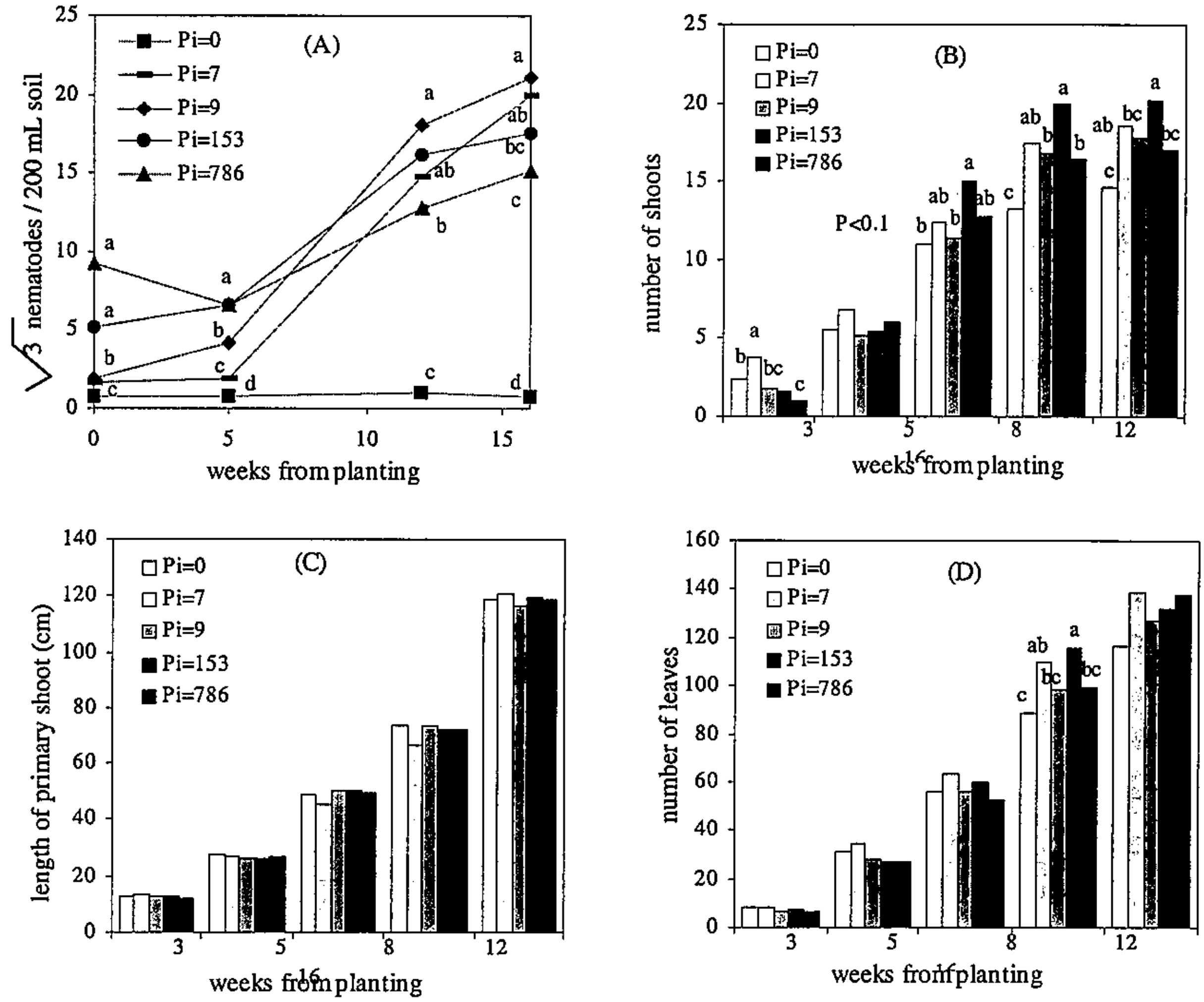

Figure 15. Multiplication of *Meloidogyne javanica* at five inoculum densities (a) and effect on number of shoots (b), length of the primary shoot (c) and number of leaves (d). Note: at each date, columns with the same letter are not significantly different at P=0.05.

The effect of soil moisture on the degree of damage caused by *P.zeae* was explored in another microplot experiment. Plants growing in the presence or absence of the nematode were subjected to three watering regimes: watered daily (90-100% field capacity), rainfed (50-80% field capacity) and moisture stressed (40-60% field capacity). Plant growth and nematode reproduction was measured after 34 weeks. Nematode multiplication was relatively poor, as final nematode densities were only 510, 88 and 159 nematodes/g root in well-watered, rainfed and moisture-stressed treatments, respectively. Shoot and root weight was not reduced by *P. zeae*, but nematode infestation reduced root length/g root by 74% in the moisture-stressed treatment. This suggested that nematode damage was more severe when environmental conditions limited root production, possibly because the rate of root regeneration was not high enough to replace roots lost to nematodes.

CROP LOSS ASSESSMENT USING NEMATICIDES

The non-volatile nematicides aldicarb and fenamiphos were used as a research tool to selectively control nematodes in plant and ratoon crops. Since these nematicides have little effect on root pathogens other than nematodes and do not affect soil nutrients to the same extent as the soil fumigants, the yield improvements that were obtained were attributed largely to nematode control.

At four rain-fed sites on clay loam and clay soils in the Moreton and Rocky Point mill districts (sites 1-4 in Table 24), three or four applications of nematicide per season reduced nematode populations by 60-95 % and increased yields by 2-19%. Nematicide-treated root systems were lighter in colour than untreated root systems and also had more feeder roots.

Table 24. Early and mid season densities of *Pratylenchus zeae* (Pz) and *Meloidogyne* spp. (Mj) in untreated plots at ten sites, and yield responses to nematicide treatment.

Site no.+	Clay content (%)	Irrigated (I) or rainfed (R)	Nematodes/200 ml soil (early season)		Nematodes/g dry weight root (mid season)		Yield response (%)
			Pz	Mj	Pz	Mj	
Plant crops							
1	8	I	359	0	10404	2732	51*
2	11	I	173	1	10502	2338	23*
3	8	I	340	0	14617	278	16*
4	15	I	52	5	2226	66	13*
5	66	R	16	4	2816	1174	12
6	16	I	46	6	2311	262	10
7	34	R	153	6	2321	54	13*
8	50	R	88	2	411	76	14
9	50	R	55	4	165	9	19*
10	14	I	49	0	2376	0	-1
11	8	I	98	11	1734	1237	16
12	8	I	180	2	2603	-	10
13	10	I	77	0	1209	0	11
Ratoon crops							
1	8	I	500	13	3155	108	37*
3	8	I	318	9	2531	7	0
4	15	I	353	1	1044	0	11*
5	66	R	248	5	296	69	5
6	16	I	238	14	1334	980	8
7	34	R	-	-	1877	0	2
8	50	R	176	2	38	2	11
9	50	R	172	2	165	0	2
14	13	I	800	0	83	4	7
15	13	I	456	2	145	-	20*

+Some crops were not harvested because nematode control was poor or the crop had lodged.
*Denotes a significant difference ($P<0.05$) between nematicide-treated and untreated.

Yield improvements were obtained in irrigated crops of average or above-average yield that were situated on various soils in the Bundaberg region. At the three sandiest sites (sites 8, 6 and 7, with clay contents of 8-11%), nematode populations in untreated plots were very high and nematicides controlled nematodes and increased plant crop yield by 16, 23 and 51%. At three sites (5, 9 and 10) on loam and silty loam soils (14-16% clay), yield responses in the plant crop were –1, 13 and 10%.

When nematicides were applied at Mackay (sites 11-15), nematode densities were reduced by about 90%. Nematicide treatment increased yield by 10-16% in the plant crop and 7-20% in the first ratoon. This is the first report of responses to nematicides in sugarcane in central Queensland.

When methyl bromide was compared to mancozeb and a nematicide (aldicarb plus fenamiphos) at a field site in Bundaberg, soil fumigation and the nematicide both increased the yield of plant plus first ratoon crops by about 15% (Table 25). The response to fumigation occurred only in the plant crop, possibly because nematodes re-infested fumigated plots and had reached high densities in the first ratoon. The nematicide maintained nematode control in both plant and ratoon crops and was the only treatment to significantly increase the yield of the ratoon crop.

Table 25. Sugarcane yields following various chemical biocides in a field trial at Bundaberg.

Treatment	Plant crop yield (tonnes/ha)	% increase	First ratoon yield (tonnes/ha)	% increase
Untreated	93 a	0	108 a	0
Mancozeb	99 a	6.2	119 ab	10
Nematicide	100 a	7.6	130 b	20
Mancozeb + Nematicide	103 a	10.4	127 b	18
Fumigation	120 b	29.4	108 a	0
LSD (P=0.05)	11.3		17.4	

ROTATION EXPERIMENTS

Rotation experiments at Tully, Ingham, the Burdekin, Mackay and Bundaberg were used to quantify the effects of various rotation practices on nematodes. Samples were collected periodically from each site, with most emphasis being placed on the period immediately prior to returning the land to sugarcane, and in the first year of the sugarcane crop.

P. zeae was present at all sites but population densities were lower at Tully than at the other four sites. Population densities were always highest following continuous cane than after other treatments. Methyl bromide generally gave good initial control of this nematode, as it was undetectable in soil samples taken a few weeks after fumigation at all sites except Mackay. Although lesion nematode re-colonised fumigated plots, population densities six months after planting sugarcane were always significantly lower than continuous cane. Bare fallow for 30-42 months controlled lesion nematode at all sites. Nematode populations at planting were never greater than 5 nematodes/200 mL soil in fallowed plots, and population densities remained low throughout the plant crop.

When legumes were grown for 12, 18 or 30 months, control of *P. zeae* was almost as good as with bare fallow. A 6-month crop gave some control, but a substantial nematode population was still present at planting. The effects of the legumes on lesion nematode persisted through most of the plant crop, provided the legume break was maintained for at least 18 months. A pasture break of 30-42 months reduced densities of lesion nematode in comparison to continuous cane, but the reduction was not always significant. Moderate numbers (10-40 lesion nematodes/200 mL soil) were generally present following long-term pasture, and population densities soon returned to high levels when land was returned to cane.

Several species of plant-parasitic nematodes other than *P. zeae* were present at all sites. Stunt and reniform nematodes, which are mostly hosted by grasses, responded to treatment in much the same way as lesion nematode. At Bundaberg, population densities of root-knot nematode were reduced following pangola grass, pintoi peanut and bare fallow, and some of these effects were still apparent in the second ratoon. Root-knot nematode was increased by the 18-month crop treatment at Tully.

Populations of free-living nematodes (i.e. nematodes that feed on bacteria and fungi rather than plants) were always reduced following fumigation and bare fallow. At some sites, their population densities remained significantly lower than other treatments for at least the first 6 months of the plant crop. Substantial increases in free-living nematodes were sometimes observed during the legume or pasture phase of the rotations. These elevated populations remained for some time after cane was replanted, but populations were not always significantly higher than continuous cane.

Yields increased at all trial sites when fumigation, bare fallow, crop or pasture treatments were returned to sugarcane. Since populations of plant-parasitic nematodes were reduced by each of these treatments, nematodes are one of the biotic factors that could have contributed to these responses.

ESTIMATES OF CROP LOSSES DUE TO NEMATODES

Data from previous experiments with nematicides and soil fumigants, together with information derived from this study, were used to determine the average yield response that can be obtained when nematodes are kept under control with an appropriate biocide. Crop loss estimates were then derived for various soil texture and crop stage categories, as they appeared to be the main factors that affected the degree of the response. These estimates suggested that in plant crops, crop losses due to nematodes are as high as 23-33% in sand and sandy loam soils, but are only 9%-13% in finer-textured soils. Equivalent estimates for ratoon crops are 17-26% and 3-9%, respectively.

Soil maps and descriptions of the major soil types in each mill district were used to estimate the area of each mill district that is located in various soil textural classes. This information, and estimates of the % loss due to nematodes in various soil types, was used to calculate a crop loss figure for Queensland. This process showed that nematodes are probably costing the sugar industry about $100 million per annum, and demonstrates that they are a far more important pest than is currently recognised by the industry.

ROLE OF NEMATODES IN YIELD DECLINE

Evidence obtained in this study suggests that nematodes are associated with two types of poor growth problem in sugarcane.

Poor growth syndrome in sandy soils. This problem is largely caused by root-knot and stubby root nematodes, which reach high population densities in sandy soils. Root-knot nematodes limit root elongation by producing terminal galls on primary roots. Stubby root nematodes feed in the meristematic region of roots, causing swelling of root tips and stunting and forking of roots. Affected root systems have a reduced capacity to explore the soil for water and nutrients. Since sandy soils are infertile and have a low water-holding capacity, nematodes cause severe damage in such soils. Crop losses of 30-60% can occur, and responses to registered rates of nematicide are often obtained. Despite its severity, this syndrome is not of major importance to the sugar industry because it is restricted to relatively small areas of very sandy soils.

Chronic nematode damage in all soils. This problem is mainly caused by lesion nematode (*Pratylenchus zeae*). This nematode lives and feeds in roots, destroying fine roots and causes purplish black lesions on primary and secondary roots. Since about 80% of the sugarcane root system consists of fine roots, damage from lesion nematode reduces the efficiency of the root system. Other widely distributed nematodes (e.g. root-knot, stubby root, dagger, stunt, reniform, ring and spiral nematodes) contribute to the problem.

Chronic damage from this complex of nematode species results in yield reductions that are high enough to implicate nematodes as significant contributors to yield decline. Because every field is infested and yield losses are not high enough to devistate crops, the effects of nematodes are insidious. They only become apparent when nematode-free areas are available for comparison.

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SOIL INVERTEBRATES

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QDPI

The rotation experiments were regularly sampled for soil invertebrates during the period when they were under breaks and continual sugarcane. The main findings to emerge were:

- The herbivore group dominated the numbers of soil invertebrates recoverd from all sites. Of this group the family Margarodidae had the largest number of individuals. This group is a known pest of sugarcane. At one site (Ingham) numbers reached 34,000 per m^2. Levels of this order could be expected to have an adverse effect on sugarcane yield.

- Predator numbers were low at all sites and in most areas spiders were the major predator.

- Detrivore numbers were less than herbivore numbers and the majority were worms or cysts.

- Tully was the main experimental sites where numbers of "other invertebrates" were recovered.

- It was difficult to demonstarte an effect of pastures on the different groups of invertebrates as the pasture composition varied with site and season. However, herbivore and predator groups were able to survive year round in the pastures at all sites.

- Of the cropping treatments maize was not a good host of margarodids whereas peanut and soybean crops supported and increased numbers of all herbivores. Indian mustard, used as a cover crop at one site, did not have any noticeable effect on invertebrate populations.

- Bare fallow treatments reduced most populations, except margarodids, and this could have been due to the resting populations moving to the surface in search of food.

- The effect of trash being removed or retained from the cane treatments is inconclusive as there were no differences in margarodid populations at some sites but differences at others.

Publications from the Soil Inertibrate Studies

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SOIL CHEMICAL PROPERTIES

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BACKGROUND

The working definition of sugar yield decline as used for the Sugar Yield Decline Joint Venture (SYDJV) is that it is the *decline in productive capacity of soils under sugarcane monoculture.* Thus, the rationale of the soil chemistry sub-program has been that, under long term sugarcane monoculture, changes in soil chemical properties have effected a decline in the soils' productive capacity. Notwithstanding the known effects of root pathogens (Magarey 1994), such changes in soil chemical properties may be directly detrimental to root health, may also have the indirect effect of increasing plant susceptibility to the effects of pathogens, or may simply result in a decline in the inherent fertility of the soil. Any or all of these effects would have the net effect of decreasing sugar yield. Much of the work carried out in the first phase of the SYDJV was therefore aimed at identifying soil chemical properties that might be associated with, or even precursors to, the yield decline phenomenon. With respect to soil chemical properties and soil organic matter, this report summarises the Phase 1 key findings from the paired sites study, the northern and southern rotation trials and the Bundaberg trash management trial.

THE PAIRED SITES STUDY

The approach of this study was to compare a range of soil chemical properties in samples taken from paired adjacent blocks of land which had either been under sugarcane monoculture for many years, or which had either never been planted to sugarcane or were in their first year of sugar production. The work has been fully reported by Bramley *et al.* (1996), and has also been discussed by Garside *et al.* (1997).

The key findings of the study were:

- There was little evidence of a consistent effect of time under sugarcane monoculture on soil chemical properties across all sites. In contrast, when individual sites were considered separately, marked effects of time under monoculture could be seen. However, the direction of these effects was not always the same across all sites. Since all the soil samples were taken from non-virgin sites, and were subject to normal farmer practice with respect to tillage and fertiliser management, this was not an unexpected result.
- At most sites there was some evidence of acidification under sugarcane monoculture, either in the surface soil or at depth. This acidification was reflected in a decline in soil pH and/or an increase in Al saturation of the ECEC.
- At several sites, higher amounts of DTPA-extractable manganese were noted in old compared to new land.
- The amounts of DTPA-extractable zinc, iron and copper tended to be depleted in old compared to new land.
- There was evidence of loss of CEC in old caneland compared to new. The reason for this loss was unclear, but it could be due to either a decline in soil organic matter and/or a loss of the clay fraction. While the former decline is probably associated with frequency of tillage, the latter is most likely a consequence of soil acidification.

Taken overall, these results suggest a general decline in soil fertility over time under sugarcane monoculture, with gradual soil acidification a common occurrence. It is suggested that these conditions may limit microbial diversity in the soil microflora as well as pre-disposing the cane root system to pathogen attack because of unthrifty growth. Both these consequences are commensurate with the yield decline phenomenon.

NORTHERN ROTATION SITES

Soil chemical analyses following 3-4 years of crop rotation

Soil samples were taken during 1997 immediately prior to the harvesting which signalled the end of the rotation phase at the Mackay, Ingham and Tully sites. The rotation phase treatments had been in place for 3-4 years. There were few changes in soil chemical properties during this period, indicating that the trials will need to be maintained for several more years to obtain significant effects (Bramley, 1999). At all sites, soil pH indicated that all treatments (cropped, pasture, bare fallow, continual cane) showed evidence of acidification compared to baseline values at the commencement of the rotation treatments. The cane treatments appeared to be the most acidifying.

SOUTHERN ROTATION SITE

Soil chemical analyses following 12 months of crop rotation

Soil samples were taken immediately prior to planting the sugarcane crop following 12 months of various fallow period treatments that included short term cropping. There were minimal changes in soil chemical parameters, although significant ($P<0.05$) treatment effects were evident in the Walkley-Black organic C content of the 0-10 cm layer. The short term cropping treatments of maize and grain legumes, and the bare fallow treatment, had the lowest contents of organic C. The highest contents were recorded under long term Pangola grass and Pinto peanut swards.

SOIL ORGANIC CARBON AND KEY SOIL PROPERTIES

The maintenance of soil organic matter levels in soils is essential for several key chemical, physical and biological properties. For example, soil organic matter has been variously shown to be positively correlated with CEC, pH buffer capacity, and aggregate stability. All these properties are critical for the maintenance of the productivity of the soil. These considerations have prompted an investigation of the role of soil organic C in determining key soil properties at the various SYDJV field sites, and the effects of fallow management on organic C.

Soil organic carbon characterisation

Prior to the establishment of the rotation trials at Ingham, Burdekin and Mackay, and the rundown site at Tully, composite profile samples were taken and analysed for total C and protected C (mainly charcoal). Protected C as a percentage of total C ranged from 16% to 48% indicating there were large differences between sites in the amount of soil organic C present as inert charcoal (Skjemstad and Janik, 1999).

Soil organic carbon and cation exchange capacity

All treatments at the Tully, Ingham and Mackay rotation sites were sampled immediately prior to the end of the rotation phase, and samples analysed for CEC, total C and labile C (organic C oxidised by 33 mM permanganate). There was no correlation between either total C or labile C and CEC when data for the 0-10 cm samples of all treatments were pooled across the three sites. However, when data from individual sites were considered, there was a significant correlation between total C and CEC at Tully ($r^2 = 0.48$) and Mackay ($r^2 = 0.56$), with labile C being a better predictor of CEC than total C at both sites (Tully: $r^2 = 0.48$; Mackay $r^2 = 0.83$). No significant correlations were obtained between organic C and CEC at Ingham.

Soil organic carbon and microbial biomass

Microbial biomass C, total C and labile C were determined on bulked 0-10 cm samples taken from the Bundaberg rotation trial in November, 1996. For the unfumigated treatments, there was no significant relationship between total C and microbial C, but the relationship with labile C was significant (r^2=0.77, P<0.01). The fumigated plots lay below the trend line, a consequence of having a C status similar to the unfumigated plots, but a greatly reduced microbial population.

Soil organic carbon and aggregate stability

Aggregate stability following immersion [measured as mean weight diameter (MWD)] was determined on 0-10 cm samples taken from the Bundaberg rotation trial after harvest of the plant crop, or after 2 years of cropping, Pangola grass or Pinto pastures. Results indicated that pastures (especially Pangola grass) were particularly effective at improving the stability of aggregates compared to continual cane, while annual cropping tended to produce lower aggregate stabilities than under continual cane (Table 26).

Table 26. Concentrations of total C and C1 in soil at the Bundaberg rotation trial site, and Mean Weight Diameter (MWD, mm) of aggregates after immersion wetting.

Treatment	C fraction 1 (C1) (mg/kg)	Total C (Leco) (mg/kg)	Mean Weight Diameter (mm)
2 y cropping	1.15	14.67	0.90
2 y Pangola	1.26	12.43	5.16
2 y Pinto	1.22	13.17	1.99
Burnt cane monoculture	0.92	12.00	1.46
GCTB monoculture	1.05	12.33	1.34
lsd (0.05)	**n.s.**	**4.14**	**0.84**

An examination of the relationship between MWD and the concentration of either total C or labile C showed a clear separation of the 2 y Pangola plots from all others, and a highly significant correlation between the labile C fraction and MWD in the plots other than those in Pangola (Figure 16). The separation of the Pangola plots probably reflects the role of the fibrous root system in the grass pasture in stabilising aggregates. Once those root and hyphal networks are destroyed during preparation of the land for cane planting, the primary role in aggregate stabilisation reverts to the labile fractions of soil organic C.

Effects of fallow management on soil organic carbon

Soil samples were taken from the Mackay, Ingham and Tully rotation sites immediately prior to the harvesting which signalled the end of the rotation phase. Total C and labile C were determined to assess the effects of rotation management on soil organic carbon levels.

There were no significant (P=0.05) effects of rotation treatment on organic C, but trends were evident after the 30 or 42 month rotation phases (Table 27). In particular, the results reinforced the beneficial effect of pasture treatments on increasing soil organic C, the decline of soil organic matter under clean fallow, and the benefit of trash retention compared to trash removal. The proportion of the total C present as labile C was higher under pasture than other rotation treatments, and the proportion under continual cane was higher than that under fallow.

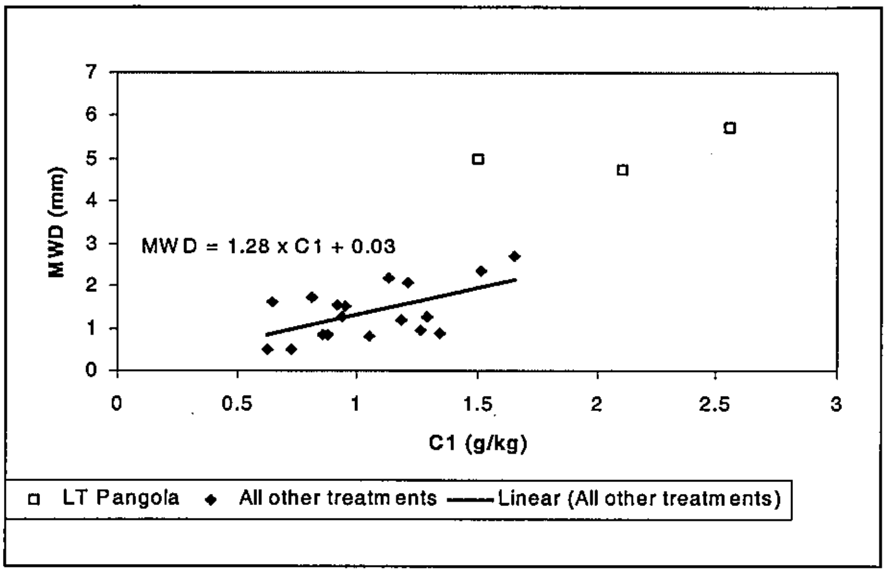

Figure 16. Relationship between C1 and the MWD of aggregates from the Bundaberg rotation site.

Table 27. Total C and C1 in the 0-10 cm layer at the Mackay, Ingham and Tully sites following various rotation treatments. Mean standard errors are in parentheses.

Site	Treatment	Total C (mg/kg)	C1 (mg/kg)	100C1/Total C (%)
Mackay	30 mth pasture	11.79 (2.44)	1.08 (0.31)	9.2
	30 mth crop	9.71 (1.22)	0.83 (0.15)	8.5
	30 mth fallow	9.50 (0.89)	0.84 (0.17)	8.8
	cont. cane	10.14 (0.40)	0.97 (0.13)	9.6
Ingham	30 mth pasture	17.00 (1.47)	1.65 (0.19)	9.7
	30 mth crop	12.91 (0.56)	1.04 (0.07)	8.1
	30 mth fallow	10.36 (2.34)	0.79 (0.22)	7.6
	cont. cane trash removed	13.74 (0.31)	1.27 (0.11)	9.3
	cont. cane trash retained	15.72 (1.14)	1.41 (0.16)	9.0
Tully	30 mth pasture + 12 mth falllow	13.51 (0.19)	1.41 (0.08)	10.5
	42 mth pasture	17.84 (1.17)	2.20 (0.19)	12.3
	30 mth crop + 12 mth fallow	8.58 (0.08)	0.73 (0.02)	8.5
	42 mth crop	10.46 (1.53)	0.93 (0.14)	8.9
	42 mth fallow	8.67 (1.25)	0.69 (0.02)	8.0
	cont. cane trash removed	11.22 (0.21)	1.07 (0.05)	9.5
	cont. cane trash retained	13.77 (1.65)	1.38 (0.09)	10.0

Effects of trash blanketing on soil organic carbon

In the Bundaberg Trash Management experiment, there were trends for total C and labile C to be higher in the 0-5 cm soil layer 5 months after trash blanketing than in the trash burnt or trash incorporated treatments (total C: 1.24 $\pm$0.02% vs 1.12 $\pm$ 0.01%; labile C: 1.42 $\pm$0.08% vs 1.17 $\pm$0.06%). These differences persisted for at least 8 months. It is apparent that trash blanketing has an early effect on improving soil organic C status, and the effects of this increase on soil properties and cane productivity need to be quantified.

SUMMARY

The several rotation trials of the SYDJV have provided opportunities for selective sampling of treatments to elucidate the relationships between soil organic C and soil properties, and the effects of rotation phase treatments on soil chemical properties and soil organic C levels.

Results suggest a general decline in chemical soil fertility over time under sugarcane monoculture, with gradual soil acidification a common occurrence. It is suggested that these conditions may limit microbial diversity in the soil microflora as well as pre-disposing the cane root system to unthrifty growth.

Clear links have been demonstrated between total organic C and the key soil properties of CEC, aggregate stability and microbial biomass. In all cases, an equivalent or greater proportion of the variation in the soil property was explained by labile C than by total C. This indicates that the easily oxidisable fraction of the total C is a primary determinant of the key soil properties. Total C, while measuring labile C, also measures the inert charcoal fraction of the soil organic matter, and is therefore not a sensitive indicator of changes in labile C. The proportion of the total C which is present as charcoal has been shown to vary between the rotation sites, and this highlights the necessity to measure the labile soil C when assessing the effects of fallow management on soil properties.

Green cane trash blanketing has been shown to increase total C and labile C in the surface soil relative to burnt cane systems. Of greater significance, different managements of the fallow (rotation) phase have also been shown to affect the amount and proportion of total soil C which is present as the labile fraction and which, by inference, can be assumed to have differential effects on key soil properties. Management of this phase therefore offers an opportunity for producers to improve the sustainability of the cane system by capturing the benefits of an improved labile soil C component. It is also possible that increased levels of labile soil C will lead to increased diversity in the soil microflora, and improved soil suppressiveness to root pathogens. These aspects warrant investigation as they may well be contributing to the yield decline phenomenon.

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SILICON STUDIES

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The Joint Venture has focused some of its activities on studies of soil silicon because it is well established that sub-optimal levels can result in decreased cane and sugar yields. Sugarcane responses to silicon can be attributed to a number of factors, including protection from insect and fungal disease damage and improved structural strength (more lodging resistance) of the sugarcane plant.

Soil maps developed for virgin soils on the wet coast showed that out of some 34,000 ha of land rated suitable for sugarcane production in the area between Tully and Innisfail, 67% is low to very low in soil silicon and a further 28% is marginal. To make matters worse, paired site analysis shows that many of these soils are becoming more deficient under the long-term sugarcane monoculture system. Conversely, analysis of the Joint Venture rotation sites has shown that breaking the monoculture with rotations can increase the availability of silicon. Further, it appears that varieties can also play a part, with the more recently released varieties having lower stalk silicon levels than historical varieties. This probably has important implications for crop lodging.

Research into silicon, particularly with regard to the most suitable products to apply and application rates, is continuing.

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SOIL PHYSICS AND MODELING

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INTRODUCTION

The effect of long term monoculture on soil physical properties was regarded as a critical component of the yield decline problem in sugarcane. In this report we summarise key issues associated with soil physical studies carried out as part of the SYDJV. The key work areas included the paired sites studies, the Rundown experiment, and modeling and systems analysis.

PAIRED SITES STUDIES

Soil physical properties of 'new' and 'old' land were determined for the seven sites in the Burdekin (2), Herbert (2) and Tully (3) sugar growing regions in North Queensland as part of the Sugar Yield Decline 'Paired sites' investigations. The aim of this work was to improve understanding of the soil physical properties in sugar growing areas and to assess the degree of physical degradation as a result of sugarcane monoculture.

The paired sites were selected to cover a range of soil types, climates, and management practices. In most cases measurements on the 'old' land (which had been cropped to sugarcane for more than 20 years) were made on the mounds and furrows to distinguish between the two major soil zones that characterise sugarcane farming systems. The soil physical properties measured as part of this exercise included:

- gravimetric water contents
- soil strength measurements obtained using an automated field penetrometer
- water infiltration properties obtained using a disc infiltrometer
- saturated hydraulic conductivity (k_s) measured on undisturbed soil cores
- bulk density based on oven dried soil of a known volume
- soil water retention data determined in the laboratory on undisturbed soil cores using hanging water column and pressure chamber apparatus
- soil bulk density determined on the soil cores used for soil water retention measurements
- particle size distributions determined in the laboratory using the Pipette method

Results of the soil physics studies have been detailed in several reports by Ford and Bristow (1995a, 1995b) and Garside et al. (1997a,b). Although spatial variation between pairs of individual sites with respect to soil texture to some degree masked differences between 'old' and 'new land', analysis of the soil physical data yielded some distinct trends, with 'old land' in general tending to have

- higher bulk densities
- higher soil strengths, with values greater than 2 MPa at 5 of the 7 sites
- greater levels of compaction at depths of 10-30 cm
- lower water holding capacities, and hence less plant available water

The higher values for bulk density and soil strength values >2 MPa would in many cases have the potential to restrict rooting depths and highlighted in particular compaction problems associated with old land that had been subjected to a sugarcane monoculture. More detailed statistical analysis of the paired sites soil physical data confirmed that the sugarcane monoculture has indeed resulted in physical degradation, especially when compared with originally forested areas (McGarry et al., 2000).

Although the soil physical data obtained through this work yielded typical spatial variability, they have provided much needed data and improved knowledge of some of our key sugar soils. They have added to our data base of soil physical properties and assisted in the development and testing of pedotransfer functions. The soil water retention data have proved particularly useful in this regard, and added to our ability to estimate soil hydraulic properties from more readily available data such as particle size distributions (Bristow et al., 1999b; Smettem et al., 1999; Smettem and Bristow, 1999). This has played an important role in adding to our understanding and prediction of soil hydraulic properties, an area of particular importance when attempting to improve management of water and nutrients within sugarcane production systems.

THE RUNDOWN EXPERIMENT

The Rundown experiment was established in 1995 at a site near Tully in north Queensland. It was established on a site with no previous history of sugarcane, the aim being to analyse changes in soil properties with time in an attempt to establish critical factors which lead to a break down in the soils productive capacity, as expressed by a decline in crop yield. The basic questions underpinning the Rundown experiment are captured in Figure 17, where the biological response (A) could be measured using fumigation. The remaining response (B) could then be attributed to physical and chemical factors. The intent was to use the information coming from the Rundown experiment to develop more targeted research and/or management strategies to limit the negative impact of changes in soil biophysical properties on sugarcane yield. The Rundown experiment and rationale are covered in more detail in the reports by Bristow (1996, 1998)

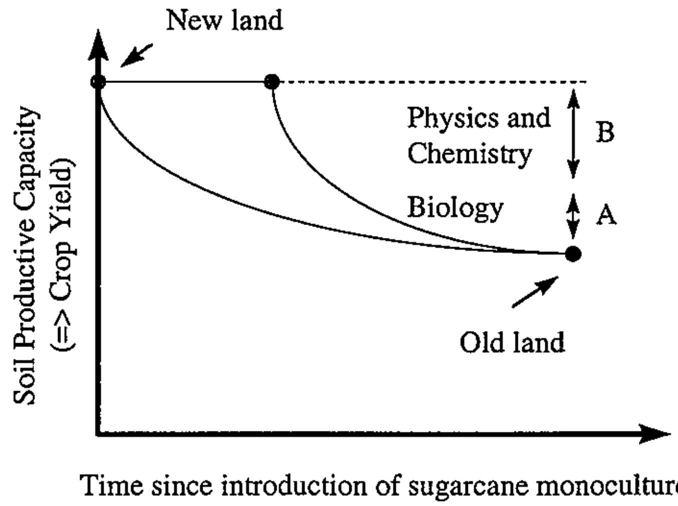

Figure 17: Schematic of changes in soil productive capacity under monoculture systems. 'A' gives the response to fumigation, which is attributed to biological factors, 'B' the response to changes in soil physical and/or chemical properties, and 'A+B' the overall loss of productive capacity of the soil (ie decline in soil health).

Full physical, chemical, and biological characterisation of the site was carried out prior to introducing sugarcane to the site. A variety of routine sampling and monitoring procedures were set in place to follow changes in time, with a goal to carry out a complete physical, chemical and biological characterisation of the site at the end of the first crop cycle. The experimental design was such that it would have provided a range of cropping histories at the end of the first plant cycle when the whole site was to be put back to plant cane, and an ability to determine which soil properties had changed and how those changes had impacted on crop growth and yield. By knowing how the soil properties had changed it was felt that more targeted studies could be implemented to avoid, minimise, or manage some or all of the negative impacts associated with undesirable changes resulting from the monoculture system. Details of the Rundown experiment and initial characterisation are provided in the report by Bristow et al. (1999a), while details of the field site instrumentation and measurements of the physical environment are provided by Goding et al. (2000).

One 'problem', or 'opportunity', that showed up soon after establishing the Rundown site, even though it was established on a freely draining soil, was the presence of a shallow fluctuating water table (Figure 18). The weather patterns experienced in recent years meant that the shallow ground water generated extended periods of water logging at the site. This added extra challenges to the experimental program, in terms of obtaining reliable experimental data, and in interpreting the data obtained from the site. Experimental procedures and analyses of the shallow groundwater are provided in the report by Goding and Bristow (2000).

The soil data obtained at the beginning of the experiment also proved invaluable in adding to our physical, chemical and biological knowledge of sugar producing soils. These data have all been documented (Bristow et al., 1999a), and the soil physical data (especially the water retention data) used to add to our database along with the paired sites data for constructing and testing pedotransfer functions for northern Australia (Bristow et al., 1999b; Smettem et al., 1999).

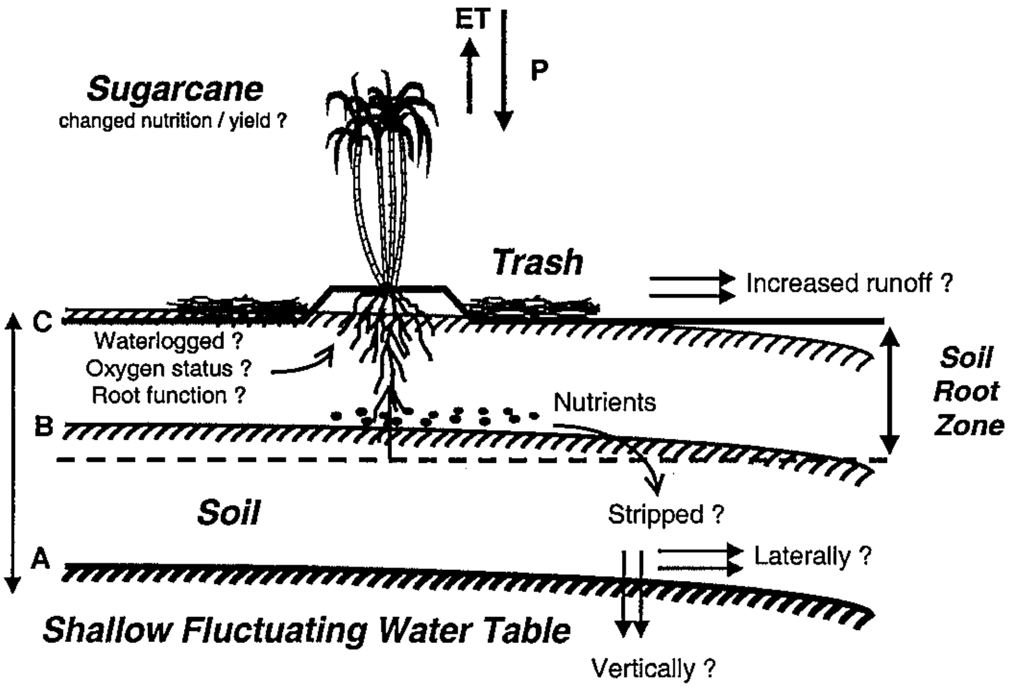

Figure 18: Schematic showing a shallow fluctuating water table and potential movement of nutrients in the rootzone. A, B, and C indicate water table depths at different times

Opportunity was also taken to install a network of piezometers at the Rundown site to monitor the dynamics of the water table, and this allowed in the time available one sampling of groundwater quality. The water quality data were grouped to reflect three different depths in the groundwater, namely the 45 to 65 cm depth, 100 to 120 cm depth, and greater than 150 cm depth. The aim in doing this was to 'stratify' the groundwater to determine whether there were trends with depth. The Main results have been documented by Goding and Bristow (2000).

When comparing the mean values for the three different groups, the water quality data indeed suggested that there were trends with depth in EC, pH, nitrate, and to some extent calcium, potassium and magnesium. The other major elements that were analysed showed very low concentrations (in some cases below detection levels) and no clear trend with depth.

Nitrate, in terms of magnitude and trend with depth was the most interesting of the measured water quality data as there were fairly high values of nitrate near the surface (mean 44 ppm) and a decline to 18 and 5 ppm with depth into the groundwater. This suggests that nitrate was being sourced from the surface and that at the time of sampling it was not yet fully mixed through the groundwater. The source of nitrates is not clear, but could have been fertiliser-N applied to the sugarcane and/or surrounding pasture, as well as N from mineralisation following conversion of pasture to cane land. Based on the above concentrations there could be in excess of 100 kg NO_3^- ha^{-1} in the groundwater at depths between 50 and 150 cm (at least at the time of sampling), and its fate will no doubt be controlled in some way by the groundwater. This nitrate could be stripped laterally and/or vertically by the groundwater, or some of it could be left in the soil profile when the groundwaters recede (Figure 18). Not enough is known about these issues yet to make any definitive statements about the source or the fate of the observed nitrate, or likely changes in the nitrogen dynamics with time as the period of the sugarcane monoculture increased, and it is unfortunate that closure of the Rundown experiment did not allow further study of these issues. Given the widespread occurrence of relatively shallow groundwaters in many of the sugar producing areas this is certainly an issue that warrants further research.

Although difficulties caused by waterlogging at the field site and the early closure of the Rundown site due to restructuring of research programs meant that the original objectives of the Rundown experiment were not fully realised, the experiment did through the time it ran provide useful insights into aspects of sugarcane production in very wet environments. It was also very useful in highlighting the need for improved understanding of a wide range of issues associated with shallow fluctuating ground water systems, including the likely

- impacts of shallow groundwater systems on soil physical, chemical and biological soil properties
- impacts of extended periods of waterlogging on the oxygen status of the root zone and on root function (especially nutrient and water uptake)
- impacts of shallow fluctuating groundwaters on nutrients in the root zone
- fate of nutrients and other chemicals that enter shallow groundwater systems
- role of shallow groundwater systems in terms of crop water supply, and ultimately crop growth and yield

Some aspects of the above are now being addressed in other studies, including two LWRRDC funded projects titled "Sustainable management of the Burdekin delta groundwater systems" and "Improved irrigation scheduling for crops underlain by shallow, fresh watertables".

MODELING AND SYSTEMS ANALYSIS

Considerable progress was made in our ability to model water and nutrient dynamics in sugarcane systems. This was achieved by using the above paired sites and Rundown studies to improve our knowledge of soil properties and their parameterisation for use in analysing water and nutrient balances, and by collaborating with other sugar projects and APSRU to progress development of our simulation capabilities. This collaboration also allowed access to the sugar model (generally referred to as APSIM-Sugarcane) for analyses as needed within our work. Experiences within the SYDJV, which involved working across a range of soils and climates, have provided many challenges to the ongoing modeling efforts, and we believe considerable stimulus for adding to and improving our modeling capability, several aspects which are now being followed up by APSRU.

A workshop on "Modeling the Soil Water and Nutrient Balance of Sugarcane" was also held as part of this project and provided an important focal point for an evaluation of our current modeling capabilities. The workshop was funded jointly by the SYDJV, CSIRO, and the Sugar CRC, and provided an ideal opportunity to expose a wide range of sugar researchers to the challenges and benefits of using simulation models to help with their research work. Workshop materials and proceedings are compiled in the report by Bristow et al. (1997). The hope is that as more researchers are exposed to the benefits of modeling, more of them will use a modeling and measurement approach in their work to gain maximum return from the effort invested in their research program. The APSIM-Sugarcane model is now well advanced for many applications, and opportunities for its use in Yield Decline Phase 2 are currently being explored.

Examples of where these models were used to highlight some of the issues associated with yield decline include 1) analysis of the impacts of compaction on sugarcane growth and performance, and 2) analysis of the impact of poor 'root health' on sugarcane growth and performance. The Rundown site was used for these analyses, which proved especially challenging given the shallow fluctuating water table and the fact that we do not yet understand just what impact these shallow water tables have on nutrient dynamics, root growth and function, or crop growth and yield. The analyses were however useful in illustrating the issues involved and the ability of modeling to help identify gaps and integrate and compare various scenarios.

As an example, Table 28 provides results of simulations for a situation where compaction was introduced at the 20-30 cm zone, as could happen when changing from the pasture to a sugarcane monoculture system. In these simulations we also used a freely draining soil profile scenario. Although we see a distinct increase in the runoff in the compacted situation, this could still be somewhat of an underestimate, as the simulations did not account for potential changes in near surface structure and development of surface seals. The increased runoff in this case was almost totally accounted for by a similar reduction in deep drainage. Realistic rainfall storm structures could also be used to evaluate more accurately what happens at short time scales. The fact that transpiration does not change much indicates that at this site at least, crop yield will be similar under both the compacted and non-compacted scenarios. This is to be expected for this climate given the regular and large amounts of rainfall

Table 28: Simulated cumulative water balance (mm) for non-compacted (new land) and compacted (old land) scenarios (1/1/96 – 30/40/98)

	Compacted (Old land)	**Non-compacted (New land)**
Water balance terms		
Soil evaporation	1500	1533
Plant transpiration	1682	1723
Runoff	1426	0
Drainage	4876	6231
Change in soil storage	96	93

Attempts were also made to analyse nitrate dynamics and nitrate leaching at the Rundown site with and without a water table. The aim was to assess what could happen by introducing drainage at the site and in what way that would benefit the crop. The simulations showed that nitrate leaching would in fact increase in the absence of a water table (Figure 19). This resulted from the freely draining nature of the soils and the large amount of water that passed through the soil profile in the absence of a water table. Inclusion of a water table in the analyses suggested increased runoff and not as much flow downward through the soil profile, hence the reduced amount of nitrate leaching in this scenario. What the model could not tell us is how much lateral movement of nitrate there is likely to be with lateral movement of the regional groundwater.

As part of this work we also simulated profile nitrate nitrogen for the various treatments at the Rundown site to analyse what will happen to the soil nitrate as time progressed following introduction of sugarcane monoculture. The simulation results are shown in Figure 20. The marked impact of the wet season on soil nitrate levels is clear and the no-input crop treatment (retained N0) shows that nitrogen in the system can be depleted rapidly by the crop. The bare fallow system also shows some seasonal variation and a gradual decrease with time in soil nitrate levels.

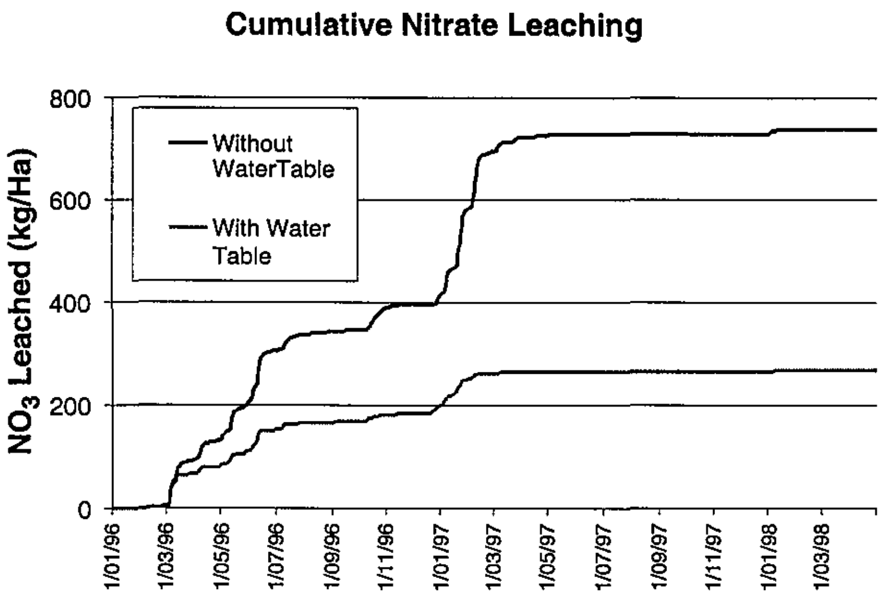

Figure 19: Simulated nitrate leaching in the presence and absence of a shallow water table

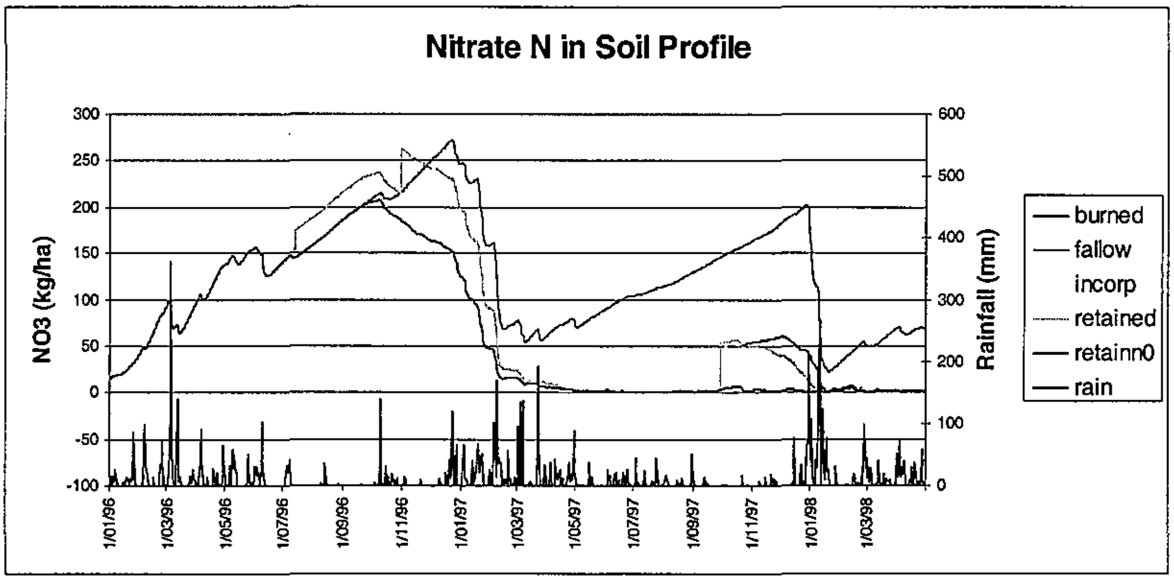

Figure 20: Simulated nitrate nitrogen in the soil profile for 'non-waterlogged conditions' for key treatments at the Rundown since 1/1/96

Whether the above simulation results reflect what actually happens under field conditions with shallow groundwater systems warrants further study, as the model (which captures our current best understanding of how the system works) is suggesting there would be some important consequences of introducing drainage at the Rundown site. These issues would need to be resolved in order to differentiate between groundwater effects and yield decline effects due to introducing sugarcane monoculture systems in regions with shallow groundwater systems.

Impacts of 'poor root health' that can occur as a result of yield decline were also analysed by simulating conditions in which the amount of water (and hence nutrient uptake) by the roots was limited to 20% of that of healthy roots, again using freely drained profile conditions for the simulations. A summary of these results are given in Figure 21 which shows total biomass as a function of time. The model predicts that sugarcane biomass production might be quite sensitive to reductions in root health, with a significant reduction experienced by reducing root health to 20% of a healthy root system. The relative reduction in biomass is less than the relative reduction in root acitivity, which suggests the model may be capturing aspects of the compensatory ability of cane root systems as discussed in the SYDJV root report by Magarey et al. (1999).

Comparing the simulated biomass production with actual data obtained at the Rundown site indicates that simulations with healthy roots overpredicted biomass, but that there was a substantial decrease and underestimation in biomass with the unhealthy roots. Here again the model is telling us that we do not yet adequately understand how roots grow and function in these very wet conditions, at least not well enough to capture adequately in the current model.

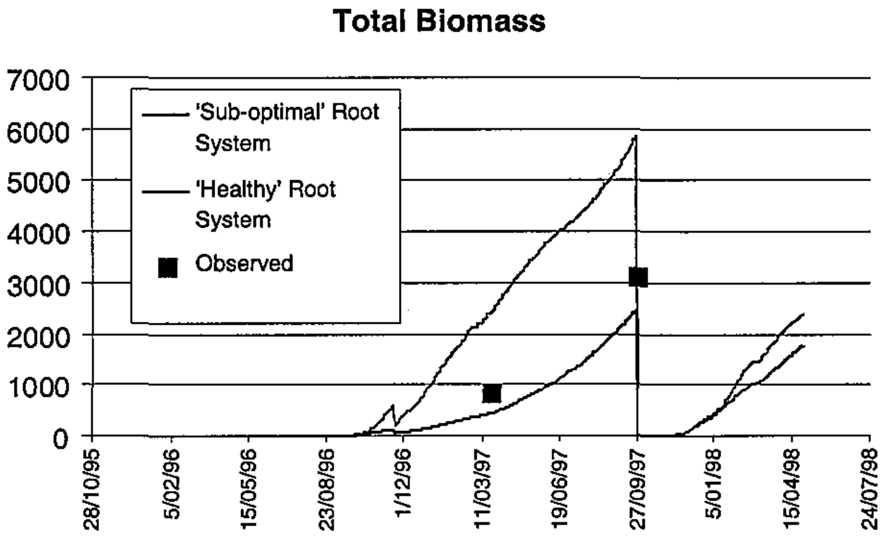

Figure 21: Simulated biomass (g/m^2) as a function of time for 'healthy' and 'unhealthy' roots

The above results provide examples of how systems models such as APSIM-Sugarcane have been and can be used to address a wide range of issues associated with yield decline. One of the particular strengths of developing and applying models such as these is that they challenge our current understanding of how the systems work, and force us to think more creatively about the types of experiments we need in our search for improved management strategies. Results of this work clearly demonstrate that we need to improve our understanding of a wide range of issues associated with soil water and nutrient dynamics associated with yield decline, especially in areas with shallow fluctuating water tables. Issues that need to be addressed include waterlogging effects and the impact of variations in oxygen status of the root zone, water uptake from root zones dominated by shallow ground water, denitrification, leaching, and the impact of lateral water movement on nutrient dynamics.

CONCLUSIONS

Results of the paired sites work showed that 'old land' in general has higher bulk densities, higher soil strengths (with values often greater than 2 MPa which can be limiting to root growth), greater levels of compaction at depths of 10-30 cm, lower water holding capacities, and hence less plant available water when compared with 'new land'. This shows that sugarcane monoculture can indeed lead to physical degradation of the soil which results in yield decline.

Although early closure of the Rundown experiment meant that the original objectives were not fully realised, it did provide useful insights associated with introduction of a sugarcane monoculture system, especially in very wet environments. The Rundown experiment was also very useful in highlighting the need for improved understanding of a wide range of issues associated with shallow fluctuating ground water systems, including the impacts of shallow groundwater systems on soil physical, chemical and biological soil properties, impacts of extended periods of waterlogging on the oxygen status of the root zone and on root function (especially nutrient and water uptake), impacts of shallow fluctuating groundwaters on the dynamics and fate of nutrients in the root zone, and the role of shallow groundwater systems in terms of crop water supply, and ultimately crop growth and yield. Some of these issues are now being addressed in other experiments.

Our ability to model and analyse sugarcane production systems has progressed significantly in recent years, and results of simulation analyses as part of this study have clearly shown that soil compaction and development of poor root 'health' are intimately involved in yield decline associated with long term sugarcane monoculture. As noted earlier though, a range of soil properties are affected by yield decline, and the 'controlling' factor or factors may vary from site to site. Appropriate application of simulation models will therefore be needed to help further our understanding of yield decline and to help develop strategies to minimise the impacts of yield decline associated with sugarcane monoculture.

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SOIL PHYSICAL PROPERTIES OF THE ROTATION EXPERIMENTS

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INTRODUCTION

Soil physical properties have been alluded to and implicated in the phenomena of sugarcane yield decline, but have not been studied in any great detail (Croft *et at* 1990; Hudson, 1990; SRC, 1990; Magarey, 1994). A recent review of the effect of soil physical properties on the growth and yield of sugarcane found some evidence of reduced yield with increasing soil bulk density (Braunack, 1997).

Sugarcane is grown as a monoculture and the crop is mechanically harvested using large and heavy equipment. Studies are currently determining the effect of harvesting traffic on soil properties and crop response (Braunack, 1995). To further examine the soil constraints to sugarcane growth, a series of rotation experiments were established to determine the effect of soil physical, chemical and biological properties on sugarcane growth.

Rotations are seen as a strategy to induce a change in soil conditions, which may or may not be beneficial for subsequent crop growth.

This report details the effect of different management treatments within the rotation experiments on soil physical properties.

MATERIALS AND METHODS

A series of rotation experiments were established at several sites (Tully, Herbert, Burdekin and Mackay) to provide different environmental conditions and cover a range of soil types (Garside, 1995).

All sites were sampled for soil physical properties in 1995 after treatment instigation in 1993 and 1994 at Tully and the other sites respectively and again in 1997 prior to plots going back to sugarcane. Treatments sampled were the longest break for each management strategy of pasture, break crop and bare fallow, with the continual cane (+ trash) being sampled as the control treatment. The break crop was not sampled in 1995 at Mackay as it had been recently cultivated.

Undisturbed soil cores (0.05 m high by 0.075 m diam) were collected from the row position to a depth of 0.3m, using a split barrel corer. The cores were sectioned using a thin blade, capped with plastic end caps and stored in a cool room at 4°C until processing through the laboratory. For the pasture and bare fallow plots, cores were collected from the previous row position, by aligning with cane rows in adjacent plots.

Saturated hydraulic conductivity was measured (constant head, Denholm, 1976) and the bulk density was determined for each core. A bulk sample (0-10cm) was collected for wet aggregate stability determination (Gradwell and Birrell, 1979), with the exception that the aggregates were sieved for 15 min and sieve sizes used were 4, 2, 1, 0.5, 0.25 and 0.125mm.

Soil cone resistance was measured on an opportunistic basis using a recording cone penetrometer (Rimik CP20, 12.5mm diam cone of 30° included angle). Measurements were recorded at 15mm intervals to the depth of insertion, nominally 600mm.

Prior to land preparation for planting plots back to sugarcane, field hydraulic conductivity was also measured using disc permeameters (Perroux and White, 1988).

After planting seedbed conditions were measured, to determine if the various break treatments resulted in different soil conditions (Håkansson, 1990). Only the Mackay site was assessed, as continued wet conditions prevented seedbed assessment at the other sites.

RESULTS

There was no obvious separation between treatments at each site for the initial sampling for soil physical properties. Also, there was no consistent order of treatments with respect to soil physical properties at each site. After treatment instigation the pasture plots tended to have the greatest densities, while the crop or bare fallows had the lowest densities. The Burdekin site was reverse of this trend with the continual cane having the lowest density. Prior to plots being replanted to sugarcane, the pasture plots were still the highest density at all sites. The bare fallows were the next highest, except for the Tully and Burdekin site where they were the lowest. The crop and continual cane plots were between these two, but not in the same order at all sites. The saturated hydraulic conductivities and air filled porosities largely reflected the density data.

With few exceptions there has been an increase in soil bulk density at all sites, except the Tully site. The continual cane plots decreased in density at Mackay and Ingham, but increased in density at Tully and the Burdekin.

Cone resistance was only measured before cane was replanted into the various break treatments. Again there is no particular treatment order for all sites. The crop plots tended to have the lowest strength in the surface 250mm at three sites (Tully, Ingham and Macky). The pasture plots tended to have the highest strength at Tully, Ingham and the Burdekin in the surface 100mm.

Pore densities and size distribution tended to be more consistent across sites than any other parameter measured (Figure 22). The bare fallows had greater porosity at 10cm than at the surface at all trial sites. The pasture plots also had a higher proportion of 3mm diameter pores in the surface at all sites except for the Burdekin, while at 10cm a higher proportion of finer pores were present. The crop plots tended to have an even distribution of pores in the surface with a trend to a higher proportion of 3 mm pores at Ingham and Tully. There was a tendency to finer pores in the crop plots at the 10cm depth at all sites. The continual cane plots contained a high proportion of 3 mm diameter pores in the surface at all sites, except for Ingham. There was a high proportion of fine pores at the 10 cm depth at all sites for the continual cane plots.

Data for wet aggregate stability showed that the pasture, crop and continual cane plots were the most stable, with the bare fallow plots being the least stable.

Seedbed conditions are reported for Mackay only, since it was not possible to sample the other sites due to rainfall after planting resulting in changed conditions. There was no significant difference in seedbed conditions between any of the break treatments. There were, however, differences between aggregate size ranges within a treatment with significantly more fine (<1mm) material being present than any other size range. The 30 month crop plots tended to have greater amounts of fine aggregates compared with the other plots.

DISCUSSION

With respect to the bulk properties measured at each rotation site with few exceptions, there are no significant changes between break treatments. This is probably due to insufficient time for major changes to occur, primarily under natural conditions. The most important agent for change would be wetting and drying cycles. If sites remained wet or dry for extended periods there would be little opportunity for change to occur. Lack of water infiltration, through surface sealing, into the profile would also contribute to the lack of wetting and drying through the profile.

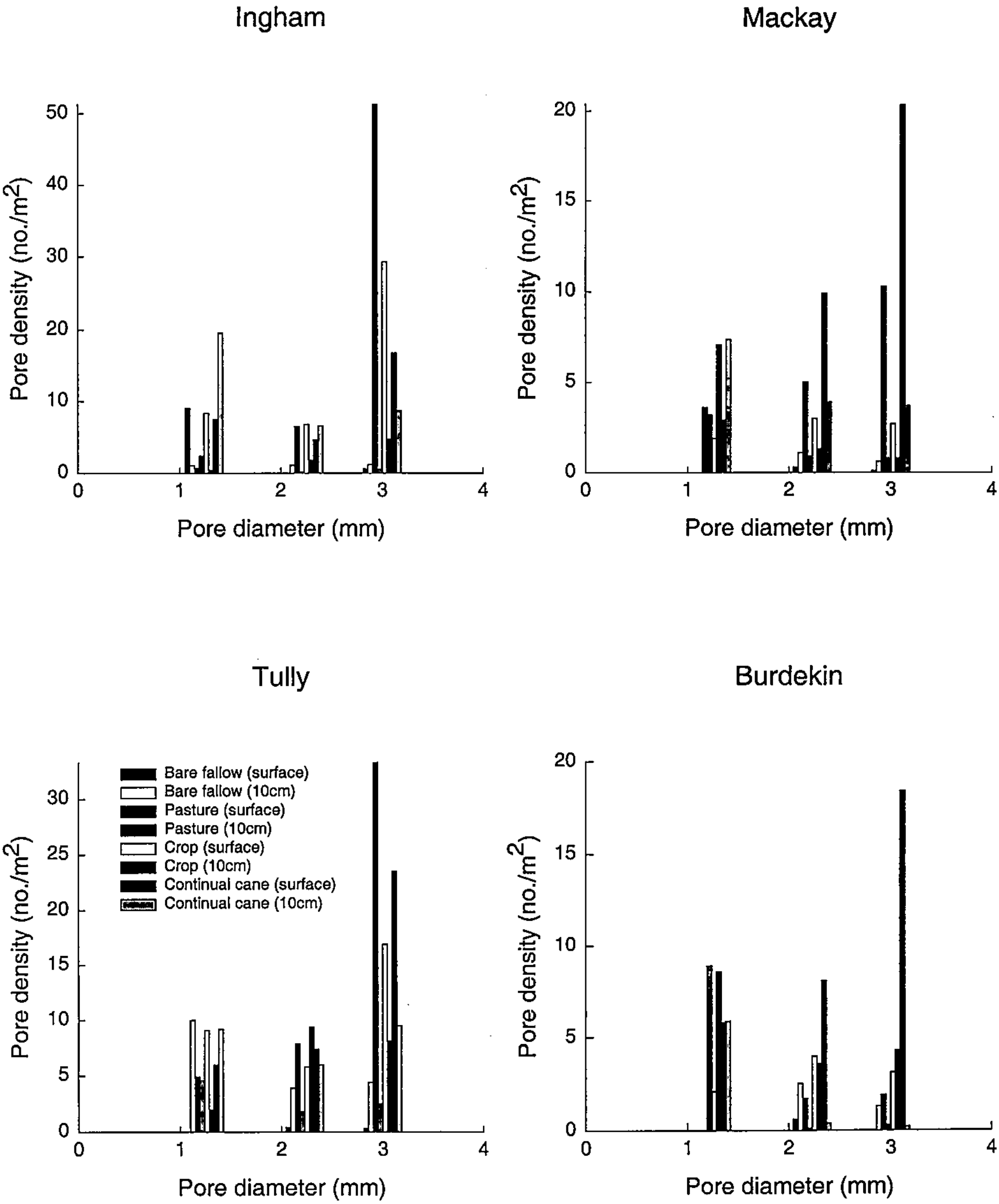

Figure 22. Pore densidity and size distribution at the Tully, Ingham, Burdekin and Mackay Rotation Eperiments.

Another vector for altering soil structure would be soil fauna and soil microbial biomas. There is a possibility that some soil physical degradation may have occurred during treatment instigation, due to cultivation operations and then subsequent planting, slashing and spraying operations. It would take time before the soil biology to readjust and then exert some influence on soil physical properties.

The initial loss of organic matter during treatment establishment may have resulted in structural instability in the first instance and an initial increase in soil bulk density through slaking and dispersion of surface soil, and this material washing into the profile with percolating water. These effects may in fact have persisted through until being disrupted by tillage for planting cane after the break period.

Tully Site

There was no difference between break treatments and no consistent trend between treatments. Also, there was no change in soil properties between times of measurement, 1995 and 1997, except for the immediate surface soil under continuous cane and crop, where there was an increase in soil bulk density.

Ingham Site

The pasture was significantly denser than the other break treatments, except for the immediate soil surface. The only significant difference between times of measurement was on the bare fallow and crop break, where there was a significant increase in soil bulk density down to 20cm on the bare fallow and to 30cm on the crop plots.

Burdekin Site

No significant difference between breaks except for the 10cm depth where the bare fallow and crop had lower soil bulk densities than the pasture and continual cane. There was a significant trend for increasing soil bulk density on all breaks between times of measurement. This, however, varied with depth in the profile. There was an increase in density in the pasture and bare fallow plots to a depth of 20cm. The crop plots were significantly different at the 20-25cm depth and the cane plots increased in density through the whole profile, except for the immediate surface.

Mackay Site

The pasture plots tended to have the highest density in the surface (10-15cm), while the continual cane plots had the lowest density at depth (20-25cm). The crop and bare fallow plots fell between the two. Soil bulk density increased at depth (30-30cm) over time on the pasture plots, while density increased in the surface (5-10cm) on the bare fallow plots. The density on the continual cane plots, however, decreased over time.

GENERAL DISCUSSION

Very few long-term and short-term rotation studies have assessed soil physical properties (Leigh and Johnston, 1994; Anderson *et al,* 1990; Francis and Clegg, 1990).

Previous studies have shown that soil compaction and soil bulk density decreased under crop rotation (Bolton *et al* 1982; Anderson *et al* 1990), which is in contrast to the findings of the current study where soil density tended to increase. Soil bulk density remained higher in continuous soybean (Santos and Clegg, quoted by Francis and Clegg, 1990) compared with a soybean grown in rotation. This supports findings from the present work, since the break treatments are not rotations in the true meaning of the word, as the treatment has not altered since instigation of the treatment. The only variable has been the length of the break from sugarcane. The only treatment that could be viewed as a rotation is the crop plot where crop rotation has been practiced as part of the break from sugarcane.

Saturated hydraulic conductivities in the surface were higher in the pasture, crop and continual cane plots. Other workers have also measured higher saturated conductivities on crop and pasture plots (Anderson *et al* 1990), and pasture plots (Greacen, 1981). At the 10cm depth the continual cane and bare fallow plots tended to have the greatest saturated hydraulic conductivity with the crop and pasture plots having the least. This suggests that surface sealing may have reduced the conductivity on the bare fallow plots, but that porosity has been maintained at depth through not disturbing the soil. Old root channels and fauna burrows would remain intact thereby increasing conductivity at depth compared with the surface. This result agrees with the measured pore densities, where there are a greater number of large pores in the surface on the pasture, crop and continual cane plots compared with the bare fallow. This trend is reversed at the 10cm depth, where the pasture, crop and continual cane plots have a greater number of small pores compared with the bare fallow plots. Anderson *et al* (1990) measured a smaller proportion of fine pores under continuous corn and wheat at the 2.5 to 10cm depth, and a larger number of fine pores under continuous pasture. This is consistent with present study where a larger number of fine pores occurred at the 10cm depth under pasture.

The effect of soil management has been assessed using water stable aggregation as an indicator of structural stability. Work has established that continuous cultivation had a major influence on soil aggregate stability, and even after ten years of pasture the soil stability had not returned to what it was in the virgin state (Greacen, 1958). Mercik (1994) found that soil aggregation increased with continual addition of farm yard manure over a seventy year period. If is difficult to compare the results from the present study since, strictly speaking, the treatments are not rotations. Notwithstanding this, there have been changes in aggregate stability with breaks from continual cane. It is speculated that these changes may be due to the prior history of the trial areas, the initial establishment of break treatments and subsequent management of the breaks. The trials were established on areas which had been growing cane for long periods of time. During the establishment of the breaks some stability due to organic matter would have been lost during cultivation. After the treatments were established the bare fallow was maintained by herbicide application so no further organic input occurred, but the residual roots from the previous sugarcane may have provided some organic matter until decomposition was complete. This may have resulted in a loss of stability, which did not recover due to no further input of organic matter into the system.

The crop plots have had a history of cultivation for seedbed preparation and planting, so there would have been periods of organic matter input and then rapid break-down. It is suggested that this may have resulted in reduced aggregate stability. The pasture plots on the other hand, once established, would have a continued input of organic matter. This should contribute to maintaining and possibly increasing the aggregate stability in these plots. The continual cane plots have not been disturbed so could, perhaps, be viewed as the control with respect to soil stability. Organic matter input has continued throughout the trial and no soil disturbance has occurred, suggesting that aggregates should be relatively stable compared with the other treatments where massive soil disturbance occurred initially.

These perturbations may also be reflected in soil fauna populations and the composition of these populations (Brown *etal* 1998, in press).

Overall there have been few significant changes in soil physical properties due to the different breaks from sugarcane. This is probably due to insufficient time having elapsed for changes in properties to occur, or perhaps the measurements used are not sensitive to subtle changes in a short period of time. Anderson *etal* (1990) found no significant change in soil water holding capacity or pore size distribution in soils after 100 years of manure additions, which tends to support the lack of change in soil physical properties in the short term.

CONCLUSIONS

There is no consistent order of treatments at each site. Changes in soil physical properties have occurred largely in the top five centimeters of the soil at each site. With few exceptions, soil physical parameters have tended to increase between the initial and final sampling times at all sites and for all break treatments.

Insufficient time has elapsed for large changes in soil physical properties to occur under the break treatments.

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STRATEGIC TILLAGE

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ABSTRACT

On yellow earth soils (Yellow Kandosols) at each of Bundaberg and Feluga near Tully conventional cultivation was compared to tillage strategies where only the row was cultivated with the inter-rows being left intact. These strategies consisted of stool ploughout, stool sprayout (both with a fallow period) and zonal ploughout/replant (with no fallow period). Data collected were: soil bulk density, sugarcane root weights, image analysis of soil structure, soil pore numbers, soil strength, seedbed assessments at planting, tractor efficiency data and cane yield/sugar content. Results showed that conventional ploughout was quite ineffectual in reducing the bulk density of inter-rows, that it did not homogenise the soil structure of the fields, and that it even increased the bulk density of the rows at Feluga. Conventional cultivation required double the fuel and one-third more tractor hours than the stool strategic tillage procedure. Cane yield and CCS were not reduced by the experimental methods of stool removal. In fact at Bundaberg strategic tillage yielded best but only significantly more than ploughout/replant. The study concluded that the experimental techniques of stool removal tested here show strong promise to reduce expensive establishment costs in cane without ill-effects on production. At the end of a crop cycle stool removal is vital and the results presented here show that cultivation of only the row area achieves a better (physical) and more cost efficient result with the added advantage that the high density "roadway" of the inter-row is maintained; a most attractive feature for wet harvesting. Soil fauna populations are maintained under strategic tillage and varietal rotation offers the possibility of reducing levels of *Pachymetra* spores, a known soil-borne disease.

INTRODUCTION

Vital to the long-term maintenance of productivity levels in the Australian sugar industry is the development of best practices for land preparation. This is particularly necessary in sugarcane as the land management system has been recognised as a challenging scenario in which to achieve sustainable land practices (McGarry, 1998, 1999). This arises from a combination of the necessity of stool removal on harvesting the last ratoon, and a industry-wide mis-matching of row spacing and equipment track width (Braunack and Peatey, 1999). Additionally, the location of cane lands in the wet coastal fringe of Australia commonly leads to the trafficking, cultivating and harvesting on wet soils.

Traditionally, land preparation for planting sugarcane, called ploughout, involves many, intense tillage operations. Common practice involves the complete cultivating-out of the old rows and inter-rows after harvesting the last ratoon, in preparation for planting.

Several studies have documented that cane has strong potential to maintain good soil structure in the rows through the ratoons (Conway *et al.*, 1996; McGarry *et al.*, 1996; McGarry *et al.*, 1997). It is paradoxical, therefore, that at ploughout the good soil structure of the row is mixed with the highly compacted material of the inter-row.

The current study investigates the efficiency of conventional cultivation relative to other experimental methods of stool removal. Conventional cultivation targets the whole field whereas the alternates concentrate on removing the stool, leaving the inter-row intact. The new strategies are termed "strategic tillage" as only the row is cultivated.

MATERIALS AND METHOD

There were two sites both on soils classed as a yellow earth (Yellow Kandosol). The Bundaberg site was 8km SSE of Bundaberg in 5th ratoon at commencement of the experiment. The Feluga site was 9 kilometres north of Tully in 6th ratoon at commencement of the experiment. The trials were planned to enable three consecutive years of planting and to continue through for three ratoons at each site.

Trial design was the same at both sites being 2 varieties and 4 treatments in each of 3 blocks. Varieties were Q138 and Q155 at Bundaberg and Q115 and Q117 at Feluga. The varieties Q117 and Q138 have a tolerant rating and Q115 and Q155 a susceptible rating to *Pachymetra chaunorhiza*. The four treatments were:

1. *Conventional land preparation (T1)*: 2 passes of a rotary hoe at ploughout (to 0.15m depth) parallel to the old rows, followed by 1 pass of a bank of 5 straight-tine rippers (to 0.5m depth at Bundaberg and 0.3m at Feluga) at approximately 45° to the old rows. Two off-set discings were also used at Feluga.
2. *Stool ploughout (T2)*: One pass of a rotary hoe (to 0.15m depth) along the row to "chop-up" and incorporate the old stool, then one pass of 3 straight tine rippers (to 0.5m depth at Bundaberg and 0.3m at Feluga) closely grouped behind the tractor on a tool bar to solely rip the old stool zone.
3. *Stool spray-out (T3)*: No cultivation. Stool and weeds were sprayed out (Glyphosphate). Each of T1 – T3 had a six month fallow before planting.
4. *Stool ploughout/replant*: As T2, except no fallow before planting.

Measurements were: soil bulk density to 0.8 m, sugarcane root weights from the bulk density cores, image analysis of soil structure, soil strength to 0.6 m with a recording cone penetrometer, seedbed assessment one week after planting, tractor hours and fuel use to impose each treatment were collected at the Bundaberg site, soil fauna counts were made each season.

RESULTS

The bulk density of the row at Bundaberg before treatments were imposed was significantly less than the inter-row to 0.3 m, showing the inherent ability of cane to optimise structure in the row (Figure 23a). The inefficiency of ploughout cultivation is evident in Figure 23b where despite the numerous cultivations associated with conventional practices the old inter-row location remained denser than the old row location to 0.3 m. Also, despite numerous cultivations, the rows of the conventional cultivation were no less dense than the minimal till rows. Bulk densities after harvest of the plant cane crop at Bundaberg showed that the inter-rows of both conventional and minimal till were denser to 0.25 m than all row locations, demonstrating that though the conventional cultivation treatment had complete soil disturbance, the inter-rows rapidly (in one season) re-pack to high bulk densities. Results from Tully were similar to those at Bundaberg.

Root distribution data demonstrate that at least for the data collected here, there is minimal root development in the inter-rows at Tully (Figure 24). This result was repeated at Bundaberg. In the plant cane crop, the sprayout row had by far the most roots of any treatment, particularly below 0.15 m. Similarly at 1st ratoon, the sprayout row and the conventional row had significantly more roots than the stool ploughout row from 0.2-0.5 m.

The images of soil structure on day 1 at Bundaberg relate well to the bulk density data, showing strong differences between the row and inter-row (Figure 25). Conventional cultivation resulted in large pieces of dense material in the row, most probably dense soil material from the inter-row (Figure 26). These dense fragments are not evident in the stool ploughout as the high density inter-row was left intact (Figure 26). By harvest of the plant cane crop, all rows had soil structure comparable to the rows at commencement of the trial. However, the inter-row of the conventional cultivation had already developed strongly visible platy structure from the soil surface to 80 mm, evident here at Tully (Figure 27). This type of structure is related to trafficking under wet soil conditions, as prevalent at the Feluga site, and is considered a severe type of soil compaction.

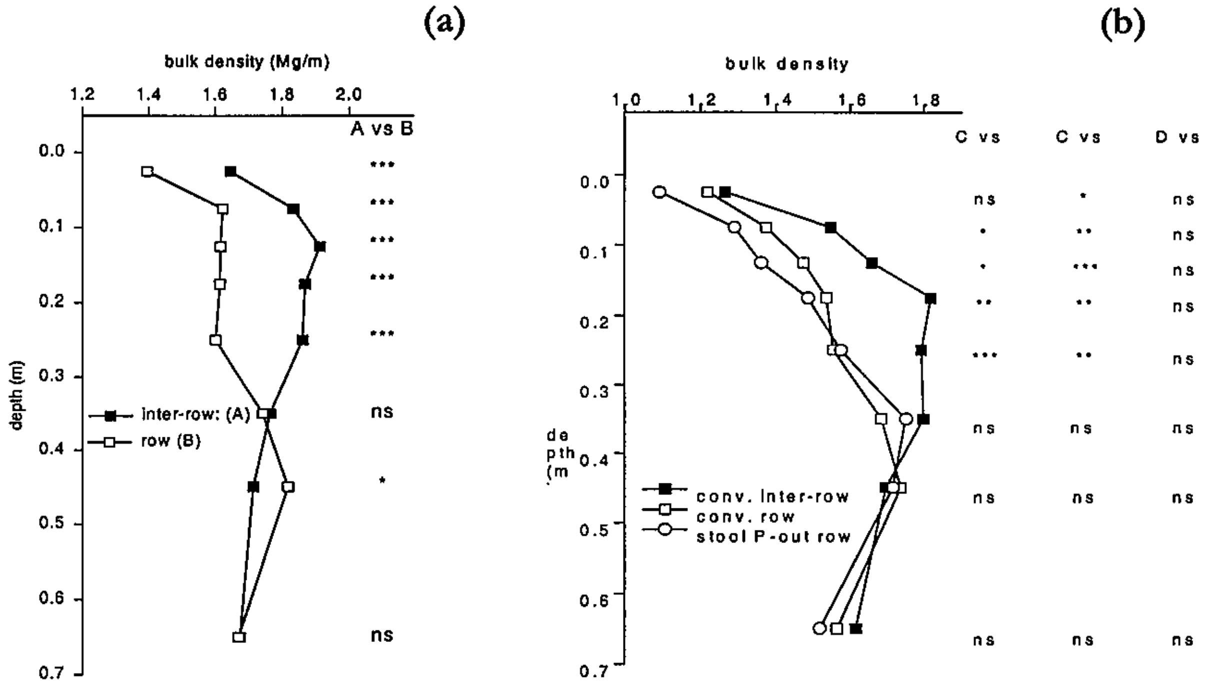

Figure 23. (a) Comparison of the pre-experiment data for the row (A) and inter-row (B) at Bundaberg, (b) Comparison of the bulk density data for the "First cultivation" data for the conventional inter-row, conventional row and stool ploughout row at Bundaberg.

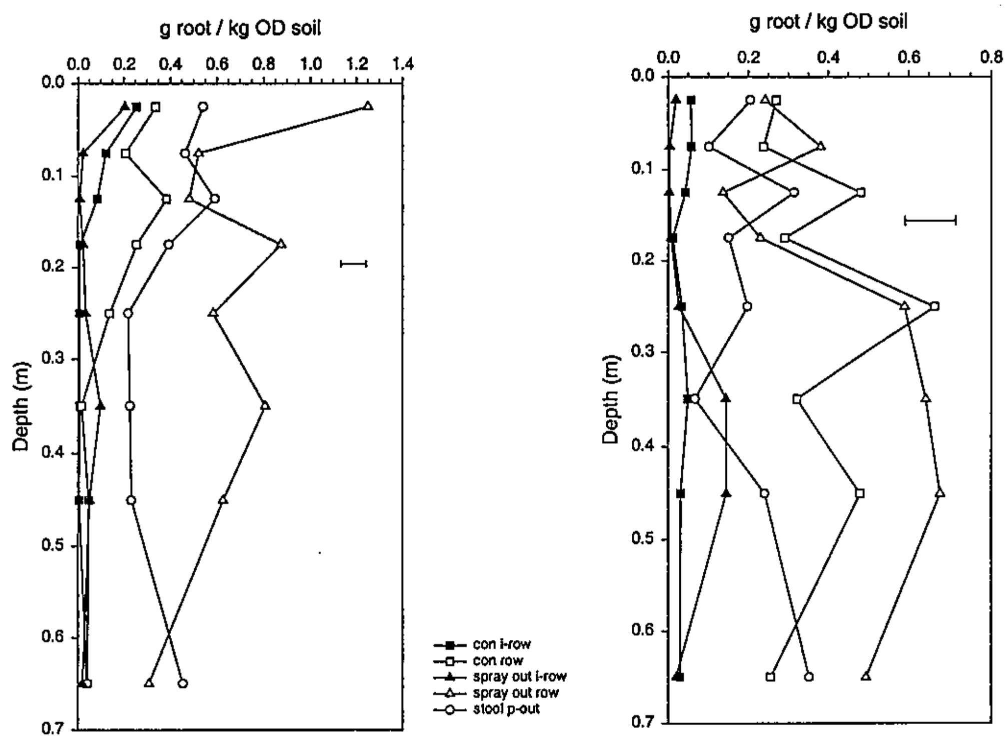

Figure 24. Root distributions in rows and inter-rows immediately after harvest of (a) the plant cane crop and (b) the 1st ratoon at Tully.

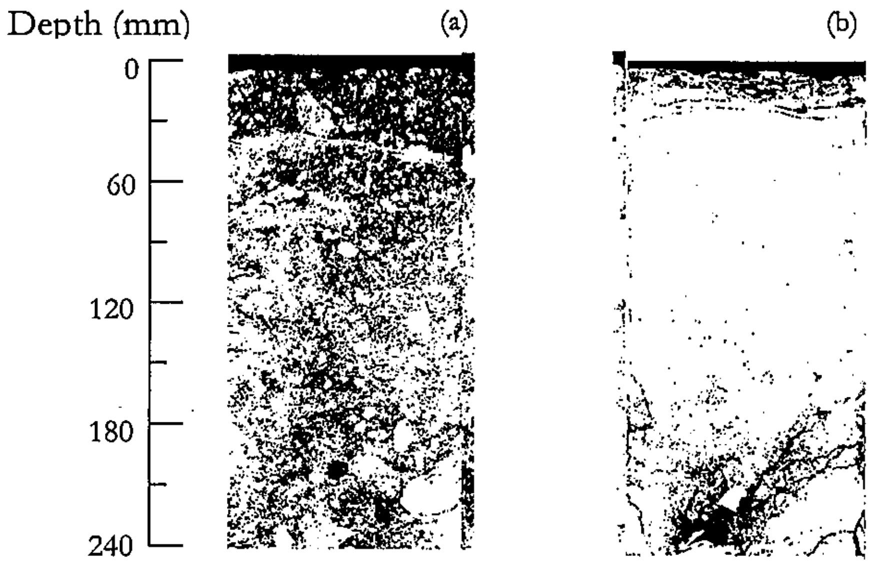

Figure 25. Bundaberg images for day 1: (a) row and (b) inter-row. In all the images, black is pore space and white is soil solid. The vertical and horizontal scale is the same in all the image figures

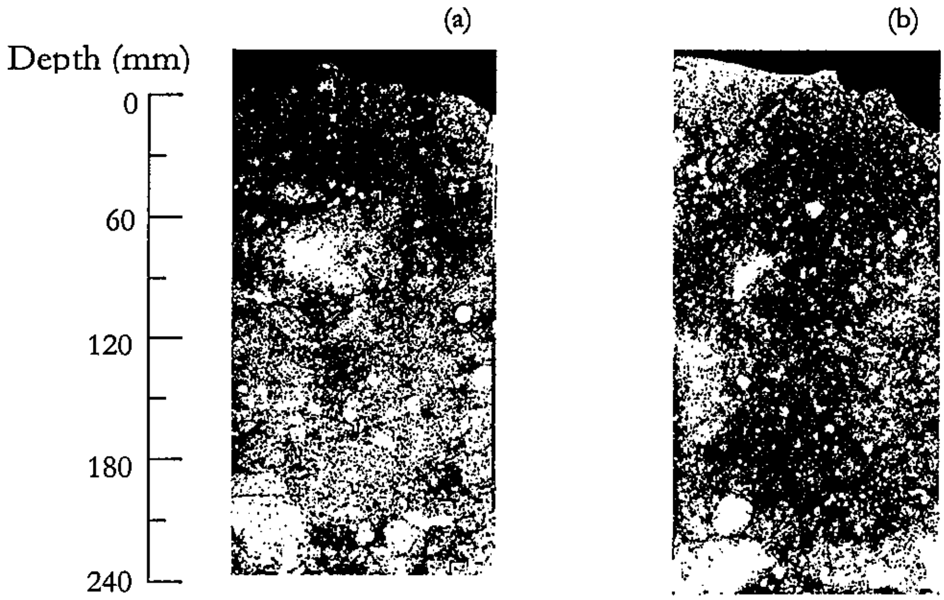

Figure 26. Bundaberg images for first cultivation: (a) conventional cultivation row, (b) stool ploughout row

Soil cone resistance profiles before cultivation show a distinct delineation between the plant growth zone (row) and the traffic zone (inter-row), with high strengths close to the surface on the shoulders of the inter-row area and low strength under the row (Figure 28). After two offset discing operations of conventional cultivation, this pattern is disrupted, but there is evidence of the development of a plough pan (> 2000 kPa) at the depth of discing (Figure 29) and it is still possible to detect the old inter-row position even after the discings, suggesting that the tillage operation has not been effective in removing the compacted inter-row. High strength zones (2500 – 3000 kPa) occur below the tractor wheels, suggesting recompaction of loose material by the tractor.

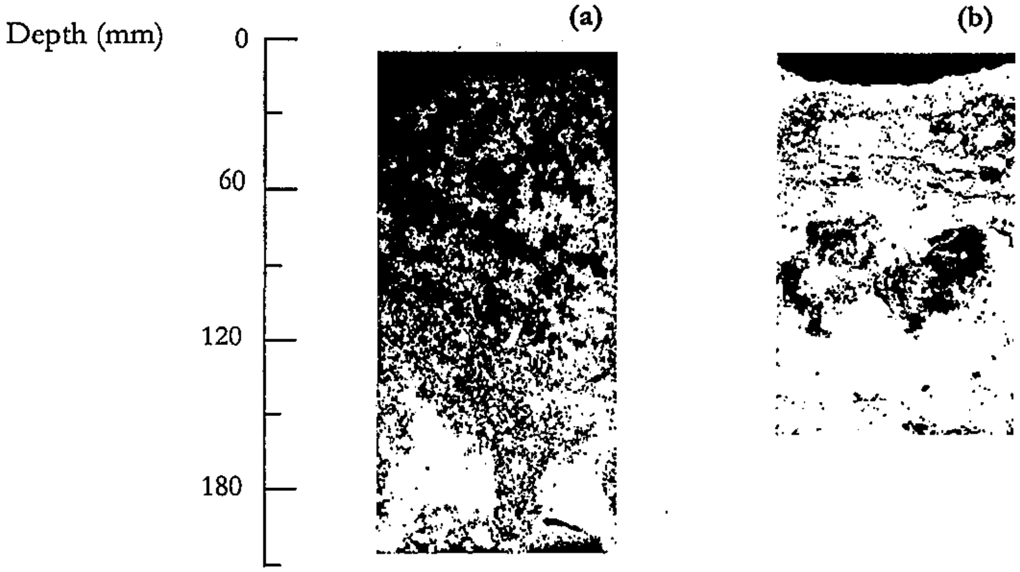

Figure 27. Tully Images at harvest of the plant cane crop (a) conventional cultivation row, (b) conventional cultivation inter-row.

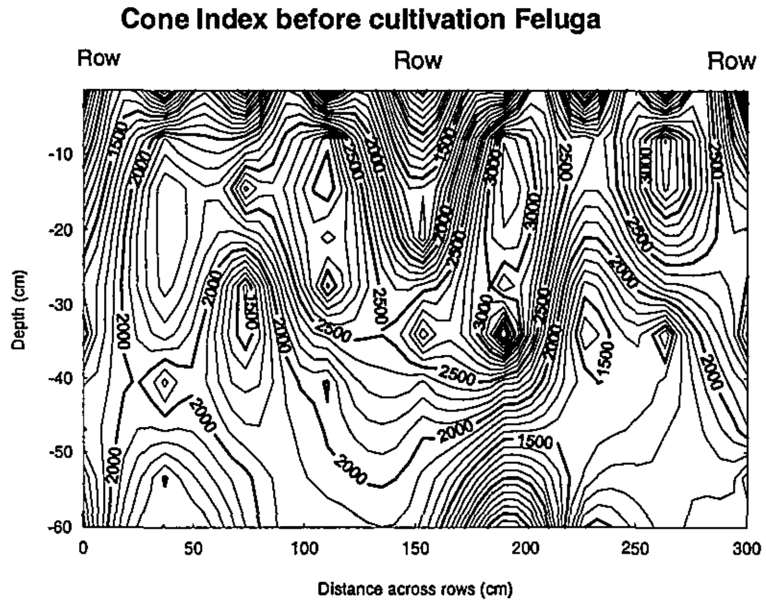

Figure 28. Cone penetration resistance at Feluga on day 1 (before cultivations)

Under stool ploughout, the pattern of soil strength before and after cultivation is similar, where soil loosening has occurred in the row to 0.35 m and soil strength has been maintained in the undisturbed inter-row (Figure 30). This demonstrates that with strategic tillage, the distinct difference between the row and inter-row developed over the crop cycle can be maintained.

The seedbed data at planting at both sites showed fine seedbeds were achieved under all tillage treatments with resulting good establishment, demonstrating that good soil tilth can be produced with less cultivation.

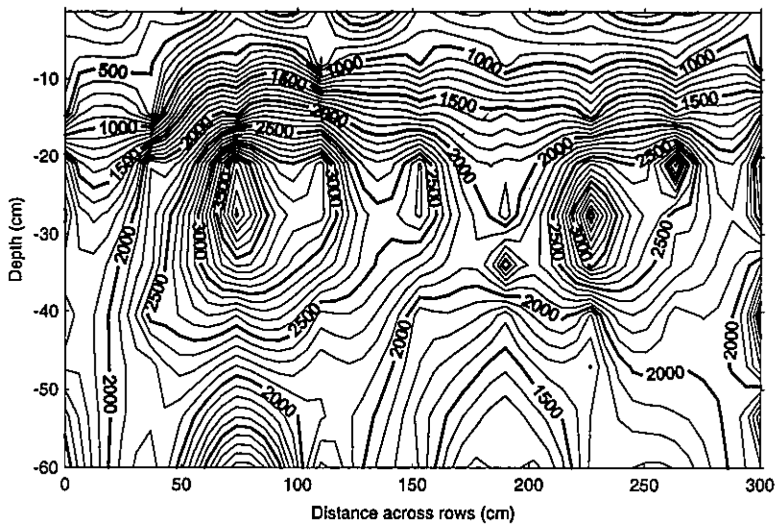

Figure 29. Cone penetration resistance at Feluga after conventional cultivation at first cultivation (2 discings

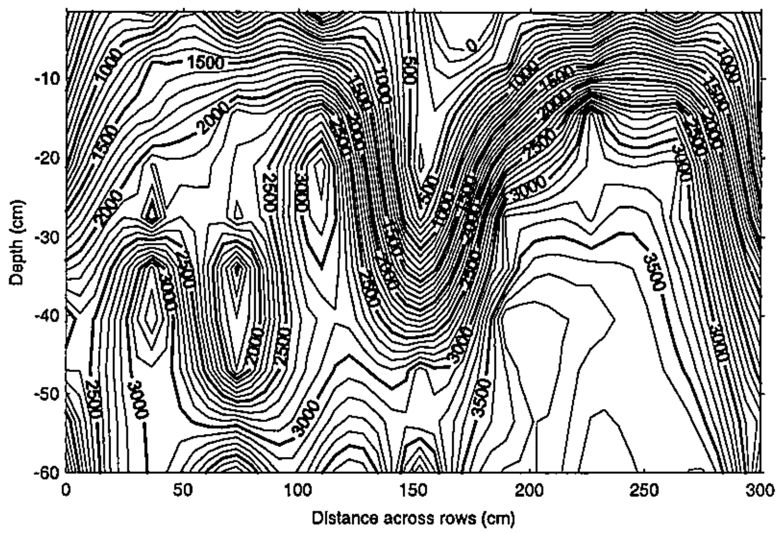

Figure 30. Cone penetration resistance after stool ploughout

The tractor data show the conventional cultivation required two times and one and a half times the number of passes of the sprayout operations at Tully and Bundaberg, respectively. Additionally, conventional cultivation used heavier equipment requiring more tractor power. As a result, the conventional cultivation used four times and five times the amount of fuel of the stool ploughout treatment in 1996 and 1997, respectively, and thirty-two times and sixty-eight times that of the spray-out treatment for the same years. In terms of work rate (tractor hours), the conventional cultivation required 20 and 34 hours/ha in 1996 and 1997, respectively and they were three times and four times more hours/ha required for the stool ploughout in the same years. Stool sprayout required only 2 and 1 tractor hours/ha in 1996 and 1997, respectively, being 92% and 97% less than conventional cultivation.

A comparison of the input costs (fuel, chemical(s) and labour) and gross incomes (yields and ccs levels) showed that in 1996 there was little difference in the costing differential between inputs and outputs. Only the ploughout-replant was less productive than the conventional treatment; giving 13% less gross margin. In 1997, however, each of the two strategic tillage practices, stool sprayout and stool ploughout for both varieties gave up to a 10% better gross margin than the conventional cultivation. Not considered here, but a strong economic consideration, will be the greatly increased tractor-life under strategic tillage practices. Not only are tractors used less often but the workloads while working are greatly reduced. There is less wear and tear when simply carrying a spray-rig as opposed to deep cultivation with rippers.

In terms of both cane yield and sugar yield, the data of plant, 1R and 2R crops from both sites showed that for any one variety, only one treatment was significantly different from one other treatment. At Bundaberg there was no pattern to significant differences in sugar production between treatments in either varieties or years. At Tully ploughout-replant was the only treatment that generally had significantly less sugar production for each variety and each of the two planting years.

Earthworm numbers tended to be greater under the strategic tillage treatments compared with the conventionally cultivated plots at both sites. This suggests that with less soil disturbance, beneficial soil fauna populations can be maintained thereby improving soil health. There were greater populations of other (other than earthworms) soil fauna in the strategic tillage plots compared with the conventional cultivation plots. These populations were not identified as beneficial or detrimental organisms.

With the known soil-borne disease *Pachymetra*, spore counts were higher under the susceptible variety at both sites (Q115, Tully; Q155, Bundaberg), with lower counts under the resistant variety. At Tully, the greatest spore count occurred under stool sprayout (P) and stool ploughout (IR) with the susceptible variety. This may have corresponded to an area of high incidence of spores initially.

At Bundaberg, the highest spore count was under the strategic tillage ploughout-replant plots for both varieties. It is not known whether the level of *Pachymetra* is significantly affecting crop yield, although the yield of the susceptible varieties is lower than the resistant variety at both sites.

DISCUSSION

The efficacy of cultivation in removing the negative structure condition of old inter-rows is now seriously questioned. Not only did the cultivation in the above experiment fail to fully alleviate the old compaction, there was evidence that the general physical fertility of the field declined as old, dense inter-row becomes mixed with the old rows. Cultivations did not alleviate soil compaction to the depth of tillage. At both sites, the inter-rows were loosened to only one-third of the cultivation depth. At Feluga, conventional cultivation actually increased bulk density by up to 15% in the row to 0.2m. In contrast, stool ploughout at Bundaberg gave a deeper, larger improvement in row structure compared to day 1 than conventional cultivation. At Feluga, stool ploughout maintained the structure of the row present on day 1; a far superior response than the increase in row density caused by conventional cultivation.

The study demonstrates the rapid return of inter-rows to dense material after one or two traffic passes, despite ploughout. These inter-rows are not important root zones – plant roots having been shown to concentrate in the rows.

Conventional cultivation has been shown to be an expensive and time consuming exercise relative to the minimal till methods investigated here. Wear and tear on tractors and equipment would also be far greater under conventional cultivation, reducing tractor life and necessitating the continued purchase of large tractors.

There were no yield penalties associated with minimal tillage practices. This has carried through to 2nd ratoon at Bundaberg. Growers' fears of increased lodging and stool tipping have been shown to be unfounded.

Pachymetra counts have increased most with ploughout-replant. The small increase with minimal till is deemed due to lower dilution factors associated with reduced tillage and mixing of soil. The situation continues to be monitored.

Earthworm numbers have increased rapidly with minimal tillage. Counts are up even after the plant crop. This is an excellent indicator of soil health.

CONCLUSIONS

The bulk density data demonstrate the potential for cane to maintain good soil structure in the row after several ratoons and the poor results of conventional cultivation (ploughout). Of note was the lack of homogenisation of rows and inter-rows by conventional cultivation. The effect of several ratoons of cane is the severe densification of inter-rows as demonstrated here by the day 1 results. Conventional cultivation is quite ineffectual in loosening these dense inter-rows. Of further concern, conventional cultivation increased density in the rows at Feluga. This may be due to the spreading of dense material from the inter-row into the rows, and generally increasing the density of the row area while only improving the inter-row in the 0.05-0.1m layer.

The strong differences in soil compaction status between the row and inter-row, and the ineffectual nature of conventional cultivation in removing row/inter-row differences, demonstrates the potential of and the need for controlled traffic in cane. If stool removal is vital, the results presented here show that cultivation of only the row area achieves a better result. Additionally, with disturbance solely of the row there is the advantage of retaining the high density "roadway" in the inter-row; a most attractive feature for wet harvesting.

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APPENDIX 2 – REPORT OF REVIEW OF SUGAR YIELD DECLINE JOINT VENTURE, DECEMBER 1996

REVIEW OF YIELD DECLINE JOINT VENTURE

Report to the
Management Committee of the Joint Venture

By
E Henzell, L Abbott, S Guazzo, D Hamilton and J Meyer

December 1996

SUMMARY

In 1993, the Yield Decline Joint Venture (YDJV) research programme was initiated by BSES, the CSIRO Division of Soils and the SRDC. The QDPI joined later and the QDNR (Queensland Department of Natural Resources) is now also involved. An external review of the YDJV was carried out for its Management Committee during the period 11 to 15 November 1996.

The YDJV has three important achievements to its credit so far: (a) it has developed a strong commitment to cooperation amongst scientists drawn from three different research organisations, (b) it has helped to define two different forms of "yield decline" (the loss of productive capacity of soils under sugarcane monoculture and the occurrence of a yield plateau), both of which warrant further research, and (c) it has established a valuable set of field trials that can now be used to study and to help solve the problem of monoculture yield decline.

The Panel was impressed with the standard of administration and management of the YDJV and concluded that the current arrangements should continue. However, there was a concern that some of the key contributing scientists may have been overcommitted by their organisations.

The major industry benefit from the YDJV so far has been the clarification of the two forms of "yield decline". Monoculture yield decline probably played little part in the failure to capitalise on potential yield gains from plant breeding over the period 1970-1990 (the yield plateau problem). This advance in understanding the nature of the two components of yield decline should now be communicated to canegrowers as a special project.

The Panel members were unanimous in their view that the YDJV is largely on course and that the project work currently in progress is consistent with the objectives of its five-year plan. Only small changes are needed. The focus of the YDJV should be maintained on monoculture yield decline and it is recommended that the name of the Joint Venture should be changed to "Monoculture Yield Decline Joint Venture" to distinguish this sugar research programme from work on the productivity trends responsible for the yield plateau. Also, the YDJV research in future should involve cane farmers in a participatory role.

The field trials that have been set up by the YDJV are not likely to repay the initial investment unless they are continued through at least two cropping cycles. Therefore, the Panel concluded that the parties to the YDJV should commence negotiations for a further phase of it well before the current agreement ends in 1999. In regard to the use of SRDC funds, the Panel recommended that the costs of leadership and of workshops conducted for the whole YDJV should be met off the top before the remaining funds are distributed to the parties. A share of SRDC funds should be provided to QDPI\QDNR in a second phase of the YDJV.

LIST OF RECOMMENDATIONS

1. That the Management Committee clarify the time commitments of the scientists involved in the YDJV to ensure that there is no double counting of their time in formal agreements.

2. That SRDC consider initiating a project to ensure that the main findings on yield decline are understood by canegrowers.

3. That the attention of the parties in the Joint Venture be drawn to the importance of multifactor productivity analysis as a means of identifying constraints to productivity such as those that caused the yield plateau in Australian sugar production between 1970 and 1990.

4. That the name of the Joint Venture be changed to "Monoculture Yield Decline Joint Venture" to distinguish this sugar research programme from work on the yield plateau .

5. That:

- the Joint Venture in future deliberately involve cane farmers in a participatory role;
- the Rural Extension Centre (UQ Gatton) be consulted and requested to provide advice and training where necessary;
- the team-building activities already undertaken successfully be continued as an integral component of this Joint Venture.

6. That:

- the costs of leadership and of conducting workshops for the whole Joint Venture should be met from SRDC funds before they are distributed to the parties; and
- a share of SRDC funds should be provided to QDPI\QDNR as well as to BSES and CSIRO in a second phase of the Joint Venture.

1. BACKGROUND

INTRODUCTION

The Australian Sugar Industry has been on a productivity plateau for 20 of the past 25 years. The reasons for this plateau are not completely understood, but it is now believed to be due to a complex of factors related to climate, soil, varieties, disease, mechanisation and other industry practices such as green cane harvesting. Various estimates indicate that the opportunity cost to the industry could be $200 to $400 m per annum. The period 1990-1995 has seen a yield improvement for the industry as a whole, though it is too soon to say if this is a long term trend or perhaps due to recent more favourable weather conditions.

In 1993, BSES in partnership with the CSIRO Division of Soils and the SRDC, initiated a six year Yield Decline Joint Venture (YDJV) research programme with the following objectives:

- identify causal factors and their contribution to yield decline in sugarcane
- develop solutions to minimise or alleviate the impact of such causal factors on productivity in sugarcane
- promote the use of appropriate technologies developed by the Venture.

The Joint Venture Agreement was signed in May 1993. The Queensland Government, through its Department of Primary Industries (QDPI), joined the Joint Venture in the 1995-96 financial year. The Queensland Department of Natural Resources (QDNR) is now also involved.

TERMS OF REFERENCE

This programme is now half way through its funding cycle and the Executive Director of the SRDC, Mr Eoin Wallace, on behalf of the Management Committee, commissioned a review with the following terms of reference:

1. Assess the appropriateness of the YDJV objectives and progress in achieving them.

2. Evaluate the current and proposed R&D programme of the Joint Venture , its relevance to the objectives of the Joint Venture and the adequacy of the resources provided for Joint Venture activities.

3. Evaluate the strategic direction of R&D in the Joint Venture and its appropriateness in achieving the objectives.

4. Comment on the operation of the Joint Venture and identify any enhancements that could be made to administrative and management arrangements.

5. Recommend any changes to the management, implementation or dissemination of the Joint Venture considered appropriate.

6. Submit a report addressing these Terms of Reference to the Management Committee of the Joint Venture by 31 December, 1996.

PANEL MEMBERSHIP

The Panel comprised the following members:

E Henzell (Chairperson)
L Abbott (University of Western Australia)
S Guazzo (Canegrower, Ingham)
D Hamilton (Qld Dept of Primary Industries)
J Meyer (South African Sugar Experiment Station)

CONDUCT OF THE REVIEW

The schedule for meeting with various researchers and for visiting field experiments was as follows:

Monday 11th - Brisbane Airport - Discussion with Anne Campbell (BSES), Eoin Wallis (SRDC) and Colin Chartres (CSIRO, by phone) - members of Management Committee.

Tuesday 12th - Bundaberg - Crop rotational, tillage and nematode trials. Meeting with Mike Bell, Geoff Cunningham, Graham Stirling (all QDPI), Peter Whittle (BSES), Brenden Blair and Julie Taylor (both QDPI).

Wednesday 13th - Tully - Long-term rotational trials, rundown site and root studies. Meeting with Alan Garside (Research Leader), Mike Braunack, Rob Magarey and John Reghenzani (all BSES). Also briefing by John Leslie (Visitor). Clive Hildebrand (Chairman, SRDC) and Kelso Greenwood (Deputy Chairman, SRDC) attended for part of the morning and Keith Bristow (CSIRO) was present for the field tour.

Thursday 14th - Townsville - Discussion with CSIRO scientists on soil physics/modelling, root and soil acidity studies. Participants - Susanne Berthelsen, Rob Bramley, Keith Bristow, John Holt, Andrew Noble, Christian Roth (all CSIRO) and Alan Garside. Briefing by Bob Lawn (JCU), CRC for Sustainable Sugar Production.

Friday 15th - Review panel discussions and report writing.

STRUCTURE OF THE REPORT

The remainder of this report is structured in the following way:

Section 2 Assessment of progress in achieving the objectives of the YDJV.
Section 3 Benefits for the sugar industry.
Section 4 Analysis of productivity trends in the Australian sugar industry.
Section 5 Recommendations on the future of the YDJV.

2. ASSESSMENT OF PROGRESS IN ACHIEVING THE OBJECTIVES OF THE YIELD DECLINE JOINT VENTURE

RESOURCES

During the financial years 1993-94, 1994-95 and 1995-96, a total of $3.64m was committed directly to the Yield Decline Joint Venture (YDJV) by the four parties:

	1993-94	1994-95	1995-96
SRDC	280 000	305 000	313 000
BSES	472 750	529 757	361 546
CSIRO	413 436	323 436	347 042
QDPI	na	na	294 000

In addition, SRDC allocated $110 000 to projects related to the subject of yield decline in 1992-93 before the Agreement was signed, and over the period 1993-94 to 1995-96 invested a further $939 000 in special projects that were related at least partly to this subject. QDPI carried out some research on yield decline in 1994-95 using State Government funds allocated through the SIRP (Sugar Industry Reference Panel) process; $412 000 of the SIRP money spent by QDPI in 1995-96 was also allocated to yield decline projects . Thus, the total amount committed to research on the problem of yield decline to June 1996 appears to have been about $5.1m. Total expenditure on the 1996-1997 workplan is estimated will be about $2.0m.

Human resources have also been of great importance to the performance of the YDJV, notably the appointment in August 1993 of Dr A L Garside as Research Leader and champion of the Joint Venture principles and the appointment of Dr J K Leslie as Visitor (with similar responsibilities to CRC visitors) in January 1995. These two distinguished scientists were able to draw on broad experience of research with crops other than sugarcane.

RESEARCH

The YDJV has three important achievements to its credit so far. Firstly, it has developed a strong commitment to cooperation amongst scientists who have been drawn from organisations with very different research cultures. These scientists are communicating well, as evidenced by the fact that all those that we interviewed had a ready familiarity with the work being done by other members of the YDJV and at other field sites. At Bundaberg, for instance, a QDPI staff member has been located in the BSES Laboratory to foster interaction between the two organisations. The location of the Research Leader first at BSES Tully and now at CSIRO Townsville has also helped to encourage collaboration.

This spirit of cooperation has established a platform for the realisation of significant synergies in future research by the YDJV and is one of the major reasons why the Panel is confident in recommending that the parties should negotiate a second phase well before the first one ends in 1999 (Section 5).

Secondly, the YDJV has made a valuable contribution to elucidating and redefining the yield decline problem in its various meanings. The review of the literature on the yield plateau that occurred in the Australian sugar industry from 1970 to 1990 by A L Garside and his coauthors for the Sugar 2000 Conference makes it clear that the loss of productive capacity of soils under long-term sugarcane monoculture (what we call monoculture yield decline in this report) probably was a minor factor in the yield plateau problem. In other words, the hypothesis underlying the setting up of the YDJV was largely wrong.

Nevertheless, there is evidence of a loss of yield associated with sugarcane monoculture, which has probably restricted yields in Australia ever since cane was first replanted on the same fields, and that warrants further research in its own right. The evidence comes from the findings that substantial cane yield responses to fumigation occur in all sugar growing areas in Queensland, and that growth is better on new sugar land than old (Garside 1996). Evidence is beginning to emerge of a benefit from rotation of cane with broadleaf crops.

It is hard to estimate the potential benefits of successful research on monoculture yield decline. It is a difficult kind of research. However, if an annual yield loss of 2.5 to 5.0% could be recovered economically, that would be worth an extra $50m to $100m a year to an industry with a gross value of production of $2bn a year.

While it would have been extremely helpful to the YDJV parties to have known about the two components of yield decline in 1993, it is too easy to say that with the benefit of hindsight. It ignores the fact that a problem of this complexity has to be studied closely and in depth by specialists before the statistics and the literature can be interpreted properly. It also ignores the benefit of bringing new experience and independent insight to bear on the matter.

Thirdly, the YDJV has been able to establish a series of field trials (the rotation and rundown experiments) with measurements being made on them by a very wide range of specialists in soil physics, chemistry and biology. The work involved in their design and in the selection of the sites has been of a very high standard. They are a precious resource that can now be used for years to come to search for an understanding of and solutions to monoculture yield decline.

In addition, a number of short term trials were established during the first three years of the YDJV. These have not provided any solutions to the problem of monoculture yield decline but they have helped to eliminate a number of possibilities.

To sum up, the YDJV has defined a part of the yield decline problem that can now be studied in detail. While no practical solutions have yet been discovered, it is already apparent that crop rotations, if they were commercially attractive to growers, could overcome much of the monoculture effect. There are likely to be interactions with other soil fertility factors that could provide even better possibilities for the future. Moreover, although the yield plateau probably has other causes, further careful analysis of productivity trends over the last 25 years is likely to generate other opportunities for efficiency gains in the sugar industry.

ADMINISTRATION AND MANAGEMENT

The Review Panel was impressed with the general administration and management of the Joint Venture. In particular, the chair of the Management Committee has shown independence and leadership and provided continuity during a significant turnover of its membership. In spite of the lack of continuity of membership of the Management Committee, the Joint Venture has been effectively established and supported by the parties. The arrangement under which the Research Leader reports to the Management Committee seems to provide effective accountability. The Management Committee has empowered the Research Leader to effectively coordinate and lead without undue interference. The level of bureaucracy has been kept to a commendable minimum. The Panel's conclusion is that the current administration and management arrangements of the YDJV should be maintained.

We hope that the current amalgamation of the Division of Soils with other units in CSIRO and the QDPI/DNR split will not impede the important task of the Management Committee.

The Panel was concerned to learn that certain key contributing scientists may have been over-committed by their organisations. In Australia, there is now a wide variety of special centres and projects each requiring a formal commitment of human and other resources from the participants (CRCs, ACIAR projects, R&D Corporation projects). Taken separately they are defensible, but their combined effect is increasingly to create conflicts of interest and credibility problems for the individual scientists. There is evidence that this has happened to scientists in the YDJV, notably in relation to the CRC for Sustainable Sugar Production, and more generally the Panel was informed that the resources of all three research organisations in the Joint Venture are under increasing pressure from outside.

Recommendation 1

That the Management Committee clarify the time commitments of the scientists involved in the YDJV to ensure that there is no double counting of their time in formal agreements.

3. BENEFITS FOR THE SUGAR INDUSTRY

The YDJV has been highly successful at drawing on a pool of scientific resources for the benefit of the sugar industry. The YDJV has enabled participation of scientists from organisations with limited prior involvement with the sugar industry to direct their expertise onto the issue of monoculture yield decline. These added skills and perspectives have given new insight into the problem of yield decline in sugarcane.

The major benefit from the YDJV is clarification of the components of 'yield decline'. This understanding now needs to be communicated to growers. The main findings from the YDJV and related work have been outlined in the review paper by Garside *et al* (1997):

(a) Failure to capitalise on potential yield gains from plant breeding over the period 1970 to 1990 has had various causes and monoculture yield decline has probably played little part in this loss of potential productivity.
(b) There is a loss of production associated with the repeated growth of sugarcane on the same land, which we term monoculture yield decline. This effect can be large under sub-optimal growing conditions.

Benefits will accrue to the industry once it understands the yield decline issue. To achieve these benefits, we recommend that SRDC consider initiating a special project to ensure that the two forms of yield decline are understood. An example of how this project could be conducted would be to have a project officer analyse local production data, involve farmers and members of the YDJV in this analysis and then involve groups of both farmers and YDJV team members in discussion of this information.

Understanding could be facilitated by a special issue of the YDJV newsletter (or other industry publication) that provides a general introduction to the issues related to yield decline. This would be followed by local meetings, but the information presented at this level must relate to local production problems and must be part of a continuing communication process. If the information can be placed in the context of grower's decision-making processes (incorporating financial aspects and production risks), then a much better insight will be gained into the potential benefits of alternatives.

We would expect the major benefit from the rotation work (including legumes) to be in understanding the influence of the rotation on the components of soil fertility (physical, chemical biological). A benefit is not expected in terms of the wide adoption of grain legume rotations under current industry circumstances. However, there is considerable scope to improve the standard of short-term legume fallows, which are still used widely by growers, and this may help to reduce the impact of monoculture yield decline.

At this stage, it is too soon to judge the possible benefits from the research on nematodes and tillage.

Recommendation 2

That SRDC consider initiating a project to ensure that the main findings on yield decline are understood by canegrowers.

4. ANALYSIS OF PRODUCTIVITY TRENDS IN THE AUSTRALIAN SUGAR INDUSTRY

One of the important achievements of the YDJV has been to clarify the distinction between monoculture yield decline and the much broader problem of the yield plateau that was experienced in the sugar industry between 1970 and 1990.

Although not strictly within the Panel's terms of reference, we propose that the Management Committee draw the attention of SRDC and the other parties in the Joint Venture to the desirability of undertaking further analysis of productivity trends in the industry. As Dr Leslie has pointed out in his report to the Management Committee, the amount of statistical information available for sugarcane is much greater than that for other crops, in Australia at least. The Panel's conclusions about the value of further analysis was confirmed by a briefing it received from Dr Leslie on the findings of a separate study carried out by him and Prof Wilson on the problem of low CCS in cane grown in the wet tropics (Leslie and Wilson 1996).

Our recommendation is that this further analysis should not be part of the future Joint Venture on monoculture yield decline, but it is so important to the understanding of constraints to the improvement of industry productivity that it should be conducted as a separate entity. An appropriate technique is that of multifactor productivity analysis as defined by agricultural economists (Craig and Pardey 1996), because it is not just output that is of interest but output as a function of inputs. Successful technological innovations increase the efficiency of inputs such as varieties, water, fertiliser and farm machinery, while soil and water degradation reduce their efficiency as factors of production.

The analysis should be carried out jointly by economists and biophysical scientists and with strong industry involvement in order to address the important questions, though with sufficient independence so as not to be inhibited by industry politics.

Recommendation 3

That the attention of the parties in the Joint Venture be drawn to the importance of multifactor productivity analysis as a means of identifying constraints to productivity such as those that caused the yield plateau in Australian sugar production between 1970 and 1990.

5. RECOMMENDATIONS FOR THE FUTURE OF THE JOINT VENTURE

The Panel members were unanimous in their view that the Yield Decline Joint Venture (YDJV) is largely on course and that the project work currently in progress is consistent with the objectives contained in the five-year programme plan (1994-1999) as approved by the Joint Venturers in 1994. Members are of the opinion that only small changes are needed to enhance the sugar industry's perception of the project and to improve the focus of some areas of research in the various sub-programmes. These are listed below and in Attachment 1 for the management committee's consideration.

OBJECTIVES AND NAME

While members concur that yield decline is still largely an uncertain phenomenon, for the purposes of the YDJV there is good reason to uphold the current definition of yield decline "as the decrease in productive capacity of soils under sugarcane monoculture". Considering that the main thrust is to quantify the effects of monocropping on yield and changes in the physical, chemical and biological properties of soils, changing the name of the project is not a major issue. However, a slight change in name from "Yield Decline" to "Monoculture Yield Decline" would in the Panel's opinion be more appropriate and impart the correct focus.

Recommendation 4

That the name of the Joint Venture be changed to "Monoculture Yield Decline Joint Venture" to distinguish this sugar research programme from work on the yield plateau .

PROPOSED PROGRAMME 1996 TO 1999

The focus of the YDJV should be maintained on monoculture yield decline. The projects should define the environments where monoculture yield decline is important and the ancillary experiments should relate to the main aim of understanding its cause(s). In addition, the Panel supports experiments to follow up on promising leads originating from the core field experiments and from farmer experience. These should be the major source of ideas for new experiments. However, the project teams are encouraged to take a wider view from science generally. For example, they should continue to monitor advances in solving similar problems in crops other than sugarcane. Monoculture yield decline in sugarcane is similar to replant diseases in crops such as potatoes, asparagus, corn, tobacco, apples and citrus (Magarey 1996).

The Review Panel recommends that it is now appropriate to deliberately involve canegrowers. The involvement of canegrowers is necessary for two important reasons. Firstly, they will bring a separate and different insight to the problem of yield decline, and they will help to find creative solutions. Secondly, they will learn about the research results and as a result, will be far better positioned to apply them at the appropriate time. This "ownership" of the research will enhance the application of the work considerably. The complex issues involved in yield decline require understanding, not the application of simple recipes. A joint understanding will be a far more effective one.

To help the various research and extension professionals develop this participatory approach, we recommend that the Rural Extension Centre (UQ Gatton) be consulted and be requested to provide advice to the management committee and training and support where necessary.

The panel recommends that the team-building activities already undertaken be continued as an integral component to the success of this Joint Venture. This programme has the potential to become a model for collaborative field-crop research.

Recommendation 5

That:

- **the Joint Venture in future deliberately involve cane farmers in a participatory role;**
- **the Rural Extension Centre (UQ Gatton) be consulted and requested to provide advice and training where necessary;**
- **the team-building activities already undertaken successfully be continued as an integral component of this Joint Venture.**

NEGOTIATIONS FOR A FURTHER PHASE OF THE YDJV

The field trials that have been set up by the YDJV are not likely to repay the initial investment unless they are continued through at least two cropping cycles. Changes in soil biology and chemistry, particularly those related to soil organic matter dynamics and rotations, typically have time scales of several years, even decades. Therefore, the Panel concluded that the parties to the Joint Venture should commence negotiations for a further phase of it well before the current agreement ends in 1999. In view of the present tendency of research organisations to overcommit the time of their key scientists, mentioned earlier in this report, it would not be too soon to commence negotiations in 1997.

The duration of the second phase of the YDJV should probably be five years, but this may become clearer as results come to hand over the next two years. The Panel debated the desirability of introducing additional parties but decided to advise the Management Committee to continue with the current four - BSES, CSIRO Soils, SRDC and QDPI. It is true that the Queensland Department of Natural Resources is now responsible for some research in the Joint Venture and that other CSIRO Divisions such as the former Division of Tropical Crops and Pastures and various Universities have valuable contributions to make in future, but the Panel sees real advantage in keeping a tight focus amongst the Joint Venture parties.

There will be many aspects of soil fertility that will be studied extensively outside the Joint Venture, but that could have important interactions with the causal factors of monoculture yield decline, as these are elucidated by the YDJV. These include soil acidity and plant nutrition, management of soil organic matter levels and trash, and soil physics. Unless the current hypothesis, that monoculture yield decline is caused by deleterious changes to the biology of cane roots, has to be substantially modified or even discarded in the light of new evidence, these other aspects of soil fertility will be relevant to the YDJV primarily because they may influence the severity of the effects of monoculture yield decline, as may seasonal weather conditions generally.

So the YDJV will need to maintain effective links with a number of important areas of cane research for which it does not need to have the primary responsibility. This is the principle that guided the Panel in its deliberations on future relationships between the YDJV and the CRC for Sustainable Sugar Production. The Panel also had the benefit of a briefing from the Director of the CRC and was reassured that the CRC's objectives were clearly distinguishable from those of the future YDJV as set out in the recommendations of this review. While the Panel does not see any case for amalgamating the two entities or for the CRC for SSP to work on monoculture yield decline as defined in this report , there is a need for effective communication between the two. The Panel was informed of good progress to this end in recent months. In future, they should be prepared to conduct joint workshops in areas of common interest, such as those mentioned above. The problem they will both have is that there is currently no industry-wide mechanism for allocating the responsibility for conducting such workshops.

The Panel also considered the future funding requirements of the YDJV. Its recommendation to the management committee is that:

- The costs of Joint Venture leadership and of planning and reporting workshops should be taken from the top of the SRDC funds before they are distributed to the parties. In contrast, the costs of running the long-term field trials that will be used by many of the YDJV scientists should be met from the resources available to individual parties.
- a share of SRDC funds should be provided to QDPI/QDNR as well as to BSES and CSIRO, when the SIRP funds revert to BSES.

On present indications the YDJV research in the second phase is likely to require about the same funding as at present with allowance for inflation of costs. The Panel is unable to suggest an absolute amount because that will depend on the relative priority of monoculture yield decline in the research portfolios of the Joint Venture parties and on the amounts of other funds available to them.

Recommendation 6

That:

- **the costs of leadership and of conducting workshops for the whole Joint Venture should be met from SRDC funds before they are distributed to the parties; and**
- **a share of SRDC funds should be provided to QDPI\QDNR as well as to BSES and CSIRO in a second phase of the Joint Venture.**

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ATTACHMENT 1

DETAILED COMMENTS ON SUB-PROGRAMMES

b) Rotation and Run Down Trial Sites. This core research programme which is structured around a farming research approach based on the rotation and rundown sites, is in many ways unique and essential to successfully breaking the effects of sugarcane monoculture. It is pleasing to see the progress that has been made in establishing the various rotation experiments and that these cover a wide range of climate/soil conditions in the industry. Clearly, the QDPI contribution in Bundaberg has greatly enhanced this part of the programme and will provide valuable information under conditions which differ from those of the northern sites. However, all the programmes have some way to go to demonstrate that crop rotation will arrest the deterioration in physical and chemical properties as well as providing a more favourable balance in the microbial population. There will be a continuing need to understand the effects that monoculture has on the soil/root interface to ensure that relevant control measures are being tested.

Panel members recognised the possibility that some of these trials may well have to continue beyond 1999 before a complete assessment of the effects and solution to monocropping can be made. Members also felt that more emphasis should be given to testing fallow legumes which maximise economic benefits to the farmer especially in terms of potential savings that can be made in N use. To this end, legumes such as forage peanuts as well as better nodulating soybeans should be pursued rather than cowpeas and mung beans. In the same way that economic considerations motivated the industry's move to green cane harvesting, so the economic benefits related to N savings, additional crop yields as well as a potential income from the peanuts will need to be understood.

c) Companion Cropping/Biofumigation. Panel members felt that this part of the work will need to be accelerated and expanded. In practice it will be difficult to maximise the benefits from rotation using the traditional fallow system. Growing rotation species as a companion crop with ratooning sugar cane in the inter row on an annual basis is successfully practiced in countries such as Fiji and Mauritius. Quantifying the effects of companion crops such as Brassicas on soil health particularly in relation to possible nematocidal as well as fungal (*Pachymetra, Pythium*) benefits also needs to be evaluated in the light of the responses that are being shown in current experiments. An aspect that the YDJV group should also consider in evaluating the rotation/companion crop strategies is the potential benefit in controlling ratoon cane stunting disease (RSD) as this would add economic value to rotation.

d) Soil Organic Matter. The Panel suggests that the researchers in the YDJV include a broad based study of organic matter dynamics using the run down trial and other available sites that:

1. demonstrates links between soil biota and organic matter
2. demonstrates links between N cycling and organic matter
3. demonstrates links between soil structure and organic matter.

Strong interaction between the soil biologists and the physical scientists and chemists would be desirable.

e) Root Growth and Health. The aeroponic system has considerable merit as a tool in better understanding the physiology of top and roots and this technique should be extended to factors directly related to the YDJV problem, eg water stress, acid soil solutions, Al toxicity, low levels of Ca etc. The three researchers involved with root studies should try to collaborate more closely in this field. The field root monitoring study is very commendable but the undisturbed core sample technique is very labour intensive and time consuming. Has the boroscope system of quantifying root distribution been considered? Exposing soil profiles followed by root washing is also a useful method for studying treatment effects in the field.

Some attempt has been made at analysing water uptake in the existing research projects. With grain crops, water extraction patterns have given good insight into root activity and plant growth and have allowed yield-constraining factors to be identified. The applicability of this technique to sugarcane is worth more of a look.

f) Strategic Tillage. Include consideration of tillage practices such as vertical mulching within the framework of rotation. Incorporation of organic matter to depth (filter press mud, chopped trash) has been shown to have longer lasting effects than surface application and will act as a buffer under conditions of compaction. Further use of models to predict compaction hazards in soils is encouraged.

Management strategies for minimising compaction need to be developed for transfer to growers.

g) Nutrition. Data should be accessed from other industry databases (CSR mills, Incitec) and used to establish trends in acidification, K and Ca trends. With regard to developing criteria for lime requirement, there could be merit in collaborating with other research groups such as the BSES, CRC and CSIRO in conducting a joint programme of trials. Silicon has been referred to on a number of occasions as a possible factor limiting growth under a system of monoculture. As there are a number of players already researching Al/Ca relationships in degraded soils, there could be merit in concentrating the YDJV efforts on Si and K nutrition of degraded soils.

h) Trash blanketing. Maintenance of the programme of measurement of water use, soil and chemical properties is supported. There is also merit in the following measurements:

- mineral N, S and C
- pathogen bioassays
- nematode bioassays (pathogen free)
- microfauna assays (mites/collembolans)
- bulk density
- aggregate stability
- cations
- CEC
- acid saturation.

The other area that is considered to be potentially important in yield decline is the negative effect of trashing under water logging. The reasons for this in terms of possible phytotoxic effects from released gases such as ethylene needs to be addressed as a new project by the root research specialists.