



FINAL REPORT - SRDC PROJECT YDV002 SUGAR YIELD DECLINE JOINT VENTURE PHASE 2 (JULY 1999 - JUNE 2006)

by

AL GARSIDE and MJ BELL

With contributions by
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The research agencies and SRDC were partners and joint venturers in this project. However, any publications of substantive details or results of the project will only legally bind SRDC if SRDC personnel share authorship of the publication.

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SUMMARY

The Sugar Yield Decline Joint Venture defined 'Yield Decline' in the early stages of Phase 1 as "the loss of productive capacity of sugarcane growing soils under long-term monoculture". That definition was still appropriate at the start of Phase 2, although it has clearly emerged that yield decline is a complex issue largely associated with many factors being out of balance in the way we grow sugarcane. The approach taken in Phase 2 has been to appreciate that complexity and conduct a research and development program that accommodates many of those factors, at least to some extent. Such an approach may not provide the perfect solution for each individual factor, but will result in overall improvements to the farming system.

Phase 2 of the Sugar Yield Decline Joint Venture (SYDJV) started in July 1999 and finished in June 2006. Research in Phase 2 has greatly increased our understanding of how farming systems operate, the key components of farming systems, and how they can be manipulated to provide better outcomes. This understanding has been made possible through the component research that has been carried out within a farming-system framework. Probably the most important factor to emerge from Phase 2 has been the further confirmation of the importance of organic matter in the farming system and the very positive impact that the conservation of cane trash and legume residue has on the chemical, physical and biological properties that contribute to soil health. The impact of adequate organic matter is such that one is left wondering as to how much the previous farming system was exposed to yield decline simply through the practices of burnt cane harvesting and trash removal.

In the series of experiments conducted in Phase 2, organic matter has been shown to enhance suppression of adverse biological factors, increase nutrient cycling, and enhance hydraulic conductivity and water infiltration. Further, measurements on long-term bare fallows have shown that nitrogen mineralisation is substantially reduced and more N fertiliser is required to maintain yields when the system is denuded of organic matter. This situation exists on many cane farms. Long-term bare fallows, which deplete organic matter, have operated very similarly to fumigation in initially enhancing crop growth because of a substantial reduction in pathogenic soil organisms. However, they have subsequently ended up resulting in yield reductions, due to increased susceptibility to re-invasion of organisms pathogenic on sugarcane. Unlike a system that has breaks in terms of other crop and pasture species, a balanced biology is never established. Of the many lessons learnt through the 12 years of the SYDJV, an important one is that retention of cane trash (the main source of organic matter on a sugarcane farm) can go a long way towards producing a sustainable farming system. We are becoming more convinced that our original premise, that the monoculture itself was the major cause of yield decline, is not entirely correct. The way the monoculture has been practiced with excessive tillage, uncontrolled traffic and removal of organic matter has probably played a role that is at least as important as the lack of species rotation.

At the start of Phase 2 it was known that there were large yield responses (20-30%) to breaking the sugarcane monoculture and that these responses continued into the ratoons. It was not known whether the improved ratoon yields were associated with the sustaining of improved biology into the ratoons or simply associated with the production of a healthy plant-crop root system that had the resilience to provide better conditions for ratoon

establishment. The research conducted in Phase 2 suggests that the establishment of a healthy plant-crop root system is the major controlling factor. Several assessments have shown that measurable soil biota return to pre-break levels within 12 months of re-planting sugarcane. Of course, the possibility remains that positive biological factors promoted by the break, which we are currently unable to measure, may still be present in the system. This is an area that needs further investigation, although the diagnostic tools required to monitor pathogens, other than *Pachymetra* and nematodes, or to quantify soil microbial diversity and function are not available.

In Phase 2 it has been clearly shown that all sugarcane growing areas experience yield decline (the adverse effect of long-term monoculture), but its ultimate effect on productivity is clearly associated with the growing conditions. In high-input situations, such as the Burdekin, poor crop establishment (a classic symptom of yield decline) is often masked by high inputs of nitrogen and water (that enhance tillering), so that by crop maturity, yields are only slightly reduced. In production terms, this approach is hard to argue against, but the cost of wasting nitrogen and water resources and the potential long-term consequences of degrading soils and polluting river systems are a concern.

The need to change the traditional row spacing from 1.5 m to at least 1.85 m to minimise compaction and establish controlled traffic has resulted in a substantial amount of research into different row spacings and the interaction between variety and row spacing. There is mounting evidence of an interaction between row spacing and varietal performance, and this has important implications for the variety-evaluation program. The pre-cursor to the SYDJV getting involved in row spacing and plant density research was the High Density Planting Program (HDP) that operated in BSES during the late 1990s. This program promised substantial yield increases with narrower rows and higher planting densities. The SYDJV seriously doubted these claims and believed that the responses to higher density were associated with poor soil health adversely affecting the growth of individual plants. We hypothesised that if soil health was improved, individual plants would grow better and there would not be a need for higher planting densities. Subsequent SYDJV research has shown that sugarcane possesses enough environmental plasticity to produce maximum yields under a range of densities and row spacings when soil health is improved. Thus, by seriously questioning the outcomes of the HDP program, the SYDJV saved the industry millions of dollars by truncating the implementation of a very expensive industry change that was likely to provide little benefit.

Management of legumes in the sugarcane cropping system has been a very important part of Phase 2. It has now been comprehensively demonstrated, many times over, that well-managed legumes are a very important component of any sugarcane cropping system - they improve soil health and fix atmospheric nitrogen. This latter virtue has resulted in it being possible to grow a plant-cane crop following a legume fallow without fertiliser N, and there are indications of a carryover N benefit into the ratoons. Further, the finding that legume N can be better utilised by the cane crop if the residue is retained on the soil surface as opposed to the traditional incorporation has been very important in allowing the development of a minimum/zero-till farming system. Surface management of legumes has reduced the rate of mineralisation and thus provided legume nitrogen for the cane crop later into the growing period.

The SYDJV can pride itself on having substantial industry interaction through workshops, topical articles, field days, and publications in conference proceedings. The publication list at the end of this report testifies to a large number of productive papers. Further, the papers re-printed in Appendix 4 clearly demonstrate the quality of the research. A characteristic of Phase 2 has been the willing involvement of extension and development staff, particularly through BSES and FutureCane, assisting in taking the SYDJV message to industry. This was something that was seriously lacking in Phase 1.

Notwithstanding the above specific research outcomes, the main legacy of the SYDJV has been the development of a new sugarcane cropping system that is now being adopted in all sugarcane growing regions in Australia. This new cropping system is based on legume breaks, minimum/zero-tillage and controlled traffic within green-cane harvesting and trash retention. The development of the new system was largely underpinned by a solid research base, much of which was initiated in Phase 1 (1993-1999) and continued into Phase 2. The capacity to move into minimum tillage and controlled traffic was largely based around the development of suitable planting equipment by the BSES engineering section.

The SYDJV has been a resounding success regardless of how it is evaluated: on a benefit-cost basis, on the basis of research knowledge gained, on the basis of adoption of outcomes, or on the basis of a multi-disciplinary, multi-organisational project. The success of Phase 2 (in particular) was largely due to a team of mature scientists who were willing to work as a team and had a single focus as to what was needed. The result is a new farming system that will take the industry into the future and prove to be profitable, sustainable and environmentally responsible.

1.0 INTRODUCTION AND BACKGROUND

The Australian sugar industry had been on a productivity (sugar yield/harvested hectare) plateau (yield decline) for the 20-year period between 1970 and 1990. Although a substantial amount of single-discipline research into numerous production factors had been carried out since the mid-1970s, particularly by BSES, very few answers as to the reasons for the productivity plateau had emerged. SRDC (and earlier the Sugar Research Council) had funded much of this work and decided that there were few indications of a resolution to the problem. The BSES approach had gravitated towards attempting to identify the soil pathogen/pathogens responsible for unhealthy sugarcane root systems that were intimately related to yield decline. The idea was to isolate the pathogen/pathogens and subsequently breed resistant varieties. This approach followed the success achieved in isolating the fungal pathogen *Pachymetra chaunorhiza*, which certainly contributed to yield decline, and the subsequent breeding of resistant varieties.

In the early 1990s, SRDC decided that a new approach was required and that all expertise needed did not reside within BSES. The Sugar Yield Decline Joint Venture was initially established in 1993 as a joint venture between SRDC, BSES and CSIRO Division of Soils. The Queensland Government Departments of Primary Industries and Natural Resources joined in 1995. Phase 1 of the SYDJV ran from 1993-1999. Numerous publications (Garside 1999a), particularly in the *Proceedings of the Australian Society of Sugar Cane Technologists* (ASSCT), resulted from the research carried out in Phase 1 and a comprehensive final technical research report (Garside 1999b) and topical publication (Anon. 1999) were produced.

Essentially, Phase 1 involved reviewing all the possible causes, re-evaluating soil factors that may have been influencing yield decline, and carrying out a research program to show how degraded soil properties could be improved resulting in productivity increases. In effect, Phase 1 was an identification and understanding period. Initial research with paired old and new land sites (Garside *et al.*, 1997) demonstrated that there was a range of degraded properties (chemical, physical and biological) in soils that had been under sugarcane monoculture. Subsequent studies demonstrated that both the sugarcane monoculture and how it was practiced greatly contributed to soil degradation and yield decline. As it was not feasible to address all of the degraded soil properties directly, it was decided to focus on researching practices that were likely to improve a number of soil properties and therefore enhance soil health. Consequently, much of the research in Phase 1 focussed individually on breaking the monoculture with different species (e.g. legumes, pasture) or bare fallow, reducing tillage and controlling traffic. Each of these practices either resulted in productivity improvement and/or substantial cost savings. In experiments investigating these three particular research areas, detailed measurements were made of changes in soil chemical, physical and biological properties. In effect, degradation was arrested to some extent with each of these practices.

In arguing the case for a second phase, it was believed that the real benefits of legume breaks, controlled traffic and minimum/zero tillage would only be realised if they could be combined in an improved sugarcane cropping system. Thus, much of the focus in Phase 2 has been on developing a new sugarcane cropping system along with a much greater emphasis on extension, industry involvement and practical initiatives. In addition,

detailed soil property measurements have been continued, particularly of biological parameters, so the proposed farming system changes have a firm research base.

2.0 OBJECTIVES

1. To quantify the impact of factors identified as important in yield decline through rotation experiments.
2. To identify if, and understand how, soil chemical, physical and biological properties interact to produce yield decline.
3. To utilize organic matter, reduced tillage and acidity ameliorants as soil amendments and research tools to further understand and counter the causes of yield decline.
4. To develop, demonstrate and extend changes to the farming system that will result in more sustainable sugarcane production.
5. To substantially increase the extension component of the Joint Venture to promote early adoption of the outcomes of Phase 1 and emerging outcomes of Phase 2.

Progress has been made with all the objectives, although there is still more research needed to explore fully issues associated with objectives 1, 2 and 3. These objectives are being further explored in a new project (BSS286 – Improved sugarcane farming systems).

Objectives 4 and 5 have received major input from the SYDJV team, as it was deemed necessary to develop practical solutions to the problem of yield decline as soon as possible. The results have been very positive with the development of a new sugarcane cropping system that is being adopted rapidly throughout the industry (see later). This clearly testifies that objectives 4 and 5 have been met.

The Joint Venture, as the term implies, saw the participation of a range of people from different agencies, in particular (apart from the authors) Dr C Pankhurst, Dr G Stirling, Dr R Magarey, Dr B Blair, Dr P Moody, Mr B Robotham, Dr M Braunack, and Mr J Agnew. SRDC provided the majority of the operating funds for the project and the salary of the Research Leader, Dr A Garside.

3.0 METHODOLOGY

The methodology adopted in Phase 2 of the SYDJV can be considered in five broad areas.

Understanding Responses. There was continued research into understanding the impact of soil properties (chemical, physical and, particularly, biological) on the growth and yield of sugarcane. The procedures here were a combination of further glasshouse experiments on soils selected from rotation and farming-system experiments, in addition to specific experiments established to manipulate soil biology and measure response. Most of these experiments focused on the early growth period of sugarcane (first 60 days), as poor early growth under long-term monoculture was a major feature of yield decline. Techniques

used in these experiments revolved around organic matter enhancement, soil fumigation and other biocides, inoculation of fumigated soil with different pathogens, and studies into suppression. Nematodes (both beneficial and pathogenic) and *Pachymetra chaunorhiza* were widely used as indicators of soil health. Monitoring changes in soil properties in rotation and other agronomic experiments were also a component of these activities. The effects of changing practices on soil chemical and physical properties were also investigated.

Agronomic Studies with new rotation experiments (additional to those carried out in Phase 1) were established to allow more detailed crop physiological measurements to be made. In addition, other experiments were established to investigate:

- the effect of row spacing and plant population in fumigated and non fumigated soils;
- the effect of soil health on sugarcane yield and yield components;
- management of legume break crops; and
- the impacts of compaction on water infiltration, crop growth and yield, and the growth of sugarcane under different tillage systems.

Farming System Experiments. Large scale (3-9 ha) experiments were established in several cane-growing regions (Mulgrave, Herbert, Mackay and Bundaberg) to investigate how controlled traffic, minimum tillage and legume breaks could be combined into a practical sugarcane cropping system. These sites were widely used as extension tools with numerous field days and farm walks being held at the sites. The development of machinery to allow minimum/zero-tillage planting was an important component of this part of the program.

Extension and Development. A major effort was put into extension and development work through workshops in all regions, including New South Wales. Three series of workshops were held. The first series was targeted at reporting Phase 1 results to growers (16 meetings between 31 May 2001 and 15 March 2002), while the second series was targeted at reporting Phase 2 results to growers (13 meetings between 8 February 2005 and 2 March 2006). In addition, three 2-day workshops were held for extension officers, productivity services staff and agri-business in October 2004.

Evaluation. This project was developed and commenced before self-evaluation of projects was introduced. The formal evaluation was a mid-term review and the project was assessed twice by Agrans Research, who carried out benefit-cost analyses of the project in 2002 and 2005.

4.0 OUTPUTS

These are covered under the five different sections detailed in the methodology. They are brought together in the Executive Summary.

4.1 UNDERSTANDING THE IMPACT OF SOIL PROPERTIES (CHEMICAL, PHYSICAL AND, PARTICULARLY BIOLOGICAL) ON THE GROWTH AND YIELD OF SUGARCANE

4.1.1 Soil biology

Research has focused on the impact of more sustainable farming practices on soil biological properties. In particular, nematodes, and to a lesser extent *Pachymetra chaunorhiza*, have been used as tools in understanding the broader issues of soil biology. Beneficial and pathogenic nematode species have been used as indicators of soil health. Much of the focus with soil biology has been on the early stages of crop growth.

There is little doubt that soil pathogens are associated closely with yield decline. However, the work carried out by the SYDJV in Phase 1 showed that, although soil pathogens were the ultimate cause of yield decline through impairing the development and functioning of cane root systems, their impact was very much influenced by the sugarcane monoculture and how it was being practiced. Thus much of Phase 2 has focused on the impact of changing management practices (eg. legume breaks, controlled traffic, minimum/zero tillage and other practices that affect levels of soil-organic matter) on soil biology. A change in philosophy for the sugar industry has been to accept that adverse soil biology cannot be controlled but has to be managed, and to manage soil biology properly there needs to be understanding of how it functions in the sugarcane-cropping system.

Our approach with the soil-biology research has, therefore, been to utilize breaks to the monoculture, fumigation, biocides, inoculation and organic amendments as tools to aid in the understanding of how soil biology and crop growth interact. Importantly, most of the soil biology investigations have been incorporated in the larger scale agronomic field experiments. Hence, the research has been carried out at both the field and glasshouse scale.

Much of this work has been published in both technical journals and ASSCT proceedings, as shown in the publications list. Some of the more important publications have also been included in Appendix 4.

- *Soil biologists focused on the impacts of more sustainable management on soil biology.*
- *They used nematodes and pachymetra as indicators of soil health.*

Soil biology studies in the rotation experiments

The positive response to rotation breaks measured in the original rotation experiments reported in Phase 1 encouraged further investigations in a second series of rotation experiments planted at Tully (Garside *et al.* (2002a) – copy in Appendix 4), Burdekin and Bundaberg (Milestone Reports 7 and 8 and Appendices 1 and 2). The agronomic aspects of these experiments are summarised in the agronomy section and detailed in Appendix 2.

The Tully experiment was analysed intensively by soil biologists. It was established as a rotation by biocide experiment that included continual cane or plough-out/re-plant (PO/RP) and 54-month breaks of other crops, pasture and bare fallow. These basic treatments were split to six biocide treatments – fumigation, fungicide, nematicide applied twice, nematicide applied four times, fungicide + nematicide, and control. Details of the soil-biology measurements are provided in Pankhurst *et al.* (2002, 2005a).

Pankhurst *et al.* (2002) reported that at 54 days after planting (DAP) all of the breaks had a positive effect on % bud germination and sett-root growth. Fumigation, fungicide and fungicide + nematicide increased a number of plant growth parameters, while nematicide alone had little effect, even though it reduced lesion nematode numbers. The results from this experiment therefore indicated that the early growth responses were largely due to the control of detrimental fungi, although other experiments did show that nematodes could also cause substantial crop losses.

Pankhurst *et al.* (2005a) (copy in Appendix 4) reported on soil-biology experiments conducted in the field and glasshouse using soil from the rotation by biocide experiment. In the glasshouse studies, fumigated soil from land that had been under sugarcane monoculture for 30 years produced markedly larger sett and shoot-root systems and stimulated primary shoot growth and secondary shoot numbers. This appeared to be due largely to a substantial reduction in the numbers of culturable fungi and lesion nematodes. However, exposure of the developing sett-root system to monocultured sugarcane soil for 14 days was sufficient to retard subsequent plant growth. In field experiments, the combination of fungicide and nematicide applied together was as effective as fumigation in improving early sugarcane growth and final yield.

The crop yield data for this experiment is presented in Garside *et al.* (2002a) – (copy in Appendix 4). Rotation breaks (crop, pasture) of 54 months improved sugarcane establishment and final sugarcane yield by 20%, levels similar to that recorded when sugarcane monoculture soil was fumigated. Fumigation of soil that had been under the rotation breaks gave further increases in plant growth and final yield. A fungicide + nematicide treatment was as effective as fumigation in increasing yields after a bare fallow but did not achieve the same plant growth and yield as fumigation following crop and pasture breaks. Plant-growth responses to fumigation and fungicide + nematicide treatments that were manifested in final sugarcane yields were evident as plant-growth responses (sett root, shoot root and primary shoot dry weight) at 54 days after planting. The experimental results supported the concept that when sugarcane is grown as a monoculture, deleterious fungi and nematodes retard establishment and early plant growth and this leads to reduced sugarcane yields.

Early growth in field experiments:

- *Breaks had a positive effect on bud germination.*
- *Early growth responses were more due to control of fungi than nematodes control although this is not always the case.*
- *Nematicide provided a synergistic effect once fungi were controlled.*
- *Combination of fungicide and nematicide was as good as fumigation in improving early growth.*
- *Organisms killed by fungicides and nematicides retard establishment and early growth.*

Final yield in field experiments

- *The breaks out-yielded PO/RP by around 20%.*
- *Similar yields were recorded for fumigated PO/RP, fungicide + nematicide, and rotation breaks (crop, pasture). Bare fallow yields were slightly lower.*
- *There was no direct response to nematicide.*
- *However, nematicide had a synergistic effect with fungicide.*
- *Fumigated rotation breaks (pasture, crop) produced still higher yields indicating a possible nutrition effect and/or some remaining biological impediment.*

In glasshouse experiments:

- *Fumigation increased sett and shoot root systems.*
- *Fumigation reduced fungi and lesion nematode numbers.*
- *Growth in fumigated soil could be readily retarded by exposure for 14 days to non-fumigated soil from a sugarcane monoculture.*

Pankhurst *et al.* (2005b) (copy in Appendix 4) showed that, relative to continual sugarcane, breaks of 30-42 months under pasture increased microbial biomass, while similar duration breaks under annual crops or bare fallows either did not change or decreased microbial biomass, respectively. The lack of change in microbial biomass under the alternative crop was probably associated with the impact of tillage between each crop planting reducing organic matter, while the reduction in microbial biomass with the bare fallow was probably due to the lack of input of organic matter. Populations of lesion nematodes decreased under all breaks while those of free-living nematodes increased following the crop and pasture breaks but decreased following the bare fallow.

Stirling *et al.* (2002) (copy in Appendix 4) discussed the effects of break treatments on different species of nematodes in more detail. In effect, the breaks improved soil health by decreasing detrimental biota (all breaks) while increasing beneficial biota with the crop and pasture breaks. There were clear indication that the positive effects on soil biota may be relatively short lived, as measurements taken at the end of the plant crop suggested that all the biological properties measured had returned to levels similar to those under continual sugarcane. Regardless, sugarcane yields were still enhanced by the breaks up to the third ratoon in most of the rotation experiments (see later). Thus, it appears that there were either unmeasured biotic factors that were improved by the breaks and did not revert rapidly under continual cane, and/or improved plant crop establishment resulted in a resilience that was not as severely affected by detrimental biota as they re-established.

Soil biology changes with breaks

- *Microbial biomass increased under pasture breaks, did not change under crop breaks, and decreased under bare fallow.*
- *Response of free-living (i.e. beneficial) nematodes was somewhat similar, as they increased under pasture and crop breaks.*
- *Response under crop break may have been different had no tillage been used.*
- *Populations of lesion nematode (pathogen) decreased under all breaks.*
- *Populations of measurable soil biota had returned to pre-break levels within 12 months of returning to sugarcane.*

Impact of organic matter amendments on soil biology

The soil biota responses measured under bare fallow, and to a lesser extent alternate crops where tillage was employed, compared with pasture where no tillage was used, suggested that organic matter was an important component of enhanced soil biology under the rotation breaks. Field and glasshouse studies were, therefore, commenced to quantify the benefits of enhanced organic matter inputs.

Pankhurst *et al.* (2005c) (copy in Appendix 4) and Stirling *et al.* (2003, 2005) (copies in Appendix 4) summarized the work with organic matter amendments, while Bell *et al.* (2006b) (copy in Appendix 4) considered organic amendments in large-scale field experiments. A range of organic amendments was used to measure their ability to induce suppression of detrimental soil pathogens. The work of Stirling *et al.* clearly showed very strong suppression of lesion nematode in soils in which concentrations of organic matter had been enhanced. They concluded that high C:N ratio organic matters (eg. grasses) provided greater suppression of lesion nematode than organic matter with a low C:N ratio (e.g. legumes) and reported figures for grass-hay incorporation that demonstrated 96% fewer lesion nematodes than with continual sugarcane 6 months after re-planting. Interestingly, sugarcane trash itself incorporated into the soil on long-term sugarcane land also had positive benefits for managing lesion nematode. Stirling *et al.* concluded that low concentrations of nitrate nitrogen in the soil, a fungal dominant soil biology and high numbers of omnivorous nematodes were most closely associated with suppression of lesion nematode.

Pankhurst *et al.* (2005c) had considerably less success in measuring suppression of other detrimental soil organisms when they evaluated the amended soils studied by Stirling *et al.* They concluded that organic matter amendments had only a minor effect on suppressing other more general populations of soil organisms associated with yield decline. However, they did find that 7 years of pasture had improved the soils capacity to suppress yield decline organisms. Collectively, these studies indicated the importance of lesion nematode in the yield decline equation, supporting studies done in Phase 1 (Blair and Stirling 2006).

Stirling *et al.* have subsequently been developing nematode assays as a measure of soil health, based around the relative numbers of differing types of nematodes present in the soil. Large numbers of free-living nematodes, relative to known plant pathogenic nematodes and more diversity within the nematode community, are usually indicative of improved soil health.

- *Inputs of organic matter can foster suppression of adverse soil biota.*
- *Nematodes appear to be more sensitive than other pathogens to organic inputs, particularly to amendments with a high C:N ratio.*
- *Cane trash conservation is likely to improve soil health.*
- *The nematode community (numbers and diversity) is one possible indicator of soil health.*

Fallow-length, organic-amendments, break-crop and tillage studies (field experiments at Bundaberg and Abergowrie)

Like the rotation experiments in Phase 1 of the SYDJV, these two experiments were regarded as the core experiments for Phase 2 and were designed to investigate further outcomes from the rotation experiments. Although good responses to breaking the monoculture were measured in the rotation experiments, doubts remained as to the critical components of those break responses - the type of break, the species used in the break or the duration of break, and whether the amount of tillage during the break would have any moderating effect on these benefits. Furthermore, we wanted to know whether it was possible to obtain the same benefits from a bare fallow with added organic material prior to re-planting compared to growing the organic matter *in situ*. The results have been summarized by Bell *et al.* (2006a) (copy in Appendix 4).

In brief, field experiments established at Bundaberg and Abergowrie were aimed at quantifying the effects on soil biota and cane growth and yield of different bare fallow lengths (1-35 months) and inputs of organic material of different quality (grass, legume or grass/legume mixture) and origin (grown *in situ* or imported). *In situ* organic matter was either tilled or not tilled prior to re-planting sugarcane, while fumigation was used to benchmark the quantum of potential biological constraints in the bare fallow treatments.

Significant differences were measured between treatments for soil carbon, general soil biology and the incidence of known sugarcane pathogens, with all parameters declining with increasing length of bare fallow. Root lesion nematode declined more rapidly than general soil biology (as measured by the rate of FDA hydrolysis). Imported organic matter caused only small changes in soil biology, but *in situ* grass pastures were able to achieve increases in soil carbon and biological activity. Long-term legume cropping generally resulted in less soil carbon and biological activity, especially when tilled conventionally. Tillage after both grass pasture and legume cropping increased the rate of recovery of lesion nematode populations upon re-establishment of a sugarcane crop. The results indicate that future cropping systems need to maximize the soil health benefits of sugarcane cropping (perennial crop, regular returns of organic matter) by adopting complementary management strategies such as short legume breaks, reduced tillage and optimizing the use of cane trash.

- *Bare fallow applied to long-term sugarcane land causes a decline in soil carbon, the general soil biology, and lesion nematodes, with the decline being greater as the length of the bare fallow increases.*
- *Growing a grass pasture has the most positive effect on soil carbon.*
- *Introducing organic matter to a bare fallow break has little effect on soil carbon.*

- *Tillage after grass pasture and legume cropping increased the rate of reinfestation of lesion nematode when cane was re-planted.*
- *Short-term legume breaks, reduced tillage and retaining cane trash are positive management options.*

4.1.2 Soil physical properties

Much of the work on soil physical properties has focused on soil compaction, hydraulic conductivity and water infiltration. Braunack *et al.* (2003a) and Braunack and McGarry (2006) (copy in Appendix 4) showed that sugarcane culture can provide relatively good soil physical conditions in the cane row, provided wheel traffic and resultant compaction can be avoided. This emerged as a key issue during Phase 2, with studies by Bell *et al.* (2001) (copy in Appendix 4) clearly demonstrating how compaction adversely affected hydraulic conductivity and water infiltration. These studies also showed that trash blankets could aid infiltration in non-compacted soils by avoiding surface sealing, but that trash blankets had little effect when soil was compacted. Because of mismatched wheel (1.8-1.9 m) and row (1.5 m) spacing, compaction near the cane row cannot be avoided. Bell and Halpin (Milestone Report 6) demonstrated a 13% yield reduction in a plant crop due to compaction. With mismatched wheel and row spacing, the adverse effects of compaction can be expected to become more significant with later ratoons.

Braunack *et al.* (2003b) (copy in Appendix 4) demonstrated that, as well as improved soil physical properties, reduced tillage and permanent inter-rows (controlled traffic) can have a significant effect in reducing costs of production (reduced tractor hours and fuel usage) without any adverse effect on crop yield. In comparisons between conventional tillage (whole field prepared) and strategic tillage of the old row area with retention of permanent traffic lanes, they showed that land preparation costs could be reduced from \$474/ha (conventional) to \$112/ha minimum tillage.

- *If compaction is avoided, sugarcane culture provides good soil physical conditions.*
- *Compaction directly and indirectly reduces cane yield.*
- *Compaction reduces hydraulic conductivity and infiltration.*
- *Trash blankets can improve infiltration in non-compacted soil, but have little effect in compacted soil.*
- *Substantial cost reductions with reduced tillage and permanent inter-rows.*

4.1.3 Soil chemical properties

Most of the soil chemical investigations were based around nitrogen mineralization from legume residues, with subsequent crop uptake or leaching down the profile. These are covered in the section on legume management (see later).

In other nutrient management studies, Bell *et al.* (2002) (copy in Appendix 4) and Bell *et al.* (2003a) clearly showed the relationship between nutrient uptake and soil health, with uptake of a range of nutrients being much more effective with a healthy root system. Importantly, it was demonstrated that with nutrients whose concentration was not changed by fumigation or breaks (e.g. potassium, silicon) uptake was enhanced following fumigation, pastures or break crops.

- *Nutrient uptake is enhanced following fumigation or breaks because of healthier root systems.*

4.2 AGRONOMIC STUDIES

The agronomic studies conducted during Phase 2 generally fall into five different categories:

- Rotation experiments continued from Phase 1;
- New rotation experiments in Phase 2;
- Legume-management experiments;
- Row-spacing and crop-density experiments;
- Farming-system experiments.

These are dealt with below in separate sections. The rotation experiments (both Phase 1 and Phase 2) are discussed in Appendices 1 and 2, respectively. The results are summarized below.

4.2.1 Phase-1 rotation experiments

The Phase-1 rotation experiments were continued into Phase 2 to measure the longevity of the break effects into the ratoons. Details are provided in Appendix 1.

In all cases except for the Tully experiment (discussed in more detail in the next section), higher ratoon yields were recorded following breaks and/or fumigation than in plough-out/re-plant, and these effects were still being recorded to the end of the third ratoon. Hence, by assessing cumulative yields, the cost associated with missing a sugarcane crop to incorporate a break could be measured over a crop cycle.

The cumulative sugar yield increase with one legume crop break compared with PO/RP was around 11 t/ha for Bundaberg and Mackay, with a similar advantage for the longer (predominantly legume) crop break in the Burdekin (Appendix 1). Any analysis must allow for the year of cane production that has been foregone in favour of a break crop. If a fourth ratoon was grown in the PO/RP and it was assumed that it had performed as well as third ratoon at each of the sites (and this is extremely doubtful), the sugar yield that would have been foregone over the 6-year period by opting for the legume break would have been only 1.3, 2.0 and 1.6 t/ha in Bundaberg, Burdekin and Mackay, respectively. Further, there is a good chance a grower will take advantage of an additional ratoon with the break system compared with PO/RP, as well as getting a cash flow out of growing the

legume for grain. Hence, we conclude that growers are unlikely to be worse off financially by adopting the break crop system. In addition, mill throughput is unlikely to be jeopardized, as we envisaged only 20% of a farm being out of cane and in a break at any one time, while the response to the break has been measured at 20%.

- *Response to breaks carried through into the ratoons.*
- *The majority of the break response can be achieved with a single break.*
- *Growers are unlikely to be financially disadvantaged by including a break in their system.*

4.2.2 Phase-2 rotation experiments

Three rotation experiments were established in Phase 2 to investigate further the interesting findings from Phase 1. These experiments were at Bundaberg, Burdekin and Tully. These are dealt with separately below.

Tully

In the first Tully rotation experiment, there was no response to breaks beyond the plant crop. This was the only rotation experiment where break effects did not carry through into the ratoons.

The second Tully rotation experiment was planted with the same variety at the same site on the same row spacing (1.5 m), and in this experiment the break responses did carry through to the ratoons.

It is strongly suspected that mismatched wheel (1.85 m) and row spacing (1.5 m) with a wet harvest of the plant crop in the first experiment caused severe stool damage, thus negating the chance of a response carrying through to the ratoons. By contrast, with the second rotation experiment, both the plant and first-ratoon crops were harvested under dry soil conditions. Details are provided in Garside *et al.* (2004a) (copy in Appendix 4).

- *Mismatched wheel and row spacings can have substantial impacts on ratoon yield under wet harvest conditions.*

The yields and responses to various breaks and biocide treatments for the second Tully rotation experiment are discussed in the biology section and are detailed in Garside *et al.* (2002a) (copy in Appendix 4) and Appendix 2.

Burdekin

The second Burdekin experiment was established into two separate pre-histories in September 2001. There were three sets of contrasts within the treatments:

- i. the previous experiment was repeated with new break plots (bare fallow, crop and pasture histories), but the breaks were split to soil fumigation this time - this was done to quantify any remaining yield constraints after the various breaks;

- ii. sugarcane was re-planted on the old break histories that had been planted to cane in the previous crop cycle begun in 1998. The cane was ploughed out after harvest of the second ratoon and re-planted as under a plough-out/replant system. The aim here was to measure whether any residual effects of those breaks persisted in the soil (as compared to the observed residual effects during ratoons that may have been due to establishment of a healthy stool in the early stages of a plant crop);
- iii. we wanted to follow the effect of added nitrogen because in the first Burdekin rotation experiment it was demonstrated that increasing the N rate could reduce the quantum of response to breaks because higher N rates promoted tillering which compensated for poor establishment.

Details are provided in Appendix 2.

Repeat of the rotation breaks split with soil fumigation

In this experiment, unlike all other rotation experiments, there was no significant history effect. However, there was a fumigation effect (156 versus 143 t/ha) and a small response to nitrogen. Furthermore, the fumigation response was larger with PO/RP (21%) than with the breaks (average 5%). However, when data analysis was restricted to the unfumigated treatments, responses were comparable with the other rotation experiments with the yield following PO/RP being 27% less than following the pasture break (Table 1).

Table 1 Cane yields (t/ha) for the first and second rotation experiments in the Burdekin for PO/RP, and crop, pasture and bare fallow breaks. In experiment 1, data shown is for 180 kg/ha N treatment, while in Experiment 2 it is for 150 kg/ha N treatment.

History	Cane yield (t/ha)	
	First experiment	Second experiment
PO/RP	121	126
BF	163	139
Crop	152	154
Pasture	158	153

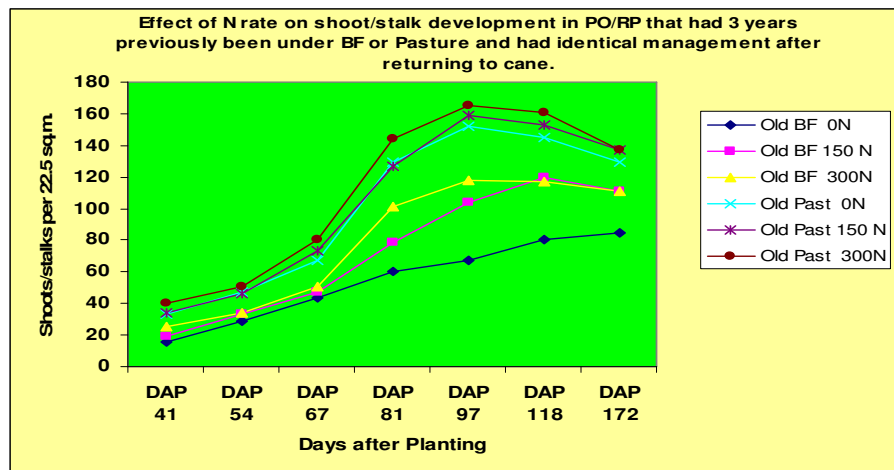
The choice of the same variety and cane-planting system on the two Burdekin rotation experiments allows direct comparisons to be made between yields and treatment effects. This resulted in one very obvious difference emerging between Experiments 1 and 2. Although PO/RP, crop and pasture histories yielded similarly between Experiments 1 and 2, the bare fallow history was substantially lower in Experiment 2. These differences may be associated with the different duration of the bare fallow for the two experiments. In Experiment 1, the bare fallow was 42 months, while in Experiment 2 it was 66 months. Bell *et al.* (2006a) (copy in Appendix 4) reported a tendency for yields to decrease with long bare fallows. Such trends may be associated with biology and nutrient deficiencies after such a long period without plant growth. Data from the replant of the first cycle (see below) suggests a strong link with declining N status.

Re-plant of the original break treatments after the first cycle (1998-2001)

In this experiment, all plots were PO/RP, but some had been in crop, pasture or bare fallow breaks until 1998. Cane yields clearly show that, in the presence of adequate N (and the levels of N needed for adequacy varied with history, from 0 in the old pasture treatment to 300 kg/ha in the old bare fallow - see Table 3, Appendix 2), there is no residual effect of the previous break treatment after 3 years of sugarcane cropping. This clearly suggests that the strong residual effect of break histories seen in the ratoons during the first cane cycle is more likely to be due to the health of the established cane stool than to residual benefits in the soil.

The large variation in N requirements of cane grown after the different breaks appear to be a reflection of the effect of those breaks on soil organic matter and N pools during the breaks and subsequent ability to mineralise N during the crop cycle. Bare fallows have consistently been shown to run down soil organic carbon and N stores, while pastures have been shown to have the opposite effect - this is consistent with the N responses recorded here. This effect is clearly demonstrated by the contrasting shoot/stalk numbers responses to different N rates in the pasture and bare fallow treatments (Figure 1).

Figure 1 **Effect of N rate on shoot/stalk development in PO/RP that had 3 years previously been under BF of pasture and had identical management after returning to cane**



- *Response to crop and pasture breaks very similar in both Burdekin experiments.*
- *Response to bare fallow break not as good in Experiment 2, probably because of longer bare-fallow break.*
- *Pasture breaks have a much better capacity to mineralize N later into the crop cycle than crop breaks and particularly bare fallow breaks.*
- *More N is required to produce maximum yield following a bare fallow. Similar yields were produced with no additional N on a pasture break and 300 kg/ha N on a bare fallow break.*

- *Poor establishment can be compensated for by enhanced tillering in high-input systems. Hence, the often-quoted, erroneous conclusion that yield decline is not an issue in the Burdekin.*

Bundaberg

The second Bundaberg rotation experiment contained long (72-month) and short (12-month) breaks. After harvest of the third ratoon of the first rotation experiment in 2000, the short breaks were re-instated for 12 months and then both long and short breaks were re-planted in 2001 after being split to fumigation or no fumigation. After harvest of the plant crop in 2002, all cane was removed and all plots were then re-planted in an attempt to measure the longevity of break effects.

Prior to any re-planting in 2001 the rainfall simulator was used to measure water infiltration over the various break and continual cane treatments. Details are provided in Appendix 2. Rainfall infiltration ranged from 100 mm/h under grass or legume pasture to 25 mm/h under continual cane, undoubtedly due to compaction from heavy traffic with continual sugarcane.

Yield response to short- and long-term breaks – 2001 planting

This experiment suffered badly from water stress, particularly during stalk filling, which probably had a major effect on potential responses. Overall, there was a response to fumigation of about 19% and this was consistent with results from other rotation experiments. However, responses to break were inconsistent, with no particular trend. In the first rotation experiment at this site, there was a positive response to short-term breaks, due mainly to differences in stalk size more so than stalk number. The late water stress would have reduced the chance of responses with this planting. Results are shown in Appendix 2, Table 4.

Effect of re-planting in 2002

There was no residual history effect on cane yield, a result similar to the Burdekin re-planting discussed above. This further supports the idea that improved ratoon yields following breaks are more associated with the establishment of a good initial stool in the plant crop than continued enhanced soil biology into the ratoons. It was interesting in this experiment that the re-plant (none of which was fumigated) showed a significant effect of the previous fumigation treatment in that non-fumigated plots out-yielded fumigated plots. This is consistent with biota establishing more quickly following fumigation than where no fumigation has been used. Similar responses have been recorded in the southern grain belt (D. Roget, pers. comm.)

- *Experiment badly affected by water stress.*
- *Response to fumigation consistent with other rotation experiments.*
- *Further evidence that higher ratoon yields following are associated mainly with good plant-cane establishment.*
- *Management strategies that establish healthy plant-cane stool is critical to maximising yields*

4.2.3 Legume-management experiments

Much of the legume research was carried out in Phase 1, and this was reviewed by Garside and Bell (2001) (copy in Appendix 4). In Phase 2, the legume work revolved more around management of the legume residue to maximise benefits to the following cane crop in terms of nitrogen nutrition.

Studies on both the wet coast (Garside and Berthelsen 2004; Garside *et al.* 2006b (copies in Appendix 4); Noble and Garside (2000) and the dry sub-tropics (Bell *et al.* 2003b, 2006b (copies in Appendix 4)) confirmed that the most effective use of legume nitrogen by a sugarcane crop occurred when the legume residue was retained on the soil surface, as opposed to incorporating it into the soil. The latter practice resulted in rapid N mineralisation and leaching of N out of the root zone, particularly on the wet coast. In numerous other studies, it has been again demonstrated that there is no need for fertilizer nitrogen on a plant crop following a good legume crop. Studies are continuing into the carryover effect with the ratoons.

- *Legume residues more beneficial when left on soil surface as opposed to being incorporated.*
- *Surface legume mineralizes N more slowly, so more N available later in the cane crop to fill stalks.*
- *No N required on a plant crop following a good legume break.*
- *Research continuing on what is required for the ratoon crops.*

4.2.4 Row-spacing and crop-density experiments

The SYDJV became involved in row spacing and density studies because of concerns that the high-density planting (HDP) program within BSES was neglecting issues such as soil health, and that there were concerns with regard to the interpretation of experimental results. Yield increases of up to 50% were being claimed by moving from a 1.5 m to 0.5 m row spacing. We believed that these large yield increases could be associated with poor soil health producing below optimum yields from individual plants, and that this was being compensated for by moving to higher plant densities. To test this we commenced investigations using fumigation, different planting densities and different row spacings. The outcome of this research was that, if soil biological constraints were removed with soil fumigation, there was no yield difference between 1.5 m rows with low density and 0.5 m rows with high density. This is detailed in Garside *et al.* (2002b) (copy in Appendix 4). In other experiments conducted by the JV, the environmental plasticity of sugarcane in response to row spacing has been demonstrated, with significant compensatory capacity in individual stalk weight able to make up for quite large variation in stalk density (see Bell and Garside (2005) – copy in Appendix 4).

Despite this compensatory ability, we have started to accumulate evidence of significant variation in the ability of cane varieties to yield at different row configurations. Initial studies showed that plant cane yields from 1.8 m single rows were 10-20% lower than from 1.8 m dual rows or 1.5 m single rows (Garside *et al.* 2005b - copy in Appendix 4), but the differences disappeared in the ratoons. However, more recent work is indicating

substantial variety by row spacing interactions may exist (Garside *et al.* 2006a - copy in Appendix 4), with significant implications for the controlled traffic component of new sugarcane farming systems. This work is being followed up in project BSS296.

- *Sugarcane possesses considerable environmental plasticity and can produce similar yields under quite varying row spacings and plant densities.*
- *The positive responses to high density planting recorded elsewhere were probably associated with poor soil health reducing the productive capacity of individual plants.*
- *There appears to be variety by row spacing interactions for cane yield.*

4.2.5 Crop-physiology studies

Bell and Garside (2005) (copy in Appendix 4) used data from the rotation and density experiments to explore the relationship between stalk number and stalk size, and clearly showed the importance of both in yield accumulation. Crop rotation or soil fumigation resulted in significantly improved crop establishment with greater numbers of primary and higher order shoots. The data from these studies showed that nitrogen had little effect on initiation of secondary tillers, but in combination with adequate water supply, had an important effect on tiller survival that was also influenced by the initial population of primary shoots. Subsequent work with more extreme levels of N has shown that N can have an important impact on tiller initiation (Figure 1).

Varieties had an important impact on whether the major contributor to yield was stalk number or stalk weight. The analysis showed that although it was necessary to establish and retain an optimum stalk number, yield would only be maximised if growing conditions were such to fill those stalks adequately. Improvements in soil health through crop rotation and soil fumigation deliver yield benefits by achieving both higher population densities and heavier stalks.

- *Both stalk number and stalk size are important in yield accumulation.*
- *Yields will only be maximised if growing conditions are such to fill stalks adequately.*
- *Varieties have an important impact on whether the major contributor to yield is stalk number or stalk weight.*

4.3 FARMING-SYSTEM EXPERIMENTS

Both small- and large-scale farming-system experiments have formed an important part of Phase 2 of the SYDJV. Most of the results of these have been published, primarily in ASSCT proceedings. This work is covered in Bell *et al.* (2003b, 2006a), and Garside *et al.* (2003a, 2004a, 2005a, 2006b). Copies are in Appendix 4.

The large-scale experiments (3-9 ha) have been an important extension tool, as they have been of sufficient size for growers to readily accept as demonstrating practical commercial options. These experiments have been based around demonstrating the importance of combining legume breaks, minimum/zero tillage and controlled traffic, and were located at Gordonvale, Ingham, Mackay and Bundaberg. In most cases, yield improvements have not been recorded when compared to standard full cultivation practices, but yields have been maintained while substantial cost savings have been achieved. Data for the Gordonvale, Ingham and Bundaberg experiments have been published in Garside *et al.* (2004a, 2005a), while the Mackay experiment is reported in Milestone Report 12, Appendix 4 (copy attached as Appendix 3).

In all of these experiments, comparisons were made between conventional cane planting on 1.5 m rows after full tillage and direct planting of single rows on 1.5 and 1.85 m beds or dual rows on 1.85 beds. All of these large-scale experiments had a soybean fallow prior to cane planting. The availability of double-disc-opener planters and suitable bed formers were crucial to the establishment of these experiments. This machinery had been developed by the BSES Engineering Section under the leadership of Brian Robotham. Details of much of this machinery are provided in *BSES Bulletin* articles listed under Publications.

Unfortunately, most of these experiments suffered extremely dry conditions in both the growing and harvesting periods, so growth was restricted and wet harvests did not occur. As a result, the expected stool damage from mismatched wheel and row spacings with the 1.5 m rows did not eventuate, and the advantages of controlled traffic in ratoon crops were minimal.

The small-scale research experiments were conducted at Tully, Bundaberg (2) and Abergowrie, and these combined various treatments involving legume management, trash management and tillage (Bell *et al.* 2003b, 2006a; Garside *et al.* 2006b) (copies in Appendix 4). The important points to come from these experiments were:

- *There is no need to apply N fertiliser following a well-managed soybean fallow.*
- *N is released more slowly when the legume residue was surface mulched or left standing as opposed to being incorporated. Surface management resulted in N being available later in the life of the following plant cane crop and this enhanced individual stalk weight without reducing CCS.*
- *At the end of a cane cycle, cane trash could be incorporated at different times prior to legume planting without any adverse effect on the legumes.*
- *Under marginal water conditions, cane yields were higher with zero-tillage and surface mulched legume residue than they were with a tilled bare fallow, due to better rainfall infiltration and more available water in the profile.*

- *There were indications that cane yield would be enhanced on non-tilled permanent beds once they were in place for several years.*
- *With permanent beds and a continual cane system, no tillage and cane trash retained on the surface produced higher yields than surface tillage with cane trash incorporated.*
- *When soybean was included in the system to break the sugarcane monoculture, cane yield was increased further.*
- *The combination of direct-planted cane into the permanent beds with legume residue left on the surface out-yielded surface-tilled permanent beds in a cane monoculture by 47%.*
- *Bare fallows with introduced legume, grass or grass + legume organic matter did not produce as good a cane yield as when legume or grass was grown in situ.*

Overall, the farming system experiments have been successful in demonstrating that the three basic principles of the new farming system (legume breaks, minimum/zero tillage and controlled traffic) can be combined with substantial cost savings, no loss in productivity during establishment and every indication of enhanced productivity once permanent beds become stabilised.

The farming system now being implemented by the industry is described by Garside *et al.* (2005a) (copy in Appendix 4).

4.4 EXTENSION AND DEVELOPMENT WORK

In Phase 2 there was a much better working relationship between BSES extension staff and the JV research staff. This improved the uptake of JV research outcomes by the farming community. The appointment of John Agnew as the extension representative on the SYDJV team facilitated much better linkages between research and extension. The extension development side was further enhanced with the establishment of FutureCane by QDPI&F and BSES in 2004. The FutureCane agronomists were given an almost fulltime role of promoting JV outcomes, and this has had a major impact on adoption. Furthermore, the FutureCane economists have been able to assess the economic potential of the new cropping system and have been able to show clearly substantial economic benefits, even in the absence of yield increases. The development of FEAT (Farm Economic Assessment Tool) by Trish Cameron and Paul Stewart has been a key outcome, as it has allowed growers to obtain an economic assessment of the changes to the cropping system being promoted by the SYDJV using their own farm data.

The grower information meetings and extension officer workshops have also been very successful in extending the message about the new farming system. Three series of workshops were held.

- *Series 1 was aimed at reporting the results of Phase 1 to growers. Meetings were held in all cane-growing regions, with 16 meetings between 31 May 2001 and 15 March 2002.*

- *Series 2 was targeted at reporting Phase-2 results and integrating the outcomes of Phase 1 and Phase 2 into a farming-systems package. There were 13 of these meetings between 8 February 2005 and 2 March 2006.*
- *Series 3 targeted extension officers, productivity services officers and agribusiness. These were intensive 2-day workshops that were aimed largely at providing a good background on research outcomes. Three of these meetings (Cairns, Mackay and Bundaberg) were held in October 2004.*

The intensive 2-day workshops had three real purposes:

- Provide a good background on research outcomes for extension personnel;
- Encourage advisory staff to promote a consistent message;
- Allow the advisory staff to feedback practical application issues to the researchers.

In all of these meetings, we have been careful not to provide recipes, instead emphasising that all farms and environments can require slightly different combinations of management strategies. We have insisted on presenting the basic principles underlying improvements to the farming system, so growers can make their own decisions on how they implement the various strategies on their own farms. There has been genuine appreciation shown by growers to our approach of explaining the basic research behind the new farming system development. All of the recommendations we have made have been backed up by solid research results, so we have never made assertions without solid evidence. This has really been appreciated by growers.

These formal SYDJV activities have led to a greater understanding of new farming system principles by advisors and farmers, spawned a multitude of farmer demonstrations, provided discussion at shed meetings and encouraged adoption, experimentation, fine-tuning and evolution of the system. Ready access to researcher knowledge and problem solving ability is a vital ingredient in the ultimate success of adoption and this has been a feature of the SYDJV.

We have also been active in the print media through the *BSES Bulletin*, *Australian Canegrower* and *Australian Sugarcane*. Details are provided under Publications.

4.5 EVALUATION

The SYDJV Phase 2 was reviewed by an external panel in December 2002. Associated with this review was a benefit-cost analysis carried out by Agtrans Research and updated in August 2005 as part of a review of QDPI&F investment in sugar research and development. In addition, Troedson and Garside (2005) (copy in Appendix 4) reviewed the structure, functioning and outputs of the JV.

The review in 2002 was very positive and recommended another farming-systems project be developed for SRDC funding to continue farming-systems work after the SYDJV was to finish in June 2005. This recommendation was taken up, and the new project BSS286 (Improved sugarcane farming systems) was funded for the period 2005-2008. QDPI&F, through its investment in BSES, have also contributed funds to this project.

The summary provided by the review panel is given below. SRDC has a copy of the full report.

“The review panel concluded that the research carried out by the SYDJV team has been outstanding with respect to its quality, breadth, diversity and applicability to the problems of sugar yield decline. The project team has tackled a difficult and multi-faceted problem in an integrated way with exceptional teamwork and strong collaborative links between participating agencies. The circumstances under which the experimental program has been conducted have been challenging in relation to the nature of the crop, the climate, and the geographical spread of the industry and the SYDJV personnel. The success of the research program and the benefits that have accrued to the industry through uptake of innovations reflect the contributions of an experienced and dedicated team.

*The scientific outcomes of the research conducted in Phases 1 and 2 include major advances in understanding of sugarcane’s response to soil biological, physical and chemical characteristics, which have enabled many of the causal problems of yield decline to be defined. The project has also developed a range of farming systems solutions to these problems that have demonstrated yield increases ranging from 20 to 30%. Such increases, if realised by a majority of growers, will have a huge impact on the viability and profitability of the sugar industry. Concurrently, the farming systems approaches recommended by the SYDJV will reduce off-farm losses of sediments and nutrients through reduced fertiliser use, reduced tillage, reduced compaction, and possibly reduced pesticide use through improved soil biological health. With the current state of the sugar industry, these productivity and environmental benefits may be seminal to its longer-term survival. The panel note that, consistent with the objectives of and expertise available to the SYDJV, the focus has been on agronomic farming systems approaches with little emphasis on genetic plant improvement solutions, apart from acknowledgement of the role of *Pachymetra* resistance in varietal selection and management.*

The benefit-cost analysis conducted by Agtrans Research documented the broad range of outputs and outcomes from the SYDJV and estimated the quantifiable economic benefits based on reasonable and conservative assumptions. Under a range of scenarios, the investment outcomes were positive and the most likely case produced a benefit-cost ratio of 4.7 to 1 and an internal rate of return of 18% from the full twelve years investment in Phases 1 and 2. The expected return from the planned investment over the final two years of Phase 2 was substantially greater.

Rapid publication of research outputs in appropriate journals and conference proceedings is a feature of this project that is highly commended. All researchers have contributed to the impressive documentation of SYDJV outputs. The extensive contributions to the annual ASSCT conference over several years have ensured that industry personnel and other researchers are aware of the research outputs and recommendations. Communication of outputs to growers has been promoted by workshops in all cane growing regions. These have provided substantial awareness of the work of the SYDJV and have encouraged adoption of improved farming practices.

Several experiments are still underway, and much work remains to fully mine the information available in the extensive data collected to date and still to come from current

experiments. The panel expects that this work will open up further understanding of soil health and productivity in sugarcane cropping systems and provide new leads that can be followed up in the years to come. Topics of particular interest include pathogen suppression and the role of soil organic matter, management of legume crop residues and persistence of break effects in subsequent ratoons.

The review panel concluded that the collaboration between researchers and organisations had been outstanding, and a key factor in the success of the SYDJV. Several submissions to the review highlighted the genuine collaboration in the planning, conduct and reporting of the work of the SYDJV. The researchers and organisations in the SYDJV have been recognised in the sugar industry for the success of the collaborative R&D program. All project participants should be congratulated on their achievements, but special mention of the role of the project leader, Dr Alan Garside and senior researchers from all participating organisations is justified. These include Dr Mike Bell (QDPI), Mr Brian Robotham (BSES) and Mr Derek Sparkes (QDPI) who have been involved with farming systems developments, and the soil biology team of Dr Rob Magarey (BSES), Dr Clive Pankhurst (CSIRO), Dr Graham Stirling (Biological Crop Protection) and Mr Brendan Blair (QDPI). This team is to be congratulated for creating and maintaining such a successful, multi-disciplinary R&D activity that has been able to operate across a wide geographic area in such an integrated and focussed way.”

The Agrtrans Research benefit-cost analysis assessment in 2002 evaluated a range of scenarios and suggested that the most likely outcome from the full 12 years of the SYDJV would be a benefit-cost ratio of 4.7: 1 and an internal rate of return of 18%. The second assessment in 2005 provided an even more optimistic outcome, with a benefit- cost ratio of 8:1 and an internal rate of return of 22%. SRDC has copies of both of these reports.

Another good means of evaluating the outcomes of the SYDJV program is to consider the adoption of the principles of the new farming system that has evolved from the research of the SYDJV. FutureCane has surveyed the amount of adoption for all sugarcane-growing regions and details are provided in the tables below.

Estimates of the current levels of adoption of different farming system principles were obtained via discussions with BSES extension staff, FutureCane agronomists and Productivity Services in the different regions. FutureCane has also produced a 55-page document (Monitoring and evaluation data – Baseline data). Tables 1, 2, 3 and 4 show cane-planting statistics, adoption of legume fallow crops, adoption of controlled traffic, and adoption of zonal tillage established cane, respectively.

Far-northern Queensland had significantly more plough-out replant (39% of plant crop) than other areas (11-17% of plant crop) (Table 1).

Table 1 Queensland cane planting statistics 2003-2005 (FP = Fallow Plant)

Region	Unit	2003		2004		2005	
		Replant	FP	Replant	FP	Replant	FP
FNQ	ha	5715	9516	5886	9145	5273	8226
	%	38	62	39	61	39	61
Herbert	ha	2000	9000	2000	9000	1500	9500
	%	18	82	18	82	14	86
Burdekin	ha	3247	13441	2910	13573	1561	12460
	%	19	81	18	82	11	89
Central	ha	5114	18371	2536	16295	2332	14045
	%	22	78	14	86	14	86
South	ha	2661	7268	2141	8970	1328	6642
	%	27	73	19	81	17	83
Total	ha	18737	57596	15473	56983	11994	50873
	%	25	75	21	79	19	81

Breaking the monoculture (legume fallow crops) is the most widely adopted/accepted of the three SYDJV farming system principles. Across the Queensland industry, approximately 23% of fallow land was planted to legume crops (Table 2). The area under legumes was lower than expected in 2004/05 and 2005/06, due to dry summers creating fewer planting opportunities. Several mills had a late finish to 2005 harvest, which also reduced the window of opportunity for legume planting. Another reason for lower areas planted was due to insufficient seed supply and inferior quality seed availability.

Table 2 Estimated adoption of legume fallow crops

Region	Unit	03/04	04/05	05/06
FNQ	ha	3600	4000	4700
	%	39	49	54
Herbert	ha	2500	4000	1400
	%	28	42	15
Burdekin	ha	1100	1500	2500
	%	8	12	19
Central	ha	2250	1300	2200
	%	14	9	15
South	ha	550	1900	1550
	%	6	29	20
Total	ha	10000	12700	12350
	%	18	25	23

Example calculation: % 04/05 = (legume area 04/05 / fallow plant area 05)*100.
Average of FP area for 04 and 05 used to estimate FP area for 06.

About 3-4% of the Queensland industry has adopted controlled traffic (Table 3). There has been slightly lower adoption in the Herbert and slightly higher adoption in the Southern region.

Table 3 Estimated adoption of controlled traffic

Region	Unit	2003	2004	2005
FNQ	ha	300	400	2900
	%	0.3	0.4	3
Herbert	ha	100	240	650
	%	0.1	0.4	1.1
Burdekin	ha	1500	1900	2600
	%	2	2.6	3.5
Central	ha	2000	3000	4000
	%	1.7	2.5	3.5
South	ha	4400	4650	4800
	%	6.5	7.7	8.7
Total	ha	8300	10190	14950
	%	2.1	2.5	3.7

% based on estimated area of controlled traffic (which includes all crop classes in the year of assessment) divided by total hectares under cane in each region. 400,000 ha was used for total area under cane in Queensland.

Adoption of zonal tillage planting is at about 5% (Table 4). However, adoption of zero tillage planting would be significantly lower (0-1 %).

Table 4 Estimated adoption of zonal-tillage-established cane

Region	Unit	2003	2004	2005
FNQ	ha	1000	3000	5000
	%	1.1	3.4	5.6
Herbert	ha	1000	1500	3000
	%	1.8	2.7	5.3
Burdekin	ha	520	680	2200
	%	0.7	0.9	2.9
Central	ha	500	1000	1500
	%	0.4	0.8	1.3
South	ha	3409	2891	8250
	%	5	4.8	12.9
Total	ha	6429	9071	19950
	%	1.6	2.3	5.0

% based on estimated area of zonal tillage established cane (includes all crop classes in the year of assessment) divided by the total ha under cane in each region. 400000 ha was used for total area under cane in Queensland.
Zonal tillage establishment of cane may be a range of different options other than the traditional offset, rip and hoe of the entire paddock.

5.0 ENVIRONMENTAL AND SOCIAL IMPACTS

The new farming system developed by the SYDJV and discussed above has been based around improved whole-farm profitability (at least through cost savings, but probably also through yield increases in the medium term), greater resource sustainability and more environmental responsibility. The system described by Garside *et al.* (2005a) is based around permanent beds, legume breaks, controlled traffic and minimum/zero tillage. The benefits of this system are:

Legume breaks:

- Provide improvements in soil health through better balanced biology.
- Fewer sugarcane root pathogens.
- Biologically fixed nitrogen reducing the need for inorganic nitrogen fertilizer and consequently reducing the use of fossil fuel to produce that fertilizer.
- Better cane growth and yield and increased profitability.
- The tap root system on legumes compared with the adventitious root system of sugarcane can work to improve soil structure.

Controlled traffic:

- Isolation of the row and inter-row and limiting compaction to the inter-row area. This substantially reduces the need for tillage to remove compaction from the row area while providing positive benefits of traction and wet weather trafficability in inter-rows.
- Less tractor hours spent removing compaction saves on labour (social impact), tractor wear and tear (social and economic impact) and fuel (economic and environmental impact).
- The compacted inter-row provides better timeliness of operations. An example would be facilitating better weed management with likely savings in herbicide costs.
- The wider row spacing necessary for controlled traffic (1.8-2.1 m versus 1.5 m) reduce the distance travelled for any operation, resulting in further savings in fuel, tractor hours and labour.

Minimum/zero-tillage:

- Conserves organic matter.
- Improves soil structure through greater organic matter conservation.
- Does not disrupt beneficial biota. Earthworm numbers are substantially enhanced under a trash blanket system, especially when combined with legume fallows.
- Improved soil structure results in better water infiltration and storage and less run-off, reducing the chance of erosion and offsite movement of sediment, nutrients and pesticides.
- Improved soil structure will reduce irrigation frequency in irrigated crops
- Reduced necessity for weed control because trash blankets are maintained throughout the whole crop cycle. The combined effect of the trash blanket and the lack of tillage reduce the likelihood of weed seed germination and will result in reduced herbicide use.

Overall, the new farming system has substantial benefits in terms of environmental and social issues compared with a system that is a monoculture and requires excessive tillage, high rates of inorganic nitrogen and a heavy reliance on chemicals for weed control.

It remains to be seen whether improvements in soil structure that result from this system will increase the drainage component of the water balance, as found in many of the direct-drill systems in cereal-growing regions. This outcome would increase the risk of nutrients leaching into groundwater, and may be a negative of the new system that requires future monitoring.

6.0 OUTCOMES

The outcomes in terms of the new farming system are clearly apparent, with substantial adoption of the system already evident in all sugarcane-growing regions. This has been documented for each Queensland cane-growing region as part of the FutureCane program. Grower adoption is being supported by the SRDC Grower Innovation program, in which grower groups are provided with financial assistance to adopt aspects of the new farming system. Further, the Sustainable Landscape Program, supported by the National Heritage Trust, Natural Resource Management groups and the Australian Department of Agriculture Forestry and Fisheries, also provides assistance to farmers to adopt controlled-traffic and minimum-tillage cane and legume establishment. Growers who adopt the system, or at least parts of it, are surprised at the cost savings and many are now starting to obtain yield increases. This was expected after growers get the system fully developed and permanent beds are in place. Ultimately, the outcome of SYDJV Phase 2 will be a more profitable, sustainable and environmentally responsible sugarcane cropping system that will serve the industry well into the future.

At a more strategic level, an outcome of SYDJV Phase 2 is that it has been clearly demonstrated that multi-discipline, multi-organisational research and development programs can be highly productive and successful. However, that success has been shown to be very dependent on the willingness of the team members to work together, to develop a single-minded focus on the job at hand, and to have enough experience to appreciate that many factors interact within a farming system. It is the individuals that make or break any multi-organizational project. However, organizational support is also critical, and the decision of CSIRO Land and Water to withdraw from Phase 2 in 2003 adversely affected the later stages of the SYDJV.

7.0 FUTURE RESEARCH NEEDS

It is somewhat difficult at this time to identify further research needs. Many have been identified throughout the life of Phase 2 and work has been initiated in the most pressing areas (e.g. the row spacing by variety work through project BSS296). In addition, a follow-on project (BSS286 Improved sugarcane farming system) is investigating nitrogen cycling in the new cropping system, as we suspect it may change quite dramatically. We have also begun looking at the potential for companion crops in the sugarcane system and started to define parameters that are useful indicators of soil health. The confirmation that

cane trash can be a very important component of a sustainable sugarcane farming system has been an important outcome of Phase 2 and work is continuing on quantifying its importance.

From an industry point of view, we feel the most important issue is to continue to provide support to growers who are implementing the new cropping system. Fortunately, this is being done very well at the moment by extension officers from BSES Limited and FutureCane, as well as grower-initiated projects in various regions. It is very important that the level of this support continues into the future.

BSS286, the new farming systems project, in combination with phase 2 of the SYDJV, has probably addressed the outstanding issues associated with development of a new sugarcane-based cropping system. There are clear areas where development of supporting technology needs to be enhanced, eg. in areas such as maximizing benefits from GPS guidance systems and precision farming technologies, and where agronomic management options need to be improved, eg. refining irrigation, nutrient and pesticide management. Canegrub management is being addressed in BSS266 (Optimal canegrub management within sustainable cropping systems). Other areas likely to be important in the future involve quantification of the environmental benefits of the farming systems changes, and evaluation of other potential break crop options for sugar-cropping systems – especially on the wet tropical coast.

There is no doubt that other problems will arise as the new system becomes adopted more widely and in a greater array of climate and soil combinations, but there are no clear indications at present as to what those problems may be. In this context, there needs to be some structure that will permit the SYDJV team (or access to that expertise) to remain so that problems can be dealt with when they arise. This is probably not an issue while the current BSS286 (Improved sugarcane cropping systems) project is operational (until mid-2008), but does need some serious consideration after then. Unfortunately, there appears to be little enthusiasm within the partner organizations to keep the SYDJV alive as an entity.

8.0 RECOMMENDATIONS

We believe that everything necessary is being done to promote the outcomes of the SYDJV, as uptake is starting to increase exponentially. The grower-initiated program and FutureCane are having a very positive impact, and it is hoped that these two initiatives can be continued. The best way of getting the SYDJV outcomes adopted will be by farmers actually doing the job, while others look over the fence. Each farmer commercially proving the system is worth 100 experiments. Growers with success stories should be encouraged to document their experiences (Loeskow *et al.*, 2006; Henry *et al.*, 2006).

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APPENDIX 1 - Rotation experiments (carryover from Phase 1)

Nearly all of the rotation experiments commenced and reported on in Phase 1 were continued into Phase 2. Details of the results of these are covered in Milestone Reports 3-6. In general, very little detailed information was collected on these experiments after the plant crop. They were maintained simply to see if the responses recorded in the plant crops could be maintained into the ratoons and whether the cost associated with missing a sugarcane crop to incorporate a break could be covered over a crop cycle. In all cases except for the Tully experiment (discussed in more detail later), higher ratoon yields were recorded following breaks and/or fumigation than in plough-out/re-plant. Details for Bundaberg, Mackay and Burdekin are provided in Tables 1.1, 1.2, and 1.3, respectively.

Table 1.1 Crop class and cumulative cane (TCH) and sugar (TSH) yield (t/ha) for the first Bundaberg rotation experiment.

History	Plant		R1		R2		R3		Cumulative	
	TCH	TSH	TCH	TSH	TCH	TSH	TCH	TSH	TCH	TSH
Cane (Burnt)	107	16.5	110	17.2	107	17.4	85	12.3	409	63.4
Cane (Burnt) (Fum)	146	22.1	124	18.5	102	15.8	98	14.2	470	70.6
Cane (GCTB)	118	18.2	131	20.1	99	15.7	93	13.5	441	67.5
Cane (GCTB) (Fum)	141	22.3	150	21.0	124	19.7	106	15.0	521	78.0
Legume Crop (12 M)	124	18.6	138	21.1	125	19.1	107	15.6	494	74.4
Grass Crop (12 M)	128	19.3	145	22.0	105	16.8	79	11.6	457	69.7
Legume Past (12 M)	116	17.9	115	18.2	112	18.2	84	12.5	427	66.8
Grass Past (12 M)	121	18.3	136	21.4	116	18.5	92	12.9	465	71.1
Bare Fallow (12 M)	120	18.6	135	20.6	115	17.9	101	14.7	471	71.8
<i>Lsd 5%</i>	<i>12.8</i>	<i>2.2</i>	<i>18.2</i>	<i>3.0</i>	<i>13.8</i>	<i>2.6</i>	<i>15.5</i>	<i>2.3</i>	<i>33.7</i>	<i>5.7</i>

Table 1.2 Crop class and cumulative cane (TCH) and sugar (TSH) yield (t/ha) for the Mackay rotation experiment.

History	Plant		R1		R2		R3		Cumulative	
	TCH	TSH	TCH	TSH	TCH	TSH	TCH	TSH	TCH	TSH
Cane	63	9.8	92	16.3	77	11.8	78	12.98	310	50.88
Cane (Fum)	104	15.9	93	16.0	85	12.0	104	16.76	386	60.66
Crop 9 M	88	13.1	116	20.5	93	13.8	86	14.32	383	61.72
Crop 18 M	86	12.1	109	18.2	93	14.2	89	14.25	377	58.75
Crop 30 M	98	14.5	104	18.0	91	12.9	93	15.35	386	60.75
Past 18 M	99	15.1	112	18.8	97	14.2	91	15.13	399	63.23
Past 30 M	106	16.3	100	17.4	98	13.9	100	16.50	404	64.10
BF 30 M	116	17.4	102	17.0	98	14.4	90	14.49	406	63.29
<i>Lsd 5%</i>	<i>15.3</i>	<i>2.5</i>	<i>13.7</i>	<i>2.5</i>	<i>13.0</i>	<i>2.01</i>	<i>17</i>	<i>2.63</i>	<i>42.2</i>	<i>6.47</i>

Table 1.3 Crop class and cumulative cane (TCH) and sugar (TSH) yield (t/ha) for the first Burdekin rotation experiment.

History	Plant		R1		R2		Cumulative	
	TCH	TSH	TCH	TSH	TCH	TSH	TCH	TSH
Cane - Trash	118	21	100	17.4	81	12.6	299	51.0
Cane + Trash	120	21	88	15.3	91	13.9	299	50.2
Cane - Trash (Fum)	152	26	121	20.1	100	15.1	373	61.2
Crop 42 M	147	25	128	22.4	98	15.3	373	62.7
Past 42 M	153	26	142	23.7	93	14.8	388	64.5
BF 42 M	154	27	133	22.9	98	15.8	385	65.7
<i>Lsd 5%</i>	<i>12</i>	<i>2.9</i>	<i>18.7</i>	<i>3.5</i>	<i>10.7</i>	<i>2.1</i>	<i>46</i>	<i>8.7</i>

A primary concern within the sugar industry has been that the inclusion of a break means that one cane crop must be foregone and this could have substantial economic consequences. Our data from this cycle of rotation experiments allows us to consider this issue. For practical purposes, it is most appropriate to compare the cumulative yields over a crop cycle for a realistic break that misses only one cane crop with a burnt cane plough-out re-plant (PO/RP). Ordinarily, this would mean the Burdekin rotation experiment was not suited to making these comparisons, as the breaks were all exceedingly long (54 months). However, it is worth noting that the yield response in the plant crop to breaking the monoculture with a short legume fallow (9-12 month) ranged from 16% (Bundaberg) to 40% (Mackay), with the response in the Burdekin (25%) intermediate. These data suggest that a single break can provide a majority of the response to breaking the monoculture, and so we have included the Burdekin data with that from the Bundaberg and Mackay experiments in this analysis of productivity over a crop cycle. We opted for burnt cane as the standard because when this work was initiated (1994), a substantial percentage of the industry was still using burnt cane.

The cumulative sugar yield increase with one legume-crop break compared with PO/RP was about 11 t/ha for Bundaberg and Mackay, with a similar advantage for the longer (predominantly legume) crop break in the Burdekin. Of course this analysis must allow for the year of cane production that has been foregone in favour of a break crop. If a fourth ratoon was grown in the PO/RP and it was assumed that it had performed as well as third ratoon at each of the sites (and this is extremely doubtful), the sugar yield that would have been foregone over the 6-year period by opting for the legume break would have been only 1.3, 2.0 and 1.6 t/ha in Bundaberg, Burdekin and Mackay, respectively.

Alternatively, there is every possibility that a grower would decide to take an additional ratoon following the break than they would in PO/RP, given the higher cane yields recorded. Cane yields in R2 in the Burdekin were 21% higher in the legume crop break (98 versus 81 t/ha) and cane yields were 26% (107 versus 85 t/ha) and 10% (86 versus 78 t/ha) in R3 in Bundaberg and Mackay, respectively. This type of analysis ignores the good opportunities for improved cash flow from growing the break crops for grain. Finally, in all three of these experiments the break effect was holding up into the later ratoons and may well have held up longer had we continued the experiments. We conclude that growers are most unlikely to be worse off financially by missing a cane crop to grow a break crop and that the overall level of production is not likely to decrease but will probably increase in the long-term.

APPENDIX 2 - Rotation experiments (Phase 2)

Three rotation experiments were established in Phase 2 to investigate further the interesting findings from Phase 1. These experiments were at Bundaberg, Burdekin and Tully. These are dealt with separately below.

Tully

The sugarcane in the first rotation experiment at Tully was planted in October 1997 following 42 month breaks with the response to breaking the monoculture with another crop species being of the order of 65% in the plant crop (73 versus 44 t/ha) (Garside *et al.* 1999c). However, unlike all other rotation experiments, the break effects were not carried through to the ratoons, there being no difference in sugarcane yield between PO/RP and the breaks in the first and second ratoons.

The second Tully rotation experiment was planted in July 2000 and also grown for a plant and two ratoon crops (Garside *et al.* 2002b- copy in Appendix 4). Both experiments were at the same site, with the same variety and were grown on 1.5 m rows with harvesting and haul-out equipment on 1.83 m spacing. In the second experiment, the response to breaking the monoculture carried through to the first and second ratoons, as had occurred at all other sites. The responses were 42, 35 and 33% for the plant, first and second ratoons, respectively. Although it is not possible to categorically assign reasons for the differences in responses between the first and second Tully rotation experiments, it is very likely to be associated with the plant-crop in experiment 1 being harvested under wet conditions (with mismatched wheel and row spacings) while the plant and first ratoon in experiment 2 were harvested under dry conditions. Basically, mismatched wheel and row spacings can result in substantial stool damage and yield loss. Details are provided in Garside *et al.* (2004a) (copy in Appendix 4).

In the second Tully rotation experiment, both the breaks and continual sugarcane were split to a range of biocide treatments including fumigation, fungicide, nematicide applied twice or four times, and fungicide plus nematicide. There was no significant differences among the different breaks, but they all out yielded PO/RP by around 20%. Similar yields were achieved with fumigation, fungicide and fungicide plus nematicide, but there was no response to nematicide on its own except where it was applied four times following a pasture break. The clear implication is that, in this experiment, fungi were the main debilitating organisms. However, nematicides had a synergistic effect with fungicides when the two were applied in combination, suggesting that nematodes were having a secondary effect once the fungi were controlled. The unfumigated crop and pasture breaks produced similar yields to fumigated PO/RP, while fumigation of the crop and pasture breaks increased yields further still. The fumigation response in the crop and pasture breaks may have been due to either some detrimental biota remaining following the breaks and/or improved nutrient availability following fumigation (Garside *et al.* 2002b – copy in Appendix 4). The key point from this experiment is that crop and pasture breaks can produce a similar response to fumigation of PO/RP.

Burdekin

When the first Burdekin experiment was returned to sugarcane in 1998 all plots were split to four rates of nitrogen and the effect on growth and yield was measured. Basically, it was demonstrated that under the irrigated system in the Burdekin, higher rates of nitrogen could reduce the quantum of response to breaks. When no nitrogen was applied the response to breaks over PO/RP was 43%, but when 180 kg/ha was applied in split applications of 50 and 130 kg/ha the response reduced to 13% (Garside *et al.* 2000a – copy in Appendix 4). The higher N rates tended to promote tillering, so that poor establishment, often associated with PO/RP, could be compensated for by increased tillering.

The second Burdekin experiment was established into two separate pre-histories in September 2001. There were three sets of contrasts within the treatments:

- (i) The previous experiment was repeated with new break plots (bare fallow, crop and pasture histories), but the breaks were split to soil fumigation this time. This was done to quantify any remaining yield constraints after the various breaks.
- (ii) Sugarcane was re-planted on the old break histories that had been planted to cane in the previous crop cycle begun in 1998. The cane was ploughed out after harvest of the second ratoon and re-planted as under a plough-out/replant system. The aim here was to measure whether any residual effects of those breaks persisted in the soil (as compared to the observed residual effects during ratoons that may have been due to establishment of a healthy stool in the early stages of a plant crop).
- (iii) We also wanted to follow the effect of added nitrogen further, and so split all plots to 0, 150 and 300 kg/ha N applied at planting.

Data are presented for the different treatment groups.

Repeat of rotation breaks, split with soil fumigation

The plant cane yield for the newly planted breaks is presented in Table 2.1. In this experiment, the main effect of history was not significant, but there were significant effects of soil fumigation and N rate. Fumigated plots (156 t/ha) outyielded Unfumigated plots (143 t/ha), and yields increased slightly as N rates increased, from 146 t/ha (0N) to 149 t/ha (150N) and 154 t/ha (300N). There were no statistically significant N*history or history*fumigation interactions, although there was a trend for larger fumigation responses in the PO/RP treatment (21% higher cane yields with fumigation) than the bare fallow (8%), crop (5%) or pasture (3%) histories.

Table 2.1 Cane yield (t/ha) in response to breaks, fumigation and nitrogen for second Burdekin rotation experiment.

History	Not Fumigated				Fumigated				Mean
	0N	150N	300N	Mean	0N	150N	300N	Mean	
PO/RP	126	126	129	127	154	151	157	154	141
BF	139	139	145	141	153	149	155	152	147
Crop	141	154	150	148	153	157	159	156	152
Pasture	147	153	170	156	157	162	163	161	158
Mean	138	143	148		154	155	159		
		143				156			

Significant effects: History NS ($p = 0.18$, $\text{lsd}5\% = 18$), Fum. ($p = 0.004$, $\text{lsd}5\% = 7$), N ($p = 0.054$, $\text{lsd}5\% = 6$), History x Fum. NS ($p = 0.13$, $\text{lsd}5\% = 15$)

When data analysis was restricted to the Unfumigated treatments (ie. a comparable rotation experiment to other studies), results are more consistent with other studies. Yields were consistently lowest in the PO/RP treatment, with yield increases (averaged over all N rates) ranging from 11% after the bare fallow to 23% after the pasture. Yields after alternate crops were intermediate. Main effects of N rate were small and not significant, and while there was not a statistically significant N * history interaction, there were suggestions of a larger N response after pasture (16% increase with 300N) than all other histories (yield increases of 2-6%).

The choice of the same cane variety and planting arrangement in the two cycles of the Burdekin trial allowed direct comparisons to be made between yields and effects of treatments in the 2 crop cycles (Table 2.2), with two obvious differences between cycles 1 and 2. The first difference was the higher yield of PO/RP in the second experiment. The reasons for this are unknown, but may be related to the fact that these treatments had been under a trash-blanket management system since the experiment started in 1994, whereas the PO/RP in the previous experiment had been under a burnt-cane system since 1994. The possible improvement with PO/RP under the trash blanket in this instance is supported by the fact that the crop and pasture breaks producing very similar yields in both experiments (Table 2.2).

The other obvious difference was the poorer crop performance after the bare fallow in the second experiment (Table 2.2). This may be associated with the duration of the bare fallow, with Bell *et al.* (2006b) (copy in Appendix 4) reporting a tendency for yields to be reduced after long bare fallows, and there are suggestions from analysis of the second crop cycle after the original bare fallow (Table 2.3) that this may be associated with declining soil N status in this site. In these experiments, the fallows were 42 months in experiment 1 and 66 months in experiment 2. Such trends may well be associated with biology and nutrient deficiencies after such a long period without plant growth).

Table 2.2 Cane yields (t/ha) for the first and second rotation experiments in the Burdekin for PO/RP, and crop, pasture and bare fallow breaks. In experiment 1, data shown is for 180 kg/ha N treatment, while in Experiment 2 it is for 150 kg/ha N treatment

History	Cane yield (t/ha)	
	First experiment	Second experiment
PO/RP	121	126
BF	163	139
Crop	152	154
Pasture	158	153

Re-plant of the original break treatments after the 1998-2001 crop cycle

In this experiment, all plots were PO/RP, but some had been in crop, pasture or bare fallow breaks until 1998 before being replanted to cane and managed under a green-cane system for 3 years prior to the current planting. The PO/RP plots had been managed as burnt cane between 1994 and 1998 (4 years), but as green cane for the ensuing 3 years. Cane yield data is shown in Table 2.3. There were significant nitrogen rate and history by nitrogen rate effects. There was no soil fumigation in this experiment.

Cane yields clearly show that in the presence of adequate N (and the level of N needed for adequacy varied with history, from 0N in the old pasture treatments to 300N in the old bare fallow) there is no residual effect of the previous break treatments after 3 years of sugarcane cropping (Table 2.3). This is interesting, and clearly suggests that the strong residual effects of break histories seen in the ratoons during that first cane cycle were more likely due to health of the established cane stool than to persistent residual benefits in the soil.

Table 2.3 Cane yield (t/ha) for re-plant cane on previous break histories and three rates of nitrogen fertiliser

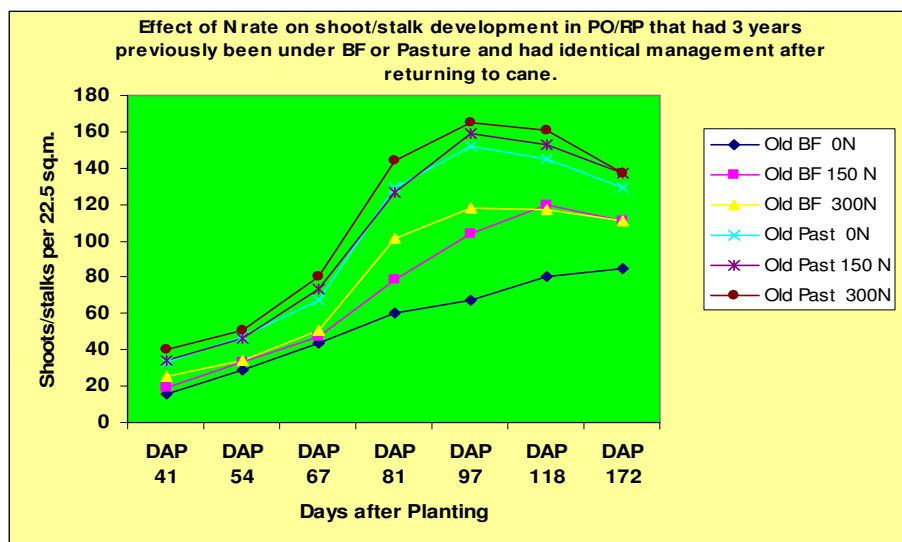
History at 1998 planting	Cane yield (t/ha)			
	0 N	150 N	300 N	Mean
PO/RP	111	128	132	124
PO/RP Fum.	113	129	136	126
Bare Fallow	73	113	135	107
Crop	109	132	135	125
Pasture	133	134	136	134
Mean	108	127	135	

Level of signif.: History (0.1, lsd5%=20), N rate (0.001, lsd5%=4.4),
hist x N rate(<0.001, lsd5%=21)

The large variation in N requirements for cane grown after the different break treatments would seem to be a reflection of the effect of those breaks on soil organic matter and N pools during the break treatments and the subsequent effect on ability to mineralise N during the current crop cycle. Bare fallows (and to a lesser extent annual cropping with conventional tillage) have been consistently shown to run down soil organic C and N stores, compared to continuous sugarcane, while pastures have been shown to have the opposite effect. This is consistent with the N responses recorded here. The old bare-fallow treatments need high rates of N to make up for the decline in soil N reserves during that bare fallow and subsequent cane cycle, while the pastures were able to at least maintain that soil N pool, and mineralise sufficient N to supply crop needs without fertiliser N input. This is well demonstrated by the contrasting shoot/stalk number responses to additional N fertiliser shown in the bare fallow and pasture treatments (Fig. 2.1), especially during the period of rapid tillering from 70-100 dap.

The similarity in N response between the crop breaks and PO/RP treatments (regardless of trash management) was intermediate between the old pastures and bare fallows – possibly for different reasons. The PO/RP treatments maintained soil organic matter levels, and hence capacities to mineralise enough N to only require intermediate N fertiliser applications (Table 2.3). The crop (mainly legumes) treatment, on the other hand, would have been expected to reduce soil organic matter stores but also to change the quality of the organic matter (in relative lability terms) to allow a higher rate of N mineralisation per unit of soil C. The N responses in Table 2.3 suggest both strategies result in similar outcomes in terms of meeting crop N requirements.

Figure 2.1 Effect of N rate on shoot and stalk development in PO/RP cane that had 3 years previously been under bare fallow or pasture and had identical management after returning to sugarcane. Note that tillering commenced around day 67 and responded substantially to N following bare fallow but little to N following pasture

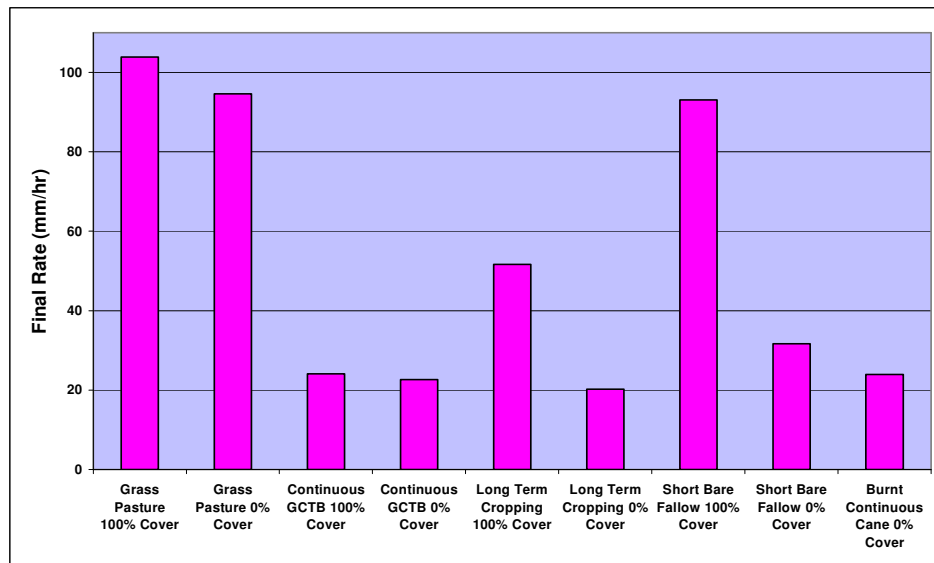


Bundaberg

The Bundaberg rotation experiment contained long (72 month) and short (12 months) breaks. The effect on the plant crop in the first experiment where all breaks were 12 months was detailed in Garside *et al.* (1999b), while the effect on the ratoons was discussed above. After the harvest of the third ratoon in 2000, the short breaks were re-instated for 12 months and then in 2001 all the short and long breaks were re-planted to sugarcane, with plots split for soil fumigation. A plant crop was harvested in 2002 after which cane was removed from all plots using strategic (zonal) tillage and re-planted to cane again in 2003. This exercise was aimed at measuring the longevity of the break effects, similar to that attempted in the Burdekin studies. Details are provided in Milestone Reports 7-10.

Prior to preparing the land for re-planting, the rainfall simulator was used to assess water infiltration rates in the various treatments. Rainfall infiltration rates ranged from approximately 100 mm/h in grass or legume pastures to approximately 25 mm/h under continuous cane. The reduction in infiltration rate with continual cane was due to soil compaction caused by the harvester and haul-out traffic, with trash management providing no improvement in infiltration (Figure 2.2).

Figure 2.2 Rainfall infiltration rate (mm/h) in selected treatments in the Bundaberg rotation trial in August 2001



Yield responses to short and long duration breaks - 2001

Plant-cane yield data for the initial replanting are shown in Table 2.4. Overall, there was a significant response to fumigation (19%) but the magnitude of the response varied with histories, being least in the short-term bare fallow (6%) and long-term pinto (8%) and largest in the short-term grass (35%), crop (37%), pinto (24%) and PO/RP (21-23%). Data for the long-term grass should not be considered in comparisons, as this treatment suffered severe nitrogen deficiency. The fumigation responses across all histories were consistent with other studies (eg Tully – Garside *et al.* (2002b); Burdekin - Table 2.4). However, the lack of positive response to the short legume break (without fumigation) was not consistent with results from the first rotation cycle (Garside *et al.* 1999b). Unlike the first crop cycle, this trial suffered severe water stress, especially during the second half of the growing season. This is the period when stalk filling (and determination of final stalk weight) was occurring, and this may have affected the relative performance of the different break treatments. The results from the first cycle showed that most of the yield benefits from the short duration legume breaks at Bundaberg occurred through increases in individual stalk weight in the second half of the growing season, rather than greater stalk number. Water stress that affected growth during the later part of stalk filling may, therefore, have had a relatively greater effect on this treatment.

Table 2.4 Plant cane yield (t/ha) for first sowing of the second Bundaberg rotation experiment. Planted 2001, harvested 2002. There are significant effects of history (lsd = 10.0) and fumigation (lsd = 5.3)

History	Not Fumigated	Fumigated	Mean
PO/RP Burnt (8,9)	81	98	89
PO/RP (GCTB)	91	112	102
ST Bare Fallow	95	101	98
ST Grain Legume	81	111	96
ST Maize	95	111	103
ST Pinto	88	109	99
ST Grass	92	124	108
LT Mixed Cropping	100	120	110
LT Pinto	103	111	107
Lt Grass	81	82	82
Mean	91	108	99

Effect of re-planting in 2002

There was no effect of residual effect of history on cane yields (Table 2.5), but there was a small but significant residual fumigation effect ($p=0.05$). The fumigation effect was the reverse of that occurring in the plant crop, with higher yields recorded in plots without fumigation the previous year. This result was consistent with effects recorded in field fumigation studies in southern grain-growing areas (D. Roget, pers. comm.), and is thought to be due to a resurgence of pathogens of a host plant (cane) in the absence of significant biological competition to regulate/suppress that population increase. Interestingly, the first cycle of the rotation experiment (Table 2.1) showed a quite rapid decline in the magnitude of the fumigation response in the PO/RP treatments after the plant crop, which could be consistent with a resurgence of cane pathogens at least partly negating a well established cane stool.

Table 2.5 Cane yields for the second planting of the second rotation experiment at Bundaberg. There was a significant residual effect of fumigation (lsd = 3.0)

History	Not Fumigated	Fumigated before first planting	Mean
PO/RP Burnt (8,9)	122	109	116
PO/RP GCTB (10,11)	114	113	118
ST Bare Fallow (5)	122	119	120
ST Grain Legume (6)	115	111	113
ST Maize (7)	123	121	122
ST Pinto (4)	116	115	116
ST Grass (3)	124	115	119
LT Mixed Cropping (12)	118	111	115
LT Pinto (2)	119	126	123
LT Grass (1)	118	110	114
Mean	119	116	118

These data are consistent with findings from the Burdekin that suggest that the positive impacts on soil health resulting from break crops do not represent long-term changes, especially once a new cane cycle is established. With the exception of the long-term

pasture in the Burdekin, all beneficial effects (as reflected by establishment and growth of a cane crop) were gone after 3 years of cane cropping, while the Bundaberg data suggests effects have largely disappeared after the plant crop (ie. 1 year under cane). These findings clearly point towards identifying management strategies that help to establish a healthy stool in the early stages of a plant crop as being critical to the success of future sugarcane-farming systems.

APPENDIX 3 – Farming-systems experiment, McLennans, Mackay

The plant crop from this experiment was hand and mechanically harvested on 11-12 and 18 August 2004, respectively. The experiment was quite involved, with a number of base treatments split to sub-treatments. The sugarcane (variety Q170^{db}) was planted on 26-27 May 2003 on land that had been fallow since May 2002 after growing a soybean crop from February that year.

The treatments involved:

- **Configurations** - four basic configuration treatments – conventional 1.5 m rows (soybean residue was incorporated and land prepared conventionally), soybean inter-row planting (cane directly planted in every second soybean inter-row and covered by moving the soil from the ridge into the inter-row), 1.5 m raised beds with a single row of cane, and 1.8 m raised beds with 2 rows of cane each 50 cm apart. The last three configurations were planted with a double-disc-opener planter.
- **Bed treatments** – the 1.5 and 1.8 m raised beds were subjected to combinations of surface tillage (ST) and no surface tillage or direct planted (D) interacted with ripping (R) and no ripping (NR) prior to planting the sugarcane. These bed management treatments were applied on 3 April 2003.
- **Nitrogen** – all plots were then split to either 0 N or 100 kg/ha N as sulphate of ammonia applied to the surface on 20 September 2003. No other fertilizer was applied to the experiment.

All plots were replicated twice.

Results

Hand harvested

Hand-harvested yields were taken from 15 m² areas of each plot. Stalks were counted, weighed, and the percentage of millable stalk measured for calculation of millable stalk yield. The millable stalk percentage of total biomass was 92% in this instance. CCS was measured on a four-stalk sample per plot using the small mill. There was substantial lodging in all but the conventional plantings and, where the crop was lodged, there was substantial rat damage. In order to get a reasonable estimate of crop production, we avoided rat-damaged areas as much as possible for hand-harvest samples and CCS samples were carried out on whole stalks that were not rat damaged.

Response to nitrogen fertiliser

Overall there was no significant response to nitrogen fertilizer in terms of cane yields, which were 103 and 108 t/ha with and without N fertilizer, respectively. However, N fertilizer significantly ($p = 0.06$) reduced CCS from 14.4 to 13.0, resulting in a near significant reduction ($p = 0.13$) in sugar yield from 15.44 to 13.52 t/ha. The lack of response to nitrogen in cane yield is consistent with the results of numerous experiments throughout the industry that show there is no need to apply N fertilizer to the plant crop following a soybean fallow. The depression in CCS with applied N fertilizer is consistent

with previous results at this site when increasing rates of N fertilizer applied following a soybean break resulted in depressed CCS (Garside *et al.* 1999b).

Response to configuration

The effect of configuration on cane yield, CCS and sugar yield is shown in Table 3.1. The highest cane yields were obtained with conventional cultivation, but these were not significantly greater ($p < 0.05$) than for the 1.5 or 1.8 m beds, but probably would have been with more than two replications. The lowest cane yields were recorded with the soybean inter-row planting.

Table 3.1 Effect of configuration on cane yield, CCS and sugar yield

Configuration	Cane yield (t/ha)	CCS	Sugar yield (t/ha)
Conventional	120	11.87	14.23
Soybean inter-row planting	89	14.91	13.25
1.5 m Single Beds	109	14.47	15.78
1.8 m Dual Beds	107	14.86	15.95
<i>lsd 5%</i>	<i>19</i>	<i>2.51</i>	<i>nsd</i>

The significance of the higher cane yields with conventional cultivation was reduced by lower CCS, to the extent that there was no significant difference in sugar yields among the different configurations. In fact, there was a strong trend for higher sugar yields from the 1.5 and 1.8 m bed plantings. The results also indicate that, at least in a relatively dry season such as this, the soybean inter-row planting is an inappropriate strategy. This was probably due to planting onto a compacted soil resulting in reduced root penetration and probably more water stress. Full analysis of the EnviroSCAN® data should clarify this situation.

Response to surface tillage and ripping with the 1.5 and 1.8 m beds

Ripping and surface tillage treatments were applied to the 1.5 and 1.8 m beds. Data for cane yield, CCS and sugar yield are shown in Tables 3.2.

Table 3.2 Effect of surface tillage and ripping on cane and sugar yield and CCS from 1.5 and 1.8 m beds

Configuration	Ripping treatment	Surface management	Cane yield (t/ha)	CCS	Sugar yield (t/ha)
1.5 m bed	Ripped	Direct Planted	109	15.18	16.60
	Ripped	Surface Tilled	106	14.77	15.53
	Not Ripped	Direct Planted	105	13.01	13.71
	Not Ripped	Surface Tilled	117	14.90	17.31
1.8 m bed	Ripped	Direct Planted	111	14.64	16.20
	Ripped	Surface Tilled	110	14.47	15.84
	Not Ripped	Direct Planted	95	15.38	14.73
	Not Ripped	Surface Tilled	114	14.93	17.03

There were some substantial interactions between these treatments that will need some further analysis and interpretation. The general response in cane and sugar yield was for an increase with some soil disturbance. The lowest cane and sugar yields were obtained with no ripping and direct planting under both configurations. However, the combination of ripping and surface tillage did not improve yields over just one of these operations. In fact, the combination of both operations tended to be only slightly better than no disturbance at all. Further, the trend was for surface tillage to have a greater impact than ripping.

Machine harvested

With machine harvesting, it was not possible to harvest all individual plots so harvesting was carried out on the basis of configuration. Mill CCS was also obtained for each configuration. Data are shown in Table 3.3.

Table 3.3 Effect of configuration on machine-harvested cane and sugar yield and CCS

Configuration	Cane yield (t/ha)	CCS	Sugar yield (t/ha)
Conventional	106	12.96	13.74
Soybean inter-row planting	85	12.96	11.03
1.5 m Single Beds	94	13.54	12.72
1.8 m Dual Beds	89	13.32	11.80
<i>lsd 5%</i>	<i>18</i>	<i>nsd</i>	<i>nsd</i>

Cane yields were generally in line with those obtained for hand harvesting, with the highest yields being obtained with conventional planting. However, the differences in CCS noted with hand harvesting tended to change substantially with mechanical harvesting. Compared with hand harvesting, there were reductions in CCS for the soybean inter-row planting and the 1.5 and 1.8 m beds (Tables 3.2 and 3.3), while the CCS measured for the conventional planting increased with machine harvesting. All configurations, except conventional, lodged and there was considerable rat damage in sections of these plots. Given the overall trends, it is reasonable to assume that the reduction in CCS in all but the conventional treatments is associated with lodging and rat damage. Apparently lodging and stool tipping (stools were removed during the machine harvesting operation in all but the conventional system) are characteristics of this variety (Q170^h). Hence, we have obviously used the wrong variety for the type of experiment we were carrying out. This has probably had an important impact on the ultimate results.

Conclusions

Given the above-mentioned variety limitations and the apparent effects on CCS of the lodging/rat damage, the outlook for a controlled-traffic system must still be regarded as very positive.

We have now harvested a number of these large-scale experiments and this is the first in which there has been a strong trend towards better cane yields under the conventional

system. In most other experiments, configuration has had little effect on cane yield. This is also the first in which Q170^{db} has been used. In a related experiment just harvested in Bundaberg using Q170^{db}, lodging and poor stool attachment have also been recorded (MJ Bell, pers. comm.).

Hence, it is becoming increasingly obvious that suitable varieties will be required to capitalize fully on the potential of the system.

APPENDIX 4 – Significant publications

Section 1	Soil biology papers
Section 2	Soil physics papers
Section 3	Soil chemistry papers
Section 4	Monoculture-breaks papers
Section 5	Legume papers
Section 6	Row-spacing and density papers
Section 7	Crop-physiology papers
Section 8	Farming-systems papers
Section 9	General papers

Section 1 Soil biology papers

Pankhurst C E, Blair B L, Magarey R C, Stirling G R, Garside A L (2005) Effects of biocides and rotation breaks on soil organisms associated with poor early growth of sugarcane in continuous monoculture. *Plant and soil* **268** (1): 255-269.

<http://dx.doi.org/10.1007/s11104-004-0287-3>

Pankhurst C E, Stirling G R, Magarey R C, Blair B L, Holt J A, Bell M J, Garside A L (2005) Quantification of the effects of rotation breaks on soil biological properties and their impact on yield decline in sugarcane. *Soil biology and biochemistry* **37**(6): 1121–1130.

<http://dx.doi.org/10.1016/j.soilbio.2004.11.011>

Pankhurst C E, Blair B L, Magarey R C, Stirling G R, Bell M J, Garside A L (2005) Effect of rotation breaks and organic matter amendments on the capacity of soils to develop biological suppress towards soil organisms associated with yield decline of sugarcane. *Applied soil ecology* **28**(3): 271–282.

<http://dx.doi.org/10.1016/j.apsoil.2004.07.010>

Pankhurst C E, Magarey R C, Stirling G R, Blair B L, Bell M J, Garside A L and Sugarcane Yield Decline Joint Venture (2003) Management practices to improve soil health and reduce the effect of detrimental soil biota associated with yield decline of sugarcane in Queensland Australia. *Soil and tillage research* **72**(2): 125–137.

[http://dx.doi.org/10.1016/S0167-1987\(03\)00083-7](http://dx.doi.org/10.1016/S0167-1987(03)00083-7)

Stirling G R, Wilson E J, Stirling A M, Pankhurst C E, Moody P W, Bell M J, Halpin N (2005) Amendments of sugarcane trash induce suppressiveness to plant parasitic nematodes in a sugarcane soil. *Australasian plant pathology* **34**(2): 203-211.

<http://dx.doi.org/10.1071/AP05022>

Stirling G R, Blair B L, Pattermore J A, Garside A L, Bell M J (2001) Changes in nematode populations on sugarcane following fallow, fumigation and crop rotation, and implications for the role of nematodes in yield decline. *Australasian plant pathology* **30**(4): 323-335.

<http://dx.doi.org/10.1071/AP01044>

Stirling G, Blair B, Wilson E, Stirling M (2002) Crop rotation for managing nematode pest and improving soil health in sugarcane cropping systems. *Proceedings of the Australian Society of Sugar Cane Technologists* **24**: 129-134.

http://www.assct.com.au/assct_main.php?page_id=300

Stirling G R, Wilson E J, Stirling A M, Pankhurst C E, Moody P W, Bell M J (2003) Organic amendments enhance biological suppression of plant parasitic nematodes in sugarcane soils. *Proceedings of the Australian Society of Sugar Cane Technologists* **25**: 11

http://www.assct.com.au/assct_main.php?page_id=300

Bell M J, Garside A L, Stirling G R, Magarey R C, Moody P W, Halpin N V, Berthelsen J E, Bull J I (2006) Impact of fallow length, organic amendments, break crops and tillage on soil biota and sugarcane growth. *Proceedings of the Australian Society of Sugar Cane Technologists* **28**: 273-290.

http://www.assct.com.au/assct_main.php?page_id=300

Section 2 Soil physics papers

Braunack M V, McGarry D and Sugar Yield Decline Joint Venture(2006) Traffic control and tillage strategies for harvesting and planting of sugarcane (*Saccharum officinarum*) in Australia. *Soil and tillage research* **89**(1): 86–102.

<http://dx.doi.org/10.1016/j.still.2005.07.002>

Section 3 Soil chemistry papers

Bell M J, Garside A L, Moody P W, Pankhurst C, Halpin N V, Berthelsen J (2002) Nutrient dynamics and root health in sugarcane soils. *Proceedings of the Australian Society of Sugar Cane Technologists* **24**: 92-98

http://www.assct.com.au/assct_main.php?page_id=300

Section 4 Monoculture-breaks papers

Garside A L, Berthelsen J E, Pankhurst C E, Blair B L, Magarey R C, D'Amato C, Bull J I (2002) Effect of breaks from a sugarcane monoculture and biocides on the growth and yield of a subsequent sugarcane crop. *Proceedings of the Australian Society of Sugar Cane Technologists* **24**: 82 - 91.

http://www.assct.com.au/assct_main.php?page_id=300

Garside A L, Bell M J, Magarey R C (2000) Effect of breaks from sugarcane monoculture on growth and yield of subsequent sugar cane crops. *Proceedings South African Sugar Technologists Association* **74**:12-18.

http://www.assct.com.au/assct_main.php?page_id=300

Section 5 Legume papers

Garside A L, Bell M J (2001) Fallow legumes in the Australian sugar industry review of recent research finding and implications for the sugarcane cropping system. *Proceedings of the Australian Society of Sugar Cane Technologists* **23**: 230-235.

http://www.assct.com.au/assct_main.php?page_id=300

Garside A (2004) Legume nitrogen. *BSES bulletin* 2: 6-8

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Noble A D, Garside A L (2000) Influence of soybean residue management on nitrogen mineralisation and leaching and soil pH in a wet tropical environment. *Proceedings of the Australian Society of Sugar Cane Technologists* **22**: 139-146.

http://www.assct.com.au/assct_main.php?page_id=300

Garside A L, Berthelsen J E (2004) Management of legume biomass to maximise benefits to the follow sugarcane crop. . *Proceedings of the Australian Society of Sugar Cane Technologists* **26**: 1-11.

http://www.assct.com.au/assct_main.php?page_id=300

Garside A L, Rowbotham B, Bell M (2006) Management of the interface between sugarcane cycles in a permanent bed, controlled traffic farming system. *Proceedings Australian Agronomy Conference* **13**.

http://www.regional.org.au/au/asa/2006/concurrent/systems/4513_garside.htm

Bell M J, Moody P W, Halpin N V, A L Garside (2006) Impact of management of cane trash and legume residues on N mineralisation and crop N uptake. *Proceedings of the Australian Society of Sugar Cane Technologists* **28**: 129-141.

http://www.assct.com.au/assct_main.php?page_id=300

Section 6 Row-spacing and density papers

Garside A L, Bell M J, Berthelsen J E, Halpin N V (2002) Effect of fumigation, density and row spacing on the growth and yield of sugarcane in two diverse environments. *Proceedings of the Australian Society of Sugar Cane Technologists* **24**: 135-144.

http://www.assct.com.au/assct_main.php?page_id=300

Garside A L, Berthelsen J E, Robotham B G, Berding N (2006) Row spacing effect on the growth and yield of several sugarcane varieties in North Queensland. *Proceedings of the Australian Society of Sugar Cane Technologists* **28**: 298-309.

http://www.assct.com.au/assct_main.php?page_id=300

Section 7 Crop-physiology papers

Bell M J, Garside A L (2005) Shoot and stalk dynamics and the yield of sugarcane crops in tropical and subtropical Queensland Australia. *Field crops research* **92**(2-3): 231–248.

<http://dx.doi.org/10.1016/j.fcr.2005.01.032>

Section 8 Farming-systems papers

Garside A L, Robotham B G, Chappell W, Berthelsen J E (2005) Row spacing and tillage effects on the growth and yields of sugarcane. *Proceedings of the Australian Society of Sugar Cane Technologists* **27**: 133-143.

http://www.assct.com.au/assct_main.php?page_id=300

Garside A L, Watters T S, Berthelsen J E, Sing N J, Bell M J (2004) Comparisons between conventional and alternative sugarcane farming systems which incorporate permanent beds, minimum tillage, controlled traffic and legume fallow. *Proceedings of the Australian Society of Sugar Cane Technologists* **26**: 1-12.

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Bell M J, Halpin M J, Garside A L, Moody P W, Stirling G R, Robotham B J (2003) Evaluating combinations of fallow management, controlled traffic and tillage options in prototype sugarcane farming systems at Bundaberg. *Proceedings of the Australian Society of Sugar Cane Technologists* **26**: 17.

http://www.assct.com.au/assct_main.php?page_id=300

Section 9 General papers

Garside A L, Bell M J, Robotham B G, Magarey R C, Stirling G R, Sugar Yield Decline Joint Venture (2005) Managing yield decline in sugarcane cropping systems. *International sugar* **107**: 16-26.