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Final report - SRDC project BSS286 : Improved sugarcane farming systems

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FINAL REPORT – SRDC PROJECT BSS286

IMPROVED SUGARCANE FARMING SYSTEMS

by

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SD10005

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SUMMARY

This project – Improved Sugarcane Farming Systems (BSS286) - was designed to build on the outcomes of Phase 1 and 2 of the Sugar Yield Decline Joint Venture (SYDJV). Thus its main focus was on issues that had been identified in the SYDJV that were not fully researched in the earlier programs and/or required further development.

In Phase 2 of the SYDJV it was demonstrated that a 'new' sugarcane farming system based around legume breaks, controlled traffic, minimum tillage and residue retention could be developed. However, the impact of the 'new' farming system, although very likely to be positive in terms of productivity, profitability and sustainability, had not been fully quantified. Further, there needed to be a more robust demonstration of it's suitability across different environments and some of the components required further research. For example, although it had been shown that the contribution of legume nitrogen was likely to be substantial, and permit a reduction in the amount of inorganic nitrogen applied to sugarcane, there was little information on nitrogen accumulation and loss mechanisms under different management systems. In addition, soil compaction was likely to be a major issue when heavy machinery (> 20 t) was used with non-matched wheel and row spacing, yet compaction was not necessarily accepted by the farming community as detrimental to productivity. The significance of soil compaction needed to be demonstrated. Further, if compaction was demonstrated to adversely affect cane yields it would be necessary to match wheel spacing on heavy machinery with row spacing which would likely mean the widening of row spacing to match wheel and row spacing. Concerns were raised that productivity would be reduced if row spacing was widened. Finally, recent research in soil biology during Phase 2 had indicated that the return of sugarcane trash, an inherent component of the green cane trash blanket (GCTB) harvesting system, was providing substantial biological benefits to the farming system and this needed to be further explored. Notwithstanding the above research initiatives, one of the major activities of the current project was the development and extension of the SYDJV Phase 1 and 2 outputs. T he research team was very much involved with BSES extension officers and FutureCane staff in extending these outputs.

Species x Tillage x Nitrogen Experiments

In tackling the issue of the robustness of the 'new' farming system and quantification of the effect of individual components, two major experiments were established in the southern (Bundaberg) and northern (Ingham) cane growing regions. These involved taking long-term sugarcane land that was under matched wheel and row spacing and applying three basic break treatments for a period of 6-8 months. The break treatments involved sugarcane monoculture, maize and soybean. When cane was re-planted, the break treatments were split to two tillage treatments (tilled and direct planted), which were further split to two nitrogen rates (0 and 150 kg/ha in the plant crop followed by a further split to 0 and 150 kg/ha in the first ratoon).

At Ingham the plant crop N was 20 kg/ha instead of 0 kg/ha. Plant crop yield was significantly affected by treatments at Ingham where there was a 27% increase in yield following soybean compared with the sugarcane monoculture. There was also a trend for cane yield following maize to be better than with the cane monoculture (11%) but this effect was not significant. There was a significant overall effect of nitrogen (76 t/ha vs 91 t/ha for 20 and 150 kg/ha, respectively) but no overall effect of tillage. In the first ratoon, the tillage effect was again not significant while the species effect was no longer significant. However, there was still a response to N applied in the plant crop and a further response to N applied to the first ratoon. The combination of 150 kg/ha N applied in each of the plant and first

ratoon crops compared with 20 and 0 kg/ha, respectively, produced first ratoon yields of 105 and 75 t/ha, respectively.

The results from the Bundaberg experiment were less clear, as they were confounded by poor cane establishment of the direct drilled plots in the continual sugarcane treatment. Further, there were indications that large populations of parasitic nematodes across the entire experiment may well have masked potential responses.

The main point to emerge from both experiments was the fragility of mineral nitrogen to environmental conditions. There seems little doubt that de-nitrification under flooded conditions during the wet season at Ingham and leaching at Bundaberg resulted in considerable losses of mineral nitrogen. The nitrogen dynamics from these experiments are discussed in detail in Bell *et al.* (2010). Overall, these experiments have emphasized the complexities of the sugarcane farming system and, in particular, the interaction between the environment and the usefulness of large stores of mineral nitrogen. It is now obvious that the realization of benefits of large quantities of N contributed by legumes and/or N fertilizer will be very environment dependent. This area warrants further research and development of strategies to best manage N in different environments.

Tillage and Compaction Experiments

Experiments involving row spacing and tillage that were established in Mackay and Ingham in SYDJV Phase 2 in 2001 were continued into this project where they were modified to quantify the adverse effects of soil compaction on productivity. In each experiment sugarcane growth on recently prepared land was compared with growth on land that had not been cultivated for the previous 5 years. During that 5-year period the land had been traversed some 20 times with harvesting and haul-out vehicles that were not fitted with guidance.

Tillage (removing compaction) increased cane yield in the plant crops by 57% (141 vs 90 t/ha) at Ingham and 14% (128 vs 112 t/ha) at Mackay. Measurements of soil strength at Ingham with the hydraulic cone penetrometer showed more severe compaction that could be related to the greater difference in yields. Interestingly, there were no yield differences between the tillage treatments in the first and second ratoons in either experiment, indicating that compaction returned to the tilled treatment after the first passage of the harvester and haul-out. Tillage treatments were also implemented in three other trials. No difference between tilled and un-tilled treatments were found in two of these trials (Bundaberg and Ingham Species x tillage x N) and in the third there was a significant advantage in not tilling (Ingham variety x tillage trial). Overall this leaves a variable outcome to tillage treatments most likely associated with different environments (soil, climate, etc.) at each site. This highlights why the principle of reduced tillage was recommended rather than a specific ‘recipe’.

It is expected that GPS guidance would improve the situation considerably and that no tillage and tillage may produce similar yields under guidance. Although these were extreme treatments in terms of alleviating compaction or maintaining it, they clearly show the adverse effect of compaction on productivity. This research is reported in detail in Garside *et al.* (2009a).

Row Spacing Experiments

Row spacing experiments were necessary to show whether moving to 1.8 m row spacing (the minimum for controlled traffic) was likely to result in yield penalties. A considerable amount of row spacing research was carried out in Phase 2 of SYDJV and has been reported in Garside and Bell (2009a, b) and Garside *et al.* (2009b). This research indicated that there was substantial flexibility in row spacing and that a movement from the traditional 1.5 m spacing to 1.8 or greater would not adversely affect yield providing dual rows were adopted. In high input situations 1.8 m single rows would also be quite suitable.
Trials in this project confirmed the response found during SYDJV Phase 2. Three trials (Bundaberg variety by row spacing; Mackay tillage x row spacing; Ingham tillage x row spacing) contained a row spacing treatment and no significant difference among yields on the different row spacings was present at any of the three sites.

Research in this project also focused on whether variety influenced the response to row spacing. No interaction was found and this work was reported in detail in Garside and Bell (2009b) and Bell *et al.* (2007). A further SRDC project BSS296 was also initiated to explore this issue further.

Soil Biology Experiments

The soil biology program was largely based around the use of nematodes (both parasitic and beneficial) as biological indicators and their response to various breaks, organic matter inputs, nutrients and tillage. Identifying the host status of different crop species was also investigated. Some of the major findings included:

- Populations of free-living nematodes increase rapidly when high levels of soybean residue are incorporated into soil.
- There seems to be a close relationship between the population of free living nematodes and nitrogen mineralization. Possibly further development of this relationship could lead to free-living nematodes being used as an indicator of N mineralization.
- There were general indications from the two large scale species x tillage x nitrogen experiments that nematode responses were similar at both Bundaberg and Ingham with some specific exceptions. In particular, populations of *Xiphenima* (dagger nematode) at Bundaberg were substantially enhanced by a soybean break and it is thought that the high population of these may have masked break, tillage and N effects in the plant cane crop. Conversely, *Xiphenima* was not recorded in the Ingham experiment. Although soybean tended to substantially reduce the populations of lesion and root knot nematode, their populations tended to resurge more rapidly following soybean than following sugarcane. Free-living nematodes were enhanced by tillage and initially by soybean as opposed to sugarcane, although this latter effect was later reversed.
- Multiplication of lesion nematode *(Pratylenchus zeae* – the most important in sugarcane system*)* is enhanced by tillage and suppressed in non-disturbed soils. The exact mechanisms by which this occurs are not known and require further research.
- Mulching with sugarcane trash was shown to reduce the populations of both root knot and lesion nematode. Again, the reasons for this response are unknown and require further research although inputs of labile carbon just below the surface in a trash blanket situation are likely to be involved. However, if the response proves to be robust it will have very positive consequences for the green cane trash blanket system.

Development and Extension

A very important aspect of this project was the enhanced development, extension and communication initiatives that were continually in focus. Through publications, field days and group meetings we were able to effectively promote the outcomes of the SYDJV which are of major significance to the future of a sustainable sugarcane cropping system. In particular the collaboration developed with the QDPIF/BSES FutureCane program was a major positive aspect. The annual meetings that permitted frank and open discussion of issues helped focus both groups. We were able to report on the advances in the research program, while they could advise us on what was happening in the industry, and most importantly, where we needed to focus to better facilitate adoption of the 'new' system.

The grower reference group attached to this project also provided valuable input into the program. All members contributed very openly and precisely and clearly told us if they thought we were going in the wrong direction. They provided useful reports after every meeting and always displayed enthusiasm for their role.

Final Overview

In summarizing this project it is necessary to also consider the two phases of the SYDJV, as together they provide a continuum for the past 16 years. The farming system approach taken by the SYDJV and continued in this project has been shown to provide major advances in developing a more productive, profitable and sustainable sugarcane cropping system. Much of this has to do with maintaining a broad focus on the problem and not getting diverted by side issues. There is little doubt that the pillars of the 'new' sugarcane cropping system – legume breaks, controlled traffic and minimum tillage in a green trash blanket harvesting system – are correct and the obvious future. It is time to stop questioning their validity and to focus on the best way of adopting /amending them to best suit regional/individual situations. For example, opportunities exist within this 'new' system to improve other aspects of sugarcane production such as weed and pest control, rotation with other cash crops, time of planting of sugarcane. Further, issues have emerged from this project that require more attention. For example, the concerns raised in this project regarding nitrogen management need to be addressed. However, this and other issues that emerge need to be addressed *within* the pillars of the 'new' farming system. Thus they will need to be addressed *within* legume breaks, *within* minimum/zero tillage, *within* controlled traffic and *within* a green cane harvesting system. The Australian sugar industry needs farming system projects to overview the production system. Administrators and funding bodies need to appreciate that need.

1.0 BACKGROUND

The Australian sugar industry was on a productivity (sugar yield per harvested hectare) plateau, known commonly as yield decline, for at least a 20 year period from 1970. The Sugar Yield Decline Joint Venture (SYDJV) was established in 1993 as a multi-organisational (SRDC, BSES, CSIRO, Qld Government Departments of Primary Industries and Natural Resources) and multi-disciplinary (agronomy, soil chemistry, soil physics, soil biology and agricultural engineering) research and development program to identify the cause/s of and develop solutions to the problem of yield decline. Prior to the establishment of the SYDJV, BSES was the sole research and development organisation tackling the issue of Yield Decline in the Australian sugar industry. BSES believed that Yield Decline was caused by root pathogens and had focussed their research efforts on identifying the pathogens with the ultimate aim of breeding resistant cultivars. Although there was little doubt that root pathogens were involved in yield decline, researchers in the SYDJV suspected that their effects were being exacerbated by other deficiencies in the sugarcane farming system and, therefore, took a much broader approach to researching the issue.

The SYDJV consisted of 2 phases. Phase 1 from 1993 – 1999 (summarised by Garside 1999) was primarily an identification and understanding period. Research showed that sites under long-term sugarcane monoculture had a range of degraded soil properties (chemical, physical and biological). The monoculture and how it was practised contributed greatly to the degraded condition of the soil. Phase 2 (summarised by Garside and Bell 2006) focussed on how these soil deficiencies (poor soil health) may be improved. The approach taken was to look at how farming practices may be changed and thus create an environment that would result in improved soil health. Practices such as including legume breaks (which reduced sugarcane-specific pathogens and replaced at least some inorganic nitrogen fertiliser), controlling traffic (which removed compaction caused by heavy machinery from the cropping zone by isolating traffic and crop zones) and minimum/zero tillage (which reduced soil disturbance and limited the loss of organic matter by keeping the green cane trash blanket (GCTB) in place) became main research initiatives. Although some research had been carried out on all of these issues during Phase 1, little attempt had been made to integrate them in the farming system. In Phase 2 they were researched more thoroughly and integrated to form a ‘new’ sugarcane farming system. The second phase of the SYDJV ended in June 2006.

During the second phase of the SYDJV various planned extension activities were commenced to demonstrate the benefits and encourage adoption of the principles of the ‘new’ farming system. These extension initiatives included the FutureCane program, SRDC/QDPIF funded projects such as the Central region farming systems projects (BSS269 and BSS306) and general extension activities by BSES. BSS286 (the current project) followed the second phase of the SYDJV. It allowed the core participants in the SYDJV to continue the development of the new farming system as well as provide technical support for the various extension programs that were underway.

Although the basic pillars of the new system – legume breaks, minimum/zero tillage, and controlled traffic in a GCTB harvesting system – are now well proven and accepted by the industry as means by which soil health, productivity and profitability can be improved, questions still remain as to how they may be best managed to maximise their effectiveness. Consequently, BSS286 – Improved Sugarcane Farming Systems - was established for a four year period from July 2005. Effectively BSS286 was SYDJV Phase 3.

2.0 OBJECTIVES

The project sought to:

1. Promote further development and adoption of the new farming system developed by the SYDJV.
2. Provide technical support to related extension/development projects such as FutureCane, Back on Track, New Farming systems for Central Queensland (BSS269), and Canegrub management in the new sugarcane farming systems (BSS266)
3. Co-ordinate activities of these groups.
4. Continue research activities to fill knowledge gaps necessary for better adoption of the new farming system.
5. Continue large-scale, commercially orientated, farming-system experiments underway in SYDJV Phase 2.

As detailed below, progress was made with all the objectives through a number of specific activities in research, development and extension.

A continuation of trials from SYDJV phase 2 allowed experiments to be continued at sites where treatments had been in place for a number of years. A continuation of long-term experiments is the only way that changes to farming systems can be validated. Improvements to the soil's condition occur over a much longer time frame than the average three year project cycle and the long term funding commitment to the SYDJV has been integral in its ability to explore soil processes.

Within objectives 1, 2 and 3 the following activities were carried out:

- Reporting of research results from experiments in Phases 1 and 2 was continued with a substantial number of papers being published. These are detailed later in the report.

- The project co-ordination role was carried out through regular meetings, teleconferences and e-mail exchange with BSES and QDPIF extension staff, FutureCane, grower meetings, and publications in the *BSES Bulletin* and *Australian Canegrower* magazine. The project also had a grower advisory group which met five times to review progress and advise on any changes that needed to be made to enhance the project's relevance to cane growers. A high priority of BSS286 was interaction with projects and operatives listed in objective 2 above. In particular the project made a significant contribution to the FutureCane program with 2-3 day meetings every year to discuss results, obtain feedback and plan future activities. The FutureCane program was a major extension vehicle for the SYDJV outputs.

Within objectives 4 and 5 the following activities were carried out:

- Two large scale multi-disciplinary experiments combining all aspects of the 'new' farming system were established at Bundaberg and Ingham in which detailed measurements were carried out. These experiments combined crop species (sugarcane monoculture, maize and soybean breaks), tillage (tilled or no tilled) and nitrogen rates (0 or 150 kg/ha N) on controlled traffic (1.8 m row spacing) beds. Both experiments were grown for a plant and first ratoon crop. Within the experiments, a significant effort was invested in trying to understand changes to nitrogen cycling which in tropical and sub-tropical environments is difficult to quantify given the different pools of nitrogen and potentially large and variable loss pathways. The results have raised some interesting questions about our understanding and ability to manage nitrogen cycling in sugarcane farming systems. The main results are available in Bell *et al.* (2010).

- Two large scale long-term farming system experiments established during Phase 2 at Ingham and Mackay were continued and modified, mainly to demonstrate the adverse effects of soil compaction on productivity. Results for the plant and first ratoon crops are presented in Garside *et al.* (2009a)

- Further studies into changes in soil biology with different cropping practices were carried out in a number of experiments. These were stand alone experiments on specific soil biology issues in addition to data collected from the large scale field experiments discussed above. Some of results of this work have been formally published or are in press *viz.* Stirling *et al.* (2010a,b). Further, a review paper on the impact of farming systems on soil biology and soil borne diseases which covered much of the soil biology work carried out during Phase 1 and 2 of the SYDJV was published in 2008 (Stirling 2008).

- Some initial studies into cultivar x row spacing were carried out as it was essential that if controlled traffic was to be adopted, current machinery dictated that it had to be on row spacings of 1.8-1.9 m. It was necessary to ensure that a widening of row spacing from 1.5-1.8 m did not come with a yield penalty (Bell *et al.,* 2007) and that current cultivars were suitable for these spacings. This research was later expanded in a subsequent SRDC/QDPIF project (BSS296).

3.0 METHODOLOGY

3.1 Research

A number of agronomic, farming system and soil biology experiments were conducted. These were designed to further the understanding of the impact of the new farming system on cane production and soil physical, chemical and biological properties. In many cases trial sites with a history of controlled traffic either from SYDJV Stage 2 or from early adopters of the new system were used. These experiments were detailed above under objectives 4 and 5.

3.2 Extension and development

The project group contributed to the extension and development of the new farming system by interacting and guiding the focus of the FutureCane group as well as other new farming system projects. Formal meetings were held with QDPIF/BSES FutureCane and industry extension officers on a number of occasions. These meetings were used to keep the extension teams updated on the projects latest results and also allow the extension groups to provide feedback to the researchers on potential issues of concern with the new farming system.

A grower reference panel was formed at the beginning of the project. The members of this panel were from different cane production regions and were chosen as they were innovative early adopters of the new system. Meetings were held with this group throughout the project. This was a valuable process where researchers were able to gain grower feedback on new farming system issues.

Information meetings were held throughout the industry in May 2010. These meetings were designed to provide the industry with the key outcomes of the project. The meetings were in conjunction with BSS268 (Accelerated adoption of best-practice nutrient management).

Further, the project team participated in numerous local industry meetings throughout the duration of the project where trial results were discussed.

The research staff published much of the research conducted in the project. This included peer reviewed scientific journals (see section 8) as well as general industry publications (newsletters, etc.).

3.3 Quantification of adoption

Adoption of the new farming system components were quantified during SYDJV Phase 2. This process was continued as part of BSS286. Data consisted of estimates obtained from FutureCane agronomists, local productivity boards and extension officers located in each region.

4.0 RESULTS

In this section a brief description of each experiment is provided as well as a summary of the major outputs. Detailed accounts of the work conducted can be found in the appendices.

4.1 Comparison of zero and conventional tillage on different row spacings (Tillage x Row spacing)

Two experiments were established on sites previously used during SYDJV Stage 2. At both sites, cane was either planted back into permanent beds or was planted into newly formed beds following multiple tillage operations. This occurred on three row configurations at each site (1.5 m single, 1.8 m single and 1.8 m dual row). Differences in growth, yield and soil properties were assessed.

The results from these experiments were presented at the Australian Society of Sugar Cane Technologist (ASSCT) conference in 2009 (Garside *et al.* 2009a). This paper is included as an appendix to this report.

Additional yield data from second ratoon crops, not reported in Garside *et al.* (2009a), was collected during 2009. These data (Tables 1 and 2) did not change the conclusions presented in the paper. No significant difference was found between tillage treatments and row configurations in the second-ratoon crop at either site.

Table 1 - Effect of tillage on second ratoon yield components at Ingham and Mackay

Tillage	Ingham			Mackay		
	Cane yield	CCS	Sugar yield	Cane yield	CCS	Sugar yield
No Till	124.9	16.7	20.8	102.6	17.2	17.7
Till	117.8	16.5	19.5	108.3	17.1	18.5
Level of signif. Lsd 5%	nsd	nsd	nsd	nsd	nsd	nsd

nsd – no statistically significant difference (P>0.05)

Table 2 - Effect of row spacing on second ratoon yield components at Ingham and Mackay

Tillage	Ingham			Mackay		
	Cane yield	CCS	Sugar yield	Cane yield	CCS	Sugar yield
1.5 S	121.6	16.7	20.3	104.3	17.2	17.9
1.8 S	120.6	16.6	19.9	105.1	17.2	18.1
1.8 D	121.9	16.6	20.2	107.0	17.0	18.2
Level of signif. Lsd 5%	nsd	nsd	nsd	nsd	nsd	nsd

nsd – no statistically significant difference (P>0.05)

Conclusions

- Compaction reduces sugarcane yield
- GPS guidance systems will improve the effectiveness of widening row spacings
- Planting sugarcane using zero-tillage resulted in a yield reduction in the plant crop largely because of compaction caused during the previous experiments at these sites when no GPS guidance was available. However, in the following ratoon crops yields were the same for both zero and conventional tillage
- Despite the yield reduction zero-tillage treatments were more profitable for the grower
- Reducing tillage is a viable option for the industry but minimum tillage options need further investigation
- Cane yield was maintained on different row configurations

4.2 Determining Cultivar x Tillage effects

An experiment was established near Ingham to determine whether tillage had an effect on cane yield and to determine whether the response was variety dependant. This work was conducted in order to gain further information on the effect of zero-till farming systems on cane growth. The experiment was located on a heavier textured soil than the two experiments described in section 4.1.

Results from this work are to be presented at ASSCT in 2010 (Park *et al.* 2010). This paper is included as an appendix to this report.

Conclusions

- The zero-tillage treatment produced significantly more yield and was more profitable than a treatment that was tilled twice
- Tillage reduced soil moisture in dry conditions but also exacerbated waterlogging during wet conditions
- Tillage promoted stool tipping, due to the loss of soil structure
- Varieties KQ228$^{\Phi}$ and Q208$^{\Phi}$ responded to tillage in a similar manner
- Response to tillage is highly likely to differ depending on soil type and environment

4.3 Exploring Cultivar x Row configuration interactions

Initial research work conducted during SYDJV Phase 2 (Garside *et al.* 2006a) showed that the performance of a cultivar changed significantly when it was grown on different row configurations. Potentially, this could have created an issue with adoption of the new farming system as selection of cultivars was taking place on the 'old' conventional farming system and performance of cultivars on wider row configurations was mostly unknown. In response to this issue, an experiment was established at Bundaberg where four cultivars with differing growth habits were grown on five row configurations. A SRDC/QDPIF funded project was also established to investigate this issue further (BSS296).

Results from this work were presented at ASSCT in 2007 (Bell *et al.* 2007). This paper is included as an appendix to this report.

Conclusions

- Sugarcane has the ability to produce similar yields on a wide range of row spacings/configurations
- Cultivar performance did not change significantly on different row configurations
- Cultivars achieve their final yield via different growth pathways (stalk numbers, size, growth rates)
- Cultivars are unlikely to constrain adoption of the new farming system

4.4 Species x Tillage x Nitrogen trials at Bundaberg and Ingham

Research by the SYDJV has shown the benefits of introducing a legume break into the crop cycle, reducing tillage and controlling traffic. A legume rotation crop reduces the need for fertiliser nitrogen, provides some control of sugarcane pathogens and improves crop yields. However, the longevity of these effects required further work. More recent studies of new farming systems combining the elements of reduced tillage, controlled traffic and fallow cropping have highlighted the interactions of these system changes on different soil properties that impact crop performance. For example, soil N dynamics are significantly altered as the amount of tillage is reduced (Bell *et al*. 2006a; Garside *et al*. 2006b), with significant implications for N management. In a similar fashion, pathogen incidence and biological pathogen suppression can be influenced by different combinations of crop rotation and residue management (Bell *et al*. 2006b; Pankhurst *et al*. 2005; Stirling *et al.* 2005).

Field experiments at Ingham and Bundaberg in which combinations of rotation crops (ploughout-replant versus a short fallow of soybeans or maize), tillage prior to cane re-establishment and N fertiliser applications were assessed in plant and first ratoon cane crops. The experiments were established to further investigate the interaction of the various cropping system components, with particular emphasis on crop yields and soil and crop N dynamics. The effects of the cropping system on soil biology are reported in section 4.5.2.

Results from this work are to be presented at ASSCT in 2010 (Bell *et al.* 2010). This paper is included as an appendix to this report.

Conclusions

- There was a positive response to soybeans at Ingham but not at Bundaberg, perhaps because the latter site had a wider range of pathogenic nematode species, not all of which declined during the soybean fallow period
- There was no residual benefit of the legume break beyond the plant crop at either site
- The rate of nitrogen mineralisation is affected by moisture, temperature and tillage

- High soil mineral N (fertilizer or legumes) is vulnerable to loss. The major loss pathway at Ingham was denitrification whereas leaching occurred at Bundaberg
- Denitrification reduced the residual nitrogen benefit after the soybean fallow at Ingham
- Despite large difference in crop nitrogen uptake at the two sites, yields were similar

4.5 Soil biology experiments

4.5.1 Free-living nematodes as biological indicators

Since free-living nematodes feed on bacteria, fungi, protozoa, algae or small invertebrates and their populations respond to changes in the availability of their food sources, the number and type of nematodes in soil provides a good indication of what is happening within the soil food web. Nematodes also contribute to the mineralisation of nitrogen and other nutrients, as they feed on the bacteria and fungi that decompose organic matter. Their numbers may therefore provide a good surrogate measurement of the rates of mineralisation in soil.

The results of three studies conducted to investigate this issue are summarised below and detailed in Appendix 1.

Conclusions

- Fungal-feeding nematode populations predominate in bare or weedy fallows because in the absence of organic inputs, recalcitrant carbon compounds (which are primarily utilised by fungi) are the main food source available to soil microorganisms
- Bacterial feeding nematodes increase to very high levels after legume residues are incorporated, indicating an intense period of biological activity as residues decompose and nitrogen is mineralised from the legume
- The proportion of bacterial-feeding enrichment opportunists in the nematode community is a potentially useful indicator of N mineralisation

4.5.2 Impact of cropping history, tillage and nitrogen on the nematode community

Nematode numbers and species were measured sequentially in the experiments involving species x tillage x nitrogen at Ingham and Bundaberg detailed in section 4.4. The results of these studies are summarised below and detailed in Appendix 1.

Conclusions

- A soybean fallow reduces populations of some pathogenic nematode species but has little effect on others
- Pathogenic nematode species can resurge following legumes crops to numbers similar to a sugarcane monoculture by the time the plant crop is harvested
- Lesion nematode (*Pratylenchus*) populations are initially reduced by conventional tillage but then resurge strongly and tend to be higher than in reduced tillage treatments later in the season
- Application of N does not affect populations of *Pratylenchus* in the plant crop

4.5.3 Impact of management practices on suppressiveness to plant-parasitic nematodes

Plant-parasitic nematodes and other soil-borne pathogens do not multiply to the same level or cause the same amount of disease in all soils. Pathogens will cause crop losses in a conducive soil but may cause little or no damage in a suppressive soil. Suppressiveness is due to the action of soil organisms that compete with, prey on or in some way disrupt the pathogen, and is therefore broadly related to total soil microbial biomass. Soils with high levels of microbial activity and diversity are more suppressive than sterilised soils, fumigated soils or soils where the biology has been markedly modified by the practices used to grow crops. A number of studies were conducted to determine whether disturbing soil or adding crop residues as an amendment or mulch had an impact on the suppressiveness of sugarcane soils to plant-parasitic nematodes (see Appendix 1).

Figure 1 - Sugarcane roots from the region (0-2 cm) immediately below the trash blanket (left) and from 15 cm below the soil surface (right), showing the pathogen-suppressive nature of the surface soil

Conclusions

- Pathogenic nematode species multiply faster in disturbed soil, with greatest multiplication in the most disturbed soils
- A sugarcane trash mulch enhances suppression of pathogenic nematode species possibly via inputs of labile carbon and by maintaining a more suitable moisture and temperature environment for biological activity

- The region immediately below the trash blanket contains a large percentage of the sugarcane root biomass and these roots are much healthier than those further down the profile. Soil from this region is strongly suppressive to plant parasitic nematodes
- The most likely reason for the suppressiveness of surface soils is that root exudates, turnover of roots and labile carbon inputs from the trash blanket are sufficient to support an active and diverse soil food web capable of limiting the multiplication of *Pratylenchus* and other plant-parasitic nematodes

4.5.4 Crop rotation as a tool for managing lesion nematode (*Pratylenchus zeae*)

Legumes such as soybean and peanut are relatively poor hosts of lesion nematode (*Pratylenchus zeae)* and, when used as rotation crops in a sugarcane farming system, they markedly reduce populations of the nematode. However, there were limited data on the host status of other rotation crops that might have a place in the sugarcane farming system, while the capacity of common weeds to host *P. zeae* was also not known. The effect of the inclusion of a winter rotation crop following a summer legume on the level of nematode control obtained with the legume crop was also assessed (see Appendix 1).

Conclusions

- *Pratylenchus* multiplies rapidly on sorghum and sugarcane
- Some cultivars of wheat, oats and Rhodes grass support low nematode multiplication and three crops (*Setaria* cv. Splenda, barley cv. Grimmett and cowpea cv. Red Caloona) are non-hosts of *Pratylenchus*
- Breaking the sugarcane monoculture with a summer legume followed by a winter crop (e.g. wheat, barley, oats, linseed, canola, field pea or chickpea) will not markedly affect the level of nematode control that is achievable with a legume crop alone

4.5.5 Chemical and biological properties of soils under different management systems

Although there is a strong body of evidence from farming systems used for other crops to suggest that soil health will improve under the new sugarcane farming system, any improvements are expected to take many years to manifest themselves. This study therefore measured a range of properties of conventionally managed cane-growing soils with the aim of providing baseline data for future comparisons with soils managed in other ways. However, the data obtained also provided an indication of short-term changes that had taken place since the new farming system was introduced. Soil properties were measured at 11 sites where sugarcane had been grown for 5-7 years using at least some components of the new farming system. Measurements were compared with nearby examples of soil managed under the conventional sugarcane farming system or maintained as a permanent grass pasture. Perennial pasture was included in the comparison because it is often used as a standard reference when monitoring the ecological condition of soils used for agriculture (see Appendix 1).

Conclusions

- Biological and chemical differences between soils under the new and conventional sugarcane farming system were not significant. However, trends for improved soil condition under the new farming system were evident
- Pasture soils had nearly twice as much total C, total N, labile C and water-soluble C as cropped soils and this was the reason for their superior biochemical and biological status

- Significant changes to a soil's condition are unlikely to occur in the short term following integration of legume break crops, minimum tillage and controlled traffic into the farming system

4.6 Extension and development

4.6.1 Co-ordination of farming system projects

Combined meetings were held with staff from FutureCane and other farming system projects on 7-9 March 2006, 6-8 March 2007 and 26-28 March 2008 in Bundaberg, Mackay and Cairns, respectively. There were also many informal interactions between members of BSS286 and these groups. These meetings and interactions were used to discuss results and identify problems associated with the new farming system. There was a mutual benefit from these interactions. BSS286 participants assisted extension officers and FutureCane Agronomists with implementing trials, discussing trial designs, treatments, and analysis. Many of these are reported in FurtureCane publications. Ultimately the success of these activities will be based on the adoption of the new farming system. Access to the Farm Economic Assessment Tool (FEAT) developed by the FutureCane team contributed to the economic analysis of experiment results (eg Garside *et al.* 2009a). Demonstrating a lower cost of production has been a valuable tool for encouraging adoption of the new farming system.

Evidence of these collaborations can be seen in ASSCT publications by participants in both BSS286 and FutureCane as demonstrated below:

Dougall AJ; Halpin NV (2008) The influence of depth and method of cane planting on stool tipping and yield on a red-ferrosol at Bundaberg. *Proceedings of the Australian Society of Sugar Cane Technologists* **30**: 241-250

Halpin NV; Cameron T; Rosso PF (2008) Economic evaluation of precision controlled traffic farming in the Australian sugar industry: A case study of an early adopter. *Proceedings of the Australian Society of Sugar Cane Technologists* **30**: 34-42

Garside AL; Poggio MJ; Park G; Salter B; Perna J (2009) Long-term Ingham and Mackay farming system experiments: Comparison between permanent non-tilled beds and re-formed beds. *Proceedings of the Australian Society of Sugar Cane Technologists* **31**: 282-295

Stirling GR; Halpin NV; Dougall A; Bell MJ (2010) Status of winter cereals, other rotation crops and common weeds as hosts of lesion nematode (*Pratylenchus zeae*). *Proceedings of the Australian Society of Sugar Cane Technologists* **32**: 62-70

4.6.2 Grower reference panel

A grower reference panel was established for the project. It initially consisted of George Henry (Tully), Robert Quirk (NSW), Terry Granshaw (Burdekin) and Roy Price (Bundaberg). Peter Russo (Bundaberg) joined the group following the resignation of Roy Price when he sold his farm.

Meetings were held with the grower reference group on 17 October 2005, 3-4 October 2006, 10-11 October 2007, 7-8 October 2008 and 10 May 2010 at Brisbane, Townsville, Bundaberg, Tully and Bundaberg, respectively. Numerous phone conversations and email exchanges occurred during the project. As with the collaboration with extension officers, the grower reference group was able to highlight issues they were facing with the adoption of the new farming system and contribute practical ideas to trial work. By keeping the grower reference group up to date with research results, extension of these results back to each region, by the grower reference group, took place.

The success of the grower reference group concept is heavily dependant on the participant's interest and knowledge of the topic. This grower reference group's enthusiasm and understanding of the major issues involved in the project is to be commended. Each grower provided a report on their assessment of progress after each reference group meeting. These reports were included in Milestone reports. In addition, the growers in the reference group were asked to comment about their experience as part of the project. These comments can be found in the Appendix 2 of this report.

4.6.3 Industry wide meetings May 2010

Meetings were held at Mackay, Ayr, Ingham and Innisfail on 24-28 May 2010. Four presentations were delivered:

Salter	Varieties for wide row spacings: BSS296 Evaluation of genotypes for a controlled traffic farming system
Garside	Soil compaction in sugarcane cropping systems: Soil type has important implications
Stirling	Improving the biological status of sugarcane soils – what are our options?
Bell	The new farming system – it's not a foolproof recipe

The meetings were attended by growers and extension staff. Feedback during the meetings has been included in the Future needs and Recommendations section.

4.7 Adoption of farming systems

Estimates of the level of adoption of fallow cropping, zonal tillage and controlled traffic were obtained after discussions with local extension officers, productivity services and FutureCane agronomists. Adoption of legume fallow crops is represented as a percentage of the total area of fallow ground in each region. Adoption of zonal tillage and controlled traffic is represented as the percentage of area established using these practises compared to the total area of sugarcane land under production (it includes all crop classes). Zonal tillage represents a range of different options other than the traditional offset, rip and hoe of the entire paddock.

Adoption of legume fallow cropping has increased in all regions (Figure 2). The level of adoption is influenced by many factors including the price of soybeans on the market, the price of nitrogen fertiliser, timing of the on-set of the wet season and the timing of the end of the sugarcane harvesting season. The combination of high soybean prices at the start of 2008, a high urea (nitrogen) price and a relatively early finish to the cane crushing season at the end of 2008 resulted in a large increase in the percentage of fallow area planted with a legume. These factors were not present for the 09/10 crop and planting of legumes fell, particularly in the Southern region.

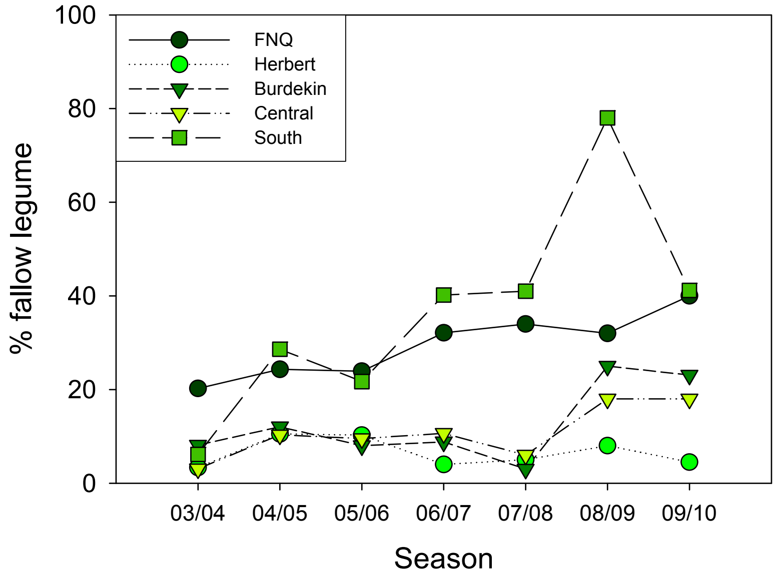

Figure 2 - Percentage of fallow land planted with a legume crop

The adoption of reduced tillage practises such as zonal or zero tillage has been slow (Figure 3). However, it is increasing as the cost of tillage is becoming more apparent to growers. The availability of equipment is also an issue and only recently has commercial zonal tillage equipment become available. Many growers have also accessed zonal tillage equipment through federal government ReefRescue funding. A SRDC/QDPIF project BSS306 is also making zonal tillage equipment available to growers in the Central region. This should see greater adoption of this practise in the future. Some changes to farming practises not captured in this figure have also occurred. In the Burdekin there is widespread adoption of planting into pre-formed beds. Tillage is used prior to forming the bed but not thereafter.

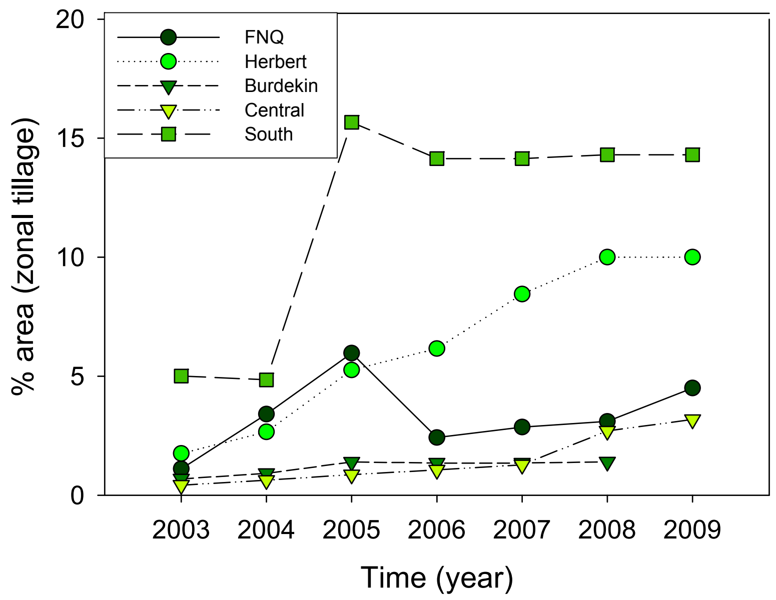

Figure 3 - Percentage of total area, including all crop classes, established using zonal tillage

Controlled traffic is being adopted in all regions (Figure 4). It should be noted that these data represent the adoption of row spacings of 1.8 m or wider, GPS guidance systems may be required for true controlled traffic. The data from FNQ are slightly distorted as there has been large scale adoption of controlled traffic in Tully but very limited adoption in some of the other areas (Innisfail, Babinda, etc.). There is evidence that the increase in adoption of controlled traffic will continue for a number of years. A survey by the Agriserv Mackay revealed that 34% of plant cane to be harvested in 2010 in the Mackay area was planted on 1.8 m spacings or wider. If this value is extrapolated one could assume that at least 34% of the area will be using wide row spacings in 4-5 years. Similarly, over 13% of the 2009-2010 plant cane crop in the Herbert region was planted on spacings wider than 1.8 m.

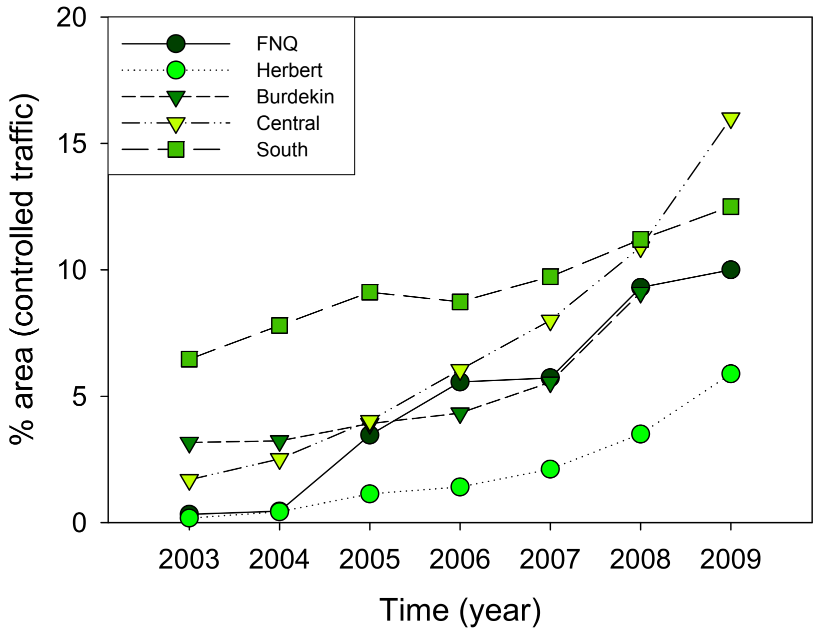

Figure 4 - Percentage of total area (including all crop classes) using controlled traffic farming systems

4.8 Successes and lessons

Successes

- Widespread acceptance of legume break crop rotation with the added benefit of no 'N' application in following plant crop and possibly reduced N in the first ratoon.
- Controlling the movement of machinery in the field as a means of reducing yield losses due to compaction. Guidance has also become more affordable and has been widely adopted in the past 3 years.
- Minimum tillage via double-disk opener planters has made it possible to plant sugarcane and legumes through heavy cane trash.
- Researches and farmers have a better understanding about soil biology and the benefits of a healthy soil.
- FutureCane (involving both BSES and QDPIF) improved extension services for growers.
- Lowering inputs have been the bonus with the new farming system when fully implemented.

- Profitability via economic analysis has become the driver for change. Previously productivity was used as the benchmark.
- While adoption of the system is not 100%, most Australian farmers, and in fact many around the world, have adopted parts of this BMP for sustainability.

Lessons

- Legumes provide many benefits to the sugarcane farming system, including a degree of nematode control for about 6 months after planting. However, results from the Species x Tillage x Nitrogen trials have shown that a legume rotation crop does not necessarily reduce the impact of nematodes later in the cropping cycle. Nematode populations were relatively high following soybean in both the Bundaberg and Ingham trials and even when a soybean rotation crop was combined with minimum tillage and trash retention, at least four nematodes species (*Meloidogyne*, *Pratylenchus*, *Paratrichodorus* and *Xiphinema*) caused significant damage in the Bundaberg trial
- Nematode populations were relatively high throughout most of the soil profile, but were much lower in the zone immediately under the trash blanket. Also, an unexpectedly high proportion of the crop's roots were found in this zone, and they were much healthier than roots further down the soil profile. Indicative of a positive effect of trash blanketing on nematode management.
- Compaction can cause significant yield losses. It is likely to do this by reducing moisture and nutrient availability and restricting tillering.
- Without guidance (and possibly even with guidance) there will still be a need for some tillage in the system to alleviate compaction from un-controlled traffic, alleviate potential nutrient stratification and allow for the use of traditional mouldboard style planters.
- Controlled traffic and tillage experiments should be conducted with the use of guidance systems on all machinery. Harvesters specifically designed to cut particular row configurations should be used. Currently a standard machine is used to cut all row configurations, possibly creating a bias in the following crops due to varying degrees of harvester damage.
- Current cultivars have an ability to be productive over a range of row spacings.
- No system can be all things to all people.
- Without well co-ordinated research by groups like the SYDJV, production in Australia would be much lower.

5.0 OUTPUTS

Outputs are highlighted in bold in the Results section. These were brought together as the successes and lessons and in the summary.

6.0 EXPECTED OUTCOMES

The project has contributed to the increased adoption of new farming systems principles in all regions. Further increases in adoption are expected to continue into the future. Adoption has been facilitated via a combination of additional research and a co-ordinated extension effort. There was a particularly strong association between BSS286 and the FutureCane program, both of which contributed greatly to new farming system extension activities throughout Queensland.

There is little doubt that production costs are substantially reduced when legume fallows, reduced tillage and controlled traffic are adopted. This has been demonstrated in a number of studies in recent years (Poggio *et al.* 2007; Schroeder *et al.* 2009). Lowering the cost of production is a critical part of maintaining the industry's sustainability.

Adoption of new farming system principles will ultimately lead to improved soil health (chemical, physical and biological properties). While a survey of soil properties throughout the industry found that there were no significant changes compared to the old conventional farming system as yet, there were some signs of improvement. Ultimately the envisaged improvements to soil health should result in yield increases and also a farming system that is more robust and resilient to climate variability.

While research data on the changes to water quality leaving the farm after the adoption of new farming systems is only now being collected, it is expected that adoption of the new farming system will assist the industry in meeting the environmental requirements for agriculture in the Great Barrier Reef catchments. The research conducted by the SYDJV has allowed the industry to respond to the environmental challenges that have occurred in recent years. In many ways it has been used as the blue-print for responding to these challenges and one wonders what position the industry would be in if the outputs of the SYDJV were not available.

Environmental and social impacts of the new farming system have not changed significantly since SYDJV Phase 2 was completed. Garside and Bell (2006) outlined the likely impacts in the final report of Phase 2.

While many things have been achieved and adoption of the new farming systems is increasing, there are issues that require further work.

7.0 FUTURE NEEDS AND RECOMMENDATIONS

There are a number of issues that still require further investigation. At this stage some of these issues are often used as reasons for not embracing the principles of the new farming system. This will probably remain the case until work is done to address these issues. There is also a tendency for blanket adoption of a new farming system recipe without thinking about the issues and how they may best be applied in different situations. In general the Australian cane grower has been used to recipe farming. The new farming system requires a change to principle thinking. Continued reliance on recipes is likely to result in some adverse responses following adoption leading to doubt about the effectiveness of the new farming system.

GPS Guidance

Zero-till/minimum till systems may only be feasible if all traffic, and particularly harvesting traffic, can be restricted to the inter-row space. Evidence from this project showed that wider row spacings by themselves may not adequately provide controlled traffic, such that soil compaction may still be a problem. To what extent tillage can be reduced is likely to be associated with soil type and the effectiveness of guidance systems. Extension activities promoting reduced tillage will be hampered until this type of work is conducted.

Water Management

Work is required to determine whether reduced tillage practises and fallow cropping result in changes to water holding capacity, infiltration rates, management of water/irrigation and changes to water quality leaving the farm. These issues are being addressed in a recently funded SRDC/QDPIF project (BSS329). The outcomes are critical given the current environmental issues being faced by the industry. New farming system practises are also receiving significant funding from the federal government Reef Rescue program. It remains to be seen whether there is a significant improvement in water quality leaving the farm following the adoption of the new farming system, although intuitively it seems likely. Further, it is likely that the amount of water required to sustain yields at current levels can be substantially reduced with the new farming system. If so, this will also be an environmental benefit.

Nitrogen management

Although significant improvements to nitrogen management in the sugarcane industry have occurred with the ‘Six Easy Steps’ program (Schroder *et al.* 2005), the understanding of processes and management of nitrogen in sugarcane farming systems needs to be improved. Particularly, practical cost-effective methods to reduce the potentially large losses of nitrogen from soils are required. This needs to be done by timing nitrogen availability with the main period of crop demand. Currently, split fertiliser applications are not practical due to access issues around and following the wet season, polymer coated fertiliser and urease inhibitors are either too expensive or needing further work, and using formed beds to reduce losses associated with waterlogging are not popular in some regions due to an almost equal chance of both wet and dry years. New investment is required to address these issues given the environmental constraints that will continue to be imposed on any agriculture that adjoins the Great Barrier Reef.

Management of the interface between cycles (fallow crops and cane)

The SYDJV showed the benefit of fallow crops to the sugarcane farming system. These benefits will only be fully realised if the two crops are grown in a complimentary manner. This issue is being dealt with by a recently funded project in the southern region and the likely funding of similar work in the Burdekin region.

Machinery

Although problems with double-disc opener planters have been relatively minor, some issues remain (Hurney and Skocaj 2010). Planting depth, soil-sett contact and harvester damage are the main concern.

Nutrient Stratification

Significant adoption of zero-tillage/minimum tillage is required before nutrient stratification becomes an issue. However, it is likely to become an issue in time and investment in research in this area will be required. Similarly, the application of lime to acidic soils in a minimum till farming system will also need to be addressed.

Row configuration

Dual row configurations are unpopular in some regions. Farmers are more likely to adopt controlled traffic if they are confident that single row systems will maintain yield. Despite the large amount of work conducted on row spacing, large scale demonstration trials are still required in some regions to convince growers that yield reduction is not an issue. This is particularly the case in the Wet Tropics.

Weed control on wide single rows is also a perceived problem and is often cited as a reason for not adopting wide single row configurations. Growers believe that the extra time it takes for a wide single row to reach canopy closure (especially erect cultivars) will result in more weed growth in the interrow space and increase management costs. Work is required to determine whether this is a 'real' issue.

Biological suppression of pathogens

One of the main outputs of this project was that sugarcane trash and the region of soil immediately below it is highly suppressive to sugarcane pathogens. Understanding the mechanisms of suppression is required as it may allow improvements to be made to farming systems in the future.

Resurgence of nematodes following legumes

Although legume breaks markedly reduce populations of key nematode pests, nematodes resurge strongly when sugarcane is planted. Since the residue remaining following a legume crop decomposes readily (due to its high quality and relatively low biomass) it is possible that there is insufficient organic carbon late in the season to maintain the soil food web required to suppress nematodes and other pathogens. This hypothesis should be tested and options explored for increasing residue inputs during breaks.

Value of crop residues

The finding that crop residues on the soil surface are important for maintaining a soil food web that is suppressive to pathogens provides further support for the practise of trash blanketing. Given this result, the value of trash as a mulch on a sugarcane field needs to be re-assessed. This could then be weighed up against its value as a garden mulch, a source of energy for the production of electricity, or any other product.

Group to respond to emerging issues

There are likely to be many issues that emerge as adoption of legume fallow crops, reduced tillage and controlled traffic increases. Some issues will be general in nature while others may be region specific due to the large differences in soils and climate within the sugarcane industry. There is a need for some structure that allows issues with farming systems, particularly those associated with fallow crops, minimum tillage and controlled traffic to be addressed. This need was raised in the final report of SYDJV Phase 2 and was addressed by BSS286 until now. Many of the issues are often small and do not require individual projects, however some form of funding is necessary to address them. It is likely that an ad-hoc approach to each issue will be less effective than a co-ordinated effort, a finding that the SYDJV has demonstrated very effectively.

8.0 PUBLICATIONS ARISING FROM THE PROJECT

8.1 Scientific papers published from BSS286

Bell MJ; Halpin NV; Garside AL (2007) Performance of sugarcane varieties with contrasting growth habit in different row spacings and configurations. *Proceedings of the Australian Society of Sugar Cane Technologists* **29**: 215-225

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Bell MJ; Garside AL; Halpin N; Salter B; Moody PW; Park G (2010) Interactions between rotation breaks, tillage and N management on sugarcane grown at Bundaberg and Ingham. *Proceedings of the Australian Society of Sugar Cane Technologists* **31**: 119-139

Park G; Garside AL; Salter B; Perna JM (2010) Effect of zero and zonal tillage on cane growth and yield on a heavy cracking clay soil in the Herbert valley. *Proceedings of the Australian Society of Sugar Cane Technologists* **31**: 97-109

Stirling GR; Halpin NV; Bell MJ; Moody PM (2010) Impact of tillage and residues from rotation crops on the nematode community in soil and surface mulch during the following sugarcane crop. *Proceedings of the Australian Society of Sugar Cane Technologists* **31**: 152-168

Stirling GR; Halpin NV; Dougall A; Bell MJ (2010) Status of winter cereals, other rotation crops and common weeds as hosts of lesion nematode (*Pratylenchus zeae*). *Proceedings of the Australian Society of Sugar Cane Technologists* **31**: 62-70

8.2 Additional papers published from SYDJV Phase 2

This project has allowed the members of the SYDJV to continue working together within the sugarcane industry. One of the outcomes of this continued collaboration is the publication of further scientific papers from work that was conducted as part of SYDJV Phase 2 and also other farming systems work not directly funded by this project.

Garside, A.L., Robotham, B.G., and Bell, M.J. (2006). Management of the interface between sugarcane cycles in a permanent bed, controlled traffic farming system. Proceedings of the 13th Australian Society of Agronomy Conference, Perth, W.A. 10-14 September, 2006

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Bell MJ; Stirling GR; Pankhurst CE (2007) Management impacts on health of soils supporting Australian grain and sugarcane industries. *Soil and Tillage Research* **97**: 256-271

Garside, A.L. and Bell, M.J. (2007). The value of legume breaks to the sugarcane cropping system – cumulative yields for the next cycle, potential cash returns from the legume, and duration of the break effect. *Proceedings of the Australian Society of Sugar Cane Technologists* **29**: 299-308

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Hurney, A.P., Grace, D., and Garside, A.L. (2007). Effect of direct drill planting onto raised beds on cane growth and yield under rainfed conditions in north Queensland. *Proceedings of the Australian Society of Sugar Cane Technologists* **29**: 290-298

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Stirling GR (2008) The impact of farming systems on soil biology and soilborne diseases: examples from the Australian sugar and vegetable industries – the case for better integration of sugarcane and vegetable production and implications for future research. *Australasian Plant Pathology* **37**: 1 - 18

Garside AL; Bell MJ (2009) Row spacing and planting density effects on the growth and yield of sugarcane. 1. Responses in fumigated and non-fumigated soil. *Crop & Pasture Science* **60**: 532-543

Garside AL; Bell MJ; Robotham BG (2009) Row spacing and planting density effects on the growth and yield of sugarcane. 2. Strategies for the adoption of controlled traffic. *Crop & Pasture Science* **60**: 544-554

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8.3 Topical articles

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Salter, B. 2009. Calculating the nitrogen delivered by a legume crop. Mackay Cane News (February)

Salter, B. 2010. Row spacing – is there a difference? Canegrowers Mackay Newsletter (February 25)

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Garside AL; Bell MJ (2009b) Row spacing and planting density effects on the growth and yield of sugarcane. 3. Responses with different cultivars. *Crop & Pasture Science* **60**: 555-565

Garside AL; Bell MJ; Robotham BG (2009b) Row spacing and planting density effects on the growth and yield of sugarcane. 2. Strategies for the adoption of controlled traffic. *Crop & Pasture Science* **60**: 544-554

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11.0 APPENDICES

Appendix 1. Soil biology studies

Appendix 2. Comments from grower reference group

Appendix 3. Scientific papers produced from BSS286

APPENDIX 1 – SOIL BIOLOGY STUDIES

SYDJV PHASE 3: FINAL REPORT (SOIL BIOLOGY)

Graham Stirling

This report covers the soil biology work done in project BSS286. It is subdivided into five sections as follows:

1. Free-living nematodes as biological indicators
2. Impact of cropping history, tillage and nitrogen on the nematode community
3. Impact of management practices on suppressiveness to plant-parasitic nematodes
4. Crop rotation as a tool for managing lesion nematode (*Pratylenchus zeae*)
5. Chemical and biological properties of soils under different management systems

1. FREE-LIVING NEMATODES AS BIOLOGICAL INDICATORS

Although many different tests are available to assess a soil's physical and chemical status, there is a paucity of information on the biological status of various soils. One reason for this is that there are a myriad of organisms in soil, they vary in size from bacteria to earthworms. Since the smallest and most numerous inhabitants (bacteria, fungi and protozoa) are difficult to enumerate and their populations may change rapidly with time, many ecological studies over the last 20 years have been done with larger soil organisms. This work has shown that nematodes are perhaps the most useful biological indicator for a number of reasons: 1) they are relatively easy to extract from soil, 2) they are readily identified using morphological characters and 3)their feeding habits can be inferred from the structure of their mouth parts. Since free-living species feed on bacteria, fungi, protozoa, algae or small invertebrates and their populations respond to changes in the availability of their food sources, the number and type of nematodes in soil provides a good indication of what is happening within the soil food web.

Another reason for studying free-living nematodes is that they contribute to the mineralisation of nitrogen and other nutrients. When nematodes feed on the bacteria and fungi involved in the decomposition of organic matter, the excess N that is assimilated nematodes during growth or is used to meet the C needs of respiration is excreted in mineral form as NH_4^+. It is therefore possible that free-living nematodes are a useful indicator of N mineralisation rates in sugarcane soils.

The following work is the first serious attempt to fully assess the nematode communities in sugarcane soils. The objectives were to determine the impact of practices such as crop rotation, tillage and incorporation of crop residues on the biological status of soil and rates of N mineralisation.

Impact of rotation, tillage and fallowing on the nematode community

This work was published in the following paper, and a copy is included in the appendix to this report.

Stirling GR, Moody P, Stirling AM (2007) The potential of nematodes as an indicator of the biological status of sugarcane soils. *Proceedings of the Australian Society of Sugarcane Technologists* **29**, 339-351.

Impact of tillage following soybean

This study utilised three trials in the Bundaberg/Maryborough area that were established by Andrew Dougall as part of the Future Cane program. The aim was to examine relationships between the nematode community and N mineralisation from soybean residue when sugarcane was planted into tilled or non-tilled soil.

Methods

Soybeans grown during summer/autumn 2005 were either rotary hoed or left undisturbed and sugarcane was planted in spring 2005 to produce two tillage treatments: conventional tillage (CT) and direct drill (DD). Soil samples (10-15 soil cores to a depth of 15 cm) were collected from 3 or 4 replicate plots of each treatment in the first 10 weeks after soybeans were incorporated in the DD treatment (Table 1). Nematodes were extracted from 200 mL soil samples using a standard nematode extraction tray for 2 days, separated into major trophic groups[enrichment bacterial feeders (mainly Rhabditida), other bacterial feeders (mainly Cephalobidae), fungal-feeders (*Aphelenchus*, *Aphelenchoides* and fine-tailed Tylenchidae)], and counted. Soil N was measured at W. Glass site using standard methods.

Table 1. Details of sites and sampling dates (in 2005) for comparisons of conventional tillage (CT) and direct drill (DD) treatments

Site	Location	Date soybeans incorporated in DD treatment	Date sugarcane planted	Sampling dates	No. days after soybeans were incorporated
W. Glass	Bundaberg	19 August	19 August	22 August	3
				12 September	24
				4 October	46
				19 October	61
Bundaberg RS	Bundaberg	13 September	5 October	23 November	71
Coutts-Smith	Maryborough	6 September	16 September	6 October	30

Results

Differences in numbers of bacterial-feeding nematodes, fungal-feeding nematodes and total free-living nematodes were observed between CT and DD 3 days after soybeans were incorporated (Figure 1). However, because the site was not sampled before the soybeans were rotary hoed, it is not possible to be sure of the reasons for these differences. Nematode numbers were lower in CT plots, possibly because tillage was detrimental to the nematode community. However, at 46 and 61 days, populations of all nematodes were much higher in CT than DD plots (Figure 1).

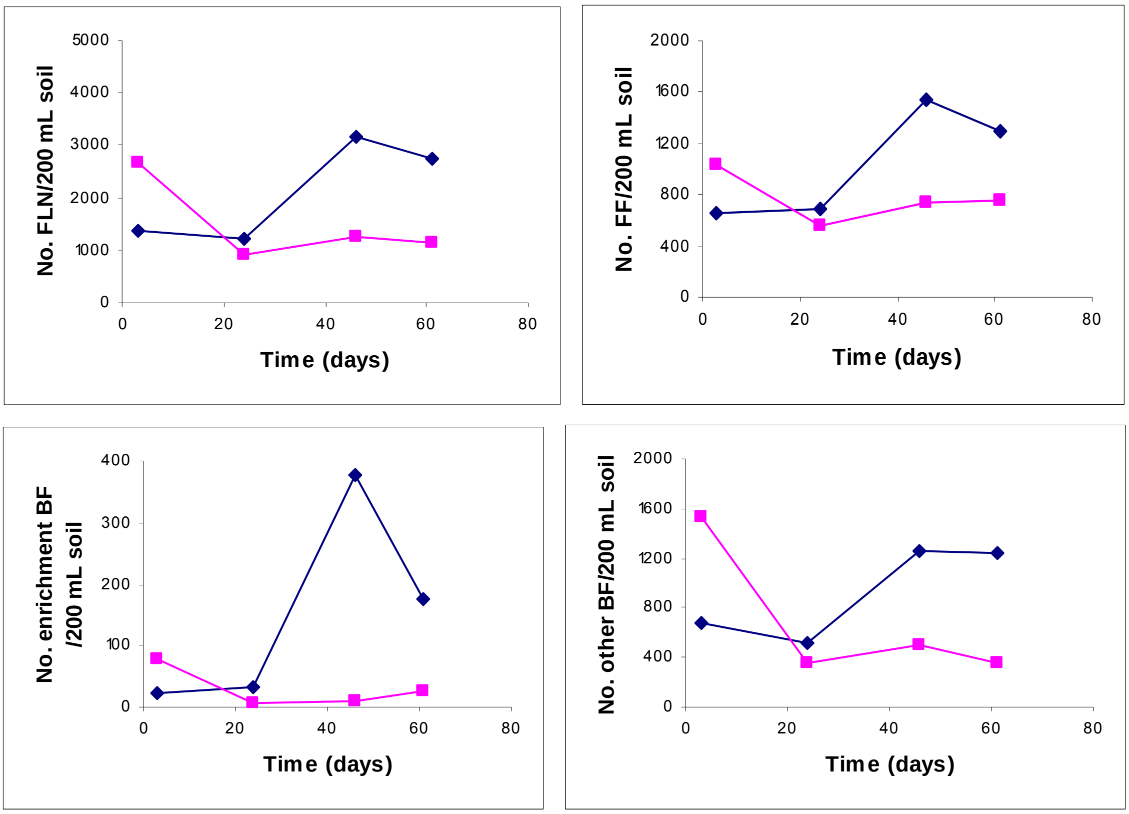

Fig. 1. Total numbers of free-living nematodes and components of the nematode community in soil at the Glass site after sugarcane was planted into a soybean fallow following conventional tillage (♦) or by direct drill (□).

The nematode channel ratio (NCR), which is the proportion of microbivorous nematodes that feed on bacteria [B/(B+F)], tended to remain constant following CT and decline in DD plots (Figure 2). Thus in the DD treatment there was a temporal trend towards a decomposition pathway that was increasingly dominated by fungi rather than bacteria. This probably occurred because the most labile C compounds in soybean residue were utilised by soil organisms during late spring and winter, leaving more recalcitrant residues with a higher C/N ratio to be decomposed mainly by fungi. Cultivation resulted in a flush of free-living nematodes, particularly bacterial-feeding species, and this arrested the decline in the NCR.

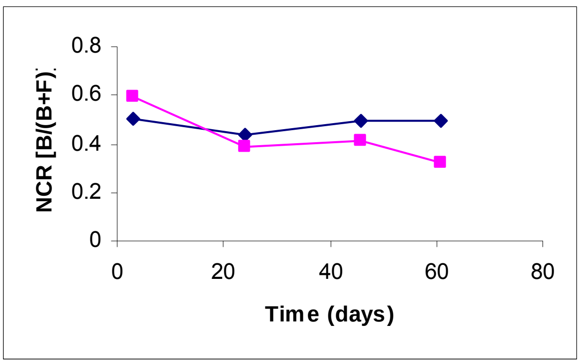

Fig. 2. Effect of tillage (♦ = conventional till, □ = direct drill) on the nematode channel ratio at the Glass site

More NO_3-N and NH_4-N were mineralised in CT than DD, with NH_4-N mineralisation commencing as soon as tillage occurred and NO_3-N mineralisation increasing with time (Figure 3). Conventionally-tilled plots were wetter than DD plots but the N data did not suggest that additional denitrification had occurred in the DD treatment (Figure 3). Concentrations of dissolved organic carbon were slightly but consistently higher in DD than CT (Figure 3).

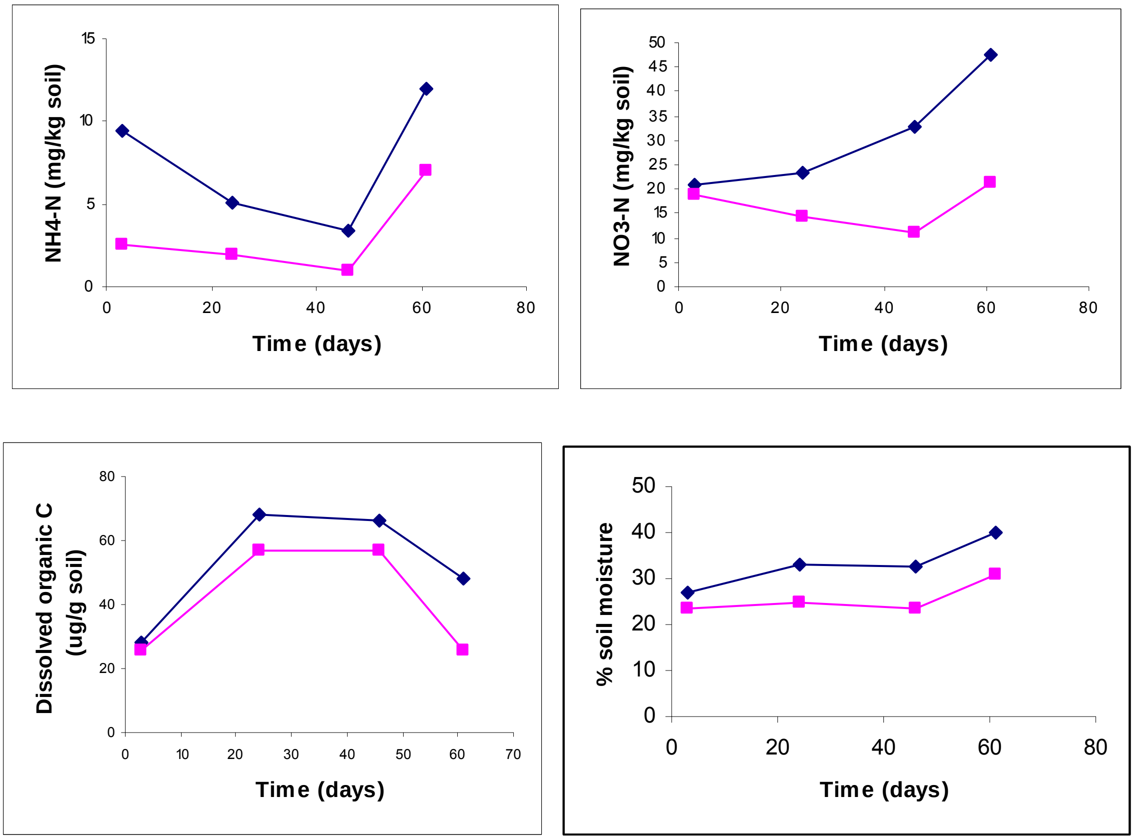

Fig. 3. Soil nitrogen, carbon, and moisture content at the Glass site after sugarcane was planted into a soybean fallow following conventional tillage (♦) or by direct drill (□).

There was a relationship between the amount of N mineralised and numbers of bacterial and fungal-feeding nematodes, as correlation coefficients (r) for relationships between NO_3-N and total N and various components of the nematode community generally ranged from 0.42 to 0.67 (Table 2).

Table 2. Matrix of correlation coefficients for selected components of the nematode community and concentrations of soil nitrogen (Glass site).

	NH_4-N	NO_3-N	Total N
TFLN	0.171	0.626	0.551
Enrichment BF	0.143	0.320	0.297
Other BF	0.119	0.476	0.416
Total BF	0.144	0.501	0.442
Total FF	0.168	0.674	0.589

Nematode counts at all sites 30-71 days after soybeans were incorporated (Table 3) clearly show that that the nematode community at the Bundaberg RS site was markedly different from the other two sites. There were large numbers of rhabditid nematodes in both treatments at this site and the nematode community was dominated by bacterial-feeding nematodes (NCR > 0.86). Although this group of nematodes feed on bacteria in water films around soil particles and are therefore favoured by wet soils, this was not the reason that these nematodes predominated. The soil drained readily at this site and moisture inputs from rainfall and irrigation were not excessive (127 mm and 105 mm in the two 35 –day periods prior to sampling). The greater interval between incorporation and sampling at this site may have been a factor, but most likely reason for the large numbers of bacterial-feeding nematodes is high N inputs in the years before the trial was established. Citrus was grown previously at this site and analyses taken before soybeans were planted showed a NO_3-N concentration of 34 mg/kg in the upper 20 cm of the soil profile. Despite the high N concentrations and predominance of rhabditid nematodes, it is interesting that CT still markedly increased populations of all groups of nematodes.

At the other two sites, tillage also increased all components of the nematode community, while an increase in the NCR showed that the importance of bacterial-feeding nematodes to fungal-feeding nematodes also increased (Table 3).

Table 3. Nematode counts for various components of the nematode community (numbers/200 mL soil), and Nematode Channel Ratios (NCR) for conventional tillage (CT) and direct drill (DD) treatments at three sites 30-71 days after soybeans were incorporated in the CT treatment

Nematode group*	Glass (61 days)		Coutts-Smith (30 days)		Bundaberg RS (71 days)	
	CT	DD	CT	DD	CT	DD
TFLN	2747	1333	7480	3507	8485	1965
Rhabditids	176	25	891	102	6105	1403
Other BF	1240	350	1993	917	1341	331
BF	1416	375	2884	1019	7446	1734
FF	1300	753	3481	1790	980	203
NCR	0.494	0.321	0.384	0.301	0.863	0.882

* TFLN = total free-living nematodes, Rhabditids = bacterial-feeding enrichment opportunists, BF = bacterial-feeders, FF = fungal feeders.

Discussion

As expected, the study at the Glass site showed that more N was mineralised when soybeans are incorporated rather than left standing. Even in the relatively cool conditions which occur in August and September in Bundaberg, clear differences in N mineralisation between tillage treatments were apparent after 24 days.

This study confirmed that FLN are a potentially useful indicator of N mineralisation in sugarcane soils. Results from the Glass site 24, 46 and 61 days after soybeans were incorporated showed that the increase in numbers of FLN in CT compared with DD was similar to the increase in concentrations of NO_3-N in soil. Numbers of FLN were 1.34, 2.52 and 2.42 times greater in CT than DD at the three sampling times, while the differences in NO_3-N concentrations at the same sampling times were 1.62, 2.95 and 2.23, respectively.

One thing that is clear from these data is that enrichment opportunists (mainly Rhabditida) were not the only group of nematodes to increase in population density following incorporation of soybeans. All major nematode groups responded to tillage, suggesting that they all contributed to the increased N mineralisation observed in the CT treatment. Interestingly, the best correlations between N and nematodes were with fungal-feeding nematodes, perhaps because at the time of incorporation, the soybean residue was no longer green and had therefore lost the sugars, carbohydrates and other labile C compounds that are favoured by bacteria. Fungi are the main decomposers of more recalcitrant compounds such as cellulose and lignins.

Studies on other crops in moist, temperate climates have shown that rhabditid nematodes multiply rapidly and reach very high population densities when organic matter is added to soil. This response occurred at the Bundaberg RS site and has been observed previously in sugarcane soils following incorporation of green manured legumes. In these situations, rhabditid nematodes may comprise >75% of the nematode community. The fact that his did not occur at the Glass and Coutts-Smith sites is of interest because it raises questions about the factors that influence populations of rhabditids in sugarcane soils.

Impact of amending soil with soybean residue

In this experiment, green soybean residue was incorporated into field soil in pots and allowed to decompose at different temperatures and moisture levels. Microbial activity, numbers of free-living nematodes and concentrations of N in the soil were measured periodically. The objective was to determine whether biological measurements were useful predictors of the rate of N mineralization.

Methods

The experiment consisted of 2 amendments (nil, soybean) × 2 moisture levels (wet, variable) × 2 temperatures (20, 30˚C) × 5 sampling times (10, 20, 30, 45, 60 days) × 3 replicates.

Soil and actively-growing soybeans were collected from the BMP trial site (Chapman) at Bundaberg on 20 May 2005. Since there had been heavy rain in the previous week and a storm the night before sampling, it was assumed that the moisture content (16.6%) was close to field capacity. Polystyrene cups (500 mL) were filled with 550 g moist field soil (i.e. 474 g dry soil). For the amended treatment, 15.4 g of moist green soybean material (leaves, pods and stems) was chopped into pieces 2-4 cm long and mixed with the soil, which was equivalent to adding 4 g dry soybean residue/ 500 mL pot or 8 t dry matter /ha to a depth of 10 cm. Given that the soybean residue contained 2.63%N, this meant that 220 mg N was added/kg dry soil. Cups were then placed in an incubator at either 20 or 30˚C. For the wet treatment, pots were covered and soil was maintained at 16-18% moisture content throughout the experiment. In the variable moisture treatment, soil was allowed to dry to a moisture content of 6- 8% over the first 30 days, was then re-wetted to field capacity and allowed to dry again from 31-60 days. The rate of drying was controlled by moving cups into and out of large plastic bags as required. Soil moisture was monitored by weighing pots every 3-4 days.

Measurements were done on days 10, 20, 30, 45 and 60. At each sampling time, the soil was mixed, nematodes were extracted by placing a 200 mL sample on a standard nematode extraction tray for 2 days, and the remaining soil was forwarded to NR&M for chemical analyses.

Results

Results are presented in figures 4-10, with the following abbreviations used in the figures: S; soil amended with soybean, N; no amendment, W; wet soil, V; variable soil moisture, 20; soil temperature of 20˚C, 30; soil temperature of 30˚C. Moisture contents in soil from the wet and variable moisture treatments are presented in Figure 4.

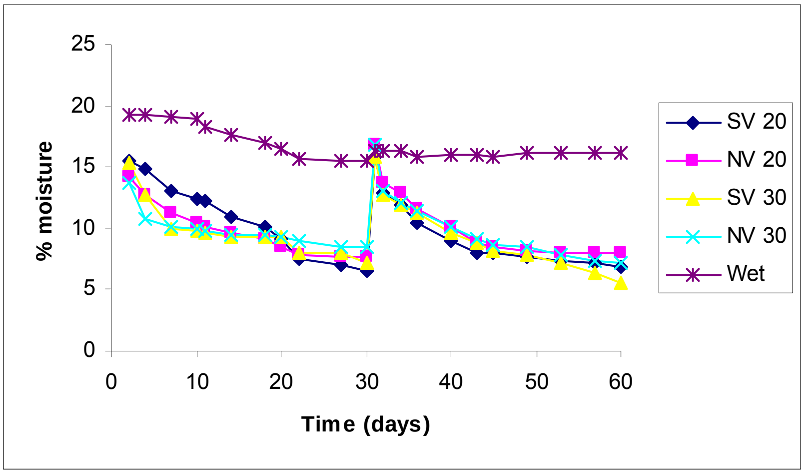

Figure 4. Soil moisture in the four treatments with varying moisture contents and mean soil moisture in the four wet treatments

The nematode community in the soil was dominated by rhabditids (bacterial-feeding, enrichment opportunists) and aphelenchs (fungal-feeding nematodes). There were very few dorylaimids (omnivorous nematodes) and only 50-100 mononchids (predatory nematodes). In non-amended soil, numbers of microbivorous remained low at all sampling times, with typical counts (/200 mL soil) less than 1000 for rhabditids and less than 20 for aphelenchs. Rhabditids multiplied rapidly in amended soil, reaching populations of more than 160,000/200 mL soil after 10 days at 30˚C. Similar population densities were obtained after 20 days at 20˚C. Moisture content did not appear to have a major effect on populations of rhabditids and numbers were still very high at both temperatures and in both moisture treatments at the end of the experiment (Figure 5).

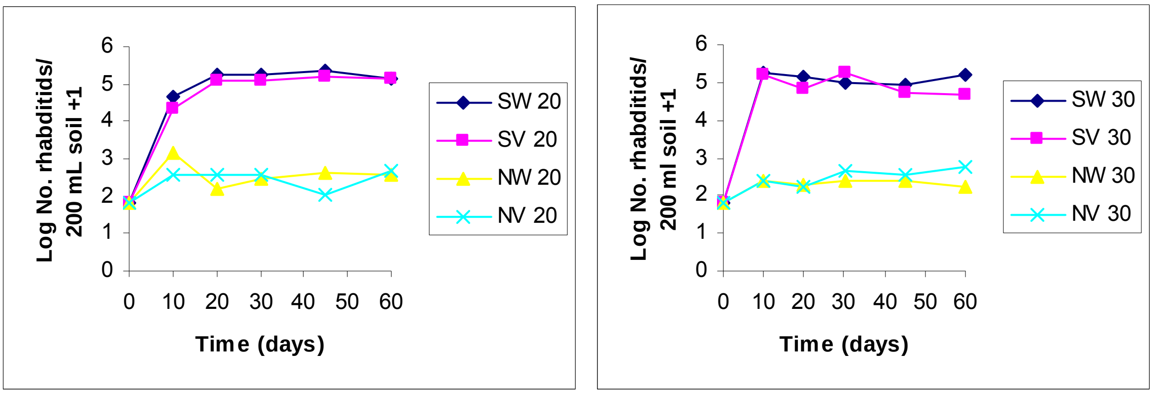

Figure 5. Effect of amendment, soil moisture and temperature on populations of rhabditids

Numbers of aphelenchs also increased in amended soils but populations were much lower than rhabditids. Initially, numbers increased more rapidly at 30˚C than at 20˚C but final population densities were higher at 20˚C than 30˚C (Figure 6).

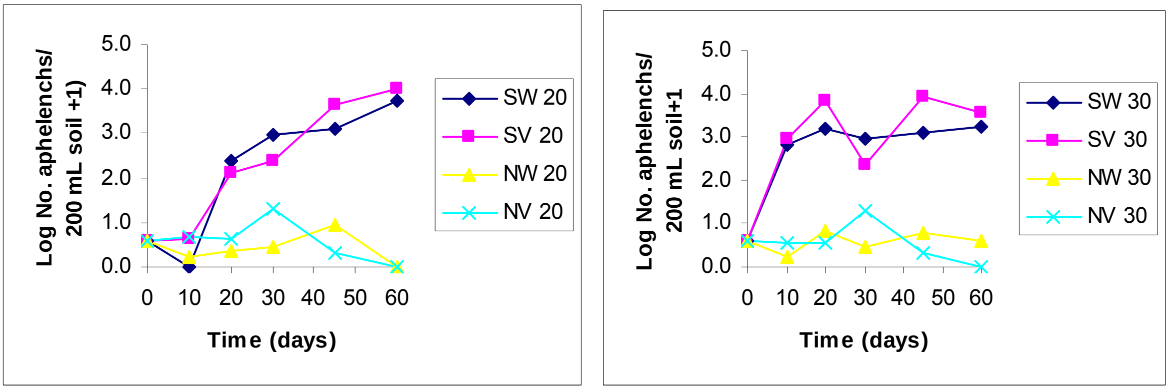

Figure 6. Effect of amendment, soil moisture and temperature on populations of aphelenchs

NH_4-N was detected in soil amended with soybean residue but not in non-amended soil. Concentrations were generally highest at 10 days and then started to decline as NH_4-N was converted to NO_3-N. Conversion to NO_3-N took place more slowly in the variable soil moisture treatment than in wet soil, which meant that concentrations of NH_4-N remained higher for longer in this treatment (Figure 7). Concentrations of NO_3-N increased with time and were generally similar in the two soil moisture treatments. However the decline in concentration in wet soil at 60 days suggested that denitrification may have been occurring (Figure 8).

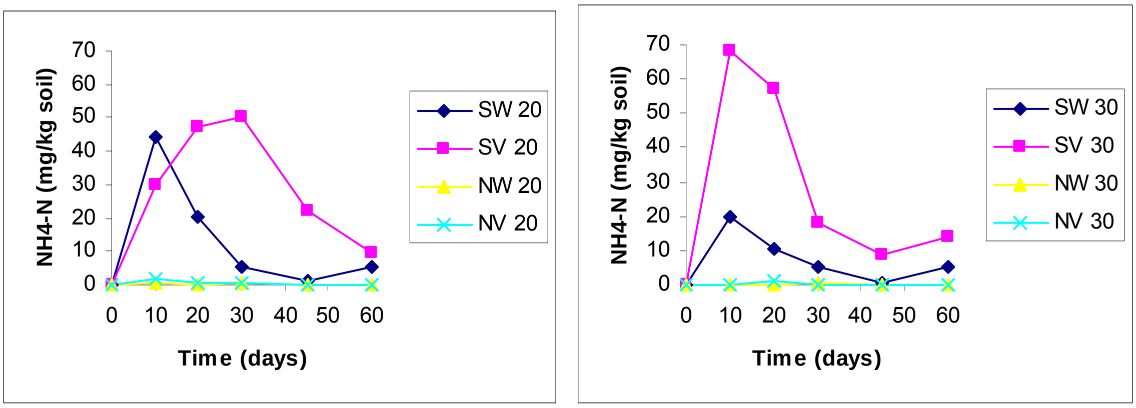

Figure 7. Effect of amendment, soil moisture and temperature on concentrations of NH_4-N

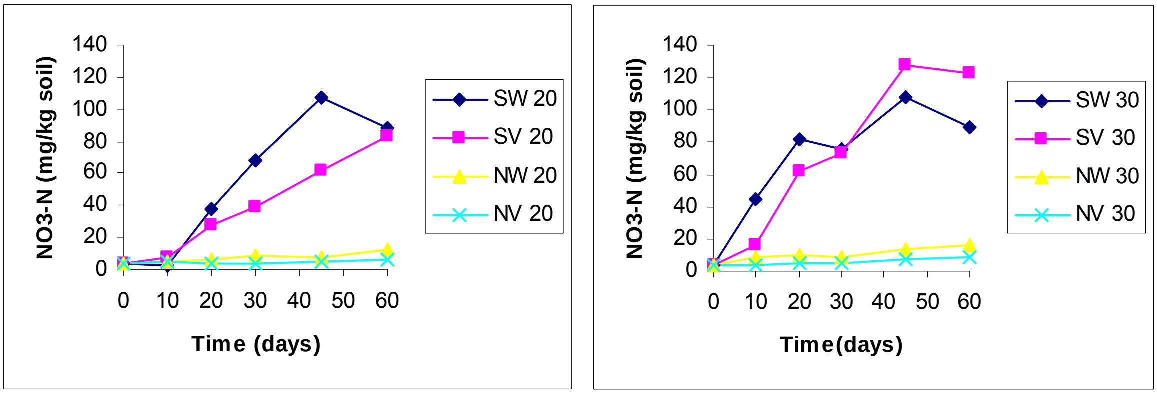

Figure 8. Effect of amendment, soil moisture and temperature on concentrations of NO_3-N

Measurements of microbial activity and dissolved organic C showed that there were no consistent treatment effects with either of these parameters (Figures 9 and 10). Microbial activity was higher in amended than non-amended soil at some sampling times, whereas dissolved organic C did not respond to the addition of soybean residue.

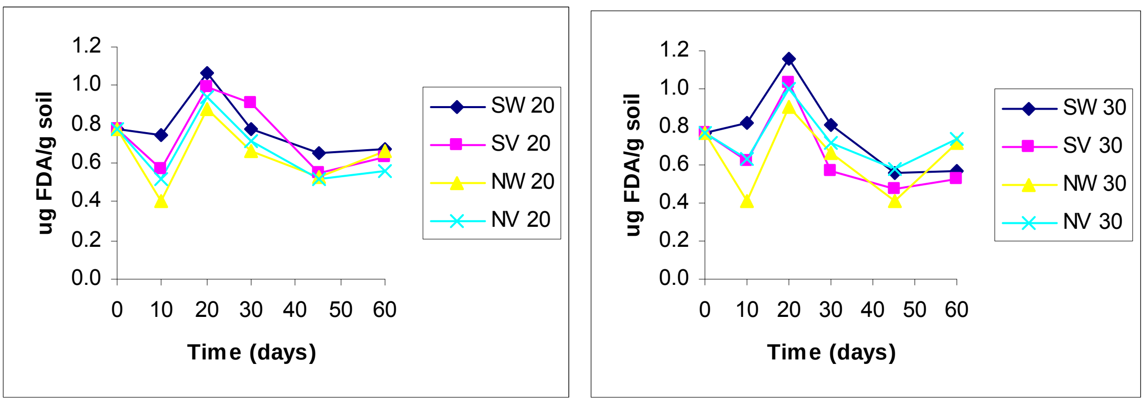

Figure 9. Effect of amendment, soil moisture and temperature on microbial activity

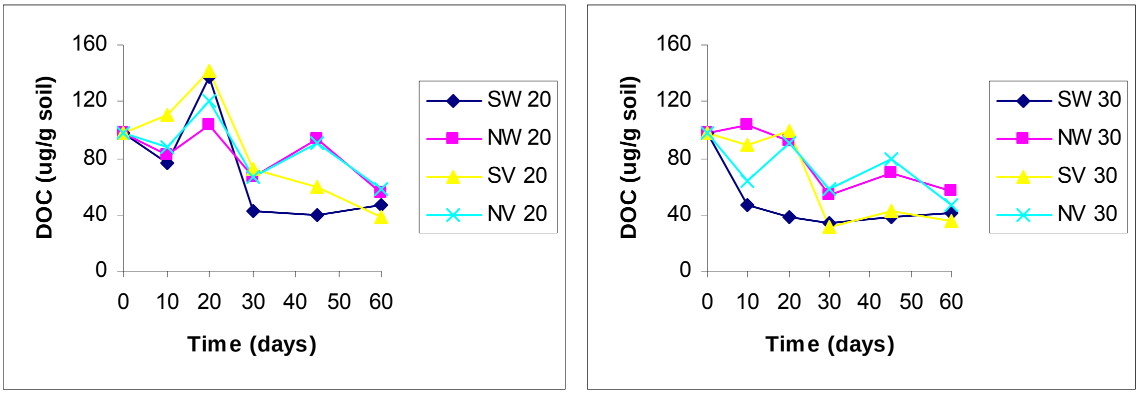

Figure 10. Effect of amendment, soil moisture and temperature on concentrations of dissolved organic C

When all the data collected during the experiment were examined using correlation analysis, there were strong positive correlations between nematode numbers and concentrations of NO_3-N. Similar correlations were obtained when data from individual sampling times were examined (Table 4). Correlations between nematode numbers and concentrations of NH_4-N were not as strong as for NO_3-N, while concentrations of dissolved organic C were generally negatively correlated with the above parameters (Table 4). When data obtained from non-amended soil were excluded, the correlations apparent in Table 4 were no longer observed (Table 5).

Table 4. Partial correlation matrix showing correlations between various parameters at different times during the experiment, and for all data collected in the experiment.

Correlation coefficients > ± 0.7 are indicated in bold

		Log Rhab	Log Aph	Log FLN	NH_4-N	NO_3N	FDA
Day 10	NH_4-N	**0.758**	0.435	0.758	1		
	NO_3-N	0.548	**0.725**	0.549	0.131	1	
	FDA	0.550	0.458	0.551	0.333	0.477	1
	DOC	-0.196	-0.284	-0.197	0.202	-0.538	-0.494
Day 20	NH_4-N	0.672	0.660	0.677	1		
	NO_3-N	**0.774**	**0.842**	**0.776**	0.469	1	
	FDA	0.573	0.632	0.579	0.237	0.627	1
	DOC	0.072	-0.198	0.067	0.408	-0.440	-0.390
Day 30	NH_4-N	0.537	0.405	0.501	1		
	NO_3-N	**0.866**	**0.841**	**0.834**	0.289	1	
	FDA	0.227	0.178	0.277	0.397	0.000	1
	DOC	-0.433	-0.518	-0.463	0.207	**-0.738**	0.269
Day 45	NH_4-N	0.453	0.529	0.457	1		
	NO_3-N	**0.875**	**0.886**	**0.880**	0.264	1	
	FDA	0.287	0.158	0.281	-0.066	0.285	1
	DOC	**-0.840**	**-0.797**	**-0.842**	-0.177	**-0.906**	-0.198
Day 60	NH_4-N	0.587	0.690	0.592	1		
	NO_3-N	**0.859**	**0.926**	**0.862**	**0.775**	1	
	FDA	-0.284	-0.347	-0.286	-0.462	-0.494	1
	DOC	**-0.764**	**-0.805**	**-0.767**	**-0.702**	**-0.833**	0.361
Days 10-60	NH_4-N	0.530	0.330	0.522	1		
	NO_3-N	**0.713**	**0.839**	**0.711**	0.083	1	
	FDA	0.173	0.132	0.183	0.257	-0.033	1
	DOC	-0.243	-0.363	-0.250	0.332	-0.550	0.243

Table 5. Partial correlation matrix showing correlations between various parameters in soil amended with soybean residue

	Log Rhab	Log Aph	Log FLN	NH_4-N	NO_3-N	FDA
NH_4-N	-0.148	-0.327	-0.189	1		
NO_3-N	0.091	0.695	0.127	-0.630	1	
FDA	0.180	-0.109	0.215	0.237	-0.321	1
DOC	-0.132	-0.411	-0.159	0.667	-0.656	0.372

Discussion

This experiment showed that populations of free-living nematodes (particularly bacterial-feeding rhabditids) increase rapidly to very high levels when green soybean tissue is incorporated into soil. The number of nematodes present was much higher than is usually observed in the field, probably because moisture and temperature conditions in pots were ideal for nematode multiplication.

Calculations based on the N content of the soybean residue incorporated into the soil indicate that 220 mg N was added/kg soil. The data in figures 4 and 5 suggest that most this N was mineralized by the soil biota during the following 60 days. Mineralisation occurred rapidly and was not markedly affected by soil temperature and soil moisture. However, it was a little slower at 20˚C than 30˚C, and in soil that was wetted and dried rather than remaining continually wet..

Although good correlations were obtained between numbers of free-living nematodes and concentrations of NO_3-N (Table 4), this is probably an artefact caused by the low numbers of nematodes and low N in non-amended soil and the high numbers of nematodes and high N in soybean-amended soil. The shapes of the curves in Figures 5, 6 and 7 do not suggest a close relationship between numbers of nematodes and N mineralization, and this is borne out by the poor correlations obtained when non-amended soils were excluded (Table 5). However, a better way of looking at these data may be to think of the nematode population as indicative of a soil biology that is capable of mineralising a certain amount of N from organic matter. In this experiment, the number of free-living nematodes remained relatively constant from days 10-60 (130,000/200 mL soil or 685 nematodes /g soil), and during this period about 125 mg/kg NO_3-N was mineralized. This suggests that when the biology is capable of supporting this number of nematodes, about 2.5 mg NO_3-N will be mineralized/kg soil/day). On this basis, the biology in typical sugarcane fields (which generally supports 1000-5000 free-living nematodes) would be capable of mineralizing 0.02 to 0.1 mg NO_3-N /kg soil/day. If mineralization rates of this magnitude could be confirmed in the field and good correlations obtained between nematode numbers and N mineralization rates, counts of free-living nematodes may provide a relatively simple way of predicting the amount of mineralization likely to occur in sugarcane fields.

2. IMPACT OF CROPPING HISTORY, TILLAGE AND NITROGEN ON THE NEMATODE COMMUNITY

Studies of the new sugarcane farming system (which combines reduced tillage, controlled traffic and fallow cropping) have shown that each component of the system not only impacts on soil properties and crop performance but also interacts with other components in the system. Since these interactions have not been studied in detail, two field trials, (one at Bundaberg and the other at Ingham) were established to examine interactions between rotation crops (plough-out-replant sugarcane v. short fallows of soybeans or maize), tillage practice prior to cane re-establishment (direct drill v. conventional till) and amount of N fertiliser applied (low N v normal N). The effects of these treatments on the nematode community are presented in this component of the report.

Bundaberg experiment

The results of this experiment were published in the following paper, and a copy is included in the appendix to this report.

Stirling GR, Halpin NV, Bell MJ, Moody PW (2010) Impact of tillage and residues from rotation crops on the nematode community in soil and surface mulch during the following sugarcane crop. *Proceedings of the Australian Society of Sugarcane Technologists* **32** (in press)

Ingham experiment

The objectives of this experiment and the experimental design were broadly similar to the Bundaberg experiment described above.

Methods

Details of the experiment are given elsewhere (Bell *et al*. 2010), but briefly, the soybean and maize rotation crops matured in May 2007, tillage treatments were imposed in July 2007 and the experiment was planted to sugarcane on 15 August 2007. Soil and residue sampling commenced in May 2007 and samples were collected and processed in the same way as the Bundaberg experiment.

Results

When the break crops matured in early May 2007, numbers of *Pratylenchus* were very high following maize (2650 nematodes/200 mL soil), intermediate following sugarcane and low following soybean (26 nematodes/200 mL soil). The impact of the soybeans on lesion nematode populations was apparent for at least the first 6 months after planting, as numbers were still relatively low in February 2008. Nematode populations following cane and maize also remained relatively constant during this period, but by 1 April 2008, there had been a marked increase in populations in all treatments (Figure 11). This increase coincided with the soil drying out following flooded conditions and suggested that nematode multiplication may have been limited by death of roots or lack of root activity during the wet season. In contrast to the Bundaberg experiment, the tillage effect was not significant.

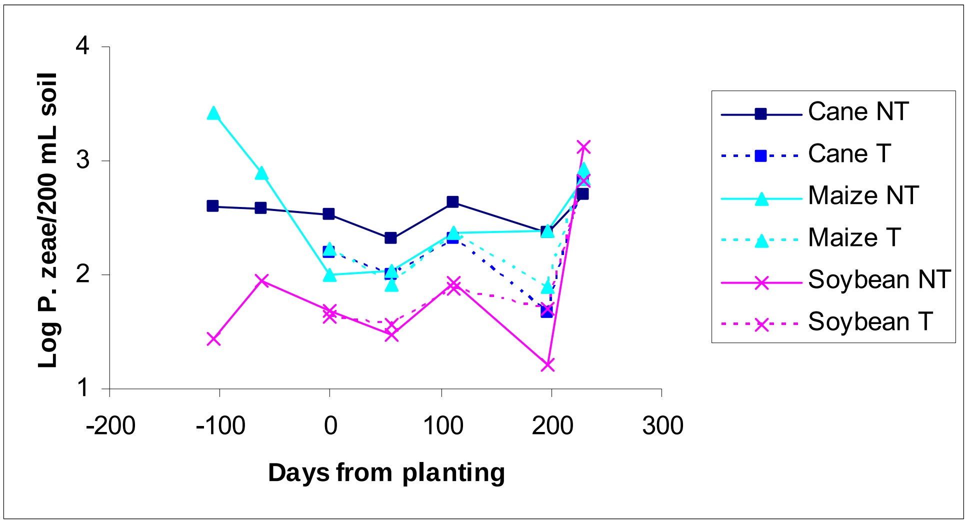

Figure 11. Effects of crop species and tillage on populations of *Pratylenchus zeae* at Ingham

Although soybean significantly reduced populations of *Pratylenchus* for the first six months after planting, samples taken at plant crop harvest (September 2008) indicated that populations were highest following soybean (Table 6). A similar effect was observed for spiral nematode (*Helicotylenchus dihystera*). These responses were probably due to more root biomass being available to the nematodes in the higher yielding soybean treatment. There was no effect of tillage or nitrogen.

Table 6. Species and tillage effects on free-living and plant-parasitic nematodes in the Ingham Species × Tillage × Nitrogen trial at plant crop harvest (September 2008).

		No. nematodes/200 mL soil*					
		Free-living		Lesion (*Pratylenchus*)		Spiral (*Helicotylenchus*)	
Species							
	Cane	2.862	(727)	2.632	(428)	1.808	(64)
	Maize	2.935	(860)	2.778	(599)	1.769	(58)
	Soybean	2.972	(937)	2.889	(773)	2.127	(133)
	LSD (P=0.05)	ns		0.146		0.315	
Tillage							
	CT	2.993	(983)	2.746	(557)	1.818	(65)
	MT	2.852	(710)	2.787	(612)	1.991	(97)
	LSD (P=0.05)	0.085		ns		ns	

*Data are transformed means [log (no. nematodes+1)], with back-transformed means in parentheses

In the ratoon crop, samples were collected at 3 and 6 months from 4 treatments (cane or soybean history × 20 or 150 kg N/ha in the plant crop). Analysis of the data for *P. zeae* using a repeated measures procedure indicated that there was no sampling time effect, but there was a significant interaction between species and plant crop N (Table 7). In the low N treatment, nematode populations were higher following soybean than cane, whereas crop history did not have a significant effect in the high N treatment. These trends mirrored the biomass results obtained at plant crop harvest, with populations of *P. zeae* in the ratoon crop highest in treatments that had the highest plant crop yields.

Table 7. Impact of previous crop species and nitrogen applied to the plant crop (kg N/ha) on populations of free-living and *Pratylenchus zeae* in the ratoon crop (3 and 6 months after plant crop harvest) in the Ingham Species × Tillage × Nitrogen trial.

		Log no. nematodes/200 mL soil*			
		Free-living nematodes		Lesion nematode (*P. zeae*)	
		20 N	150 N	20 N	150 N
Species					
	Cane	2.661	2.957	2.217	2.752
	Soybean	2.925	2.778	2.595	2.843
	LSD (P=0.05)	0.1975		0.2012	

As was observed in the Bundaberg experiment, populations of free-living nematodes were consistently higher in conventionally tilled plots than non-tilled plots during the sugarcane plant crop (Figure 12.) This tillage effect was significant until December 2007, but was not apparent in April 2008, suggesting that most of the biological activity (and N mineralisation) occurring following tillage would have taken place in the first few months after sugarcane was planted. In non-tilled soybean plots, nematode numbers peaked at the time sugarcane was planted, reflecting the fact that legume residues decompose rapidly in a tropical environment.

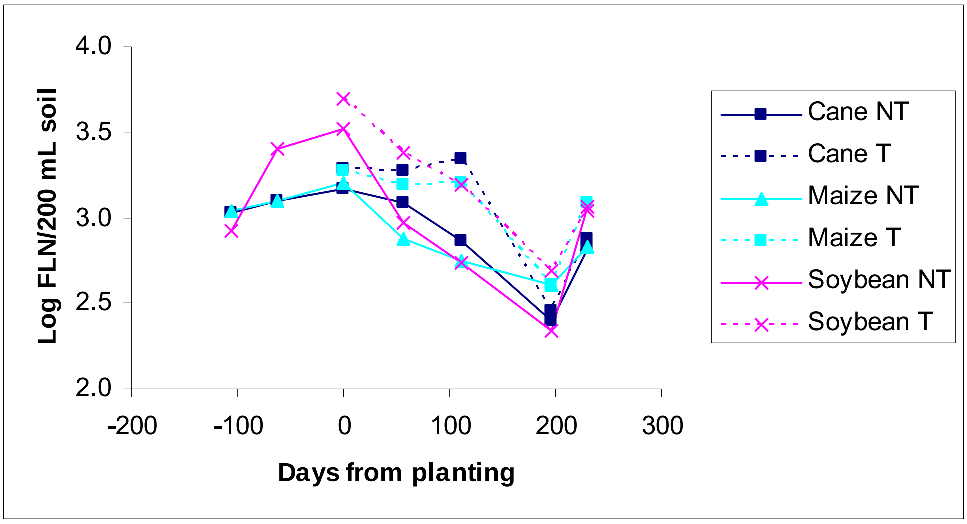

Figure 12. Effects of crop species and tillage on free-living nematode populations at Ingham

Data obtained when the plant crop was harvested (September 2008) indicated that the increase in populations of free-living nematodes due to tillage continued throughout the season, despite the fact that the effect was not significant in April 2008 (Table 6).

Crop species did not affect populations of free-living nematodes. However, in the ratoon, free-living nematodes responded to crop species and application of N to the plant crop in the much same way as *P. zeae* (Table 7). The reasons for this effect are not known, but the results are probably due to differing amounts of root biomass in various treatments. Higher yielding crops will produce more roots, and higher levels of root exudation and greater root turnover will influence the microbial biomass that is used by bacterial and fungal-feeding nematodes as a food source.

In addition to measuring total population of free-living nematodes, changes in the composition of the nematode community were monitored in trash and in soil. During the period immediately after the rotation crops matured, the nematode data (Table 8) indicated that there were a greater proportion of enrichment opportunists in sugarcane soil than either maize or soybean, presumably because the cane crop was still growing and labile C from root exudates was available to the microbial biomass. However, the NCR and Structure index indicated that soybean had significantly changed the nematode community within about 5 weeks of the crop maturing. Bacterial-feeding nematodes were now a much greater component of the community than they were a few weeks previously, and the structure index had declined, indicating a negative impact of decomposing soybean residues on the omnivorous and predatory component f the nematode community (Table 8).

Table 8. Impact of crop history on indices derived from the soil nematode community in 8 May and 12 June 2007, 15 and 9 weeks prior to planting sugarcane

Index	Date	Sugarcane	Maize	Soybean	LSD (P = 0.05)
Enrichment index*		47.6	38.8	41.1	6.6
Nematode Channel Ratio	8 May	0.26	0.33	0.16	
	12 June	0.31	0.30	0.50	0.20
Structure index	8 May	78.2	79.5	79.3	
	12 June	74.4	73.2	64.8	8.7

* The crop history effect was significant, but there was no crop history × time interaction

Indices derived from the nematode community at the time sugarcane was planted and 8 weeks later (Table 9) showed effects of both crop history and tillage. These data reinforced observations made at previous sampling times, with the Nematode Channel ratio higher and the Structure index lower following soybean than either maize or sugarcane. There was also a significant tillage effect, with the Nematode Channel Ratio lower (i.e. the nematode community more bacterivorous) after conventional tillage.

Table 9. Impact of crop history and tillage on indices derived from the soil nematode community 0 and 8 weeks after sugarcane was planted

Effect		Enrichment index	Nematode Channel Ratio	Structure index
Crop history	Sugarcane	49.8	0.32	71.4
	Maize	46.2	0.33	70.5
	Soybean	54.8	0.50	62.7
	LSD (P=0.05)	ns	0.064	4.5
Tillage	Conventional till	51.9	0.41	67.8
	Direct drill	48.6	0.35	68.8
	LSD (P=0.05)	ns	0.052	ns

As in the Bundaberg experiment, the nematode community in surface residues was relatively simple, consisting mainly of bacterivores and fungivores. The nematode genera were also similar, with *Panangrolaimus* the most common bacterivore and *Aphelenchoides* the most common fungivore in the first nine months after planting. The Tylenchidae were even more important fungivores than they were at Bundaberg, comprising 50-60% of the fungal-feeding community 6-9 months after planting. The Nematode Channel Ratio (which indicates the relative importance of the bacterial and fungal-feeding nematode communities) reacted in much the same way as it did at Bundaberg, as it was highest for soybean, intermediate for maize and lowest for sugarcane in the first 8 weeks after planting. However, over the whole season there was no effect of residue source and residue source × time interaction. However, there was a significant temporal effect, with NCR declining with time, regardless of the residue source (Figure 13). At 38 weeks after planting, the nematode community was strongly fungal dominant (NCR = 0.13 indicating that nearly 90% of the nematodes were fungal feeders.

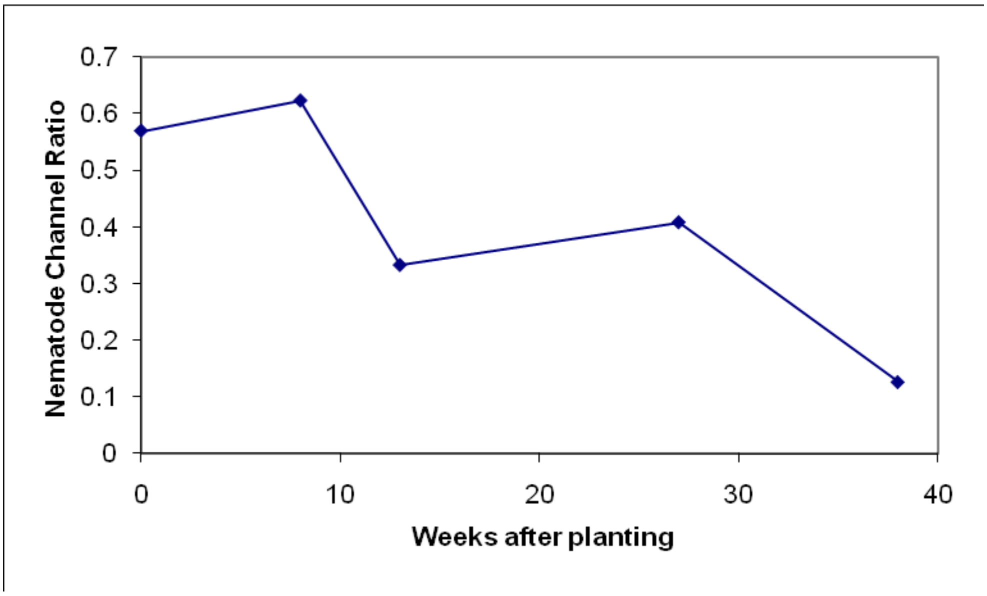

Figure 13. Temporal changes in the Nematode Channel Ratio in surface residues from previous crops as they decomposed during a plant crop of sugarcane. LSD = 0.16

Discussion

A detailed discussion of the effects of cropping history, tillage and nitrogen on the nematode community is presented in the ASSCT paper on the Bundaberg experiment (Stirling *et al*. 2010). The results of this experiment are therefore not discussed in detail here. Instead, similarities and differences between the experiments are summarised in Table 10.

Table 10. Impact of cropping history, tillage and nitrogen on various features of the nematode community: similarities and differences in results obtained at Bundaberg and Ingham

Bundaberg	Ingham
Soybean reduced populations of *Pratylenchus* and *Rotylenchulus* and increased populations of *Xiphinema* and *Helicotylenchus*	Similar effects for *Pratylenchus* (*Rotylenchulus* and *Xiphinema* were not present)
Populations of *Pratylenchus* and *Meloidogyne* resurged strongly following soybean and at plant crop harvest were higher than after sugarcane or maize	Similar effects for *Pratylenchus*. Populations of *Helicotylenchus* were also higher following soybean at plant crop harvest
Pratylenchus populations were reduced by conventional tillage 2 and 7 weeks after planting. They then resurged strongly and tended to be higher than direct drill later in the season	No effect of tillage
Application of N did not affect populations of *Pratylenchus* in the plant crop	Similar effects to Bundaberg
Initially, there were more free-living nematodes in soil following soybean than sugarcane, However this situation was reversed from 15-59 weeks after planting	Crop species did not affect populations of free-living nematodes
Populations of free-living nematodes were consistently higher following conventional tillage than direct drill	Similar effects to Bundaberg
Tillage increased the proportion of bacterial-feeding to fungal-feeding nematodes for at least 23 weeks	Similar effects to Bundaberg
Panangrolaimus was the main bacterial-feeding nematode and the Tylenchidae were relatively important fungal feeders	Similar effects to Bundaberg
The Nematode Channel Ratio in crop residues declined from 0.55 to 0.22 in about 70 weeks, indicating a change from bacterial to fungal decomposition pathways as the season progressed	Similar effects to Bundaberg

3. IMPACT OF MANAGEMENT PRACTICES ON SUPPRESSIVENESS TO PLANT-PARASITIC NEMATODES

Plant-parasitic nematodes and other soil-borne pathogens do not multiply to the same level or cause the same amount of disease in all soils. Pathogens will cause crop losses in a conducive soil but may cause little or no damage in a suppressive soil. Suppressiveness is due to the action of soil organisms that compete with, prey on or in some way disrupt the pathogen, and is therefore broadly related to total soil microbial biomass. Soils with high levels of microbial activity and diversity are more suppressive than sterilised soils, fumigated soils or soils where the biology has been markedly modified by the practices used to grow crops. This work aimed to determine whether disturbing soil or adding crop residues as an amendment or mulch had an impact on the suppressiveness of sugarcane soils to plant-parasitic nematodes.

Impact of disturbance

Populations of plant-parasitic nematodes on sugarcane are usually highest in the first few months after planting and then tend to decline as the crop age. Results from a SYDJV trial at the Chapman site at Bundaberg also showed that *Pratylenchus* populations on sugarcane returned to very high levels in soils that were cultivated or left fallow, whereas they remained at low to moderate levels in soils previously sown to pasture, particularly if they were not cultivated prior to planting sugarcane. Thus it is possible that the extensive tillage which is normally carried out when sugarcane is replanted is reducing suppressiveness and thereby increasing the capacity of plant-parasitic nematodes to multiply on sugarcane. This experiment was set up to test this hypothesis.

Methods

Soil for the experiment was obtained from two sites: J. Hubert (Bundaberg), where a crop of sugarcane (Q154) was in its eleventh ratoon and D. Halpin (Bundaberg), where sugarcane (Q138) was in its fourth ratoon. On 22 August 2005, trash was scraped from the surface of the soil and about 100 L of soil from a depth of 0-20 cm was collected at each site. Each sample was then mixed gently and divided into two similar batches. One of these batches (designated the autoclaved treatment) was autoclaved for 1 hour. The other batch (designated the disturbed treatment) was spread on a table, kept moist by periodically sprinkling it with water, and mixed with a spade on 30 August, 9 September 26 September, 6 October and 17 October. This soil was therefore mixed 5 times in the 55 days after it was collected. Soil cores that comprised the undisturbed treatment were collected from the same sites on 19 October 2005 by driving a plastic pipe (104 mm diameter, sharpened at one end) into the soil and then retrieving the cores with a shovel.

The first experiment (with *Pratylenchus*) was done in pipes 20 cm long with a saucer under one end so that the pipes could be used as pots. Each pot held about 1.7 L of soil. On 20 October 2005, ten pots were filled with either disturbed soil or autoclaved soil from each site by packing the soil to approximately the same bulk density as in the undisturbed cores. *Pratylenchus* was then added to five replicate pots (see details below) and the remaining five pots were left uninoculated. Thus the experiment consisted of 2 sites (Hubert and Halpin) × 3 soil treatments (autoclaved, disturbed, undisturbed) × 2 nematode treatments (incoculated or uninoculated) × 5 replicates.

Nematode and chemical analyses. On the day the undisturbed cores were collected, five samples (each consisting of four 2.5 cm diameter cores to a depth of 20 cm) were also collected from each field. On the following day, as the experiment was being set up, five soil samples were collected from each batch of disturbed soil. Two 500 g samples of disturbed and undisturbed soil were then forwarded to NR&M for chemical analysis (KCl extractable NH_4-N, KCl extractable NO_3-N and dissolved organic C). Numbers of plant-parasitic nematodes in five 200 mL samples of disturbed, undisturbed and autoclaved soil from each site were determined by spreading the soil on a standard nematode extraction tray, leaving it for 2 days and then sieving the nematode suspension twice through a 38 μm sieve.

Inoculation of nematodes. The number of *Pratylenchus*/200 mL soil (mean ± SE) extracted from the four samples was as follows: Halpin disturbed 180 ± 9, Halpin undisturbed 260 ± 90, Hubert disturbed 64 ± 5, Hubert undisturbed 218 ± 86. *Pratylenchus* was not recovered from the autoclaved soils. Since the efficiency of the extraction process was 63% (estimated by inoculating known numbers of *Pratylenchus* into autoclaved soil and then extracting the nematodes using the above procedure) and the weight of soil in each pot was known, the mean nematode counts were used to estimate the actual number of nematodes present in each pot. *Pratylenchus* was not added to pots in the uninoculated treatment, whereas the number of nematodes required to bring the actual number of *Pratylenchus* to 4800/pot (equivalent to 3000 extracted *Pratylenchus*/pot or 250 extracted *Pratylenchus*/200 mL soil) were added to the inoculated treatment. *Pratylenchus* inoculum was obtained by extracting nematodes from cultures of *P. zeae* on sugarcane in the greenhouse.

Planting, maintenance and harvest. A single-eye sett of sugarcane (Q188) was planted in each pot and plants were then grown in a plastic igloo (soil temperature 20-35˚C) until they were harvested at 50 days. The dry weight of shoots (which consisted of primary shoots about 1.1 m long, and a few emerging secondary shoots) was determined and then the root ball was removed, roots were cut into small pieces and the soil was mixed thoroughly. Nematodes were extracted from a 200 mL sample of soil and roots as described previously.

A second experiment (with *Meloidogyne*) was also established using soil that was collected and prepared for the previous experiment. It commenced at the same time as the previous experiment and was done in the same way, except that pipes 15 cm long (holding about 1.3 L of soil) were used and *Meloidogyne* rather than *Pratylenchus* was added to inoculated pots. Since *Meloidogyne* was not detected in the Hubert soil, and initial nematode counts indicated that numbers were relatively low in the Halpin soil (0, 2 and 20 *Meloidogyne* juveniles/200 mL soil in the autoclaved, disturbed and undisturbed soils, respectively). *Meloidogyne* was not added to uninoculated pots, but 8,000 *Meloidogyne* eggs (retrieved from nematode-infested tomato plants using NaOCl) were added to each inoculated pot. Since the number of *Meloidogyne* juveniles initially present in the soil was insignificant relative to the amount of inoculum added, all inoculated pots were considered to have an initial inoculum density of 8,000 *Meloidogyne* eggs/pot. Nematode counts obtained after samples of inoculated soil had been left for 8 days indicated that the initial number of viable nematodes extractable from the inoculated treatment was about 130 *Meloidogyne* juveniles/200 mL soil.

Results

Chemical analyses done at the commencement of both experiments showed some differences in the forms of N and concentrations of dissolved organic C between disturbed and undisturbed soils at the two sites (Table 11).

Table11. Chemical analyses of disturbed and undisturbed soil from two sites before the commencement of the experiment.

Site	Soil treatment	NH_4-N (mg/kg)	NO_3-N (mg/kg)	Dissolved organic C (µg/g)
Halpin	Disturbed	0.8	15.7	17.0
	Undisturbed	0.8	1.9	25.1
Hubert	Disturbed	0.8	22.3	53.5
	Undisturbed	31.2	23.7	59.4

Three-way analysis of variance of the dry weight data collected at harvest showed significant effects of soil treatment and site × soil treatment ($P < 0.001$). Plants grew best in autoclaved soil, although growth in undisturbed soil from Hubert matched that in autoclaved soil (Table 12).

Table 12. Dry weight of sugarcane 50 days after it was planted into autoclaved, disturbed and undisturbed soil from two sites.

Site	Shoot dry weight (g)		
	Autoclaved	Disturbed	Undisturbed
Halpin	5.73	2.82	2.81
Hubert	4.85	3.21	5.10
LSD (P=0.05)		1.15	

Four plant-parasitic nematodes were present in the soil used for the experiment, and they were present at both sites, namely lesion nematode (*Pratylenchus*), stunt nematode (*Tylenchorhynchus*), stubby root nematode (*Paratrichodorus*) and spiral nematode (a mixture of *Helicotylenchus* and *Rotylenchus*). Estimated population densities of *Pratylenchus* at the commencement of the experiment, together with the numbers of *Pratylenchus* added to each treatment are given in Table 13. *Pratylenchus* was absent from the autoclaved uninoculated treatment and were variable in the other two uninoculated treatments. However, all inoculated pots contained approximately the same number of *Pratylenchus*.

Table 13. Initial numbers of *Pratylenchus* in autoclaved, disturbed and undisturbed soil from two sites after they were either inoculated (+) or not inoculated (-) with *Pratylenchus*.

Site	Treatment		*Pratylenchus* extracted /200 mL soil	*Pratylenchus* extracted /pot	Actual number of *Pratylenchus* /pot	*Pratylenchus* added /pot	Total *Pratylenchus* /pot
	Soil	Nematodes added					
Halpin	Autoclaved	-	0	0	0	0	0
	Disturbed	-	180	2185	3496	0	3496
	Undisturbed	-	260	3114	4942	0	4942
	Autoclaved	+	0	0	0	4800	4800
	Disturbed	+	180	2185	3496	1304	4800
	Undisturbed	+	260	3114	4942	0	4942
Hubert	Autoclaved	-	0	0	0	0	0
	Disturbed	-	64	830	1328	0	1328
	Undisturbed	-	218	2941	4705	0	4705
	Autoclaved	+	0	0	0	4800	4800
	Disturbed	+	64	830	1328	3472	4800
	Undisturbed	+	218	2941	4705	95	4800

At harvest, significant soil treatment × nematode treatment effects were observed for *Pratylenchus* and *Paratrichodorus*. The results for *Pratylenchus* (Table 14) indicated that the nematode multiplied best in autoclaved soil and least in undisturbed soil. Populations of *Pratylenchus* increased about 11 times in autoclaved soil, whereas there were only 5-fold and 2-fold increases in disturbed undisturbed soil, respectively.

Table 14. Final populations of *Pratylenchus* in three soil treatments in pots inoculated with *Pratylenchus* or left uninoculated

	No. *Pratylenchus*/200 mL soil*	
	Inoculated	Uninoculated
Autoclaved	2817 a	0 d
Disturbed	1276 b	1663 ab
Undisturbed	514 c	464 c

*Nematode numbers were transformed ($\log_{10}$ (no. nematodes+1) prior to analysis. Equivalent means are presented, with numbers in both columns followed by the same letter not significantly different (P=0.05)

In the experiment with Meloidogyne, shoot biomass data at harvest showed the same trends as for the *Pratylenchus* experiment, with plants growing best in autoclaved soil (Table 15).

Table 15. Dry weight of sugarcane 50 days after it was planted into autoclaved, disturbed and undisturbed soil from two sites.

Site	Shoot dry weight (g)		
	Autoclaved	Disturbed	Undisturbed
Halpin	4.98	3.12	2.64
Hubert	4.90	3.87	4.17
LSD (P=0.05)		0.91	

Meloidogyne was not detected in soils that were not inoculated, but was present in inoculated soils. There was a significant soil treatment × nematode treatment effect, with numbers of *Meloidogyne* significantly higher in autoclaved and disturbed soil than in undisturbed soil (Table 16).

Table 16. Final populations of *Meloidogyne* in three soil treatments in pots inoculated with *Meloidogyne* or left uninoculated

	No. *Meloidogyne*/200 mL soil*			
	Inoculated		Uninoculated	
Autoclaved	285	a	0	c
Disturbed	157	a	0	c
Undisturbed	20	b	0	c

*Nematode numbers were transformed ($\log_{10}$ (no. nematodes+1) prior to analysis. Equivalent means are presented, with numbers in both columns followed by the same letter not significantly different (P=0.05)

Discussion

At the commencement of the experiment, numbers of *Pratylenchus* were lower in soil that had been mixed every 2-3 weeks over a 50 day period than they were in undisturbed soil, probably because some nematodes were damaged during the mixing process. However, despite the lower initial nematode densities in disturbed soil, numbers of *Pratylenchus* were much higher in this treatment than in undisturbed soil at the end of the experiment. The suppressive nature of undisturbed soil was confirmed when all treatments started with the same initial numbers of *Pratylenchus*, as multiplication was also much lower in undisturbed than disturbed soil. The experiment with *Meloidogyne* provided further confirmation that plant-parasitic nematodes do not multiply readily in undisturbed sugarcane soil.

Autoclaving, which is the ultimate disturbance event because it kills all soil organisms, had the greatest impact on nematode multiplication. Interestingly, *Pratylenchus* and *Meloidogyne* did not multiply as readily in disturbed soil as in autoclaved soil.

The mechanisms that prevent plant-parasitic nematodes from multiplying readily in undisturbed soil cannot be established from these experiments. Suppressive soil organisms that are killed by autoclaving or destroyed during the soil mixing process are probably involved, but it is not clear which groups of organisms are associated with the suppressive effect. The possibility that other processes also contribute should not therefore be excluded. Differences in soil physical properties (which will affect the capacity of nematodes to move to roots), changes in root growth patterns or the availability of exudates from the rhizosphere (which may affect the ability of nematodes to locate suitable feeding sites), and nutrient-induced changes in the susceptibility of root tissue to penetration by nematodes are just some of many possible factors that may differ in disturbed and undisturbed soils.

Impact of amendments and mulch

The objective of this experiment was to monitor the development of suppression in fumigated soil and determine whether the level of suppressiveness was affected by organic inputs or the presence of a sugarcane trash blanket.

Methods

The experiment was established in July 2006, when sections of pipe each 11 cm long and 10.4 cm in diameter (volume = 934 mL) were filled with fumigated soil that was either amended with sugarcane trash (CT), sugarcane trash + soybean residue (CTS) or left un-amended (Nil). Pipes were buried in the field at the Halpin site at Bundaberg, with half the pipes covered with a blanket of sugarcane trash and the remainder covered with about 10 mm of soil. Thus there were six treatments: 3 amendments (CT, CTS and Nil) × 2 mulch treatments (GCTB or Nil). Four replicate pipes of each treatment were removed at each sampling time and assayed for suppression to root-knot and lesion nematode using *Meloidogyne* and *Pratylenchus* assays. In the *Meloidogyne* assay, a tomato seedling was planted in each pot and the soil was inoculated with 6,000 eggs of *M .javanica*. The level of galling and the number of eggs on roots was measured after 7 weeks. In the *Pratylenchus* assay, maize was planted in each pot and the soil was inoculated with 2,000 *P. zeae*. The number of nematodes in roots was counted after 7 weeks. At both sampling times and in both assays, recently-fumigated soil (0.11 µL methyl iodide/L soil) was used as a standard.

Results

The first set of pipes was removed on 4 December 2006 (i.e. at 18 weeks) and the results for the *Meloidogyne* assay (Tables 17 and 18) showed that the level of root galling and the number of root-knot nematodes recovered from roots was greatest in soil that was recently fumigated. Mulching reduced both of these parameters, indicating enhanced suppressiveness of the soil to root-knot nematode.

Table 17. Suppressiveness of fumigated soil to root-knot nematode (assessed with a tomato root gall assay) 18 weeks after the soil was amended with sugarcane trash (CT), sugarcane + soybean trash (CTS) or left non-amended and buried in the field with or without a mulch of sugarcane trash

Factor	Root gall rating			LSD (P = 0.05)
Amendment	No amendment	CTS	CT	
	3.62	3.25	3.00	Not significant
Mulch	No mulch	Mulched		
	3.83	2.75		0.581
Amendment x Mulch		No mulch	Mulched	
	No amendment	4.25	3.00	
	CTS	3.75	2.75	Not significant
	CT	3.50	2.50	

The mean root gall rating for plants grown in soil recently fumigated with methyl iodide was 5.25.

Table 18. Suppressiveness of fumigated soil to root-knot nematode (assessed by counting nematode eggs on a tomato bioassay plant) 18 weeks after the soil was amended with sugarcane trash (CT), sugarcane + soybean trash (CTS) or left non-amended and buried in the field for 18 weeks with or without a mulch of sugarcane trash

Factor	Eggs/plant			LSD (P = 0.05)
Amendment	No amendment	CTS	CT	
	4.833 (68,077)	4.642 (43,853)	4.607 (40,458)	Not significant
Mulch	No mulch	Mulched		
	5.010 (102,329)	4.379 ((23,933)		0.2496
Amendment x Mulch		No mulch	Mulched	
	No amendment	5.295 (197,242)	4.372 (23,550)	
	CTS	4.885 ((76,736)	4.400 (25,118)	Not significant
	CT	4.850 (70,975)	4.365 (23,173)	

* Factorial analysis of variance was done on log transformed data, with equivalent means given in parentheses Corresponding figures in the assay for soil recently fumigated with methyl iodide were 5.419 (262,572).

In the *Pratylenchus* assay, the non-mulched non-amended treatment reacted in much the same way as the recently fumigated standard (Table 19). The addition of organic matter and mulching both reduced the number of lesion nematodes recovered from roots.

Table 19. Suppressiveness of fumigated soil to *Pratylenchus zeae* (assessed by counting the nematodes recovered from a maize bioassay plant) 18 weeks after the soil was amended with sugarcane trash (CT), sugarcane + soybean trash (CTS) or left non-amended and buried in the field for 18 weeks with or without a mulch of sugarcane trash

Factor	No. *P. zeae*/plant			LSD (P = 0.05)*
Amendment	No amendment	CTS	CT	
	3.611 (4083)	3.149 (1409)	3.187 (1538)	0.3192
Mulch	No mulch	Mulched		
	3.607 (4046)	3.024 (1057)		0.2496
Amendment x Mulch		No mulch	Mulched	
	No amendment	3.991 (9795)	3.230 (1698)	
	CTS	3.493 (3112)	2.806 (640)	Not significant
	CT	3.337 (2173)	3.037 (1089)	

* Factorial analysis of variance was done on log transformed data, with equivalent means given in parentheses Corresponding figures in the assay for soil recently fumigated with methyl iodide were 3.774 (5956).

The second set of pipes were removed on 2 February 2007 (i.e. 27 weeks after the experiment was established) and suppressiveness was assessed using the same assays. Results for the two *Meloidogyne* assays (Tables 20 and 21) showed that mulching significantly reduced galling and the number of root-knot nematode eggs produced on tomato. In the *Pratylenchus* assay, there was a significant amendment × mulch effect, with numbers of nematodes in the non-amended non-mulched soil significantly higher than all other treatments (Table 22).

Table 20. Suppressiveness of fumigated soil to root-knot nematode (assessed with a tomato root gall assay) 27 weeks after the soil was amended with sugarcane trash (CT), sugarcane + soybean trash (CTS) or left non-amended and buried in the field for with or without a mulch of sugarcane trash

Factor	Root gall rating			LSD (P = 0.05)
Amendment	No amendment	CTS	CT	
	4.50	4.08	3.62	Not significant
Mulch	No mulch	Mulched		
	4.67	3.47		0.658
Amendment x Mulch		No mulch	Mulched	
	No amendment	5.25	3.75	
	CTS	4.50	3.67	Not significant
	CT	4.25	3.00	

The mean root gall rating for plants grown in soil recently fumigated with methyl iodide was 5.75

Table 21. Suppressiveness of fumigated soil to root-knot nematode (assessed by counting nematode eggs on a tomato bioassay plant) 27 wks after the soil was amended with sugarcane trash (CT), sugarcane + soybean trash (CTS) or left non-amended and buried in the field for 18 weeks with or without a mulch of sugarcane trash

Factor	Eggs/plant			LSD (P = 0.05)
Amendment	No amendment	CTS	CT	
	5.210 (162,180)	5.311 (204,640)	5.059 (114,550)	Not significant
Mulch	No mulch	Mulched		
	5.397 (249,460)	4.990 (97,273)		0.1182
Amendment x Mulch		No mulch	Mulched	
	No amendment	5.493 (311,172)	4.926 (84,330)	
	CTS	5.530 (338,844)	5.092 (123,590)	Not significant
	CT	5.168 (147,230)	4.951 (89,330)	

* Factorial analysis of variance was done on log transformed data, with equivalent means given in parentheses Corresponding figures in the assay for soil recently fumigated with methyl iodide were 5.89 (775,350).

Table 22. Suppressiveness of fumigated soil to *Pratylenchus zeae* (assessed by counting the nematodes recovered from a maize bioassay plant) 27 wks after the soil was amended with sugarcane trash (CT), sugarcane + soybean trash (CTS) or left non-amended and buried in the field for 18 weeks with or without a mulch of sugarcane trash

Factor	No. *P. zeae*/plant			LSD (P = 0.05)*
Amendment	No amendment	CTS	CT	
	4.362 (23,010)	4.263 (18,320)	4.193 (15,600)	Not significant
Mulch	No mulch	Mulched		
	4.396 (24,890)	4.149 (14,090)		0.1991
Amendment x Mulch		No mulch	Mulched	
	No amendment	4.663 (46,025)	4.061 (11,510)	
	CTS	4.249 (17,740)	4.247 (17,660)	0.3448
	CT	4.246 (17,620)	4.140 (13,800)	

* Factorial analysis of variance was done on log transformed data, with equivalent means given in parentheses Corresponding figures in the assay for soil recently fumigated with methyl iodide were 4.405 (25,410).

At both sampling times, the biological status of the soil was assessed by sampling another set of pipes and counting free-living nematodes and measuring microbial activity using the FDA method. The results (Table 23) indicated that numbers of free-living nematodes were higher in soil amended with organic matter than in non-amended soil. However, amending soil with organic matter and mulching both increased microbial activity.

Table 23. The effect of organic amendments and mulch on the biological status of soil (measured as total free living nematodes (FLN) and microbial activity) 18 and 27 weeks after treatments were applied to fumigated soil.

Amendment	Mulch	Log FLN/200 mL soil		Microbial activity (μg FDA/g/min)	
		18 wk	27 wk	18 wk	27 wk
Nil	-	3.61	3.20	0.26	0.48
CT	-	4.27	3.93	0.49	0.56
CTS	-	3.93	3.66	0.41	0.54
Nil	+	3.37	3.30	0.32	0.47
CT	+	4.05	3.74	0.51	0.66
CTS	+	4.09	3.49	0.49	0.53
LSD (P = 0.05)		n.s.	0.12	n.s.	0.04
Amendment effect					
Nil		3.54		0.29	
CTS		4.01		0.45	
CT		4.16		0.50	
LSD (P = 0.05)		0.21		0.04	
Mulch effect					
No mulch		3.94		0.38	
Mulch		3.87		0.44	
LSD (P = 0.05)		n.s.		0.03	

Discussion

Although amendments of plant residues have been shown to enhance suppressiveness to plant-parasitic nematodes in previous experiments, these results indicated that they had little effect in soil that had been fumigated before the experiment commenced. However, mulching with sugarcane trash had a marked effect, reducing populations of both root-knot and lesion nematode and the level of galling caused by the former nematode at both the 18 and 27 week sampling times. These results were unexpected for two reasons: 1), biota capable of suppressing plant-parasitic nematodes would have been eliminated by fumigation but had re-established in some treatments within 18 weeks and 2), sugarcane trash had a greater impact when it was used as mulch rather than as an amendment. The fact that mulched, non-amended soil was highly suppressive is particularly interesting and raises questions about how mulch enhances suppression. Inputs of labile C and maintenance of a more suitable environment for biological activity (in terms of both moisture and temperature) are possibly involved.

Impact of cropping history and tillage (field trial)

Previous work has shown that populations of plant-parasitic nematodes (particularly *Pratylenchus*) are usually relatively low following soybeans and fallow and relatively high following grass pasture and sugarcane. However, when sugarcane is planted, nematode multiplication rates tend to be higher following fallow and soybean than after pasture or sugarcane (particularly in non-tilled plots). It is possible that suppressive forces are responsible for these differences in multiplication rates, but it is difficult to prove this conclusively because initial nematode population densities and a soil's suppressiveness to nematodes both influence multiplication rates and they are both affected by fallow history.

In this experiment, plots with different fallow histories were subdivided into three microplots. One of these was inoculated with *Pratylenchus*, one with *Meloidogyne* and the third was left uninoculated. This process meant that inoculated plots had similar nematode population densities but different biological backgrounds, thus overcoming (to some extent) the problem mentioned above.

Methods

From November 2005 to July 2006, four replicates of five treatments (bare fallow, amended fallow, Rhodes grass pasture, soybean and sugarcane) were established in plots 1.8 m wide x 14 m long in an area adjacent the Species x Tillage x Nitrogen trial at the Halpin site, Bundaberg. The amended fallow was the same as the bare fallow treatment, except that sugarcane trash (20 t/ha) was incorporated into the plots in November 2005 and grass hay (15 t/ha) was added in March 2006. In July 2006, plots were split for +/- tillage to produce 40 plots each 7 m long.

On the day before sugarcane was planted , three 1 m-long 'microplots' were marked out in each plot and one was inoculated with roots containing *Pratylenchus*, the second with roots containing *Meloidogyne* and the third was left un-inoculated This process resulted in 120 'microplots' (5 fallow treatments × ± tillage × 3 nematode treatments × 4 replicates). A further 12 'microplots' of cultivated fallow soil were fumigated with methyl iodide (640 kg/ha) two weeks before the nematode treatments were imposed, and this treatment was used as a non-suppressive standard. The number of nematodes inoculated into microplots (62,000 *M. javanica* juveniles and 5, 800 *P. zeae*) was estimated by placing samples of the roots used as inoculum on a nematode extraction tray for 14 days.

On 12 September 2006, five 2-bud billets of sugarcane variety Q151 were planted in each plot. Plant growth was assessed by monitoring shoot numbers at 42, 64 and 84 days after planting and by measuring plant biomass 180 days after planting. Populations of plant plant-parasitic and free-living nematodes were measured on 15 July 2006 (before tillage treatments were imposed), 13 September 2006 (at planting), 2 January 2007 (113 DAP) and 10 March 2007 (180 DAP).

Results

Analyses of early growth data showed significant effects of fallow history and tillage, but no effect of nematode inoculation. In the first 84 days after planting, shoot numbers were highest in fumigated, fallow and amended fallow treatments and lowest following soybean, Rhodes grass and sugarcane (Table 24. However by 180 days, biomass was highest in the two fallow treatments and the fumigated treatment was no better than the other treatments.

Table 24. Effects of fallow history and tillage on shoot development and biomass

	Number of shoots per plot			Biomass (t dry matter/ha)
	42 DAP	64 DAP	84 DAP	180 DAP
Fallow (fumigated)	8.2a	23.7a	45.3a	16.5ab
Fallow	6.8ab	17.0b	38.3ab	19.5a
Amended fallow	6.0bc	14.6b	41.0a	20.0a
Soybean	5.6bc	11.2c	32.0b	16.1ab
Rhodes grass	4.9c	9.3c	25.5bc	18.4ab
Sugarcane	5.2c	8.0c	24.0c	15.3b
Conventional till	6.5a	15.4a	37.2a	18.4a
Minimum till	5.3b	10.5b	28.8b	16.9a

Four plant-parasitic nematodes were present in the plots, namely lesion nematode (*Pratylenchus zeae*), root-knot nematode (*Meloidogyne* spp.), reniform nematode (*Rotylenchulus reniformis*) and dagger nematode (*Xiphinema elongatum*). Nematode data were collected before plots were tilled and again at planting and when analysed as a fallow history × tillage factorial, there was a significant fallow history effect for most nematodes (Table 25). Numbers of *P. zeae* were reduced by tillage, but tillage effects on other nematodes were not significant. The fallow had the lowest numbers of free-living nematodes in July and the amended fallow the highest, but although these trends were still apparent two months later, the differences between treatments were no longer significant (Table 25).

Table 25. The effect of fallow history on nematode numbers on 15 July 2007 (prior to tillage) and on 13 September 2007 (at the time sugarcane was planted)

	Lesion (*Pratylenchus*)		Root-knot (*Meloidogyne*)		Reniform (*Rotylenchulus*)		Dagger (*Xiphinema*)		TFLN	
	July	Sept.	July	Sept.	July	Sept.	July	Sept.	July	Sept.
Fallow	28 b	24 b	0 a	0 a	19 b	4 a	2 a	0 a	1844 a	2659 a
Fallow (amended)	1 a	1 a	0 a	0 a	1 a	3 a	0 a	0 a	9331 c	8974 a
Soybean	142 c	121 bc	46 b	0 a	114 c	17 a	5 a	6 b	2950 b	3061 a
Rhodes grass	371 c	424 c	3 a	6 b	55 bc	50 a	5 a	12 b	4187 b	6839 a
Sugarcane	449 c	266 c	442 c	49 c	45 bc	24 a	10 a	4 b	2117 a	4528 a

Data for September are means of minimum till and conventional till plots.
Numbers in the same column followed by the same letter are not significantly different (P= 0.05)

When sugarcane was planted, some microplots were inoculated with 5,800 *P.* zeae, which is equivalent to 29 *P. zeae*/200 mL soil (assuming the nematodes dispersed evenly in the 40 L of soil contained within the zone 1m × 0.2m × 0.2 m around the inoculation site). Nematode counts in inoculated and non-inoculated plots 180 days later show that tillage had no effect on populations of *P. zeae* but there was a significant history × nematode inoculum effect, largely due to the effect of inoculating or not inoculating fumigated plots (Table 26). The main trend apparent from the data was that nematode numbers in inoculated microplots were highest following a fallow or fumigation. The addition of P. zeae had little impact on nematode numbers following an amended fallow, soybean, Rhodes grass or sugarcane.

Table 26. Effect of fallow history on the number of lesion nematode (*Pratylenchus zeae*) at planting, and nematode populations 180 days after sugarcane was planted into plots inoculated or not inoculated with the nematode

	No. *P. zeae*/200 mL soil		
	At planting	180 days after planting	
		Not inoculated	Inoculated with *P. zeae*
Fallow (fumigated)	0c	3b	925a
Fallow	24b	1088a	995a
Amended fallow	1c	347a	553a
Soybean	121ab	518a	363a
Rhodes grass	424a	539a	788a
Sugarcane	266a	544a	526a

As indicated previously, populations of root-knot nematode were low in most treatments when sugarcane was planted (Table 27). Some microplots were then inoculated with 62,000 *M. javanica* eggs, which is equivalent to 310 *M. javanica*/200 mL soil (assuming the nematodes dispersed evenly in the 40 L of soil contained within a zone 1m × 0.2m × 0.2 m around the inoculation site). Tillage had no effect on nematode numbers 180 days after planting, but there was a significant history × nematode inoculum effect (Table 27). Root-knot nematode populations remained low following fumigation or fallow but increased markedly when these treatments were inoculated. Addition of nematodes made little difference to nematode populations following soybean, Rhodes grass or sugarcane.

Table 27. Effect of fallow history on the number of root-knot nematode (*Meloidogyne javanica*) at planting, and nematode populations 180 days after sugarcane was planted into plots inoculated or not inoculated with the nematode

	No. *M. javanica*/200 mL soil		
	At planting	180 days after planting	
		Not inoculated	Inoculated with *M. javanica*
Fallow (fumigated)	0a	2b	2332a
Fallow	0a	16b	633ab
Amended fallow	0a	177ab	756ab
Soybean	0a	590ab	709ab
Rhodes grass	6b	330ab	410ab
Sugarcane	49c	238ab	184ab

Discussion

One trend that was apparent in both these experiments was the rapid multiplication of the pest nematode in fallow soil and in fumigated fallow soil, provided inoculum of the nematode was present at planting. However, as differences in initial inoculum density, the amount of roots available to the nematode as a food source and the extent of the suppressive forces regulating the nematode population may have influenced nematode multiplication rates, it is not possible to be certain of the reason for this result. Nevertheless, lack of suppressiveness probably played a part, as the fallow and fumigated fallow were not the highest yielding treatments and they are likely to have had the poorest soil biology.

Although the data suggested that plant-parasitic nematodes did not multiply as readily in the amended fallow, soybean, Rhodes grass and sugarcane histories as they did in the fallow and fumigated fallow, it was not possible to draw a firm conclusion due to variability within the experiment.

Changes in suppressiveness with depth

Sugarcane roots are mainly found in upper soil layers while above-ground material is returned to the soil as a trash blanket on the soil surface. This means that the C content of sugarcane soils is likely to be highest near the surface and decline with depth. Since suppressiveness to plant-parasitic nematodes is dependent on biological activity and this is related to soil C levels, suppressiveness to plant-parasitic nematodes is likely to vary with depth. This work, which was done in the Bundaberg Species × Tillage × N trial, aimed to examine that hypothesis.

Methods

In November 2007 (soon after plant crop harvest), nematodes were extracted from soil samples collected from the soybean-DD-0-0N treatment at six depths (0-10 and 10-30 cm, and then at 30 cm intervals to 150 cm). The sampling was repeated in October 2008 (after ratoon crop harvest), except that samples were collected from seven rather than six depth intervals. At the latter sampling time, the root biomass in each sample was also measured by retrieving roots on a 4 mm sieve.

Results in both years (Tables 28 and 29) indicated that most of the free-living nematodes were in the upper 10 cm of soil and that population densities diminished rapidly with depth. In fact, populations at below 30 cm were less than 10% of populations in the 0-10 cm zone.

Plant-parasitic nematodes were much more evenly distributed through the upper 60 cm of soil and populations of some nematodes (e.g. reniform nematode) were relatively high at depth (Tables 28 and 29). Since plant-parasitic nematodes are obligate parasites of roots, a close relationship was expected between nematode populations and root biomass. However, the October 2008 data showed that these parameters were poorly correlated ($r = 0.35$). Although 62% of the roots were in the upper 10 cm of soil, only 24% of the plant-parasitic nematodes were found in this zone.

Table 28. Distribution of nematodes with depth in the Bundaberg S × T × N trial (November 2007)

Depth (cm)	No. nematodes/200 mL soil								
	TFLN	Lesion	RKN	Reniform	Spiral	Dagger	Stubby	Stunt	Total plant parasites
0-10	3756	568	291	118	82	8	11	3	1222
10-30	676	603	99	113	256	3	91	27	1468
30-60	300	304	3	51	148	3	25	18	1064
60-90	47	154	2	28	29	1	5	22	356
90-120	65	133	8	35	40	1	3	38	327
120-150	12	23	140	2	4	1	5	26	205

Table 29. Distribution of nematodes and roots with depth in the Bundaberg S × T × N trial (October 2008)

Depth (cm)	No. nematodes/200 mL soil								Dry wt. roots/L soil
	TFLN	Lesion	RKN	Reniform	Spiral	Dagger	Stubby	Total plant parasites	
0-10	1181	311	435	240	64	19	109	1178	1.68
10-20	566	294	138	214	116	11	235	1008	0.60
20-30	560	228	18	106	200	6	227	784	0.25
30-60	192	114	25	966	34	1	63	1203	0.03
60-90	68	151	1	285	28	1	17	482	0.05
90-120	86	102	3	21	29	1	11	166	0.05
120-150	56	50	1	3	39	1	7	100	0.03

In March 2008, further root and soil samples were collected from the same site to examine the distribution of nematodes and roots in the upper 20 cm of soil. The root data (Table 30) indicated that about 60% of the roots in this zone were concentrated in a 2 cm layer under the trash blanket. Roots just under the trash blanket were very healthy, with many fine white roots and few signs of the lesions and blackening usually observed on sugarcane roots.

Populations of free-living nematode were markedly affected by depth, with populations much higher in the upper 2 cm of soil than deeper in the profile (Table 30). However, populations of root-knot and lesion nematodes had a different distribution, with numbers much lower in surface layers than at depth (Table 30).

Table 30. Distribution of roots, and nematodes in roots in the upper 20 cm of the soil profile at the Bundaberg S × T × N site (March 2008)

Depth	Dry wt. roots/L soil	Nematodes/200 mL soil			Nematodes/g root	
		FLN	Root-knot	Lesion	Root-knot	Lesion
0-2 cm	2.47	2395	75	175	197	136
2-5 cm	0.59	1930	75	480	504	1066
10-15 cm	0.28	1210	260	915	624	1528
15-20 cm	0.35	900	210	835	342	848

Chemical analyses on these samples showed that concentrations of N and various forms of C were greater near the surface than at depth (Table 31). Populations of free-living nematodes were strongly correlated with total C, labile C, dissolved organic C and total N (Table 32). However, perhaps the most interesting result was the lack of correlation between the number of lesion nematodes and root-knot nematodes extracted from roots and dry weight of roots, probably due to suppressive effects in the zone immediately below the trash layer.

Table 31. Impact of depth on soil chemical parameters at the Bundaberg S × T × N site (March 2008)

Depth	NO_3-N	Total C	Total N	Labile C	Dissolved organic C
0-2 cm	6.5	1.89	0.103	2.27	91.3
2-5 cm	5.8	1.49	0.073	1.65	84.3
10-15 cm	3.8	1.18	0.058	1.05	64.8
15-20 cm	2.5	0.94	0.045	0.76	51.3

Table 32. Matrix of correlation coefficients (r-values*) for free-living nematodes, plant-parasitic nematodes in roots, root biomass and selected chemical parameters in soil samples from 0-20 cm at the Bundaberg S × T × N site (March 2008)

	NO_3-N	Total C	Total N	Labile C	Diss. Org. C	TFLN	RKN	Lesion	Dry wt. roots/L soil
NO_3- N	1								
Total C	0.660	1							
Total N	0.674	0.944	1						
Labile C	0.677	0.982	0.929	1					
Dissolved Organic C	0.523	0.892	0.790	0.922	1				
TFLN	0.336	0.806	0.798	0.834	0.834	1			
RKN	0.208	-0.130	-0.150	-0.122	-0.121	-0.308	1		
Lesion	0.074	-0.381	-0.410	-0.348	-0.193	-0.359	0.345	1	
Dry wt. roots/L soil	0.583	0.712	0.693	0.754	0.593	0.496	0.198	-0.198	1

The sampling of surface soil was repeated in October 2008 with five rather than four depth intervals. Also, roots were sieved from the soil and a sample of 10 root pieces was rated for fine roots on a scale of 0-5, where 1 = no fine roots and 5= a uniform mass of fine, healthy roots constituting a major proportion of total root length.

The results (Table 33) again showed that there was a dense layer of roots in the upper 2 cm of soil and that these roots were healthier than roots deeper in the profile. As in March 2008, populations of root-knot and lesion nematodes were relatively low in the 0-2 cm zone. Data for all depths showed that there was no correlation between the number of nematodes extracted from roots and dry weight of roots (r = -0.0.26 for lesion nematode and r = -0.07 for root-knot nematode).

Table 33. Distribution of roots, and nematodes in roots in the upper 20 cm of the soil profile at the Bundaberg S × T × N site (October 2008)

Depth	Dry wt. roots /L soil	Fine root rating	Nematodes /200 mL soil			Nematodes /g root	
			FLN	Root-knot	Lesion	Root-knot	Lesion
0-2 cm	3.1	4.4	4735	302	142	1285	117
2-5 cm	1.9	2.4	2395	698	702	1174	453
5-10 cm	2.1	1.6	1392	558	830	2951	554
10-15 cm	1.8	1.5	1127	470	823	2680	545
15-20 cm	0.9	1.4	765	392	378	1849	293

Discussion

The main conclusion that can be drawn from these results is that the region immediately under the trash blanket is very important to the sugarcane plant, as a large proportion of its roots are located in this zone. Since most of these roots are fine roots responsible for water and nutrient uptake, this layer of surface roots almost certainly plays a vital role in maintaining plant health. Measurements taken at this site showed that about 60% of the root biomass to a depth of 150 cm was in the upper 10 cm of the profile, and that about 70% of those roots were in the surface layer within 2 cm of the trash blanket. The fact that these roots are also healthier than those further down the profile further emphasises their importance to the plant.

One of the reasons that surface roots are relatively healthy is that the soil in this zone is strongly suppressive to plant-parasitic nematodes and probably also to other soilborne pathogens. Populations of *P. zeae*, for example, were relatively low in this zone, particularly when it is considered that their food source (roots) is concentrated here. Since levels of soil C and populations of free-living nematodes are 2-3 times higher in the upper 2 cm of soil than at 15-20 cm, the most likely reason for the suppressiveness of surface soils is that root exudates, turnover of roots and labile carbon inputs from the trash blanket are sufficient to support a soil food web capable of limiting the multiplication of *Pratylenchus* and other plant-parasitic nematodes.

Although it is too early to draw firm conclusions about the relationship between soil C status and suppression, these results suggest that soil C contents may have to be raised to about 2% to obtain useful suppression of sugarcane pathogens. Given the relatively low C levels of most sugarcane soils, growers may see this as an impossible task. However, the task becomes more feasible if it is viewed as increasing the C content of upper soil layers where most of the roots reside, as the required result is likely to be obtained through a combination of minimum tillage and green cane trash blanketing.

4. CROP ROTATION AS A TOOL FOR MANAGING LESION NEMATODE (PRATYLENCHUS ZEAE)

This work was published in the following paper, and a copy is included in the appendix to this report.

Stirling GR, Halpin NV, Dougall A, Bell MJ (2010). Status of winter cereals, other rotation crops and common weeds as hosts of lesion nematode (*Pratylenchus zeae*). *Proceedings of the Australian Society of Sugarcane Technologists* 32 (in press)

5. CHEMICAL AND BIOLOGICAL PROPERTIES OF SOILS UNDER DIFFERENT MANAGEMENT SYSTEMS

This work was published in the following paper, and a copy is included in the appendix to this report.

Stirling GR, Moody PW and Stirling AM (2010). Legumes, minimum tillage, controlled traffic and residue retention in the sugarcane farming system: effects on chemical, biochemical and biological properties associated with soil health. Draft paper to be submitted to *Applied Soil Ecology*.

REVIEW PAPER

A copy of the following paper, which reviews the soil biology work done within the SYDJV prior to 2008, is included in the appendix of this report.

Stirling GR (2008). The impact of farming systems on soil biology and soilborne diseases: examples from the Australian sugar and vegetable industries- the case for better integration of sugarcane and vegetable production and implications for future research. *Australasian Plant Pathology* 37, 1-18.

APPENDIX 2 – COMMENTS FROM GROWER REFERENCE GROUP

Peter Russo

I joined this committee two years after it began. I felt very privileged to have been asked to join such an elite group of scientists and growers. I was extremely impressed with the calibre of the sorts of projects that the group were undertaking.

It was very pleasing to be part of a group such as this to have my views and opinions listened to with interest and respect.
Of major concern to me is the fact that the funding for this project has run out. I feel that there is a great need in our sugar industry for projects such as this to continue into the future because of the apathy that exists among growers. HIGH SUGAR PRICES WILL NOT HOLD FOREVER.

Personally I have gained a lot from being included in this group and endeavour to use the knowledge that I have gained to continue to improve my farming practices.

A big thank you to the group leaders Allan, Graham, Mike and Barry, as well as all the other team members we met from time to time.

A special thank you to the growers in this group - Robert, George and Terry. I have enjoyed your friendship and hope that our paths cross in the future.

Robert Quirk

I have felt very privileged to have been asked by the project team to represent Australian growers as a member of the review panel for project BSS286.
Over the last 4 years we have been able to visit the trial work in the North, Central and Southern districts of QLD unfortunately we never did get to NSW, although the invitation is always open for all /any members to visit at any time.
The four meeting we have had, have been a very big learning curve for all of us , keeping us at the cutting edge of research of the project.
This has given us the opportunity to trial variations of the work on our own farms while passing on the outcomes of the research to our fellow growers in our respective areas.

I have had the opportunity to travel very widely through the international sugar industry during the last 5 years, the work of project BSS286 is talked about in every country I have visited and in most countries is also being practiced , from full adoption to trial plots. I guess the only down side to this is the international community may not getting the updates from the work, e.g. some cultivation may be necessary in some cases, and if the harvesting equipment runs on the stools there will be a reduction in productivity, also the row width by variety trials out comes. .
I think the project team should be very proud of the extent to which their research has been taken up not only in Australia but globally.
There is no doubt in my mind that the Australian industry owes its ranking as number one, as the lowest cost producer in the world to the work of the YDJV and project BSS286 Thanks to the members of project team in particular leaders Allan and Barry as well as Mike, Graham and all other that we only saw from time to time, and to the

grower members Peter, Terry and George for their friendship and robust discussion at the meetings it has been a pleasure to work with you all.

George Henry

It's been a great honour to be part of BSS286, especially to be a farmer representative for North Queensland. By having farmer representatives from all four cane growing regions, the 'Brains Trust' could get quick and timely input into their projects effect on the four regions.

Most importantly, it was having access to the knowledge and experience of Alan, Barry, Mike, Graham and fellow farmer representatives. This enabled further refinement of the design for the new farming system.

Results from BSS286 projects have led me to concentrate on the more relevant aspects of farming operations; such as compaction, break crops and associated soil biology, and although variety selection is important, row spacing is not.

Perhaps, this research concept could be progressed further into the future to address issues as they arise in the new farming system. A future project may be to address nutritional loss, especially in the light, highly leachable soil types in North Queensland. With the aid of GPS one such project could be an investigation into the economic and environmental benefits if any, of the placement of soil ameliorants such as mill mud, mill ash, bentonite or diatomeaous earth under the stool zone prior to planting. The aim of the project would be to help retain the nutrients and insecticide applied to the stool during the crop cycle.

I would also like to thank Terry, Robert and Peter for their helpful suggestions/input over the project period.

Terry Granshaw

I have felt very privileged to be representing growers from my area and taking part in the SYDJV {BSS286} discussions and outcomes of trials that have been presented to me over the years. At no time, since I have been involved with this project have I felt, that the research was going in the wrong direction or was in any way not justified. Yield decline is never an easy project to take on in any crop and sugarcane is no different. The huge differences in weather conditions, soil types, row spacing's, machinery, varieties, disease, crop pests, economics and crop management means that this was always going to be difficult to come up with common solutions for this resilient plant.

The researches approach to this problem was basically to repair soil health that had been degraded brought about from continual monoculture of the crop over time. I remember going to my first yield decline meeting for growers in the Burdekin. Presentations were shown to us on legumes, soil biology, nematodes and compaction and we were shown the difference between good soil structure and our soil structures. There was a pretty adverse reaction by the 100 or so growers that were there that day. There was also a minority group of farmers in the room that thought this information was spot on and wanted to learn more.

Our family has implemented the new farming system approach based on the SYDJV guidelines. We chose a row spacing that suited our soil, management, and the heaviest machinery that travels on our paddocks. We introduced legumes to all fallow blocks and have harvested some of them for economic purposes. GPS 2cm guidance systems have been installed on all tractors and harvest /haul out equipment and everything is based on a minimum tillage system. I am happy to say that our soils are improving. Water holding capacity and drainage are better, yield has not declined and is slowly increasing, ccs is better, disease or crop pests have not increased, economically we are better off and we have more time to pursue off farm projects.

I have had to travel to get to the BSS286 meetings along with the other researches and growers in different parts of Queensland. I have noticed in the last few years a large amount of sugarcane farms that have progressed to the new farming system, all in different ways but with similar principles. I do believe that certain areas will have a greater need to change and certain areas will benefit more quickly then others. Machinery can now be purchased from manufacturers and guidance systems have become more affordable, legume seeds are easier to purchase along with growers crops who have implemented parts of the new farming system standing out from the original systems through adverse conditions.

It has been great to be able to participate in such an important project within the sugar industry. I would also like to personally thank Alan Garside, Brian Robotham, Mike Bell, Graham Stirling, Barry Salter and all the DPI /BSES staff who presented and discussed information to Myself, Peter, George and Robert. Hopefully, our input, helped ground truth some of the trials on a larger scale and provided the researches with information that may or may not occurred in the trials.

APPENDIX 3 – SCIENTIFIC PAPERS PRODUCED FROM BSS286

Bell MJ; Halpin NV; Garside AL (2007) Performance of sugarcane varieties with contrasting growth habit in different row spacings and configurations. *Proceedings of the Australian Society of Sugar Cane Technologists* **29**: 215 – 225

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