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

By

A.L. GARSIDE[1] and M.J. BELL[2]

Sugar Yield Decline Joint Venture
[1]BSES Ltd , Townsville, Qld
[2]Qld Dept. of Primary Industries and Fisheries, Kingaroy, Qld
Alan.Garside@csiro.au

KEYWORDS : Yield Decline, Legume Breaks, Crop Cycles, Cycle Length, Cash Crops, Re-plant.

Abstract

IN ROTATION experiments conducted in Australia over the past decade, it has been demonstrated that breaking the sugarcane monoculture between cycles with another species improves sugarcane yields by 20–30% in the plant crop due largely to improvement in soil health. However, to break the sugarcane monoculture, it is necessary to forego at least one cane harvest and many growers are concerned that will jeopardise economic viability. To test this, several of the rotation experiments were carried through to second and third ratoons and the cumulative cane and sugar yields were measured over the crop cycle. The response to breaks in the ratoons was similar to those measured in the plant crop and there were clear indications that over a crop cycle the inclusion of a short-term (6–9 month) legume break would be economically viable. In general, the persistence of yield benefits into the ratoons resulted in cumulative sugar yields over a plant and four ratoons covering the loss of the one cane harvest when the break was included. In two other experiments, sugarcane that had been planted after breaks was removed, following a plant crop in one instance and a plant and two ratoons in the other, and plots were immediately re-planted to sugarcane. The yields of the subsequent plant crop were no better than those with long-term sugarcane monoculture, indicating that the break effect *per se* was short-lived. Thus the longevity of the yield response into later ratoons appears to be largely associated with very positive effects of the break on the immediate plant crop. These findings strongly support the regular inclusion of rotation breaks in the sugarcane cropping system, a strategy that is especially attractive when there are suitable break species like soybeans and peanuts that can be harvested as cash crops. Harvesting these break crops does not detract from the break effect while further improving overall grower profitability.

Introduction

The Sugar Yield Decline Joint Venture (SYDJV) was established in the Australian sugar industry in 1993 to investigate the cause/causes of a 20 year productivity (sugar yield/harvested ha) plateau (Garside *et al.,* 1997). It was thought that at least one of the reasons for the productivity plateau was the sugarcane monoculture or plough-out/re-plant (PO/RP) cropping system that had developed with the abandonment of assignment restrictions which had basically forced growers to fallow 25% of their assigned sugarcane land in any one year. In 1964 the restriction was reduced to 15% of assigned area and was totally abandoned in 1975 (Wegener, 1985).

Cane growers had traditionally fallowed land with legume break crops. However, the area sown to legumes was substantially reduced with the removal of assignment restrictions. The reduction in area was accompanied by a reduction in management input, with many legume crops being inundated by weeds, waterlogging and root diseases.

More recent research into legume agronomy during the 1990s demonstrated that well managed fallow legume crops were able to compete better with weeds, produce more biomass, fix more nitrogen and subsequently provide greater benefits to the following sugarcane crop (Garside and Bell, 2001).

Consequently, the SYDJV decided that the benefits of breaking the sugarcane monoculture with well managed legume breaks required re-evaluation.

Legumes were included in rotation experiments established by the SYDJV in the mid 1990s. In these experiments, breaks of different types and duration and sugarcane monoculture were compared for their impact on subsequent sugarcane crops.

The results showed that plant cane yields could be increased by 20–30% following a legume fallow compared with PO/RP (Garside *et al.,* 1999, 2000). The basis of the yield response was better crop establishment and early growth due largely to improvement in soil health, particularly soil biology (Pankhurst *et al.,* 1999, 2003, 2005).

Most rotation experiments were carried through to the third ratoon, yet the yield data for the ratoon crops have never been formally reported. An additional reason of collecting this ratoon information was to answer the considerable industry concerns about the economic viability of missing a cane harvest to include a break.

Many growers believed that the loss in productivity from missing a harvest would not be compensated by the increase in yield as a result of the break. Further, there was also interest in whether the positive effects of a break would last more than one cycle. This information was needed in order to determine whether the inclusion of rotation breaks needed to be a regular, or only occasional, part of future sugarcane cropping systems.

In this paper we report the results of plant and ratoon cane yields from cane grown following legume breaks and PO/RP and use these data to calculate cumulative cane and sugar yields over a crop cycle to assess the economic viability of missing a cane harvest.

We also examine the duration of the break effect, its potential impact on the length of the following sugarcane cycle, and whether a single break can provide benefits for more than one cane cycle.

Finally, we report on the yields produced by two of the break species used in these experiments, soybean and peanuts, in order to assess their potential as cash crops in the sugarcane cropping system.

Materials and methods

An initial group of rotation experiments was established at Tully (1993), Burdekin, Mackay, Herbert (1994) and Bundaberg (1995). The sites were returned to sugarcane after breaks of bare fallow, pasture or other crops (mainly legumes) for varying periods of time in 1996 (Bundaberg), 1997 (Tully, Mackay, Herbert) and 1998 (Burdekin).

A second rotation experiment was established at Tully in late 1995 and re-planted to sugarcane in June 2000. All of these experiments included plots of sugarcane monoculture which were re-planted at the same time as sugarcane was planted following the breaks.

Details of the treatments and methodology are provided in Garside *et al.* (1999, 2000, 2002). Briefly, the breaks ranged from 9 to 54 months but break duration was not necessarily consistent between experiments. Plot size was generally of the order of 6–10 rows wide x 25–30 m long. Row spacing was 1.5 m and there were three replications. Prior to returning to cane, all plots were conventionally prepared using discs, rippers and rotary hoes. Hence, there was no minimum tillage or controlled traffic in any of these experiments.

A second rotation experiment was established at Bundaberg in which long and short-term breaks (72 and 12 months) were planted to sugarcane, grown for a plant crop, removed and then re-planted to sugarcane.

Similarly, the cane in the Burdekin rotation experiment was removed after the second ratoon and re-planted to sugarcane. In both of these experiments the aim was to measure whether break effects recorded in the initial plantings carried through to a second cycle. Management of these experiments was the same as described above and by Garside *et al.* (1999, 2000).

In each experiment, sections (minimum of 15 m^2) of each plot were hand harvested to measure yield and CCS at around 12 months (e.g. Garside *et al.,* 1999, 2000). Millable stalk yields were measured by taking the whole weight of the plants in the sample area, randomly selecting 20 plants and dividing these into millable stalk and leaf plus cabbage by cutting them between leaf 5 and 6 from the top of the plant.

Both sections were weighed and millable stalk was calculated as a percentage of whole stalk weight. CCS was measured using a small mill with a six stalk sample being taken per plot. All plots were then mechanically harvested to retrieve all the cane and to set up the next ratoon.. Machine harvested weights were not recorded.

In all but the second Bundaberg experiment the row spacing was 1.5 m, which mis-matched the harvesting and haul-out machinery wheel spacing of 1.8–1.9 m. Mismatched wheel and row spacing had little obvious adverse effect when harvesting was carried out under dry conditions but severe consequences under wet conditions (Garside, 2004). Wet harvests were an issue with the first Tully experiment and the Herbert experiment. Both were abandoned after the plant crops suffered harvesting damage.

In reporting on the longevity of the break effects into the ratoons we have concentrated on the first Bundaberg (12 month break), Mackay (9 month break), Burdekin (42 month break) and second Tully (54 month break) experiments and restricted our analysis to comparisons between PO/RP and breaks of varying duration involving legume crops (peanuts and/or soybean). Details of the management, growth and yields of these legume breaks are provided in Bell *et al.* (1998).

The data from re-plant of the second Bundaberg and Burdekin experiments are used to discuss the persistence of effects of cropping breaks into a second cane cycle. In the first Bundaberg, Mackay and Burdekin experiments the PO/RP plots were based on a burnt cane harvesting system while in the second Bundaberg experiment and the Tully experiment, green cane trash blanket was used in PO/RP.

Results and discussion

Overall break effects

Cane and sugar yield data for the crop cycles in the Bundaberg, Mackay, Burdekin and second Tully experiments are presented in Table 1. Overall, the average increases in cane and sugar yields following a break compared with PO/RP were of the order of 75 and 11 t/ha respectively.

The cycles involved a plant and three ratoons at Bundaberg and Mackay and a plant and two ratoons at Burdekin and Tully.

In order to make comparisons from all trials over a similar crop cycle duration, estimates were made of crop performance for a hypothetical 3rd ratoon in the Burdekin and Tully experiments by assuming similar yields to those recorded in the second ratoon (Table 1, data in italics).

Given this assumption, the cumulative increase in cane and sugar yields following the breaks would have been 91 and 14.4 t/ha (Burdekin) and 89 and 13.5 t/ha (Tully), values slightly higher than the average recorded over the variable cycle lengths. While this comparison suggests there may have been greater responses to breaks at these two sites compared with Bundaberg and Mackay (where the break duration was shorter), an examination of the relative growth responses at all sites in the plant and first two ratoons suggests greater relative break responses in the rainfed/supplementary irrigated sites (Tully and Mackay) than in the fully irrigated sites at Bundaberg (trickle) and Burdekin (flood).

This is a more realistic interpretation of the results, and suggests that higher levels of inputs (in this case the amount and distribution of water) may be able to mask/influence the rotation response to some extent, perhaps by placing less reliance on a healthy root system. This issue has been discussed previously by Garside *et al*. (2000) and is also discussed in a companion paper in these Proceedings (Garside *et al.,* 2007).

Regardless, these data indicate that a large part of the response to breaking the monoculture can be achieved in the first 6–12 months of the break (i.e. missing only a single cane harvest). Data comparing plant cane yields after 6 and 30 month crop breaks respectively for the Mackay (95 vs 101 t/ha) and Herbert (54 vs. 56 t/ha) experiments further support this hypothesis (Garside *et al.,* 1999).

The long break periods employed at Burdekin and Tully involved the missing of four and five cane harvests, respectively, for no clear productivity advantages. As such they are simply not economically feasible, in addition to not being practical from an industry productivity perspective.

Comparison of productivity for the same cycle length

To make useful comparisons between the two systems (legume breaks vs. PO/RP) for the Bundaberg and Mackay experiments it was necessary to compare the productivity from five cane crops with PO/RP (plant + four ratoons) and four cane crops when a break was included (break + plant + three ratoons).

Unfortunately these data were only available for the Bundaberg experiment, where yield of the 4th ratoon of the PO/RP was 62 t/ha. This meant that the cumulative cane yield over the plant and 4 ratoon cycle was 471 t/ha some 23 t/ha less than produced from a plant crop and 3 ratoons after a legume fallow (Table 1).

Although 4th ratoon yields were not available at Mackay, an indication of what might have happened was obtained by assuming that a 4th ratoon in the PO/RP treatment would have yielded as well as the 3rd ratoon.

While the Bundaberg data suggested this may have been an overly generous estimate of 4th ratoon performance, this result only caused the total cane yield of the 5 year PO/RP system to be 5 t/ha greater than the 4 year rotation break treatment–a difference of *ca*. 1%.

Re-plant considerations

On the basis of yields for the third ratoon at Mackay, and particularly Bundaberg, growers may have been encouraged to extend the duration of their cane cycle following a break to include a 4th ratoon. In the 3rd ratoon the cane grown following the break was still a very creditable 107 t/ha at Bundaberg, 22 t/ha more than with PO/RP (Table 1).

The break system in Mackay was only yielding an insignificant 8 t/ha more than PO/RP and so would probably not warrant taking into another ratoon. Interestingly, in the

Burdekin and Tully experiments the breaks were still out-yielding PO/RP by 17 and 20 t/ha respectively at 2nd ratoon.

The possibility of extending the length of the cane crop cycles after rotation breaks would have significant impacts on whole-farm profitability. The data from the Bundaberg rotation trial was used to explore the extent of the combined benefits of legume cash crops (peanuts or soybeans) and longer crop cycles on whole-farm profitability.

The analytical approach described by Sing *et al*. (2003) and Sing (2004) was used, along with current peanut and soybean prices, fuel prices and a sugar price of $300/t to generate average gross margins for a whole farm growing either all sugarcane under PO/RP (25% each of a plant crop, 1st, 2nd and 3rd ratoon) or a mix of grain legumes (16.7%) and sugarcane (16.7% each of a plant crop, 1st, 2nd , 3rd and 4th ratoons).

When assessed over a common period (e.g. 12 years, representing 3 crop cycles in PO/RP and 2 crop cycles in the fallow plant system) whole-farm gross margins were from *ca.* 20% (soybeans) to *ca.* 30% (peanuts) higher in the fallow planted system.

Cash crop opportunities with the break

The cane and sugar yield data presented from rotation treatments in this paper have been based on grain legume breaks (either soybeans or peanuts), both of which can provide good cash flow if harvested for grain.

Our research indicates that the break effects were not adversely affected when the grain was removed (Bell *et al.,* 2003), although the N requirements of ratoon crops may be greater (M.J. Bell, unpublished data).

We measured grain yields from soybean and peanut crops grown as breaks in these experiments; data are summarised by Bell *et al.* (1998). However, in Table 2 we have presented the soybean and peanut yields for treatments associated with cane and sugar yield data shown in Table 1. High yields were obtained from both soybean and peanuts in these experiments. Recent economic analyses based on the Farm Economic Assessment Tool (FEAT) (Stewart and Cameron, 2006) for both peanuts and soybean indicate gross margins of $561 and $343/ha respectively for yields of 4.4 t/ha (nut-in-shell) for peanuts and 3.5 t/ha for soybean. The yields in Table 2 are similar to these benchmarks.

Carryover of break effects between cycles

Yields from the plant crop following a rotation break, and from the re-plant of those plots for the second Bundaberg and Burdekin experiments, are shown in Tables 3 and 4.

In both experiments the large responses to breaking the monoculture in plant crops directly following the breaks were not reproduced when cane was re-planted after a short cane cycle (plant crop in Bundaberg and plant and two ratoons in Burdekin). The clear implication is that legume crop break effects are relatively short lived and are only likely to have any significant influence on the crop cycle immediately following the break.

General discussion and practical implications

There has always been concern by growers and millers about the inclusion of breaks in the sugarcane cropping system. Growers are concerned whether they can withstand the cost of the loss of a cane crop when a break is included in their cropping system, while miller concerns are largely based around a reduction in area under cane and the prospect of reduced cane supply.

The data presented (Table 1) indicate that both concerns are more perception than reality. Additionally, in all of these experiments, traditional land preparation was used prior to planting both the legumes and the cane, with the legume residues incorporated into the soil profile.

Table 1—Cane and sugar yields (t/ha) for sugarcane monoculture and legume cropping breaks of varying duration for the plant and ratoon crops for rotation experiments at Bundaberg, Mackay, Burdekin and Tully.

Site	Treatment	Cane and sugar yields (t/ha)										Increase in favour of break over cycle (t/ha)	
		Plant		Ratoon 1		Ratoon 2		Ratoon 3 *		Cumulative			
		Cane	Sugar	Cane	Sugar	Cane	Sugar	Cane	Sugar	Cane	Sugar	Cane	Sugar
Bundaberg	PO/RP	107	16.5	110	17.2	107	17.4	85	12.3	409	63.4		
	12 m Break	124	18.6	138	21.1	125	19.1	107	15.6	494	74.4	85	11.0
	Lsd 5%	*12.8*	2.2	*18.2*	*3.0*	*13.8*	*2.6*	*15.5*	2.3				
Mackay	PO/RP	63	9.8	92	16.3	77	11.8	78	13.0	310	50.9		
	9 m Break	88	13.1	116	20.5	93	13.8	86	14.3	383	61.7	73	10.8
	Lsd5%	*15.3*	2.5	*13.7*	2.5	*13.0*	2.0	*nsd*	*nsd*				
										299	51.0		
Burdekin	PO/RP	118	21.0	100	17.4	81	12.6	--	--	373	62.7	74	11.7
	42 m Break	147	25.0	128	22.4	98	15.3	--	--				
	Lsd 5%	*12.0*	2.9	*18.7*	3.5	*10.7*	*2.1*						
	PO/RP							*81*	*12.6*	*380*	*63.6*		
	42 m Break							*98*	*15.3*	*471*	*78.0*	*91*	*14.4*
Tully	PO/RP	54	7.7	71	10.4	59	7.3	--	--	184	25.4		
	54 m Break	78	11.0	96	13.6	79	10.8	--	--	253	35.4	69	10.0
	Lsd5%	15.2	*1.94*	*16.1*	2.1	*15.4*	*1.8*						
	PO/RP							*59*	*7.3*	*243*	*32.7*		
	54 m Break							*79*	*10.8*	*332*	*46.2*	*89*	*13.5*

* To allow more complete comparisons between experiments it has been assumed that cane and sugar yields for a third ratoon in the Burdekin and Tully experiments were the same as the second ratoon. These data are shown in *italics*.

Table 2—Soybean and peanut yields from the rotation experiments shown in Table 1 at Bundaberg, Mackay, Burdekin and Tully.

Site	Year	Soybean (kg/ha)	Peanut (N.I.S.)[&] (kg/ha)
Bundaberg	1995–96	–	6923
	1996–97	–	5202
	1997–98	–	–
	1998–99	–	6230
Mackay	1994–95	–	3562
	1995–96	3777	6355
	1996–97	3553	3606
Burdekin	1994–95	–	3439
	1995–96	2625	–
	1996–97	3994	4456
Tully*	1993–94	–	4515
	1994–95	2551	–

[&] *N.I.S. means nut-in shell*
* *Grain yields were not measured at Tully after 1995*

Table 3—Plant cane yields (t/ha) from the second Bundaberg rotation experiment. Plant cane crops were either sown after 72 month breaks under mixed cropping or a grass/legume pasture, or were replanted into the same plots after harvest of the initial plant crop 12 months later.

Treatment	Plant cane yields (t/ha) following 72 month breaks.	Plant cane yields (t/ha) for a second cane crop re-sown after the first plant crop.
PO/RP	86	122
72 m Mixed crop	100	118
72 m Pasture legume	103	119
Lsd 5%	*10*	*nsd*

Table 4—Plant cane yields (t/ha) following either 54 month breaks or the re-plant of those breaks after a plant and two ratoon crops for the Burdekin rotation experiment.

Treatment	Cane yield (t/ha) following 54 month breaks	Cane yield (t/ha) for cane replanted into the same plots after a plant and two ratoon crops.
PO/RP	121	128
54 m Crop break	152	132
54 m Pasture break	158	134
Lsd 5%	*19*	*nsd*

More recent studies are showing that combining legume breaks that are surface managed (i.e. not incorporated) with permanent beds, controlled traffic and minimum/zero-tillage can further enhance the impact of legume breaks on productivity (Bell *et al.,* 2003; Garside and Berthelsen, 2004; Garside *et al.,* 2006). Further, when either a soybean or peanut break crop is harvested for grain, the overall increase in gross margin is substantially enhanced.

The benefits of breaking the monoculture in terms of reducing adverse soil biota have been demonstrated many times over the past decade (Stirling *et al.,* 2002; Pankhurst *et al.,* 2003, 2005). Further, it was originally thought that the improvement in yield following breaks was associated with the maintenance of enhanced/better balanced soil biology later into the sugarcane cycle.

However, subsequent studies on the rotation experiments have indicated that the impact of legume breaks on biology is relatively short lived with enhanced soil biological properties following break treatments returning to pre-break levels within 12 months (Stirling *et al.,* 2002).

The yield data presented here tend to support short-lived enhanced soil biology, as the re-plants in the second Bundaberg (Table 3) and Burdekin (Table 4) experiments did not show any evidence of a residual legume break response.

Consequently, it appears that the strong residual benefits of a legume break through the subsequent crop cycle (Table 1) are mainly due to a carry over from a well established and high yielding plant crop.

However, it is also possible that the lack of residual legume break benefit seen in both of these experiments (re-plants Bundaberg and Burdekin) (Tables 3 and 4) may be at least partly due to the mechanical removal of the previous cane stool.

In more recent studies PO/RP cane yields have been enhanced on permanent beds that have not been disturbed, compared with yields from crops grown on beds that have been tilled (Garside *et al.,* 2006) suggesting that possibly some residual break effects may have occurred if the cane had been removed without soil disturbance.

Further, data are presented in a companion paper in these proceedings that a 42 month pasture break in the Burdekin experiment, which was not cultivated during the break period, appeared to have some carryover break effect into the re-planting (Garside *et al.,* 2007*)*. This is an area that warrants further evaluation.

Legume rotation breaks on the wet coast (Ingham to Mossman) are certainly less attractive than further south as wet conditions are likely to be a major problem with harvesting grain, particularly with soybeans. However, we believe there are some possibilities for peanuts with the release of new foliage disease resistant varieties, a once-over peanut harvester and artificial drying. Further, there may also be some potential for legume grain crops grown over the winter or dry season period, with further studies clearly warranted.

Conclusions

This paper combines the results from a number of experiments to demonstrate that breaking the sugarcane monoculture with a legume break will enhance sugarcane yields not only in the following plant crop but also in subsequent ratoons. The data show that foregoing one cane harvest to accommodate a break crop is unlikely to result in economic loss or significantly reduced cane production within mill areas.

Further, if the legume break crop can be harvested for grain, economic viability from its inclusion will be clearly enhanced. Although not conclusive, enhanced ratoon yields appear to be most likely associated with good plant crop establishment and growth more so than with a long-lasting enhancement of soil biology. These yield outcomes support the contention of soil biologists that the positive break effects on soil biology are relatively short-lived.

Acknowledgements

The research reported here was funded by BSES, QDPI and SRDC as part of the Sugar Yield Decline Joint Venture program. Technical and field support was provided by John Berthelsen, Neil Halpin, Linda Phillips, Christine Richards, Norm King and Luca Pippia.

REFERENCES

Bell, M.J., Garside, A.L., Cunningham, G., Halpin, N., Berthelsen, J. and Richards, C.L. (1998). Grain legumes in sugarcane farming systems. Proc. Aust. Soc. Sugar Cane Technol., 20: 97–103.

Bell, M.J., Halpin, N.V., Garside, A.L., Stirling, G.R., Moody, P.J. and Robotham, B.G. (2003). Evaluating combinations of fallow management, controlled traffic and tillage options in prototype sugarcane farming systems at Bundaberg. Proc. Aust. Soc. Sugar Cane Technol., 25: CD-ROM.

Garside, A.L. (2004). Wet Coast Breakers. BSES Bulletin, Issue 2, 2004, 24–26

Garside, A.L. and Bell, M.J. (2001). Fallow legumes in the Australian sugar industry: A review of recent research findings and implications for the sugarcane cropping system. Proc. Aust. Soc. Sugar Cane Technol., 23: 230–235.

Garside, A.L. and Berthelsen, J.E. (2004). Management of legume biomass to maximise benefits to the following sugarcane crop. Proc. Aust. Soc. Sugar Cane Technol., 26: CD-ROM.

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

Garside, A.L., Bell, M.J., Cunningham, G., Berthelsen, J. and Halpin, N. (1999). Fumigation and rotation effects on the growth and yield of sugarcane. Proc. Aust. Soc. Sugar Cane Technol., 21: 69–78.

Garside, A.L., Berthelsen, J.E., Pankhurst, C.E., Blair, B.L., Magarey, R.C., D'Amato, C. and Bull, J.I. (2002). Effect of breaks from sugarcane monoculture and biocides on the growth and yield of a subsequent sugarcane crop. Proc. Aust. Soc. Sugar Cane Technol., 24: 82–91.

Garside, A.L., Berthelsen, J.E., Robotham, B.G. and Bell, M.J. (2006). Management of the interface between sugarcane cycles in a permanent bed, controlled traffic farming system. Proc. Aust. Soc. Sugar Cane Technol., 28: 118–128.

Garside, A.L., Smith, M.A., Chapman, L.S., Hurney, A.P. and Magarey, R.C. (1997). The yield plateau in the Australian sugar industry: 1970–1990. In: Keating, B.A. and Wilson, J.R. ed. Intensive Sugarcane Production: Meeting the Challenges Beyond 2000. CAB International, Wallingford, UK, 103–124.

Garside, A.L., Bell, M.J. and Moody, P.W. (2007). High input sugarcane production systems can mask the adverse effects of poor soil health. Proc. Aust. Soc. Sugar Cane Technol., 29: (These Proceedings).

Pankhurst, C.E., Magarey, R.C., Stirling, G.R., Blair, B.L., Bell, M.J. and Garside, A.L. (2003). Management practices to improve soil health and reduce the effects of detrimental soil biota associated with yield decline of sugarcane in Queensland, Australia. Soil Tillage Res., 72: 125–137.

Pankhurst, C.E., Magarey, R.C., Stirling, G.R., Holt, J.A. and Brown, J.D. (1999). Rotation-induced changes in soil biological properties and their effect on yield decline in sugarcane. Proc. Aust. Soc. Sugar Cane Technol., 21: 79–86.

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

Sing, N, Sparkes, D., Charleston, K. and Garside A.L. (2003). A new way of farming cane. Australian Sugarcane, 7: (3), 21–23.

Sing, N. (2004). Increasing profitability with new farming systems. Australian Sugarcane, 7: (5), 17–19.

Stewart, P.F. and Cameron, T. (2006). Improving the sugarcane farming system with FEAT: A decision making tool to facilitate on-farm change. Proc. Aust. Soc. Sugar Cane Technol., 28: 310–316.

Stirling, G.R., Blair, B.L., Wilson, E. and Stirling, M. (2002). Crop rotation for managing nematode pests and improving soil health in sugarcane cropping systems. Proc. Aust. Soc. Sugar Cane Technol., 24: 129–134.

Wegener, M.K. (1985) The contribution of science to Australian tropical agriculture. IV. The sugar industry. J. Aust. Inst. Agric. Sci., 51: 29–41.