BSES Limited

FINAL REPORT SRDC PROJECT BSS143

STRATEGIC TILLAGE TO REDUCE SOIL STRUCTURAL DEGRADATION AND IMPROVE PRODUCTIVITY

by

MV BRAUNACK, D McGARRY, RC MAGAREY and AL GARSIDE

SD04004

Principal Investigators:

Dr Mike Braunack	Dr Des McGarry	Dr Alan Garside
Senior Research Officer	Principal Soil Scientist	Research Leader SYDJV
BSES	Qld Dept Natural Resources	BSES
PO Box 566	Meiers Road	PMB Aitkenvale
Tully Qld 4854	Indooroopilly Qld 4068	Townsville Qld 4814

Funding for this activity was provided in part by the sugar industry and the Commonwealth Government through SRDC, and is gratefully acknowledged. BSES is not a partner, joint venturer, employee or agent of SRDC and has no authority to legally bind SRDC, in any publication of substantive details or results of this project.

This project was incorporated in the Sugar Yield Decline Joint Venture Program.

BSES Limited Publication
SRDC Final Report SD04004 **February 2004**

CONTENTS

SUMMARY

The project was undertaken to assess the benefits of zonal tillage, where only the crop row is cultivated and the compacted inter-row is left as a permanent traffic zone.

Focus groups of growers were convened to discuss industry attitude and reasons for non-adoption of reduced tillage planting. It was largely agreed that compared to 10-15 years ago that the industry had moved to reduced tillage practices. The question the groups focused on was 'why was it necessary to cultivate the whole block, why not just cultivate the old row'. Opinion was expressed that land preparation was undertaken the way it was, generally because that is how it had always been done. Other reasons recorded were, difficult soil types relating to soil moisture at the time of tillage, run-off and erosion, cultivation was one factor that could be controlled, risk of crop failure (poor emergence, but this could also be due to poor planting material), soil-borne diseases and insect pests and the technique had not been thought about before. Benefits that were perceived included soil structure preservation, saving of time and energy. During the discussions it was learnt that innovative growers were practising a version of strategic tillage, unknown to neighbouring growers.

Interest in the concept of strategic tillage was generated through these groups, to the extent that the strategy is being trialled by several growers.

Field trials were conducted at Tully and Bundaberg to compare conventional land preparation where the whole area was cultivated with strategic tillage where only the row was disturbed. Results demonstrated that reducing the number of cultivations did not compromise seedbed conditions at either site. This means that fewer tillage operations can be undertaken for the same end result. The inference is that time and energy can be conserved and that soil degradation can be minimised. Yield was not affected by a reduction in tillage for land preparation. With savings in time and energy the costs of planting can be reduced.

Monitoring of the known soil-borne disease *Pachymetra chaunorhiza* showed higher numbers of spores under the susceptible cultivar than under the resistant cultivar grown at each site. The yield of the susceptible cultivar was lower than the resistant cultivar. Varietal rotation is suggested to limit or minimise the effect of *Pachymetra* under strategic tillage. The BSES-CSIRO plant improvement program is providing cultivars of greater resistance for the northern areas. Caution in cultivar selection is required in the central and southern districts to minimise the effect of *Pachymetra.* New cultivars being released have resistance to *Pachymetra* and varietal rotation by growers (good hygienic practice) will minimise the effect of the known soil-borne disease on productivity and allay concerns about planting directly back into the old row.

There was a trend for the number of earthworms to recover more rapidly under less soil disturbance. This is seen as a positive benefit in that earthworms create macro porosity, which enhances water movement and aeration.

Literature sources and the collective experience of the principal researchers were utilised to establish the simple guidelines for tillage decisions. These have been written-up as an article for publication in industry publications and as a booklet *Coping with compaction.*

It is recommended for the sugar industry to derive the maximum benefit from strategic tillage, that a system be developed using controlled-traffic principles with direct drilling of cane and that a legume crop or green manure be included in the fallow period. Such a system will improve soil health over time resulting in a more sustainable sugar industry with less dependence on chemicals for soil-pest and soil-borne disease control. This will enhance the industry's environmental image.

1.0 BACKGROUND

Cultivation enhances soil degradation if conducted too often, or when the soil is too wet (causing smearing and compaction), or when the soil is too dry (causing structural pulverisation). Soil degradation results in reduced productivity and off-site pollution due to erosion losses. Reduced tillage protects the soil resource by minimising structural degradation.

The establishment of a plant crop of sugarcane, although only occurring every fourth or fifth year, costs growers between $1 300 and $1 500 per hectare. Land preparation for planting is a large component and is estimated to cost between $250 and $600 per hectare. If the number of tillage operations was reduced, savings of 20-50% in land preparation costs may be achieved.

There is a need to reassess whether frequent cultivations are required and whether it is necessary to cultivate the whole area in preparation for planting. Harvesting during the previous crop cycle results in compaction of the inter-rows. Cultivation of this area results in cloddy conditions, which require further tillage. This instigates a cycle of recompaction of loose material and decompaction that requires further tillage operations.

If strategic tillage was used to destroy the old stool without cultivating the inter-row area, a smaller proportion of the area would be cultivated and fewer passes would be required. This should result in considerable time and energy savings and produce zones suitable for plant growth (the cultivated row) and zones suitable for machinery traffic (the undisturbed inter-rows). Reduced runoff and erosion will improve the image of the industry as an environmentally responsible steward of agricultural land.

The project was undertaken to assess the benefits of zonal tillage, where only the crop row is cultivated and the compacted inter-row is left as a permanent traffic zone.

2.0 OBJECTIVES

1. Assess the industry attitude to and reasons for non-adoption of reduced-tillage planting to identify acceptable strategies.
2. Compare the effect of conventional and reduced-tillage land preparation on soil conditions at planting and subsequent crop growth.
3. Assess the status of soil-borne diseases and insect pests under reduced tillage planting.
4. Develop simple guidelines for tillage decisions.
5. Extend results to canegrowers.

All objectives were achieved.

Objective 1 - Assess the industry attitude to and reasons for non-adoption of reduced tillage planting to identify acceptable strategies

To address this objective a series of focus group meetings was convened and discussions with individual growers were conducted. The concept of only cultivating the row was considered reasonable, not withstanding some concerns. Using a rotary hoe and ripper tines to remove the old stool and generate a seedbed was generally agreed to be feasible, and relatively easy to implement. The issue of only doing one row at a time was not favoured, but to do two rows involved trafficking the rows being cultivated. This was seen as a reasonable compromise, as several growers were doing this already, albeit for different reasons. It was thought that if suitable equipment were available more growers would adopt the concept of minimum tillage planting where only the row was cultivated.

Objective 2 - Compare the effect of conventional and reduced tillage land preparation on soil conditions at planting and subsequent crop growth

Six field trials (three at Tully, three at Bundaberg) showed that seedbed conditions are not compromised by a reduction in the number of cultivations to generate them. Crop yield was not significantly affected by reduced cultivation. There were few significant differences among tillage treatments for any of the yield parameters measured.

Objective 3 – Assess the status of soil-borne diseases and insect pests under reduced tillage planting

No insect pests were present in any trial.

The soil-borne disease *Pachymetra chaunorhiza* showed higher levels under a susceptible cultivar than under a resistant cultivar grown at the same site. The yield of the susceptible cultivar was lower than the resistant cultivar. The use of resistant cultivars offers a means of minimising yield loss due to *Pachymetra*. Long-term information is required to confirm the longevity or sustainability of this strategy.

The build-up of earthworms was a positive indicator that less soil disturbance may enhance beneficial soil organisms.

Objective 4 – Develop simple guidelines for tillage decisions

Literature sources and the collective experience of the principal researchers were utilised to establish the simple guidelines for tillage decisions. These have been written-up as an article for publication in industry publications.

A further publication has been produced alerting the industry to strategies to cope with or manage soil compaction for benefit. This contains information regarding tillage operations and is a further source of information.

Objective 5 – Extend results to canegrowers

The results from the project have been widely extended throughout the sugar industry. Feedback from extension officers and individual growers suggests that interest in strategic tillage is increasing to the extent that growers are trialling areas for themselves.

Articles have been published in the *BSES Bulletin*, *Australian Sugarcane* and *Australian Canegrower*. Results have been presented at ASSCT conferences and at BSES field days.

Presentations on strategic tillage have been made at information meetings conducted by the Sugar Yield Decline Joint Venture throughout the state, as well as Future Profit meetings conducted by Queensland Department of Primary Industries. Presentations have also been made at an invitation meeting of the Ingham Young Farmers' Group, as well as meetings conducted by Sugar Solutions throughout the northern areas of the sugar industry.

3.0 METHODOLOGY

3.1 Assessment of industry attitude to reduced-tillage planting

A series of focus group meetings was convened and discussions with individual growers were conducted. The questions posed to the groups are given in Appendix 1.

3.2 Trial design and treatments

Field trials were established at Tully and Bundaberg on yellow earths. The sites were in sixth and fifth ratoon at the Tully and Bundaberg sites, respectively. The trials were planned to enable 3 consecutive years of planting and to continue each planting for three ratoons.

Planting occurred on 19 August 1996 (Site 1), 4 November 1997 (Site 2) and 21 June 1999 (Site 3) at Tully and 18 October 1996 (Site 4), 23 September 1997 (Site 5) and 23 September 1998 (Site 6) at Bundaberg. Plots at Tully were not planted in 1998 due to wet seasonal conditions. Harvesting of plots was scheduled as close as possible to 12 months, with the exception of the late planting at Tully in 1997, where the crop was harvested at 10 months. This was to provide better ratooning conditions for the crop.

Trial design was a factorial at each site with two cultivars and four tillage treatments arranged in randomised blocks. There were three replications at each site. Q115 and Q117 were grown at Tully and Q138 and Q155 were grown at Bundaberg. Q117 and Q138 are resistant while Q115 and Q155 are susceptible to the soil-borne disease *Pachymetra chaunorhiza.* The four tillage treatments are detailed in Table 1. Plot size at Tully was six rows by 1.5 m spacing by 20 m long, while that at Bundaberg it was seven rows by 1.5 m spacing by 15 m long.

Table 1 Tillage operations to instigate treatments at the Tully and Bundaberg sites

Treatment	Tully	Bundaberg[3]
Conventional (T1)	1 x rotary hoe (0.15 m) 4 x offset disc 1 x rotary hoe Plant	1 x rotary hoe 2 x tine rip (0.5 m) 5 x disc 1 x rotary hoe Plant
Stool ploughout (T2)	1 x rotary hoe skim[1] 2 x tine (0.3 m)[2] Plant	1 x rotary hoe skim 1 x tine 2 x herbicide 1 x tine Plant
Stool sprayout (T3)	2 x herbicide 1 x rotary hoe skim 1 x tine Plant	3 x herbicide Plant
Ploughout replant (T4)	1 x rotary hoe skim 2 x tine Plant	1 x rotary hoe 2 x tine Plant

[1]Rotary hoe skim - the hoe just skimmed the surface of the hill to remove the old stool, chop and incorporate leaf material.
[2]Three tines were spaced to disturb sufficient soil for planting - a central tine and two set at the base of the hill (30-50 cm apart).
[3] Trickle tape was installed prior to planting after the last tillage operation.

Conventional land preparation involves a number of tillage operations, usually discing, ripping and finishing with a rotary hoe (Figure 1). The strategic tillage concept involves only a shallow rotary hoe along the old row to chop the old stool and to leave it to desiccate on the surface, and then a ripper tine with two spring tines to loosen the soil to depth and provide width for planting (Figure 2). The inter-row area is not disturbed. Stool sprayout involves spraying the ratooning crop (Figure 3) and then, prior to planting, generating a seedbed by a shallow rotary hoe pass and the three tines.

Figure 1 Discing and ripping operations for stool ploughout in conventional tillage

Figure 2 Shallow rotary hoeing and ripper tine operation in strategic tillage

Figure 3 Sprayout operation

3.3 Measurements

Data were analysed using standard analysis of variance techniques using the Statistix® software package.

3.3.1 Soil measurements

Soil bulk density was measured before treatment instigation and after harvest of the plant crop. Image analysis of soil structure was also undertaken (Moran *et al.* 1989). Soil strength to a depth of 0.6 m was measured using a recording cone penetrometer. Seedbed conditions after planting were measured (Håkansson 1990), as was the effect of cultivation on aggregate stability. To assess the effect of tillage strategies on soil biological factors, soil faunal counts (Robertson *et al.* 1994) and counts of *Pachymetra* spores (Magarey 1989) were undertaken each season.

An instrumented tractor was used to determine fuel use and time taken during land preparation operations at Bundaberg. Equipment failure on the tractor at Tully resulted in the loss of similar data for that site. Results for Bundaberg are given in Appendix 2.

3.3.2 Crop measurements

Stalk populations were monitored during the season. Gappiness of the stands was assessed before and after each harvest. Final yield was determined by mechanically harvesting and weighing the four central rows at Tully, and hand harvesting a 5-m length from the two central rows and weighing stalks after removal of leaves and tops at Bundaberg. This enabled the effect of the various tillage strategies on tonnes cane per hectare, CCS and tonnes sugar per hectare to be determined.

3.4 Development and extension of simple guidelines for tillage decisions

No specific experiments were conducted to achieve this objective. Literature sources and the collective experience of the principal researchers were utilised to establish the simple guidelines for tillage decisions.

The results from the project were widely extended throughout the sugar industry in forums from shed meetings, to extension articles, to conference proceedings.

4.0 RESULTS

4.1 Objective 1 - Assess the industry attitude to and reasons for non-adoption of reduced tillage planting to identify acceptable strategies

Responses are summarised in Appendix 1.

In summary, the general attitude was that soil conditions for planting were something that the individual had some control over. Cultivation for planting was done the way it was because that was the way it had always been done. There was the risk of not getting good crop establishment and this risk was minimised by cultivation operations.

Most growers had reduced the number of tillage operations for land preparation, but had not considered the option of only cultivating the planting row. Growers perceived both advantages and disadvantages in only cultivating the row. The main advantages were that a smaller area was cultivated, saving fuel, time and wear-and-tear on equipment, and that they were able to harvest under adverse seasonal conditions. Disadvantages were that there were difficulties in cultivating blocks of variable soil types, that there was the need to remove compacted zones, that there was concern about potential increase in chemical use, that there was a lack of long-term trial data, and that trials had not been undertaken in each area.

The concept of only cultivating the row was considered reasonable, not withstanding the concerns expressed above. The techniques employed to remove the old stool and generate a seedbed were generally agreed to be feasible, and that using a rotary hoe and ripper tines was relatively easy to implement. The issue of only doing one row at a time was not favoured, but to do two rows involved trafficking the rows being cultivated. This was seen as a reasonable compromise, as several growers were doing this already, albeit for different reasons. It was thought that if suitable equipment were available more growers would adopt the concept of minimum tillage planting where only the row was cultivated. There are several growers currently trialling the concept of strategic tillage.

4.2 Objective 2 -Compare the effect of conventional and reduced tillage land preparation on soil conditions at planting and subsequent crop growth

Measurements of soil bulk density were undertaken prior to and after cultivation to determine the changed effected and the degree to which the difference between the crop row and inter-row could be maintained under strategic tillage. There were distinct differences in bulk density between the row and inter-row that had developed during harvesting of the crop at both sites, with the row being less dense than the inter-row (Figure 4).

These differences can also be seen in the images of soil structure from the Tully site (Figure 5). The undisturbed tree line shows the best structural condition (Figure 5c), followed by the row (Figure 5a), and with the inter-row the worst (Figure 5b).

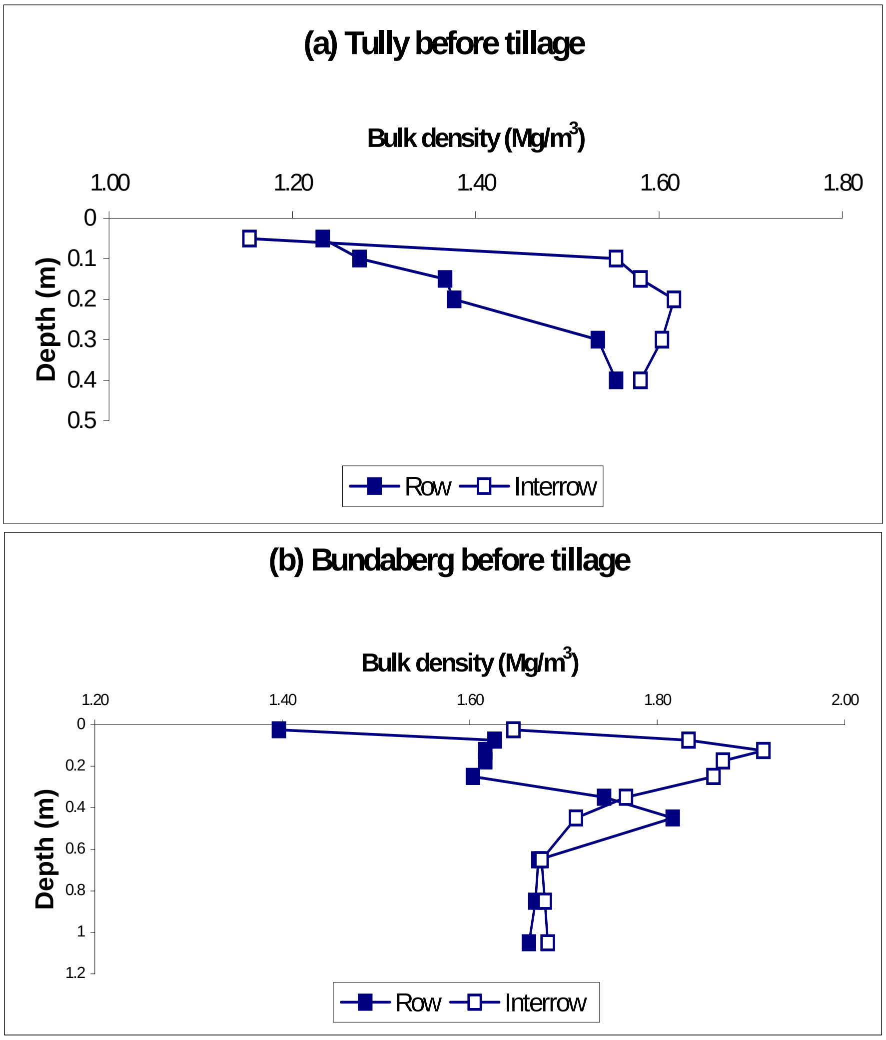


Figure 4 **Difference in bulk density (Mg/m^3) between the row and inter-row at (a) Tully and (b) Bundaberg**

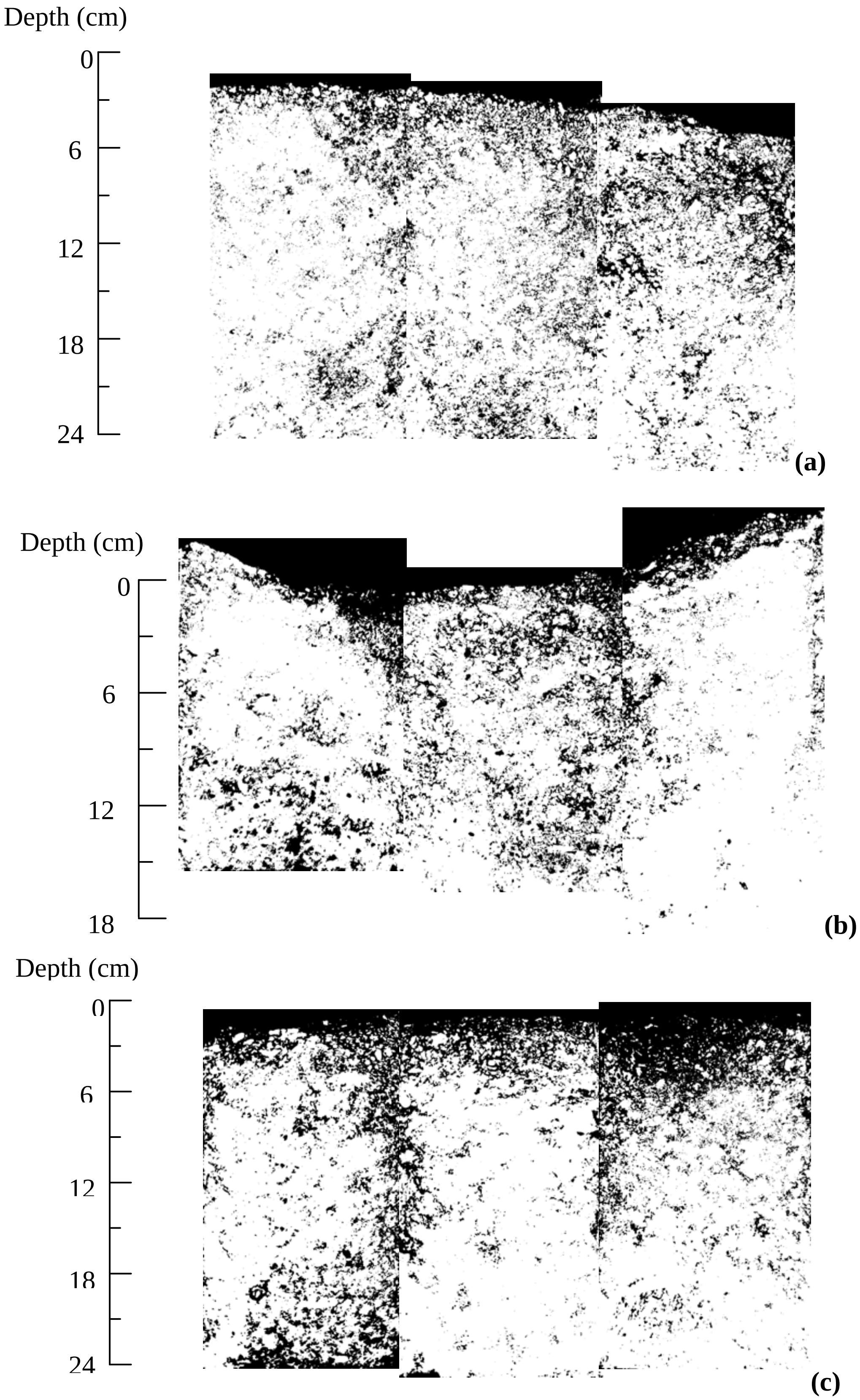


Figure 5 Tully images 'Day 1': (a) row; (b) inter-row; (c) tree line

After the first cultivation operation, the surface density has decreased at both sites. However, there has been little change in the inter-row density with depth (Figure 6). In fact, the row density at Tully closely follows that of the inter-row, suggesting some recompaction has occurred during the cultivation operation (Figure 6a).

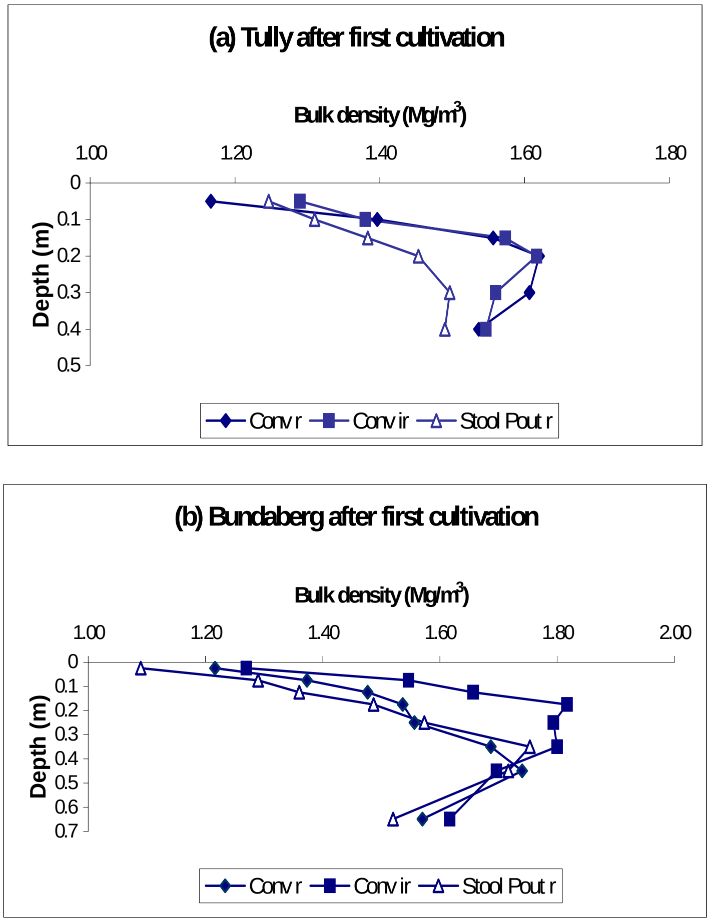
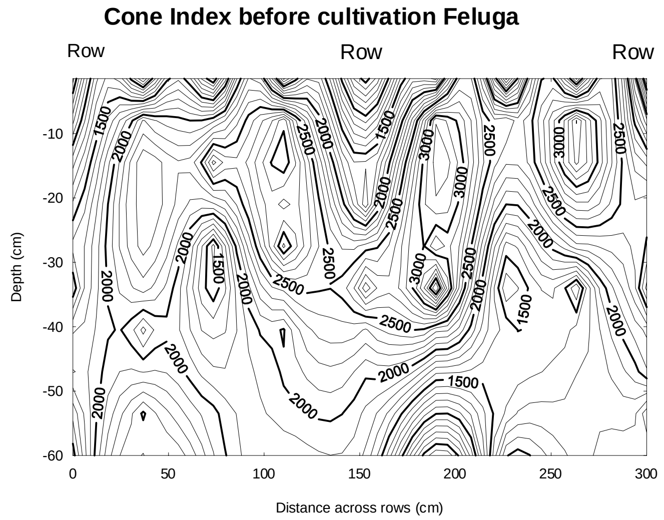


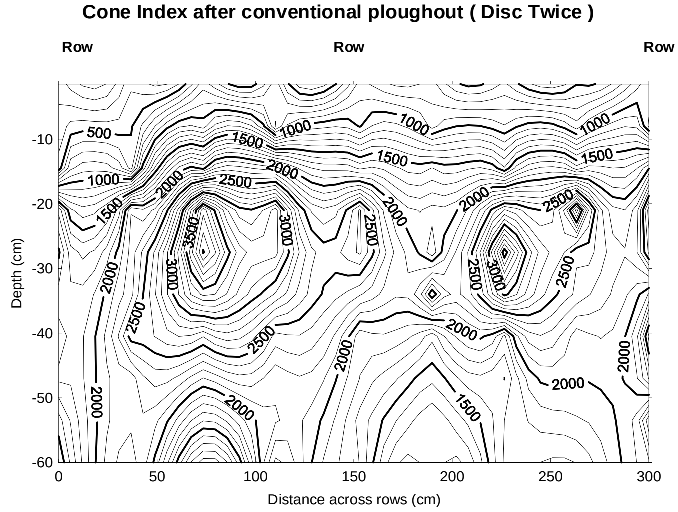
Figure 6 **Changes in bulk density (Mg/m^3) after one cultivation at (a) Tully and (b) Bundaberg**

Soil-strength measurements from the Tully site also indicate the difference between the row and inter-row position that exists at the end of a crop cycle (Figure 7a). After cultivation there is some mixing and homogenisation of the row and inter-row with respect to soil strength, as indicated by the horizontal pattern compared with a more vertical orientation that existed prior to cultivation. This orientation suggests that a plough pan is beginning to develop at the depth of cultivation (15-20 cm). After cultivating the row only, there is a similar pattern of soil strength to that at the end of a crop cycle (compare Figures 7a and 7c). The main difference between the two is that, after the recent tillage operation, a larger volume of soil under the row is weaker compared to before cultivation. The difference between the row and inter-row has been effectively maintained. This has implications for tractor efficiency and harvesting under wet soil conditions.

(a)



(b)



(c)

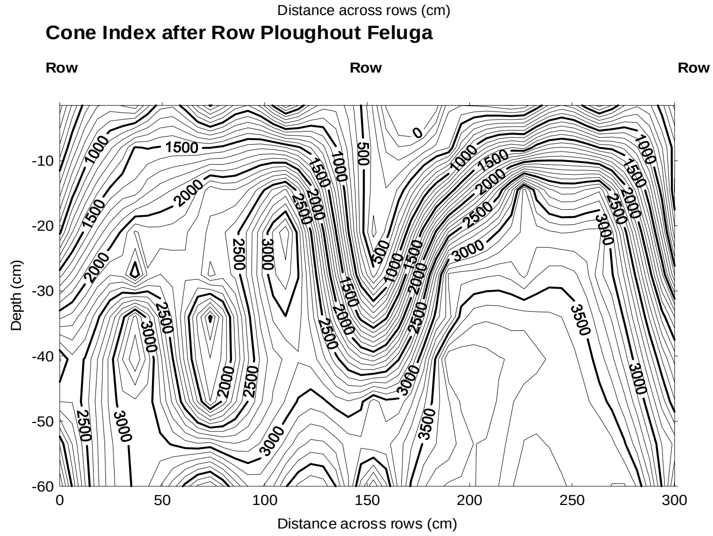


Figure 7 **Soil strength (kPa) profile of Tully trial site: (a) before tillage, indicating zones of lower strength under the row; (b) after two discings, showing homogenisation of pattern (horizontal orientation) and recompaction of loose material (thumb prints); (c) after stool ploughout, showing the maintenance of low (row) and high (inter-row) strength zones, similar pattern to before cultivation (Figure 7a)**

Assessment of seedbed conditions after planting at both sites, by determining the aggregate size distribution, shows that similar aggregate distributions occur under all tillage strategies (Figure 8). There are differences between the two sites, which reflect differences in soil moisture at tillage and the sequence and number of operations. Generally coarser seedbeds were generated at Tully (1-8 mm, Figure 8a) compared to Bundaberg, where finer conditions were evident (< 1-4 mm, Figure 8b). Aggregate size distribution does not differ among tillage strategies, indicating that reducing the number of operations does not compromise seedbeds. This provides potential for cost savings to be had in land preparation for planting.

(a) **(b)**

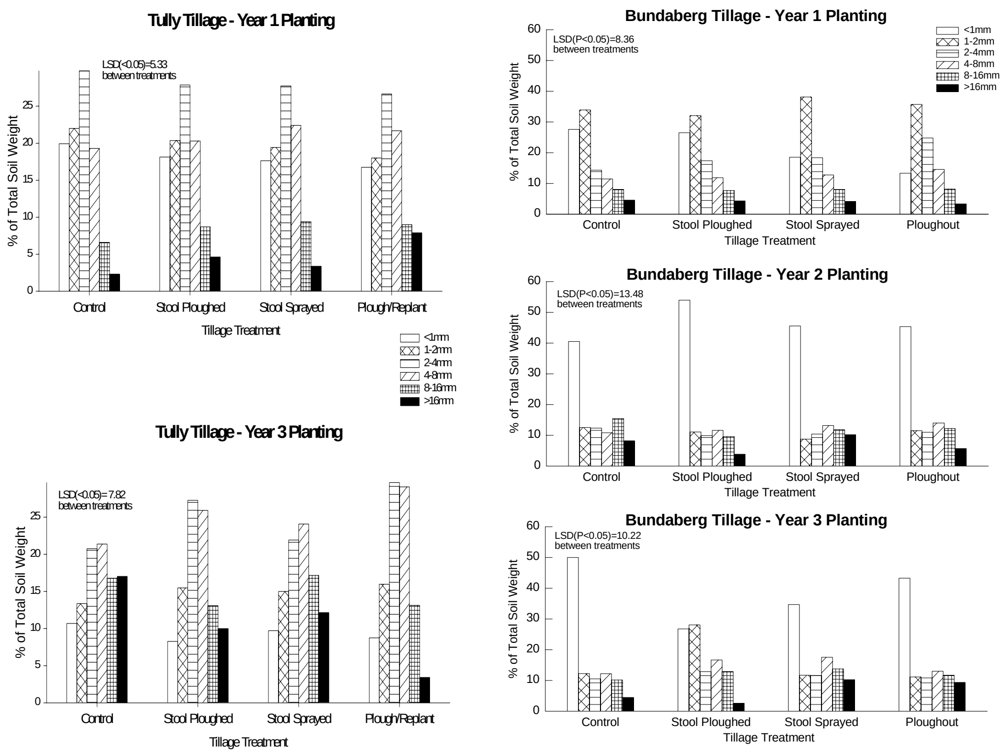


Figure 8 **Seedbed aggregate size distribution in the seedbed after planting at (a) Tully and (b) Bundaberg**

The implication of the above with respect to bulk density is that under conventional cultivation there is potential to create a condition that is worse than that existing before cultivation. It is also questionable as to how effective the operation was in removing soil compaction in the inter-row, which is one objective of tillage. The soil strength profiles show that is it possible to maintain the difference between the row and inter-row, one of the objectives of strategic tillage, and that under conventional tillage there is potential to create a pan at or slightly below the depth of tillage after two operations.

Data on stalk population for year-1 planting at Tully are provided as an indication to crop performance at each site. The stalk population response for the subsequent year-2 and year-3 planting was similar to year 1. There was no significant difference in stalk populations among the conventional, stool ploughout and stool sprayout treatments at Tully (Figure 9). At Tully the stalk population in the ploughout-replant treatment was significantly lower than in all other treatments. At Bundaberg, there was no significant difference among any of the tillage treatments (data not shown). Crop performance was not compromised by the reduction in tillage operations prior to planting.

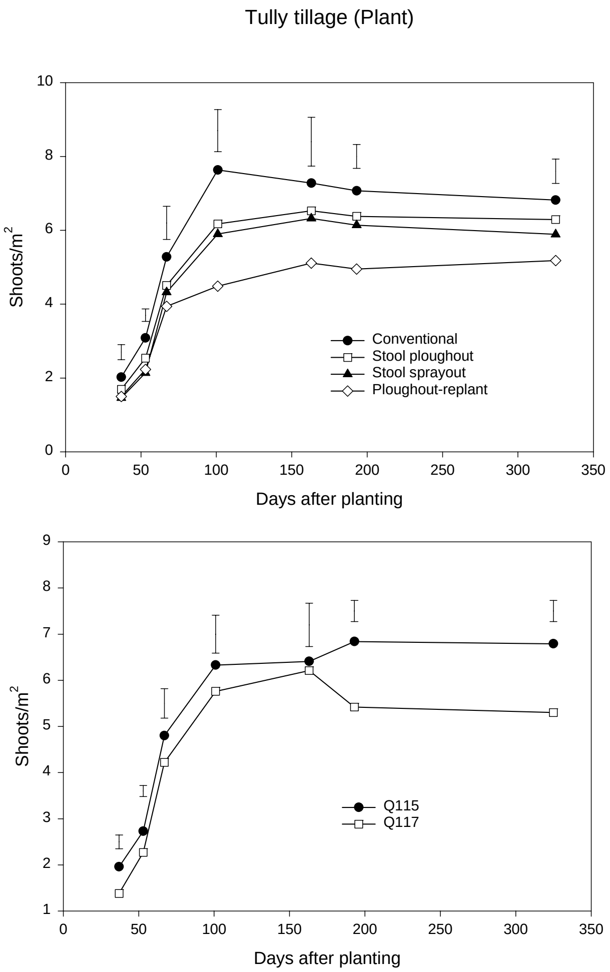


Figure 9 **Stalk populations (shoots/m^2) for each tillage treatment and cultivar at Tully for year-1 planting**

There were very few significant differences in yield parameters among tillage treatments at both sites (Tables 2-3, Figure 10). The trend was for the yield of one of the strategic tillage treatments to be greater than the conventional tillage, but not significantly so. The ploughout-replant treatment tended to produce lower yields compared with the strategic-tilled and conventional plots, but there were exceptions. There is no reason to expect a yield increase from increasing the number of cultivations. In cereals the same yield has been achieved from cultivated and direct-drilled treatments (Holland *et al.* 1987).

Table 2 Yield parameters for each year of planting and treatment at Tully (Treatments as in Table 1)

Site 1	Treatment	TCPH	CCS	TSPH
Plant	T1	81.4	13.8	11.2
Tully	T2	76.0	13.8	10.4
Planted	T3	76.3	13.7	10.4
19/08/1996	T4	71.4	13.9	9.9
	lsd	9.0	ns	ns
1R	T1	90.1	14.6	13.2
	T2	90.8	14.9	13.5
	T3	82.7	15.5	12.8
	T4	88.5	15	13.2
	lsd	ns	0.8	ns
2R	T1	77.7	15.9	12.3
	T2	77.4	15.6	12.0
	T3	76.5	15.9	12.1
	T4	71.8	16	11.5
	lsd	ns	ns	ns
3R	T1	50.7	13.8	7
	T2	44.7	14.4	6.4
	T3	49.7	13.9	6.8
	T4	45.5	14.3	6.5
	lsd	ns	ns	ns
Site 2	**Treatment**	**TCPH**	**CCS**	**TSPH**
Plant	T1	50.3	15.0	7.5
Tully	T2	55.8	14.3	8.0
Planted	T3	54.2	14.4	7.8
4/11/97	T4	46.3	14.6	6.7
	lsd	ns	0.6	ns
1R	T1	86.7	15.4	13.3
	T2	94.9	15.2	14.5
	T3	98.9	15.4	15.3
	T4	93.0	15.6	14.5
	lsd	10.6	ns	1.6
2R	T1	57.6	14.4	8.3
	T2	61.1	14.5	8.8
	T3	67.2	13.8	9.3
	T4	59.6	14.4	8.6
	lsd	ns	ns	ns
3R	T1	58.0	16.8	9.8
	T2	61.0	16.8	10.3
	T3	70.0	16.9	11.8
	T4	59.0	16.7	9.8
	lsd	ns	ns	1.6
Site 3	**Treatment**	**TCPH**	**CCS**	**TSPH**
Plant	T1	63.9	13.4	8.6
Tully	T2	54.9	13.6	7.5
Planted	T3	56.7	13.5	7.6
21/06/1999	T4	52.1	13.8	7.2
	lsd	6.6	ns	0.9
1R	T1	83.0	17.0	14.0
	T2	71.0	17.0	12.0
	T3	77.0	17.0	13.0
	T4	71.0	16.8	12.5
	lsd	ns	ns	ns

Table 3 Yield parameters for each year of planting and treatment at Bundaberg (Treatments as in Table 1)

Site 4	Treatment	TCPH	CCS	TSPH
Plant	T1	105.0	15.5	16.3
Bundaberg	T2	101.1	15.1	15.3
Planted	T3	108.5	15.6	16.8
18/10/1996	T4	97.5	15.5	15.0
	lsd	ns	ns	1.7
1R	T1	107.1	14.4	15.4
	T2	113.3	14.2	16.0
	T3	110.1	14.8	16.2
	T4	107.4	14.7	15.7
	lsd	ns	ns	ns
2R	T1	90.7	15.3	13.8
	T2	96.7	15.4	14.9
	T3	96.2	15.3	14.7
	T4	89.9	15.4	13.8
	lsd	ns	ns	ns
3R	T1	97.7	14.0	13.6
	T2	105.3	14.4	15.1
	T3	100.2	13.7	13.7
	T4	95.2	14.2	13.3
	lsd	ns	ns	ns
Site 5	**Treatment**	**TCPH**	**CCS**	**TSPH**
Plant	T1	107.8	14.3	15.4
Bundaberg	T2	106.8	13.8	14.7
Planted	T3	106.0	14.0	14.8
23/09/1997	T4	91.7	13.6	12.5
	lsd	ns	ns	2.8
1R	T1	103.0	14.9	15.3
	T2	100.2	15.0	15.0
	T3	105.6	14.9	15.6
	T4	92.8	14.8	13.7
	lsd	ns	ns	1.8
2R	T1	116.3	14.5	16.8
	T2	113.5	14.5	16.4
	T3	113.6	14.0	15.8
	T4	111.9	14.3	16
	lsd	ns	ns	ns
Site 6	**Treatment**	**TCPH**	**CCS**	**TSPH**
Plant	T1	48.2	13.7	6.5
Bundaberg	T2	44.7	12.5	5.5
Planted	T3	46.3	12.3	5.7
23/09/1998	T4	42.1	13.5	5.7
	lsd	ns	ns	ns

Figure 10 Little difference in crop growth among tillage treatments

Yields were maintained at Tully as the crop cycle continued, with no significant differences among tillage treatments, which clearly indicates there is no disadvantage in reducing tillage at planting. For the third ratoon of the second sowing date there was a significant effect of cultivar on cane and sugar yield, with Q117 having greater yield than Q115. We noted that Q115 had fewer stalks than Q117, which may account for the difference. The assessment of *Pachymetra* levels suggests that the lower stalk numbers of Q115 may be associated with stools with roots infested with *Pachymetra* being removed during harvest of the second-ratoon crop.

Harvestability of the crop was determined by assessing the gappiness of each ratoon. The number of gaps increased as the crop aged (Table 4). The conventional-cultivated plots had significantly fewer gaps than the strategic-tillage plots for all crop classes. This had little effect on crop performance, in that the strategic-tillage plots tended to produce slightly greater yields compared with the conventional plots (see Tables 2-3). The fact that gaps increased throughout the ratoon cycle is consistent with harvester damage, and this is greater under the strategic-tillage systems. It should be noted that the high number was largely due to one cultivar in the trials, namely Q117 at Tully and Q155 at Bundaberg. Varietal selection may be important for planting when using strategic tillage techniques. We do not know if this is related to the rooting pattern of particular cultivars or whether some cultivars are more susceptible to harvester damage than others.

Table 4: Number of gaps (%) for each treatment to assess harvestability of tillage treatments

Site	Treatment	Year 1						Year 2						Year 3			
		1R		2R		3R		Plant		1R		2R		Plant			
		Q115	Q117	Q115	Q117	Q115	Q117	Q115	Q117	Q115	Q117	Q115	Q117	Q115	Q117	Q115	Q117
Tully	T1	7.5	5.4	8.8	7.5	10.0	6.3	17.9	10.4	11.3	7.1	12.5	8.3	8.3	10.8	7.1	4.6
	T2	11.7	17.1	10.4	20.8	15.0	20.4	11.3	18.8	6.3	13.8	5.8	17.9	13.3	6.7	9.6	8.3
	T3	7.5	17.1	10.0	22.9	8.3	26.3	10.4	22.9	7.5	21.7	12.5	20.8	10.0	10.8	12.5	16.3
	T4	12.5	19.2	14.2	24.2	21.7	23.3	20.0	24.2	17.9	19.6	19.2	29.2	12.5	10.8	7.1	9.6
	trt*var LSD (P<0.05)	11.00		8.50		10.76		13.80		12.20		12.02		9.40		7.42	
		Q155	Q138	Q155	Q138	Q155	Q138	Q155	Q138	Q155	Q138	Q155	Q138	Q155	Q138	Q155	Q138
Bundaberg	**T1**	13.3	7.8					12.2	1.1					7.8	7.8		
	T2	7.8	3.3					4.4	0.0					16.7	3.3		
	T3	15.6	5.6					10.0	6.7					22.2	8.9		
	T4	13.3	6.7					10.0	3.3					12.2	12.2		
	trt*var LSD (P<0.05)	9.50						7.60						12.5			

(Treatments as in Table 1)

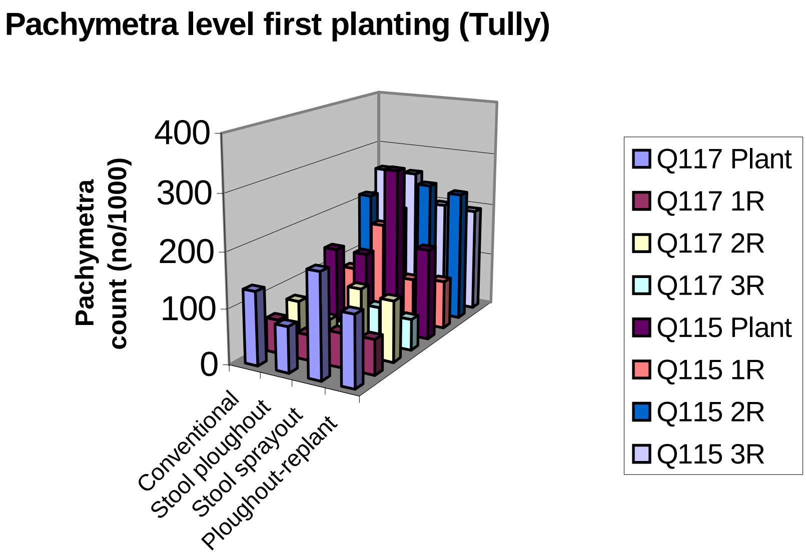
Overall the results show that seedbed conditions are not compromised by a reduction in the number of cultivations to generate them. Crop yield was not significantly affected by reduced cultivation. There were few significant differences among tillage treatments for any of the yield parameters measured.

4.3 Objective 3 - Assess the status of soil-borne diseases and insect pests under reduced tillage planting.

The concept of strategic tillage involves only disturbing the row and leaving the inter-row intact, and planting back into the old row position. Concern has been expressed about the build-up of soil-borne diseases by this practice and an increased risk of soil-insect pests.

No soil-insect pests were detected at any site during the trials. It appears that the presence or absence of soil-insects is a hit-and-miss situation. There is no evidence that subsequent populations of greyback canegrubs (*Dermolepida albohirtum*) are affected by tillage practices. However, more intensive tillage is related to lower subsequent populations of more sedentary and/or two-year species such as Childers canegrub (*Antitrogus parvulus*) (Allsopp *et al.* 2003).

Both sites were known to be infested with the soil-borne disease *Pachymetra chaunhoriza.* To test the effect of *Pachymetra* on crop yield, we grew two cultivars, one susceptible and one resistant to *Pachymetra.* At both sites, levels of *Pachymetra* were higher under the susceptible cultivar than under the resistant cultivar (Figure 11). This is consistent with observations by Croft and Saunders (1996). This difference was reflected in the yield of each cultivar (Tables 2-3), and suggests that varietal rotation will minimise the effect of *Pachymetra.* All new cultivars from the BSES-CSIRO breeding program for the northern areas have ratings for resistance to *Pachymetra*, providing a rational basis for choice when planting back into the old row using strategic tillage. Care needs to be exercised in the southern and central districts to select cultivars with the highest *Pachymetra* resistance ratings to minimise yield losses.



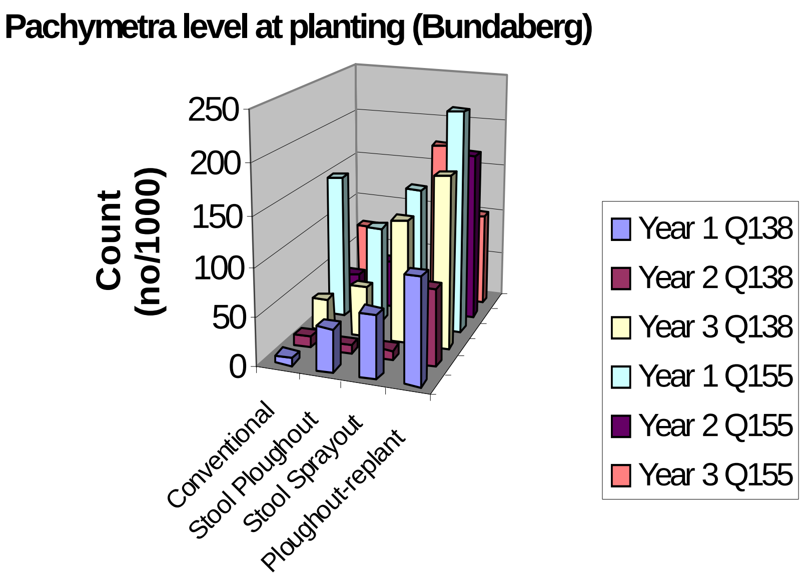


Figure 11 **Levels of *Pachymetra chaunorhiza* inoculum under each tillage treatment for year-1 planting at Tully and each plant crop at Bundaberg**

Pachymetra numbers were also measured under the two planting times to assess build-up under each cultivar (Table 5). The resistant cultivar (Q117) was effective in reducing the build-up of *Pachymetra*. The longer the duration of crop under Q115, the greater was the build-up of *Pachymetra*. There was a trend for numbers of *Pachymetra* to be higher under the stool spray-out treatment for the resistant cultivar Q117. This may reflect the minimal disturbance of the initial treatment, resulting in higher numbers from the outset (Figure 11).

Table 5 **Spore counts of *Pachymetra* ((spores/kg)/1000) under each treatment (second-ratoon and plant crop) at Tully for year 2 and 3 plantings**

Treatment	Cultivar	Year 2 second-ratoon	Year 3 plant crop
T1	Q115	101.0	47.6
	Q117	29.8	26.0
T2	Q115	129.0	60.6
	Q117	33.9	23.8
T3	Q115	82.8	87.6
	Q117	42.8	59.6
T4	Q115	151.5	41.5
	Q117	26.9	33.6

(Treatments as in Table 1)

Tillage has had minimal effect on *Pachymetra* numbers. An interesting trend seems to be developing with numbers under the stool spray-out for Q115, with numbers being relatively low after the second-ratoon crop, which may indicate the build-up of organisms antagonistic over time if the soil is not massively disturbed. This trend was not as evident under the third-ratoon crop of the first planting (Site 1), although the numbers were relatively low compared with treatments where soil was massively disturbed.

The year-2 planting with the same treatments but with the cultivars being swapped was replanted on 22 May 2002 (year-1 planting was not replanted but abandoned after a misunderstanding on protocol for continuation). With this replanting, the susceptible cultivar (Q115) was planted after the resistant cultivar (Q117) and vice versa. This was to test the effect of varietal rotation on levels of *Pachymetra*.

Early stalk development was greater under conventional cultivation but there was little difference among tillage treatments by day 152 and differences became less as the season progressed (Figure 12). The stool spray-out treatment seemed to lag behind the other treatments for most of the sampling period; this was due largely to Q115 (data not shown). Q115 is a *Pachymetra*-susceptible cultivar and there were still *Pachymetra* spores present on these plots, although the resistant Q117 was grown prior to planting Q115. This may explain the lag, but there was no significant difference in stalk numbers at the end of the sampling period (day 246).

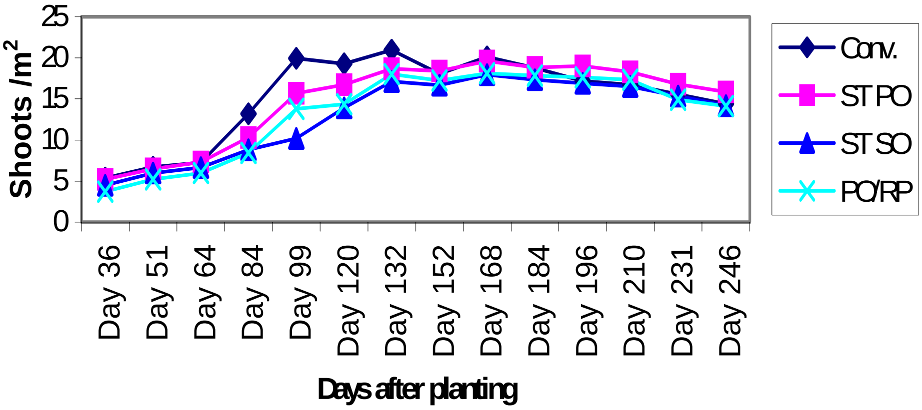


Figure 12 Stalk development for each treatment after swapping cultivars

An early biomass sampling showed no significant effect of tillage or cultivar on biomass (kg/ha) at this early stage (Table 6). This confirms the results from the initial planting and further indicates that there is no compromise in crop performance in reducing tillage for planting.

Table 6 Biomass (kg/ha) dry weight for Q115 and Q117 under the tillage treatments after cultivars were swapped

Treatment	Cultivar	
	Q115	Q117
T1	5063	6154
T2	5907	5997
T3	4943	6419
T4	5190	5036

(Treatments as in Table 1)

The final yield for the tillage treatments after swapping the cultivars is shown in Table 7. In keeping with previous results, there was no significant difference in yield among tillage treatments. There was, however, a significant difference between cultivars, with Q117 out yielding Q115, which has been consistent throughout the trial. Again the results demonstrate that reducing the number of tillage operations has not compromised yield, but the benefit of reduced cost in land preparation has been gained. The effect of swapping the cultivars may not be evident in the plant crop, since levels of *Pachymetra* are relatively low under each cultivar at planting (Figure 11). Differences may become more evident with time as the crop cycle progresses and this needs to be monitored.

Table 7 Yield of each cultivar under each tillage treatment after being swapped (Q115 followed Q117 and vice versa)

Treatment	Cultivar	Cane (t/ha)	CCS	Sugar (t/ha)
T1	Q115	60.2	10.4	6.1
	Q117	89.4	12.0	10.7
T2	Q115	79.4	10.3	8.4
	Q117	82.8	11.8	9.7
T3	Q115	78.2	10.0	7.9
	Q117	82.0	11.5	9.4
T4	Q115	78.5	9.9	7.7
	Q117	80.6	11.6	9.4

(Treatments as in Table 1)

A second survey of *Pachymetra* levels was undertaken on the year-2 planted plots prior to planting with the cultivars being swapped (Table 8). Samples were taken from the crop row, near-the-row and from the inter-row positions to determine the distribution of *Pachymetra* with respect to the position of the crop. There were considerably more spores under Q115 than Q117, suggesting that varietal rotation may be an option to minimise the effect of *Pachymetra* on crop performance. Also, the level of *Pachymetra* decreased as the distance from the cane row increased. Previous work has suggested that cane should be replanted in the old inter-row for this reason, but it is more difficult and energy consuming to generate a seedbed due to the compaction from harvesting traffic.

Table 8 Spore counts of *Pachymetra* ((spores/kg)/1000) from the Tully site as affected by tillage treatment and cultivar

Treatment	Cultivar	Row	Near-row	Inter-row
T1	Q115	73.9	14.1	11.0
	Q117	20.0	12.5	9.7
T2	Q115	155.5	20.0	15.1
	Q117	23.8	9.3	12.7
T3	Q115	86.8	17.7	11.4
	Q117	34.7	18.1	12.7
T4	Q115	159.8	31.9	11.6
	Q117	30.1	14.1	6.3

(Treatments as in Table 1)

When plots were replanted in 2002, the cultivars were swapped to determine the effect of varietal rotation as a strategy to reduce the effect of *Pachymetra* and enable the use of susceptible cultivars in known infected locations. Numbers of *Pachymetra* spores did not change greatly when plots went back into Q115 after Q117 (Figure 13). Numbers tended to be lower in all positions measured. However, when plots were planted with Q117 following Q115, there was a significant decrease in numbers of *Pachymetra* spores, especially in the row (Figure 13). This result suggests that varietal rotation is a feasible strategy to manipulate numbers of *Pachymetra* and to retain high yielding cultivars in areas where numbers of *Pachymetra* may limit their potential.

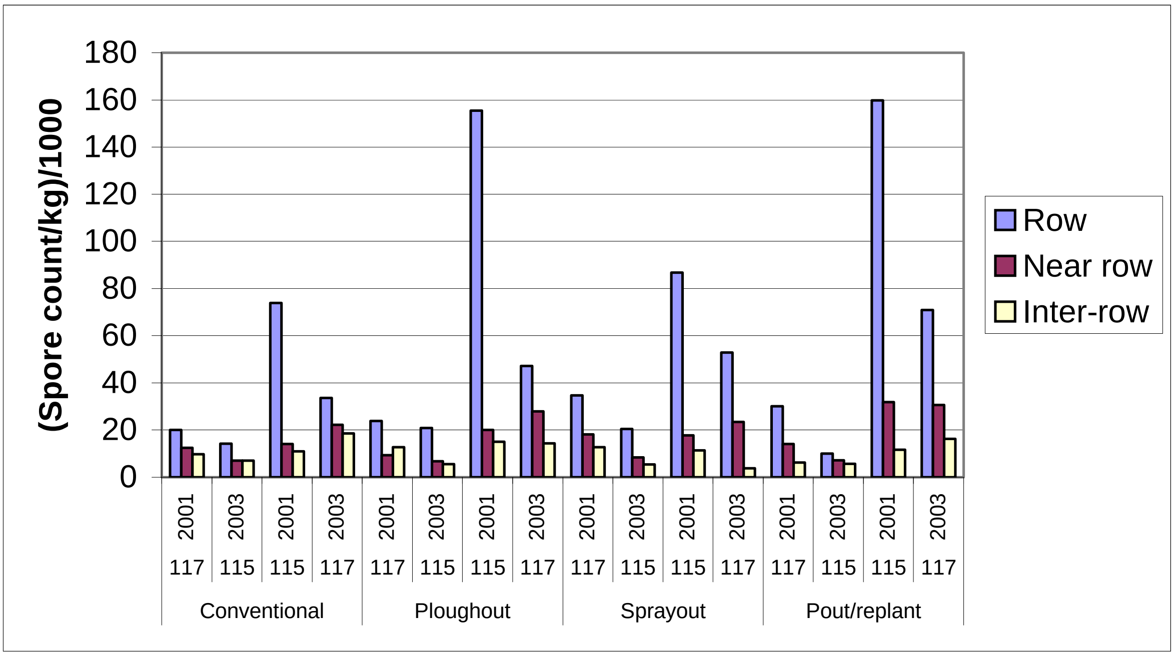
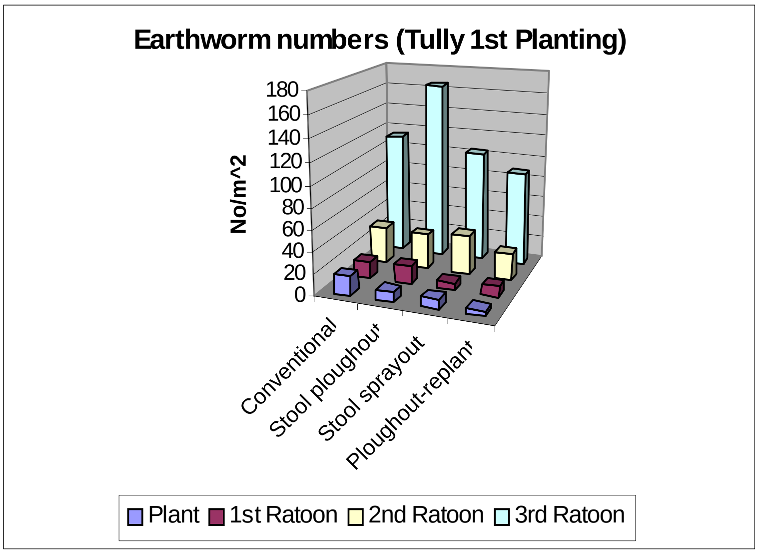


Figure 13 **Numbers of *Pachymetra* spores under tillage treatments after swapping cultivars (Q117 in 2001 now Q115 in 2003)**

Earthworms are considered to be beneficial soil fauna in that they create pathways for water and air movement and for root growth. Earthworms also incorporate organic materials and contribute to soil aggregate stability.

In the first planting at Tully and Bundaberg, numbers of earthworms built-up more rapidly and to greater levels under strategic tillage than under conventional tillage (Figure 14). This is more evident at Bundaberg than at Tully. Data for year-2 and year-3 plantings show a similar trend (data not presented).



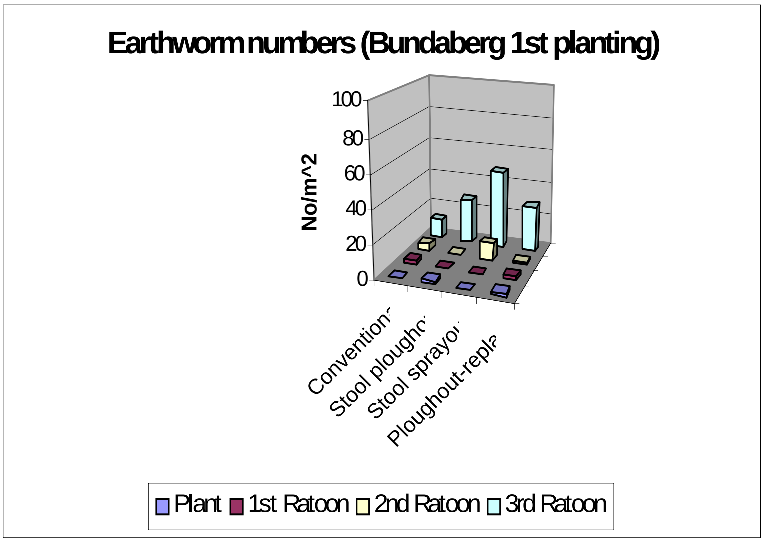


Figure 14 **Numbers of earthworms under each tillage treatment for the year-1 planting at Tully and Bundaberg**

Nematode populations were assessed at the Bundaberg site only. Counts for the two most prevalent nematodes, *Pratylenchus zeae* and *Rotylenchus*, are shown in Figure 15. There was no significant difference in the numbers of *P. zeae* under any of the tillage treatments, but there were more *Rotylenchus* under all treatments, especially the stool-sprayout strategy. It is not known why this difference occurred. A possible explanation is that an effective kill of the crop was not achieved by spraying, enabling nematodes to build up on/in the surviving roots. However, why one type of nematode should increase at the expense of the others is unknown. It should be remembered that the stool sprayout was a 6-month fallow prior to planting. This tends to contrast the *Pachymetra* counts, which were greater under the ploughout-replant treatment, but generally not significantly so from the stool-sprayout treatment. There is little indication that reducing the number of tillage operations predisposes the crop to infestation by nematodes or *Pachymetra*. Seasonal conditions may be a greater influence on the build-up of soil-borne diseases and pests over-and -above that of cultural operations.

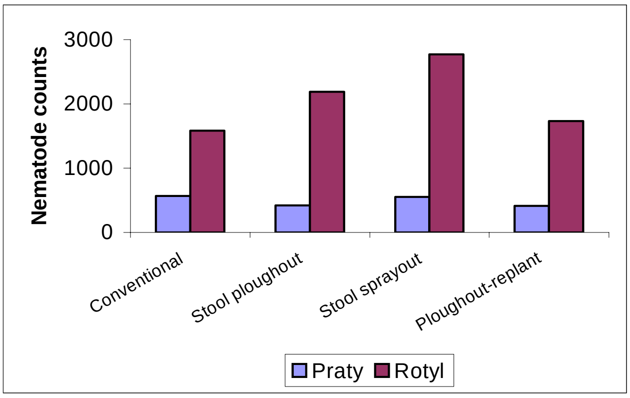


Figure 15 Numbers of nematodes under each tillage treatment at Bundaberg

Our results show that the use of resistant cultivars offers a means of minimising yield loss due to *Pachymetra*. Long-term information is required to confirm the longevity or sustainability of this strategy. The build-up of numbers of earthworms is a positive indicator that less soil disturbance may enhance beneficial soil organisms.

4.4 Objective 4 - Develop simple guidelines for tillage decisions

Literature sources and the collective experience of the principal researchers were utilised to establish the simple guidelines for tillage decisions and these have been written-up as a series of articles for publication in industry publications (see list in publications arising from the project).

A further publication has been produced alerting the industry to strategies to cope with or manage soil compaction for benefit. This contains information regarding tillage operations and is a further source of information (Appendix 3).

4.5 Objective 5 - Extend results to canegrowers

The results from the project have been widely extended throughout the sugar industry. Feedback from extension officers and individual growers suggests that interest in strategic tillage is increasing to the extent that growers are trialling areas for themselves.

Articles have been published in the *BSES Bulletin*, *Australian Sugarcane* and *Australian Canegrower*. Results have been presented at ASSCT Conferences and at BSES field days.

Presentations on Strategic Tillage have been made at information meetings conducted by the Sugar Yield Decline Joint Venture throughout the state, as well as Future Profit meetings conducted by Queensland Department of Primary Industries. Presentations have also been made at an invitation meeting of the Ingham Young Farmers' Group, as well as meetings conducted by Sugar Solutions throughout the northern areas of the sugar industry.

5.0 DISCUSSION

The sugar industry practices intensive cultural operations in generating a seedbed for planting. In doing so, there is some concern about the effectiveness of these operations in achieving the desired result. Generally the first tillage operation is the most effective in loosening the soil, with the rest tending to re-arrange the loosened material and recompact it. Each operation is a cost to the grower and results in accelerated soil degradation. Degradation occurs due to exposure and oxidation of organic material reducing structural stability. Also, losses of stored soil moisture, disruption of continuous macro-pores, disturbance of soil biology, namely earthworms, and soil compaction can occur, the removal of which, was one of the original objectives of tillage.

The project has effectively demonstrated that reducing the number of tillage operations has not compromised seedbed conditions, and as a result crop performance has not been significantly affected. There is some misconception that reducing the number of tillage operations will result in reduced yield.

The results indicate that yield is not compromised by reducing the number of tillage operations. There were very few significant differences among tillage treatments for any yield parameter measured. There is no reason to expect a gain in yield through repeated manipulation of the soil. In fact, the reverse is quite often the case, due to soil moisture loss and recompaction of soil. Harvestability of the crop was similar under all tillage treatments, with the number of gaps increasing as the crop class increased. There was a significant difference between cultivars at Tully with fewer gaps under Q115 compared with Q117. A similar situation occurred at Bundaberg with Q155 having more gaps than Q138. Varietal selection may influence the harvestability under strategic tillage for planting, but this requires further testing.

A major industry concern with strategic tillage was the increased soil-borne disease and soil-insect pest incidence due to planting directly back in the old row. BSES had previously advised against this practice to minimise the effect of soil-borne diseases on productivity. Results from this project show that reduced tillage and planting directly back into the old row has not compromised productivity. Two cultivars were grown at each trial site to assess the effect of varietal resistance to the known soil-borne disease *Pachymetra*. The resistant cultivar had the greatest yield at both sites compared with the susceptible cultivar. Numbers of *Pachymetra* spores were lower under the resistant cultivar. This suggests that the plant breeding for *Pachymetra* resistance has been and continues to produce cultivars resistant to this known disease. Varietal rotation offers a solution to the concern by industry of planting directly back into the old rows. Replanting with the two cultivars swapped has demonstrated the effectiveness of this strategy in maintaining *Pachymetra* counts at low levels. Where Q117 followed Q115 there was a significant drop in spore counts whereas when Q115 followed Q117 the counts were maintained at relatively low levels. Longer-term monitoring is required to determine if levels of *Pachymetra* will build-up to levels measured under Q115 prior to rotating the cultivars.

Soil insect pests were not a significant problem at either trial site. The effect of tillage practices on canegrubs appears to vary with the species biology and ecology.

A reduction in soil disturbance is seen as being beneficial in terms of soil invertebrates and soil biodiversity. There were more earthworms in treatments where less soil cultivation occurred. Earthworms are seen as being beneficial as they create macro-porosity, which improves water movement and aeration. These pores are destroyed during tillage.

The benefits from reducing cultivation for land preparation and planting will not be immediate, but will accrue in the medium to long-term. It is speculated that as soil structure improves, soil-water relations and soil biodiversity will change. This may translate into fewer irrigations, improved crop tolerance of drought periods, build-up of suppressive soil with less reliance on chemicals for disease and pest control, less runoff and erosion and most importantly an improved image of the industry image as a custodian of agricultural land.

6.0 OUTPUTS

- A series of focus group meetings considered the concept of only cultivating the row reasonable, not withstanding some concerns. Using a rotary hoe and ripper tines to remove the old stool and generate a seedbed was generally agreed to be feasible, and relatively easy to implement. The issue of only doing one row at a time was not favoured, but to do two rows involved trafficking the rows being cultivated. This was seen as a reasonable compromise, as several growers were doing this already, albeit for different reasons. It was thought that if suitable equipment were available more growers would adopt the concept of minimum tillage planting where only the row was cultivated.
- Seven field trials (four at Tully, three at Bundaberg) showed that seedbed conditions are not compromised by a reduction in the number of cultivations to generate them. Crop yield was not significantly affected by reduced cultivation. There were few significant differences among tillage treatments for any of the yield parameters measured.
- The soil-borne disease *Pachymetra chaunorhiza* showed higher levels under a susceptible cultivar than under a resistant cultivar grown at the same site. The yield of the susceptible cultivar was lower than the resistant cultivar. The use of resistant cultivars offers a means of minimising yield loss due to *Pachymetra*. Long-term information is required to confirm the longevity or sustainability of this strategy.
- The build-up of earthworms was a positive indicator that less soil disturbance may enhance beneficial soil organisms.
- Literature sources and the collective experience of the principal researchers were utilised to establish the simple guidelines for tillage decisions. These have been written-up as an article for publication in industry publications.

- A further publication has been produced alerting the industry to strategies to cope with or manage soil compaction for benefit. This contains information regarding tillage operations and is a further source of information.
- The results from the project have been widely extended throughout the sugar industry. Feedback from extension officers and individual growers suggests that interest in strategic tillage is increasing to the extent that growers are trialling areas for themselves.

7.0 EXPECTED OUTCOMES

The project has effectively demonstrated that reducing the number of tillage operations has not compromised seedbed conditions, and as a result crop performance has not been significantly affected. The project has also shown that the use of resistant cultivars offers a means of minimising yield loss due to *Pachymetra.* The build-up of earthworms was a positive indicator that less soil disturbance may enhance beneficial soil organisms.

The adoption of minimum-till planting techniques by the industry will reduce land degradation and production costs. This should result in longer ratoon cycles and an increase in productivity. For the sugar industry to derive the maximum benefit from strategic tillage, a system using controlled-traffic principles with direct drilling of cane should be developed and that a legume crop or green manure should be included in the fallow period. Such a system will improve soil health over time resulting in a more sustainable sugar industry with less dependence on chemicals for soil-pest and soil-borne disease control. This will enhance the industry’s environmental image.

Subsequent studies by the Sugar Yield Decline Joint Venture are utilising the outputs of this research in developing a controlled traffic, minimum tillage, legume based sugarcane cropping system.

There is strong evidence that growers are changing their farming practices to these types of systems.

8.0 FUTURE NEEDS AND RECOMMENDATIONS

This project was undertaken using current field conditions and row spacings used by the industry. To maximise the benefit of strategic tillage and improve the sustainability of the sugar industry, we recommended that work be undertaken where the crop is grown using controlled traffic and planted using minimum tillage. This effectively separates traffic from crop growth areas, which was not possible in this project.

An issue not addressed in the current work is the timeliness of operations. Future work needs to consider possibilities of timeliness of land preparation and planting, fertiliser application and weed control, all of which could be enhanced by the adoption of controlled traffic and minimum tillage options. In areas prone to waterlogging, mounding in conjunction with minimum tillage or direct-drilling planting presents an opportunity to improve early crop growth and productivity. To promote root growth, deep ripping the plant line and direct drill planting may reduce crop lodging thereby improving CCS levels. This needs to be investigated in the northern districts of the sugar industry.

Less soil disturbance should maintain soil structure and improve soil health. Some indication of this was gained in this project as greater earthworm numbers were evident where less soil disturbance occurred. Trials where minimum tillage planting or direct drilling is practiced should be monitored for soil fauna and soil-borne diseases and pests.

Further to this, the incorporation of a direct drilled legume crop or green manure should be investigated as a means of maintaining soil structure, protecting the soil surface during the fallow period and providing nitrogen for the following cane crop.

The adoption of strategic tillage has potential to reduce the cost of land preparation and planting, as well as protecting and improving the soil resource of the sugar industry.

9.0 PUBLICATIONS ARISING FROM THE PROJECT

Bell, M. 1999. Trials give green light to legume break crops, zero-tillage. *Australian Canegrower* 21(4): 24-25.

Bell, M., Halpin, N. and Cunningham, G. 1998. Reduced tillage trials are promising. *Australian Canegrower* 20(13): 21.

Braunack, M.V. 1997. Planting sugarcane: keep it simple. *Townsville Bulletin*, Friday 9 May 1997.

Braunack, M.V. 2000. How to make strategic tillage work. *Queensland Country Life*, 3 Feb 2000.

Braunack, M.V. 2000. Lower till saves cost. *North Queensland Register,* 8 June 2000.

Braunack, M. and Magarey, R. 2002. Strategic tillage and soil-borne pests and diseases. *Proceedings of the Australian Society of Sugar Cane Technologists* 24: 123-128.

Braunack, M., Magarey, R., Bakker, P. and Robertson, L. 2001. The effect of strategic tillage on soil-borne pests and disease. *BSES Bulletin* 75: 20-22.

Braunack, M.V. and McGarry, D. 1997. Is all that cultivation necessary for planting? *Australian Canegrower* 19(25): 18-20.

Braunack, M. and McGarry, D. 1998. It all that tillage necessary? *Australian Sugarcane* 1(5): 12-14.

Braunack, M.V., McGarry, D., Crees, L.R. and Halpin, N.V. 1999. Strategic tillage for planting sugarcane. *Proceedings of the Australian Society of Sugar Cane Technologists* 21: 101-107.

Braunack, M. V., McGarry, D. and Halpin, N. V. 2003. The economic advantage of reduced tillage planting of sugarcane in Australia. *Proceedings of the International Soil Tillage Research Organisation 16th Conference, Soil Management for Sustainability 13-18 July Brisbane*, CD-ROM.

Christiansen, I. 1999. Planting system saves time, money - and soil. *Australian Canegrower* 21(18): 10.

McGarry, D. 1997. Should traffic zones be preserved? *Australian Canegrower* 19(10): 19.

McGarry, D., Braunack, M.V., Cunningham, G., Halpin, N., Pillai-McGarry, U., Rahman, M.H. and Robotham, B. 1998. Plough-out - is it value for money? *Proceedings of the Australian Society of Sugar Cane Technologists* 20: 550-551.

McGarry, D., Braunack, M.V., Cunningham, G., Halpin, N., Sallaway, M. and Waters, D. 1997. Comparison of soil physical properties of row and inter-row: a basis for control traffic in cane. *Proceedings of the Australian Society of Sugar Cane Technologists* 19: 263-269.

McGarry, D., Braunack, M., Halpin, N. and Robotham, B 1998. Ploughout: are you getting value for money? *Australian Sugarcane* 2(3): 20-22.

McGarry, D., Braunack, M.V., Pillai-McGarry, U. and Rahman, M.H. 1998. A comparison of tillage practices on soil physical properties, tractor efficiency and yield of two cane soils. *Proceedings of the Australian Soil Science Society Conference Brisbane April 1998.*

McGarry, D., Halpin, N. and Braunack, M. 2001. Strategic tillage saves dollars. *Australian Sugarcane* 5(1): 3-4.

10.0 ACKNOWLEDGEMENTS

This research was carried out as part of the Sugar Yield Decline Joint Venture Program involving SRDC, BSES, CSIRO, QDPI and QNRM. Brian Harte and Gerry Borgna are thanked for cooperation and allowing trials to be conducted on their properties at Bundaberg and Feluga, respectively. Lyn Crees and Norm King provided able field and laboratory assistance at Tully, and Neil Halpin and Luca Pippa did likewise at Bundaberg. BSES extension officers are thanked for facilitating grower focus groups.

11.0 REFERENCES

Allsopp, P.G., Fischer, T.W.A., Bade, G.S. and Dall, D.J. 2003. Do farming practices influence the incidence of Childers canegrubs, *Antitrogus parvulus* Britton (Coleoptera: Scarabaeidae)? *Australian Journal of Agricultural Research* 54: 259-271.

Croft, B.J. and Saunders, M.R. 1996. Reducing poor root syndrome of sugarcane in Australia by minimum-tillage planting in previous inter-rows. *Australasian Plant Pathology* 25: 192-198.

Håkansson, I. 1990. A method for characterising the state of compaction of the plough layer. *Soil & Tillage Research* 16: 105-120.

Holland, J.F., Doyle, A.D. and Marley, J.M. 1987. Tillage practices for crop production in summer rainfall areas. In: *Tillage New Directions in Australian Agriculture* (eds Cornish, P.S. and Pratley, J.E.) pp. 48-71. Inkata Press, Melbourne.

Magarey, R.C. 1989. Quantitative assay of *Pachymetra chaunorhiza*, a root pathogen of sugarcane in Australia. *Phytopathology* 79: 1302-1305.

Moran, C.J., McBratney, A.B. and Koppi, A.J. 1989. A rapid method for analysis of soil macropore structure. Specimen preparation and digital binary image production. *Soil Science Society of America Journal* 53: 921-928.

Robertson, L.N., Kettle, B.A. and Simpson, G.B. 1994. The influence of tillage practices on soil macrofauna in a semi-arid agroecosystem in northeastern Australia. *Agriculture, Ecosystems and Environment* 48: 149-156.

APPENDIX 1 – Summary of minimum-tillage planting focus groups

Minimum tillage planting focus group meetings:
Ingham 9 March 1999 (I)
Mackay 12 May 1999 (M)
Tully 25 May 1999

What do you understand minimum tillage planting to be?

I To cultivate an area as little as possible to generate a seedbed for planting

I Three to four cultivations are not beneficial with respect to soil structure

I Problems could be seen with trash blanketing

M To plant cane with the least number of cultivations and for the lowest cost

M Perceived a need to cultivate to hold (conserve) soil moisture

M Problems associated with different soil types - 'glue-pot' for example, need to time cultivation with soil moisture

M Guidance seen as an issue, in not being able to traffic the same area each time

What are the benefits of minimum tillage planting?

I Less wear and tear on machinery during land preparation

Able to harvest under adverse seasonal conditions
Save fuel, working less ground, down-size equipment
System likely to be soil dependent, able to implement min-till on some areas but not on others
Potential for some erosion control

I Need to minimise compaction near stool, maintain compaction for traffic

I Problems - some shallow rooting cultivars may tip out need to cultivate ground to enable water to penetrate soil

M Only working a small area of block, resulting in time and cost savings

M Concerns - increased chemical usage, ability of roots to grow into the inter-row area, need research in each area due to variety of soil types before results will be believed, weed control was a concern

M Could increase the window of opportunity for tillage and planting

What are the benefits of conventional planting?

I Growers have the tools and knowledge, feel comfortable with the system

I It is what the growers know, tradition as knowledge passes from father to son

I Similar attitude as to when GCTB was first suggested

I Difficult to make valid comparisons over the long time scale involved, as only work ground at the end of each crop cycle

M Traditional to work ground

M Bigger tractors available to work ground quicker

M Best min-till equipment was irrigation, where the soil could wet and dry and break down

M Deep ripping effect was noticeable after a drainage line was put across a block; there was a noticeable improvement in growth

In your farming situation, what do you see as barriers to the adoption of minimum tillage planting?

I Variable soil types across farm

I Convention - to keep planting the same traditional way

I Would like to see results before adoption - prefer other areas to adopt min-till planting over a range of soil types

M Variable soils across farm and within blocks

Do you feel that changes are needed to current planting techniques?

I Dual rows a consideration, but filling-in perceived to be a problem, HDP could be OK

I Long term data needed on changes, more trials needed on mound planting

I At present plant in furrows, when it rains, even if block lasered the furrows fill, what is the point?

I Changes needed to row spacing due to width of current equipment

M Felt little or no changes were required

Would you adopt minimum tillage planting?

I There is a need for more information and local trials, generally prepared to trial a small area to compare it with conventional planting

I Equipment considerations, a planter needs to be built and available for hire

I Attitude to change, similar situation to adoption of GCTB

M Thought that seasons would affect the system, would work some years and not others, similar comment with respect to soil type where it would work well on some soils, but not on others

M Need to remove compacted layers and loosen soil

M Need to incorporate a green manure crop in the system

M Most willing to try small areas in the first instance, to fine-tune the system for that particular area or soil type

Do you think that min-till will make your farm more sustainable?

I Benefit in reduced erosion to conserve soil

I Costs can be reduced if go to controlled traffic and min-till; size of tractors can be reduced. Harvesters need to be modified before adoption (longer elevators, for example)

I Concern about increase in chemical use, potential residue build-up in soil and health risk to growers

M Yes, if yield is not compromised and if sugar levels are not affected

M Seedbed condition is the only factor that the grower can control. There also seems to be a variety influence as well, Q124 seems to respond to min-till

M Smaller tractor can be used resulting in fuel savings. Less time would be taken for land preparation

M The visual appearance of paddock at planting was a factor, an achievement to be proud of

Minimum tillage focus group meeting - Feluga 25 May 1999

Did not address the specific questions as circulated.

Meeting consisted of fruitful discussion on the concept of strategic tillage, since consensus was that everyone knew what was meant by minimum tillage.

Main concern in the area was surface water, especially where country was undulating and water collected in hollows. There was a need to coulter-rip the interspace to improve infiltration of this surface water.

Soil types were discussed with concern about using strategic tillage on heavier soils. There was a need to open the soil and aerate the profile. Compaction removal was another consideration.

Timing of tillage operations – due to wet conditions, had to cultivate when soil could be cultivated. This was usually too wet resulting in large clods being generated, and working back to reduce clod size. This usually involved a rotary hoe operation. Potential for plough-pans to develop.

Minimum tillage:

- ratoon sprayed out then cultivate area as per usual.

- to prepare a seedbed for planting using the minimum number of operations.

Comments:

Focus Group was useful as it provided an opportunity for growers to meet and talk in a small group.

Things were done in a particular way because historically it has been done that way (fixed in ways). Problems (perceived): ploughout-replant situation, handling trash, volunteers, weed control, run-off, erosion, waterlogging in low areas.

Benefit: cutting plants under wet conditions.

Discussion centred on how rapidly interspaces recompacted after cultivation – results were shown indicating that recompaction back to the level before cultivation occurred in a 12-month period ie after the first harvest.

The same pattern of soil strength can be maintained using strategic tillage as to that measured before any tillage operations undertaken. It was shown that after two discing operations, that a plough-pan was developing and that compaction at depth (50-60 cm) was not removed; an initial objective of tillage in the first place.

Data illustrating time, energy and cost savings was shown. It was commented that the cost of herbicide should be included in the spray-out system to enable a fairer comparison to be made.

It was suggested that a fact sheet should be produced to illustrate the various strategies, outcomes and potential cost savings, as it would be timely in the current climate of low sugar prices.

Benefits of strategic tillage discussed included, conservation of OM, less disturbance to soil fauna, less dilution of inoculum (*Metarhizium* for eg) and protection of soil structure.

Discussion also included the use of legumes in the systems as a source of nitrogen, to protect the soil surface and as a break crop. The ratoon could be sprayed out and the legume could be direct drilled into hills. The legume could be sprayed out, incorporated or the next cane crop direct drilled into the standing legume (several of the options discussed). Emphasis was on the development of a system by putting various components of the YDJV together.

APPENDIX 2 - Tractor measurements (Bundaberg only)

During the conduct of the field trials, the opportunity was taken to instrument the tractor used for cultural operations. This enabled, for the first time in the sugar industry, energy use and the time taken for the various tillage operations to be determined. These values will vary between systems due to different tractors and implements being utilised, but the relativity between systems should be similar.

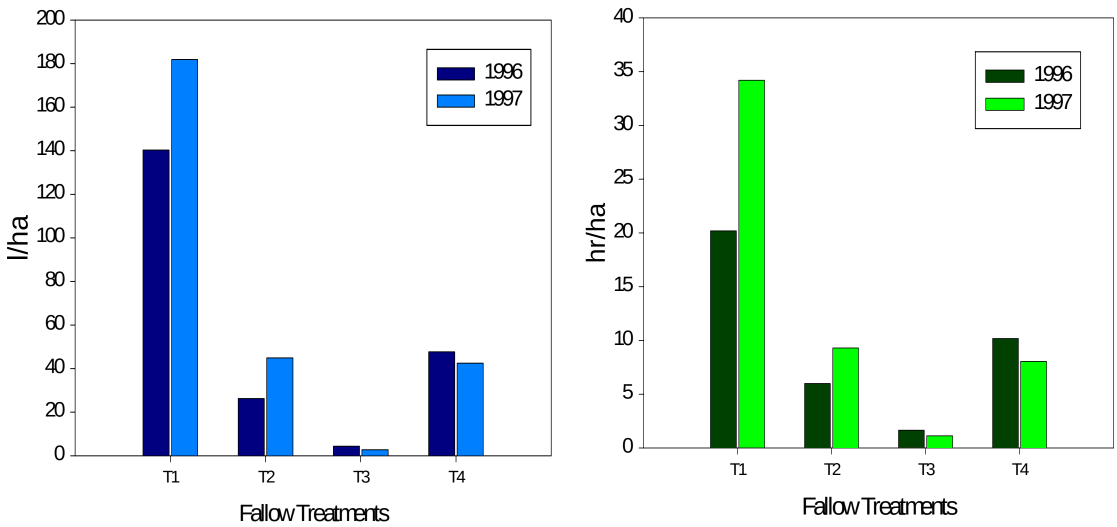


Figure 2.1 Tractor efficiency data from three treatments at Bundaberg - conventional cultivation (T1), stool ploughout (T2), stool spray-out (T3) and ploughout/replant at the Bundaberg site: (i) litres/ha of fuel; (ii) hours of tractor time per hectare

Fuel use (litres/ha) and time taken (hours/ha) and time taken (hours/ha) are given for each tillage strategy for 1996 and 1997 at the Bundaberg site (Fig1A). Equipment failure prevented the collection of similar data for the Tully site. The results show a considerable saving in fuel use and time taken in land preparation between conventional and strategic tillage practices.

Fuel savings of up to 80% were achieved by utilising strategic tillage (stool ploughout) compared with conventional cultivation. Similarly the operation used 97% less tractor hours to achieve the same seedbed condition.

To illustrate the economic advantage of adopting strategic tillage for planting a simplistic gross margin calculation was performed based on plot yield of both cultivars in 1997 (Table 2.1).

Table 2.1 Preliminary cost of land preparation operations at Bundaberg for 1997 planting

	Costs[a] : $/ha					
	Fuel	Roundup	2,4-D	Labour	Total	Total less labour
Conventional	63.14			410.40	473.54	63.14
Stool ploughout	15.58	87	18.6	111.6	232.78	121.18
Stool sprayout	0.94	152.25	18.6	13.2	184.99	171.79
Ploughout-replant	14.74					
	Income vs costs : per hectare Q138					
	Cane yield	Price ($/T)[b]	Gross income	Fallow costs	Difference	% Difference to conventional
Conventional	117.9	23.27	2743	473.54	2270	0.0
Stool ploughout	121.2	20.93	2535	232.78	2303	+1.4
Stool sprayout	118.7	22.61	2684	184.99	2499	+10.1
Ploughout-replant	108.6	21.47	2333	111.94	2221	-2.2
	Income vs costs : per hectare Q155					
	Cane yield	Price ($/T)[b]	Gross income	Fallow costs	Difference	% Difference to conventional
Conventional	97.4	24.26	2363	473.54	1889	0.0
Stool ploughout	92.2	24.50	2257	232.78	2025	+7.2
Stool sprayout	93.1	23.58	2196	184.99	2011	+6.5
Ploughout-replant	74.6	23.08	1721	111.94	1609	-14.8

[a] Assumed cost fuel ($/l) = 0.35; Labour ($/hr) = 12; Roundup ($/l) = 7.25; 2,4-D Amine ($/l) = 6.2
[b] Price ($/tonne) is based on CCS levels

This simple analysis illustrates that savings of around 50% can be achieved in land preparation costs by using stool ploughout compared with conventional land preparation. When the crop yield and CCS levels are included strategic tillage results in up to a 10% better gross margin compared with conventional tillage. The ploughout-replant results in a lower gross margin than conventional practice due to lower yield. All treatments except ploughout-replant were fallow planted. This large cost benefit is achieved in the year of planting, where the greatest costs are incurred.

Other benefits not considered here are less wear-and-tear on tractors and equipment, which may prolong the useful life of the investment. At the time of equipment renewal, the option of downsizing is real, as less power is required for cultivation, since only the row is disturbed. This would be a real cost saving. Also, the time saved on tillage can be invested in other farm operations, such as weed control or headland restoration. In the year of planting up to 50% in land preparation costs can be saved by the adoption of strategic tillage. This has also been demonstrated by a grower who, is trialing the concept, where conventional land preparation and planting cost $190/ha compared with zonal tillage land preparation and planting which cost $95/ha. Again a considerable saving in the year of planting.

APPENDIX 3 – Coping with compaction booklet

ISBN 0-949678-07-4
Coping with Compaction
Date of Publication:.01 Aug 2001

Written and prepared by Dr Mike Braunack
with contributions from Des McGarry

Contents

What is Soil Compaction?

Compaction is the reduction in pore space, between soil aggregates, which contains the water and air required for good crop growth.

Soil in good condition allows free movement of water and air, and provides a good environment allowing maximum root growth and high yielding crops.

Soil management is the key to future profit in agriculture.

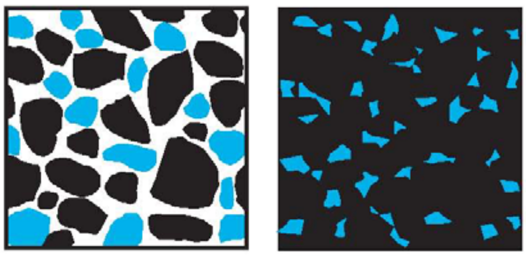
Soil is fragile and easily deformed. It provides the environment for worms, microorganisms and plants. When the soil components are packed tighter - compaction is the result. Compacted soil does not provide adequate space for soil animals, root growth or allow for easy movement of water and air.

Large, continuous pores conduct water and air the best. Tyres and tillage tools apply external force to the soil resulting in large continuous pores becoming smaller, and in some instances being sealed-off. This causes poor water infiltration, slow drainage and reduced aeration limiting root growth and nutrient uptake for maximum crop yield.

Compacted soils are **less productive**, substantially **reduce yield** and **profits** depending on the amount of compaction.

Effect of Compaction on Pore Space

(White is air; blue is water; black is soil aggregates.)



Uncompacted　　Compacted

Cost of Compaction

Soil compaction is an invisible soil limitation which **affects profits**.

Assess your management and **adopt ideas** from the following sections to **'cope with compaction'**.

Compaction is a widespread problem throughout the whole sugar industry.

Reducing soil compaction can reduce other production costs;

1) fuel costs related to high draft requirement during cultivation
2) reduced wear-and-tear on equipment, and
3) erosion and run-off

Depending on crop yield, ccs and the price of sugar it has been estimated that losses due to soil compaction vary between $145 to $430 per hectare.

If your farm is 50ha the potential loss of income ranges from $7,250 to $21,500. There is only **one person** who can **manage compaction** on the area that they farm, and that is **YOU**!

Soil compaction is an invisible soil limitation which affects profits.

Runoff and erosion causes soil loss from freshly cultivated areas.

Symptoms of Compaction

(Top and below). A wet harvest.

All soils can be compacted — soils with a range of particle sizes compact easier. Water acts as a lubricant allowing particles to be easily moved, soils compact easier as soil water content increases.

It is better to know how susceptible your soil is to compaction before harvesting or cultivating a block. With your new knowledge it will be easier to ignore neighbours who cultivate or harvest blocks $^1/_2$ to 1 day too early.

It has been shown that 80% of the compaction in the wheel track occurs in the first pass. A simple rule of thumb to determine soil suitability for cultivation is to invert a spade of soil, if the soil remains as a lump it is too wet for cultivation, if the soil crumbles it is OK to cultivate. Several positions in the field should be checked to the planned depth of cultivation. Compaction can still occur at depth, but this simple indicator should allow a seedbed to be prepared.

For harvesting, some people use the 'calibrated heel' if a heel print can be made in the soil it is too wet for harvesting.

Moderate compaction over time could cost more than the yield advantage of earlier planting. The risk of compaction is greater than the reward of planting one or two days early.

Susceptibility to Compaction

Low	High
Low soil moisture	High soil moisture
Soil particles of same size	Soil particles of differing size
High organic matter	Low organic matter
Minimum tillage	Frequent tillage
Low ground pressure equipment	High ground pressure equipment
Low axle load	High axle load

Identify the Symptoms

Before you can correct or minimise soil compaction, the nature and extent of the problem in a field needs to be identified.

(Photograph) an example of severe soil compaction - underlying a wheat field, north of Goondiwindi (Qld). The wheat crop in this field died from lack of moisture as it was unable to penetrate the compaction to subsoil moisture.

Photo courtesy D.McGarry.

Soil Symptoms

Surface crusting is a widespread symptom of surface compaction, usually as the result of excessive cultivation and exposure of the bare soil surface to intense rainfall. Poor crop emergence often results!

Surface water can be the result of a compacted layer reducing the infiltration rate. Poor drain performance may reflect the presence of a compacted soil layer preventing water reaching the drain.

Slow decomposition of organic matter may result if a compacted layer causes water logging resulting in soil with low oxygen content.

Soil erosion can be due to surface crusting or subsurface compaction. Runoff from sloping land can be worsened by slow water infiltration. This may result in a cycle of problems, since soil exposed by erosion is more susceptible to compaction due to a lower organic matter level.

Plant Symptoms

Plants often reflect soil compaction, since compacted soil does not provide a good growth environment. Some of the symptoms **may** be due to diseases or other stresses, **compaction** is often the hidden culprit.

Slow plant emergence and uneven stands can result from compacted soils. Seedlings have difficulty in emerging from compacted soil and root growth can be restricted. Gaps in the crop reduce yield!

Uneven early growth as characterised by tall and short plants may reflect **compaction**. This may also reflect restricted root growth by a compacted layer or the lack of sufficient oxygen for root respiration and microbiological activity. Crops on compacted soils tend to be shorter than normal plants at harvest. Herbicides and fertilisers are often blamed for the tall/short syndrome, but compaction may be the cause.

Off coloured leaves may reflect nutrient deficiency where root growth and water movement have been restricted by compacted soil. A common observation is yellowing of leaves due to nitrogen starvation.

Roots of soybean growing at right angles as a compacted layer is encountered.

Plant Symptoms Continued

Poor root growth due to compacted layer (left). Good root growth due to no compaction (right).

Unusual root patterns can indicate soil compaction. A frequent symptom is a shallow root system growing horizontally above a compacted layer.

Stressed plants under **wet** or **dry** soil conditions may indicate a compaction problem. A shallow root system can develop in soil kept wet near the surface by a **compacted** layer. This can result in stool tipping under windy conditions. If rain does not fall or an irrigation is missed these shallow roots may also suffer drought. In a wet season, crops may lack nitrogen in wet compacted soils although sufficient N was applied initially.

Once **identified** the **extent** and **depth** of **soil compaction** needs to be determined before plans can be implemented to minimise or alleviate the problem.

Methods to Determine Soil compaction

Look for patterns of poor stand compared with what is normally expected for the field. The soil should be examined when it is neither too wet or too dry. The best time is usually two to three days after rain or irrigation when the soil is easy to dig.

SPADE-HOLE INSPECTION

Excavate a hole in a suspected area about 600 mm square and 600 mm deep, leaving one side as free as possible of spade marks. Examine the undisturbed face for soil structural condition. Look at the shape of the clods, approximately cubed-shaped with shiny surfaces indicate natural structure, whereas platy-horizontal layering is a common feature under wheel tracks. Massive clods are a further sign of degradation, they appear dense, have few pores and appear dull. The appearance of clod faces is another indicator of structure, with shiny faces associated with good structure and dull surfaces associated with compacted and smeared soil. Shiny surfaces should not be mistaken or confused with smeared layers from tillage implements.

CONE PENETROMETER

A dial gauge or load cell records the pressure to penetrate the soil. These instruments will usually not be readily available to farmers due to the cost. Precise information is gained, but careful interpretation is required.

TALK TO AN EXTENSION OFFICER

They have access to information and equipment and have experience in data interpretation. They, will be able to assist in decisions about the need to deep rip, the best equipment to use and the optimum time for cultivations.

A cone penetrometer can be used to detect soil compaction.

Alleviating Current Compaction

Once the extent and depth of compaction has been determined, there is a need to SHATTER THE COMPACTION LAYER to provide a BETTER SOIL ENVIRONMENT for the growth of HIGH YIELDING CROPS.

Compaction commonly occurs around 400-450 mm, but it is recommended that deep ripping occur at a depth approximately 50 mm deeper. It is vital that the compacted layer is dry for optimum results to be achieved from deep ripping.

Growers considering minimum tillage strategies for planting should reduce soil compaction as much as possible to minimise yield losses. Equipment is available for deep tillage and some leave the surface relatively undisturbed. This may be an option if a one pass seedbed preparation is an option. Research has shown that sugarcane germinates and emerges well under minimum tillage planting.

Limit field operations (especially on wet soil), and use low axle load equipment otherwise recompaction will occur and no benefit will be gained from **expensive deep tillage** operations.

Fewer passes means less risk of compaction!

Surface crusting may indicate compaction.

To Minimise Compaction

Due to the time and expense in removing compaction, you need to be **unrelenting** in the quest of **no recompaction**.

There are three major ways to achieve minimum recompaction:

(i) reducing axle loads;

(ii) keep off wet soils and

(iii) keep traffic in specific tracks

(i) Reducing axle loads

A common rule of thumb is that most soils can withstand loads of about **6 tonnes per axle** when dry, without **causing severe compaction**. Recent studies indicate that there is a greater benefit using even **lower** axle loads! Minimise compaction by using multiple axles with low axle loads.

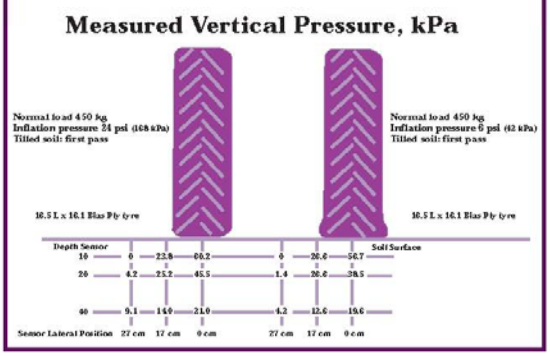
High axle loads cause subsoil compaction: determine axle loads and ground pressure of equipment before purchase.

To calculate the **axle load** of equipment, divide the total weight of the equipment by the number of axles and then divide by 1000kg for tonnes per axle.

A simple way to calculate **ground pressure** for wheeled vehicles is to add 14 kPa (2psi) for tyre carcass stiffness to the inflation pressure of the tyre. For example if the inflation pressure in the tyre is 140 kPa (20 psi) plus 14 kPa (2psi) for tyre wall stiffness the ground pressure is 154 kPa (22 psi). The **ground pressure** of a tracked machine is the total weight of the machine divided by the ground contact area of the tracks.

Keep in mind that axle loads of 6 tonnes and greater can result in severe soil compaction! When replacing equipment you should consider the cost of soil compaction. Do the simple calculations of axle load and ground pressure — **remember the lower the better to prevent recompaction!**

Lowering tyre pressure does not reduce subsoil compaction since levels of stress are similar under tyres at 24 and 6 psi.



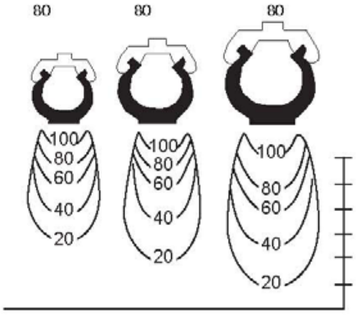
To Minimise Compaction (continued)

(ii) Keep off wet soil

Minimise traffic on wet soil and restrict use of high compacting implements, such as discs and hoes.

HOW LOADS AFFECT COMPACTION. Diagram shows the difference in soil compaction pressures of different loads in a soil with the same starting density and water content. Tyre sizes are selected proportional to the loads. Maximum compaction pressures will be the same for each load. However, a large tractor will transmit pressures deeper and over a wider area.

Tyre size:	7 x 24	9 x 24	11 x 24	13 x 30
Load kg:	300	500	750	1000
Pressure KPa	80	80	80	80



Ensure that the soil is not wet to the depth of tillage BEFORE cultivating the block. Bigger and heavier equipment increases the depth and width of soil stress when running on single tyres. Using dual tyres decreases the depth of soil stress, but greatly increases the width: the net result is an increase in volume of soil compacted.

Single tyres tend to compact the least area (similar to a tracked machine), but the traffic path left will be highly visible compared with that of a tracked machine due to a greater ground pressure.

Dual tyres double the traffic paths and in the course of cultivating a block, leave virtually no area untrafficked.

Using triple tyres adds another traffic path and virtually assures that the whole area is subject to soil compaction. Compaction is NOT

To Minimise Compaction (continued)

restricted to the harvesting operation. Remember, the compaction cycle starts with land preparation for planting, where the soil is initially loosened, and then goes through recompaction and decompaction cycles with subsequent tillage operations.

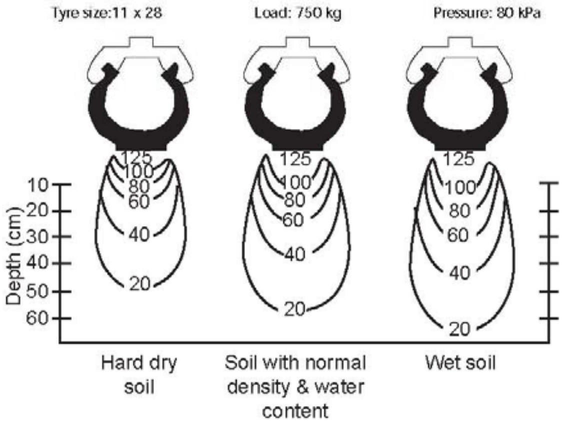
(iii)Keep traffic in specific tracks

The adoption of a system of controlled traffic will reduce the zone of compaction to the inter-row.

To ensure that the same area is always trafficked, crop rows need to be parallel and guidance systems should be fitted to harvesters and haulouts.

Strategic tillage (see photos A and B over page), where only the row is cultivated and the inter-row is left undisturbed, used in conjunction with controlled traffic should further restrict the area of a block subject to compaction.

HOW SOIL MOISTURE AFFECTS COMPACTION. Diagram shows the effect of soil moisture on compaction pressures. All three tyres are the same size and loaded equally. The wetter the soil, the deeper the pressures are transmitted.



To Minimise Compaction (continued)

One type of strategic tillage - removing the old stool with (A) a rotary hoe and (B) tine, ensuring the old inter-row remains intact.
Photos courtesy D.McGarry

Avoid Recompaction

- **Limit the number of passes.**
- **Restrict traffic to the same traffic lanes: match equipment track width with crop row spacing.(A)**
- **Avoid traffic on wet soil if possible. (B)**
- **Determine soil wetness to the depth of tillage before cultivation.**
- **Choose low axle load equipment where possible.**
- **Do not run over rows to align haulouts under elevators.(C)**
- **Do not reverse down rows.**
- **Travel down the same inter-row to exit field, avoid crossing rows. (D)**

Conclusions

Soils are most susceptible to compaction when they are in a loose and moist condition ready for planting.

It is unavoidable at times to traffic areas when soil is susceptible to compaction, for example wet conditions at harvest.

No matter what soil you have, formulate a plan to minimise compaction on the soil you farm.

Uncompacted soil has almost **unlimited yield potential** under 'ideal' growing conditions, and a **high yield potential** under more common 'less than ideal' such as dry or wet seasons. Improve the odds for high yielding crops under all conditions by:

The 3 Point Plan to Combat Compaction

1) Check for soil compaction.
2) If compaction is found — decompact (best results in dry soil).
3) Minimise recompaction, by adopting controlled traffic, minimum tillage planting and low axle load and low ground pressure equipment where possible.

BSES
Advancing Sugar

HEAD OFFICE

POSTAL ADDRESS: P.O. BOX 86,
INDOOROOPILLY, QLD, 4068

DELIVERY ADDRESS: 50 MEIERS ROAD,
INDOOROOPILLY, QLD, 4068

PHONE: 07 3331 3333

FAX: 07 3871 0383

WEBSITE: www.bses.org.au