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Final report - SRDC project BSS106: Assessing linkages between machine traffic, soil conditions and productivity

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FINAL REPORT - SRDC PROJECT BS106S
ASSESSING LINKAGES BETWEEN MACHINE TRAFFIC,
SOIL CONDITIONS AND PRODUCTIVITY
by
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SD01003

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SUMMARY

Field trials were conducted at two sites to provide a range in soil and environmental conditions. One trial quantified the effect of the position of harvesting traffic, relative to the row, on changes in soil properties and subsequent crop response. The other trial examined a strategy of minimising soil compaction in the row, thereby reducing soil degradation and improving conditions for crop growth. This was achieved by matching crop row spacing with equipment track width.

Matching crop row spacing with equipment track width resulted in less soil degradation in the row compared with the current narrow row spacing used by the sugar industry. To maintain plant populations dual rows 0.3/m apart were grown at 1.8 m centres. By increasing the distance between the row and traffic position, crop yield was up to 20% greater compared with the narrow row spacing. A system of controlled traffic offers great potential to the sugar industry in being able to manage soil compaction and potentially improve productivity. In establishing such a system care needs to be taken to ensure that all equipment runs on a common wheel track or a multiple thereof. All rows need to be parallel and all traffic to be restricted to the inter-rows. This may require fitting a guidance system to planting and harvesting equipment. Harvesters will require longer elevators to harvest at the wider row spacing. Narrow tyres or tracks should be considered to further restrict soil compaction to the middle of the inter-row. These compacted areas will provide better access under wetter harvesting conditions, thereby resulting in less damage to the crop and maintaining continuity of supply to the mill.

Traffic over the row reduced yield in the following ratoon crop compared with traffic near-the-row and in the middle of the inter-row. Soil physical conditions in the row were degraded after traffic over the row compared with the near-row and inter-row traffic. These trials were conducted at a soil water content considered to be suitable for harvesting, in that only a tyre imprint resulted from the traffic. Changes in soil properties were smaller with each subsequent trafficking, but were cumulative over the period of the trial. Yield losses of up to 20% may be expected due to traffic over the row during harvest under suitable harvesting conditions. It is speculated that greater losses would occur if harvesting occurred under wetter conditions.

It is recommended that the industry adopt a system of controlled traffic to minimise soil degradation in the row area. To maintain productivity harvesting traffic should be restricted to the inter-row. Harvesting should be undertaken under dry soil conditions where possible since trial data show that yield losses occur under conditions most growers would consider suitable. An education program should be instigated to raise the awareness of haulout operators of the consequences of traffic over the row in reducing yield potential in the following crop. This yield loss results in the economic loss to the whole industry, since there is less cane for the grower, less cane for the contractor to harvest and less cane for the mills to crush.

The effect of tracked equipment on soil properties and crop response needs to be investigated.

By reducing soil degradation the sugar industry protects its most valuable resource, the soil. This will improve and maintain the viability of the industry and enhance the industries image as a custodian of agricultural land.
1.0 BACKGROUND

There is a large amount of literature documenting that soil compaction reduces crop yield under mechanised production systems (Soane and van Ouwerkerk, 1994). The yield plateau in the sugar industry since 1975 has been linked circumstantially to the adoption of mechanical harvesting by the industry. Soil structure and the cane stool can be damaged during harvest by both the harvester and haulouts, especially under conditions of reduced mobility. Poor crop growth attributed to harvesting traffic damage is identified annually, but overall yield losses have not been quantified. Studies in Colombia under wet conditions resulted in yield losses up to 40% (Torres and Villegas, 1993) while, in South Africa, under drier conditions losses were up to 30% (Swinford and Boevey, 1984) when traffic occurred directly over the row. When traffic was restricted to the inter-row, yield losses of 10% were reported. Under dry conditions in Australia little or no yield loss due to soil compaction was measured (Braunack et al. 1993).

Yields usually decline with successive ratoon crops. This is consistent with restricted root systems due to soil compaction. In some years, a large proportion of the harvest is carried out when the soil is moist and susceptible to soil compaction. The cumulative effect of harvesting traffic on soil compaction over a crop cycle is unknown. Also, subsoil compaction must be minimised or avoided for the long-term sustainability of the industry.

Currently there is a mismatch between crop row spacing and equipment track widths in the industry (Photo 1 a,b) This results in traffic always occurring close to the row as harvesting progresses across the block. Frequently traffic is observed to occur over the row as haulouts align under the harvester elevator, or as haulouts take short cuts to exit points (Photo 1 c). The potential for soil compaction and damage to the crop increases as the size and weight of the haulout fleet increases (Photo 1 d).

The project was based on the premise that matching crop row spacing with equipment track width, would reduce soil compaction in critical zones for root growth, consequently resulting in increased yield and ratoon length. The effect of harvesting traffic on soil conditions and crop response was also quantified.
2.0 OBJECTIVES

1. Determine the effect of matching crop row spacing to harvester wheel track widths on longevity and yield of ratoon crops planted in dual rows.
2. Investigate the mechanism causing compaction due to machinery.
3. Determine any cumulative effect of harvesting traffic on soil physical properties, stool damage and ratooning in consecutive ratoon crops.
4. Develop a decision support model to manage the effect of soil compaction and yield.

Work by the University of Southern Queensland was to assist in meeting Objectives 2 and 3 above. In order to do this, a secondary set of objectives was defined as the basis for the postgraduate research program. They were:

1. Quantify the stresses that occur within a soil under a range of cane machinery.
2. Establish the extent to which soil stresses are transmitted under the crop rows from the machinery path given different soil types and water contents.
3. Identify and quantify the accumulated effects of traffic on soil structure in cane fields.
3.0 MATERIALS AND METHODS

3.1 Sites

Field trials were established at Tully and Ingham in north Queensland, to provide different soil types and climatic environments. Both sites were under grass prior to land preparation and planting. Some soil physical and chemical properties for each site are given in Table 1. The initial planting was in 1991, but poor establishment at Ingham necessitated ploughing out the crop and replanting in 1992. Two varieties were grown at each site with Q117 and Q138 being grown at Tully and Q115 and Q124 being grown at Ingham. Two trials were established at each site, details of which are given below. Trial 1 was established to quantify the effect of harvesting traffic on soil properties and crop response. Trial 2 examined the matching of crop row spacing with equipment track width on soil properties and crop response.

Table 1: Selected physical and chemical properties of soil at each trial site

<table>
<thead>
<tr>
<th>Site</th>
<th>Depth (em)</th>
<th>pH H₂O (1:5)</th>
<th>SEC dS/m</th>
<th>C</th>
<th>Si</th>
<th>FS</th>
<th>CS</th>
<th>G</th>
<th>Ca</th>
<th>Na</th>
<th>K</th>
<th>p</th>
<th>PL</th>
<th>Water Retention 33 1500 (kPa)</th>
</tr>
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<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>%</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
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<td>0-10</td>
<td>5.65</td>
<td>5.60</td>
<td>45.5</td>
<td>24.4</td>
<td>25.0</td>
<td>5.8</td>
<td>0.6</td>
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<td>0.07</td>
<td>0.2</td>
<td>13</td>
<td>32</td>
<td>29</td>
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<tr>
<td></td>
<td>10-20</td>
<td>5.59</td>
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<td></td>
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<td>2.68</td>
<td>0.06</td>
<td>0.12</td>
<td>16</td>
<td>33.5</td>
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</tr>
<tr>
<td>Ingham</td>
<td>0-25</td>
<td>4.65</td>
<td>0.14</td>
<td>44.8</td>
<td>25.5</td>
<td>24.2</td>
<td>3.1</td>
<td>0.2</td>
<td>4.24</td>
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<td>0.46</td>
<td>40</td>
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<tr>
<td></td>
<td>25-50</td>
<td>4.89</td>
<td>0.08</td>
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<td></td>
<td></td>
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<td></td>
<td>3.81</td>
<td>0.36</td>
<td>0.15</td>
<td>19</td>
<td>34.2</td>
<td>23.6</td>
</tr>
</tbody>
</table>

C: Clay, Si: Silt, FS: Fine Sand; CS: Coarse Sand; G: Gravel, PL: Plastic Limit

3.2 Treatment

3.2.1 Trial 1

The trial plots at Tully consisted of four single rows at 1.9 m spacing by 29 m long, and four single rows at 1.8 m spacing by 25 m long at Ingham. These row spacings were chosen to maximise the distance between the row traffic and inter-row traffic positions and to match equipment track widths as close as possible. The two central rows were the datum rows, with the outer two rows being guard rows.
The crop was harvested green and trash blanketted with no cultivation. Treatments were applied after harvest, and consisted of a single pass of a fully laden haulout (Photo 2,3).

1. trafficking directly over the row (R),
2. trafficking near-the-row (NR), and
3. trafficking the middle of the inter-row (IR).

Equipment used at Tully was a four tonne high flotation unit, while at Ingham it was a dual-axle, twin bin rollon-rolloff unit. The trials were harvested when soil was considered to be of a suitable moisture content, in that only a tyre imprint was left on the surface after equipment traffic.

### 3.2.2 Trial 2

This trial compared single rows at 1.5 m spacing (current industry standard traffic - conventional traffic) with dual rows (0.3 m apart) on 1.8 m centres (matched to equipment track width - controlled traffic) (Photo 4). Plots at Tully consisted of seven rows by 17m long, and at Ingham plots were four rows 30m long. Again the central 4 rows at Tully and 2 rows at Ingham were the datum rows, with the remaining rows being guard.

This trial was harvested green and trash blanketted, with zero cultivation during the ratoons. High flotation haulout equipment was used at both sites for harvesting, and no further traffic applied to the plots.

The only in-field traffic after harvest was fertiliser and herbicide applications, with all traffic being uniform across the trials.
Photo 2: Equipment and position of traffic during treatment application at Tully
Photo 3: Equipment and position of traffic during treatment application at Ingham
Photo 4: 1.5 m single rows and 1.8 m dual rows in relation to equipment track width at Tully
3.3 Soil measurements

The soil moisture-density relationship for each site was determined before treatment application (SAA, 1977). The maximum density (Proctor) was 1.49 and 1.38 g/cm$^3$ at 21 and 26% (w/w) for the Tully and Ingham sites, respectively. The maximum densities for Tully and Ingham sites were 1.34 and 1.31 g/cm$^3$ when determined after Håkansson (1990). The soil measurements were common across all trials, except where noted. Sampling was undertaken before harvest for all trials and then again after harvest for the plant crop and after harvest of each ratoon crop.

Physical properties assessed included soil bulk density (undisturbed cores 75 mm diameter by 50 mm high), saturated hydraulic conductivity (constant head technique) and soil cone resistance (recording cone penetrometer). Soil movement at two depths (150 and 250 mm) was measured during passage of harvesting equipment using stress transducers and by using a pin displacement technique.

3.4 Plant measurements

Crop response was assessed by stalk numbers and stalk height. Gap counts were made to determine harvestability. The yield for each crop was determined by mechanically harvesting and weighing the central datum rows in each plot.

3.5 Design and analysis

Trial 1

The trial design was a split-plot, with the main plot being the position of traffic and the split being made on variety. There were five replicates at Tully and four replicates at Ingham.

Trial 2

The trial design was a randomised block, with four replicates at both Tully and Ingham. Results were analysed using standard ANOVA in the STATISTIX® statistical package.

4.0 RESULTS

Data pertaining to the row only is presented (unless otherwise indicated) as this is where the crop is planted and subsequently ratoons from. Soil properties in this area would reflect any traffic encroachment due to harvesting traffic.

4.1 Objective 1

Determine the effect of matching crop row spacing to harvester wheel track widths on longevity and yield of ratoon crops planted in dual rows.
4.1.1 Soil properties

There was no significant difference between the measured soil properties in the row under the conventional and controlled traffic rows at Tully (Fig 1a).

**Figure 1:** Soil bulk density in the row under controlled and conventional traffic at the a) Tully and b) Ingham trial site

The one exception was for the saturated hydraulic conductivity in the 5-10 cm layer, where the soil in the controlled traffic rows conducted more water than that under
conventional traffic rows (Fig 2a). There was no significant difference in soil strength in the rows under both conventional and controlled traffic at Tully (Fig 3a).

**Figure 2:** Saturated hydraulic conductivity in the row under controlled and conventional traffic rows at the a) Tully and b) Ingham trial site
At Ingham, however, the soil bulk density was significantly greater under the conventional rows compared with the controlled traffic rows at all depths, except for 20 cm (Fig 1b). Saturated hydraulic conductivity was higher under controlled traffic rows than the controlled traffic rows, but only significantly greater at the 15 and 20 cm depths (Fig 2b). Soil strength was greater under the conventional traffic rows compared with the controlled traffic rows, but only significantly so between 5 to 25 cm (Fig 3b).

Figure 3: Soil cone resistance of the row under controlled and conventional traffic at the (a) Tully and (b) Ingham trial site
When the soil strength measurements are contoured, it can be seen that under both the conventional and controlled traffic rows a columnar appearance develops, with a zone of strength greater than 2 MPa approaching the surface under the inter-row areas (Fig 4), and a narrowing of low strength soil under the row area. Under the controlled traffic rows these high strength zones do not approach as close to the surface, and there is a larger volume of low strength soil under the row.

**Figure 4: Soil cone resistance profile for controlled and conventional traffic rows**

![Soil cone resistance profile for controlled and conventional traffic rows](image-url)
4.1.2 Crop yield parameters

There were very few significant differences between conventional traffic and controlled traffic for any of the yield parameters measured (Table 2). Generally at each site there was a significant difference between varieties in yield parameters, with Q138 outyielding Q117 at Tully and Q124 outyielding Q115 at Ingham. At Tully conventional traffic yield ranged from -13 to 26% over controlled traffic. However, at Ingham, the range was -2 to 18% in favour of controlled traffic. These results depended on seasonal condition and reflect the difficulty in trafficking the same area.

Table 2: Effect of matching crop row spacing with equipment track width on crop yield (t/ha cane, sugar and ccs)

<table>
<thead>
<tr>
<th>Site</th>
<th>Variety</th>
<th>Crop Class</th>
<th>Treatment</th>
<th>Conventional traffic</th>
<th>Controlled traffic</th>
<th>LSD (P&lt;0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>TCPH TSPH CCS</td>
<td>TCPH TSPH CCS</td>
<td>TCPH TSPH CCS</td>
<td>TCPH TSPH CCS</td>
</tr>
<tr>
<td>Tully</td>
<td>Q117</td>
<td>P</td>
<td>89.7 13.1 14.6</td>
<td>97.7 13.9 14.2</td>
<td>13.0 1.3 0.6</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>1R</td>
<td>94.1 10.7 11.4</td>
<td>92.3 10.1 10.9</td>
<td>17.5 2.7 1.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>2R</td>
<td>127.3 15.5 12.1</td>
<td>106.5 13.0 12.1</td>
<td>25.9 3.7 1.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>3R</td>
<td>86.4 12.5 14.4</td>
<td>96.4 13.9 14.4</td>
<td>20.2 3.3 1.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4R</td>
<td>77.6 10.4 13.5</td>
<td>87.8 11.6 13.1</td>
<td>25.8 3.6 1.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Q138</td>
<td>P</td>
<td>111.6 15.7 14.1</td>
<td>102.4 13.9 13.6</td>
<td>13.0 1.3 0.6</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>1R</td>
<td>129.4 11.1 8.6</td>
<td>101.1 9.4 9.3</td>
<td>17.5 2.7 1.2</td>
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<td></td>
<td></td>
<td>2R</td>
<td>169.3 18.4 10.9</td>
<td>125.6 13.7 10.9</td>
<td>25.9 3.7 1.6</td>
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</tr>
<tr>
<td></td>
<td></td>
<td>3R</td>
<td>115.4 15.5 13.4</td>
<td>124.4 17.9 14.4</td>
<td>20.2 3.3 1.3</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>4R</td>
<td>115.5 14.0 12.0</td>
<td>104.0 12.8 12.3</td>
<td>25.8 3.6 1.0</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Q115</td>
<td>P</td>
<td>87.1 13.6 15.7</td>
<td>91.6 14.9 16.3</td>
<td>14.9 1.3 0.6</td>
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<tr>
<td></td>
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<td>1R</td>
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<td>84.7 14.9 17.7</td>
<td>13.9 1.3 0.6</td>
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<td>14.9 1.3 0.6</td>
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<td>85.5 13.4 15.7</td>
<td>86.7 12.3 14.2</td>
<td>12.3 1.3 0.6</td>
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<td>5R</td>
<td>79.9 14.2 10.9</td>
<td>87.3 14.2 12.4</td>
<td>12.4 1.3 0.6</td>
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<tr>
<td></td>
<td>Q124</td>
<td>P</td>
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<td>113.9 18.8 16.5</td>
<td>13.3 2.1 0.6</td>
<td></td>
</tr>
<tr>
<td></td>
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<td>1R</td>
<td>97.9 16.9 17.3</td>
<td>101.6 17.6 17.2</td>
<td>17.2 2.6 1.3</td>
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<td></td>
<td></td>
<td>2R</td>
<td>119.0 16.9 14.2</td>
<td>124.6 18.4 14.7</td>
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<tr>
<td></td>
<td></td>
<td>3R</td>
<td>85.3 11.5 13.5</td>
<td>94.0 12.8 13.6</td>
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<td>104.8 16.4 15.7</td>
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<td></td>
<td>5R</td>
<td>111.1 13.8 15.3</td>
<td>109.2 13.8 14.8</td>
<td>12.6 0.5 2.1</td>
<td></td>
</tr>
</tbody>
</table>

LSD values refer to comparisons (between treatments and varieties) within the appropriate ratoon for the indicated yield parameter

4.1.3 Discussion

Results from the trial show benefits from the adoption of a controlled traffic system for sugarcane with respect to soil physical properties. The results also indicate some areas which need further consideration for the development and adoption of controlled traffic.
The soil measurements in the row show no significant benefit in soil properties at the Tully site and this was largely due to the fact that the crop lodged early making it difficult to distinguish the row position during harvesting operations. A consequence of this was that the rows were trafficked. Inexperience of the haulout drivers did not assist as it was observed during harvest that the unit moved sideways in an attempt to fill the bin. A driver education program would go some way to resolving this. Small plots with randomised treatments are not conducive to accurate positioning of large harvesting and haulout equipment. The trend, however, was for soil conditions to be better in the row under the controlled traffic system compared with the conventional system.

The benefits were more evident at the Ingham site where there were significant differences in soil properties in the row between conventional and controlled traffic. Increasing the distance between traffic position and the row has resulted in less degraded physical properties in the crop growth zone. This agrees with observations by other researchers (Tisdall and Adem, 1988). These differences in soil properties have persisted over the crop cycle. The interesting question remains as to whether these benefits can be maintained through the next crop cycle by using minimum tillage for planting.

There was little or no yield response between traffic systems at both sites (Table 2). This is not an uncommon observation when a system of controlled traffic is first adopted (Braunack et al. 1995, Gerik et al. 1987). Generally a response occurs when a soil physical limitation to production is removed before the instigation of a system of controlled traffic (Perdok and Lamers 1985). Yield responses varied between -26% to +18% when comparing the two traffic regimes and this was not consistent across variety and sites. The large negative response in yield between conventional and controlled traffic occurred at Tully with Q138. This variety tended to be taller and lodge early under dual rows resulting in deterioration and yield loss compared with the slightly shorter, more erect habit under single rows. Q117 did not lodge as early in the season and as a result did not suffer large yield reductions. For the last two ratoons, where the crop (Q138) did not lodge early, yields were greater under controlled traffic than under conventional traffic.

At Ingham the crop under controlled traffic tended to remain erect and yielded greater than the conventional traffic. Again there was a significant difference between varieties, with Q124 yielding more than Q115. Yield responses were positive and ranged from 1 to 18% when comparing controlled traffic with conventional traffic.

The results confirm previous experience with dual row systems for sugarcane where yield increases of around 20% were realised (Roach, 1977). However, consideration needs to be given to the reasons why certain varieties did not perform as well under the trialed system. It is speculated that some varieties may not be suited to 0.3m spacing between the dual rows since they tend to grow taller and lodge earlier in the season. This may be resolved by the current system using 0.5 m between the dual rows, since greater yield benefits seem to accrue. Care needs to be given to matching variety with soil type. This was one problem with Q138 at the Tully site, the variety is not particularly suited to better soils (A Hurney, personal communication, 1998) at the Tully site, whereas Q117 was.

Some traffic has encroached on to the row area under the wider row spacings. This is partly due to the haulout travelling in the wrong row and moving sideways to evenly fill the bin. It is also due to the fact that the elevator on the harvester is not long enough to deliver the cane into the haulout at the wider row spacing. This entails the haulout to
travel one row closer to the harvester and for the elevator to be slewed towards the rear. This raises safety issues through inexperience of working under these conditions. To resolve the problem, manufacturers need to install longer elevators on harvesters to enable safe operation at the wide row spacings. This issue will need to be addressed if the industry is to adopt controlled traffic in conjunction with high density planting concepts.

Given the level of yields determined it is thought that an extra ratoon could have been successfully grown at both sites thereby increasing the length of the crop cycle by one year at Tully and two years at Ingham. It is suggested that by adopting the practice of controlled traffic for sugarcane, where crop row spacing matches equipment track widths, yields will not be compromised, soil conditions in the row remain less degraded and ratoon length can be increased.

Objective 1 has been achieved.

4.2 Objective 2

Investigate the mechanism causing compaction due to machinery.

4.2.1 Soil deformation measurements

The refined grid point method developed by Bakker and Davis (1995) was used to quantify soil deformation under machinery tyres. The method is based on the movement of markers from an initial grid pattern in the soil profile.

In order to establish the initial grid of markers a 0.2 m wide pit is excavated across the plant row to a depth of about 0.5 m over a length of 1.2 m. The markers (matches) were placed in the side of the pit on a 50 mm grid and two pegs were established at the base of the pit to serve as a reference point in subsequent analyses. The pit was then backfilled carefully in an attempt to restore the initial soil density at the site.

After harvesting, the pit was re-excavated and the positions of the markers were recorded on a clear plastic sheet. This sheet is mounted on the reference pegs so that the match displacements from the original position can be established.

The soil deformation measurements were supplemented by soil density and soil water content values obtained by sampling with 98 mm diameter, 49 mm long cores.
4.2.2 Soil stress measurements

Soil stresses were measured within the soil using a stress transducer previously developed at the University of Southern Queensland. This transducer incorporates six diaphragm pressure sensors within a machined aluminium block. The signals from the sensor are logged in a data logger in real time as the vehicle moves over its position in the ground. The data provide a three dimensional representation of the stress paths in the soil that can be related to the soil deformation for computer simulations of the deformation process.

The sensor was installed under the inter-row such that it would lie approximately in line with the centre of the tyre. An access pit was excavated in the cane row adjacent to the sensor, and a hydraulic jack was used to push a metal tube from the pit to the required sensor location. This created a tunnel to the monitoring location. The sensor was then placed in the hole formed by the metal tube, and backfilled to ensure that all faces of the sensor was in contact with the soil mass. The signal conditioning unit, power supply, logging unit and operator were located two rows away from the approaching harvester during the test. Usually two passes of the harvester were recorded and then downloaded to a laptop computer.

4.2.3 Soil structure measurements

Soil macrostructure was measured using image analyses of epoxy-impregnated samples. The samples were collected in 120 mm square steel boxes 240 mm long. The open-ended boxes were made from perforated steel to ensure sufficient strength. They were pushed into the undisturbed soil profile by hand or with the assistance of a drop hammer. Three boxes were inserted at each sampling location to obtain a 360 mm long transect of the soil profile. The boxes containing the undisturbed soil samples were excavated and sealed in plastic bags to maintain the water content until they could be processed in the laboratory.

The soil samples (in the steel boxes) were vacuum impregnated in the laboratory with a fluorescent epoxy based resin. This process took approximately 30 minutes under a vacuum of about 75 kPa. The sample was left to cure overnight and then re-sealed prior to sectioning. The epoxy resin maintained the undisturbed soil macrostructure during sampling. The boxes were sectioned by angle grinder, and the sections were polished to give a smooth face using a diamond plated router in a specially built jig. The resulting section was photographed under an ultra-violet light source, which clearly highlighted the void space throughout the darker soil mass. The photographs of the section were analysed using a video camera to input the image to the computer. The analysis software was previously developed by Moran et al. (1989), and came in the form of a computer program called STRUCTURA. It estimates the pore structure attributes, and presents summaries of porosity, pore surface area per unit volume, horizontal pore star length and horizontal star length. Changes in the macrostructure of the soil were reflected in these summaries.
4.2.4 Results

The results of the field and laboratory studies on the soil structural changes have been published in separate papers at three conferences. The main findings are summarised below:

4.2.5 Soil stress and deformation

Data have been collected on the levels of stress transmitted into the soil profile by cane harvesting equipment. These data are represented by a stress path drawn in the Normal-Shear stress plane. Technically, the information allows the known tyre loadings (as functions of tyre pressure and axle weight) to be related to the resulting stress in the soil mass during the trial.

The associated database of soil deformation values is summarised by a grid of relative movement on a cross sectional representation of the soil profile. These grid point values are used to validate the deformations simulated by the computer model, as described below. The soil stress and deformation values together provide a uniquely useful data base for understanding the effects of machinery traffic on the Tully and Ingham soil types. They also establish a methodology that could be used on other soil types in the Queensland sugar industry.

4.2.6 Soil macrostructure

The soil deformation values provide an indication of the macro effect of traffic on the soil. Gross soil deformations are represented by the total movement in two dimensions (horizontally and vertically) at grid points in the profile. This information was supplemented by a more detailed analysis of the soil macrostructure in which the arrangement of voids and aggregates was digitised for computer comparisons.

The collected samples indicate that there was no significant change in structure under the crop rows through to the second ratoon stage. However traffic during planting, fertilising and subsequent operations significantly reduced the pore space in the inter-row during this part of the rotation. The harvesting operation further reduced the pore space, leaving few voids in the profile except for a few near the surface.

The changes in porosity found by image analysis were compared with air filled porosity values from soil cores. The soil cores indicated a higher porosity value, probably because the fluorescent resin used in the image analysis would only penetrate interconnected voids in the profile. A graphical comparison indicated that the two sets of values were related and that the image analysis technique provided a valid indication of soil structure degradation in soils growing sugarcane.

4.2.7 Soil modelling

The field measured values of machinery induced loadings and resulting soil structural changes (summarised above) have established that there was a significant traffic effect on the soil at the trial sites. An attempt was made to use this data to develop and validate a generic computer based model of the soil behaviour so that the results could be extended to other sugarcane growing areas.
A two dimensional finite difference model called FLAC (Fast Lagrangian Analysis of Continua) was used for this part of the study. The model parameters were set to replicate the brown medium clay soil from the Tully research site. This soil was laboratory tested to establish the Critical State parameters for this purpose. The machinery tyre load distributions were obtained from the work of Wulfsohn and Upadhaya (1992) and used in the model.

The model results to date have established that the selected approach using FLAC incorporating the Cam-Clay model for soil mechanics can adequately simulate the behaviour and effects of a loaded tyre on an agricultural soil. It is possible to closely simulate the behaviour of a soil underneath a cane harvester.

Validation of the model with the collected field data has proven to be a major task and is continuing. This work is being undertaken by Mr Conway on a part time basis. Final results will be published in the technical literature as they become available.

The model results have established that the approach adopted in this study offers significant advantage to the sugar industry, and will allow the subsequent development of a decision support package to manage the effects of harvesting on soil compaction.

Objective 2 has been achieved.

4.3 Objective 3

Determine any cumulative effect of harvesting traffic on soil physical properties, stool damage and ratooning in consecutive ratoon crops.

4.3.1 Soil properties

Soil properties in the row changed under all treatments. It was thought that by maintaining specific positions of traffic, relative to the row, that soil conditions would not markedly change in the row under near-row or inter-row traffic. The work reported under Objective 2 shows that both vertical and lateral movement of soil occurs during traffic, with the largest movement being close to the surface. This may account for some of the changes in soil properties even though no traffic occurred over the row in the near-row and inter-row treatments.

Soil bulk density in the row increased after traffic over the row at both sites (Fig 5). The increase was only significant at the Ingham site. There was a significant decrease in bulk density in the row for the near-row and inter-row treatments at Tully. There was little change in density in the row for the near-row treatment, but density increased under the inter-row treatment. There is evidence of the cumulative effect of traffic in that the soil bulk densities tended to increase after each traffic impact, especially at depth (Fig 5). There was a significant difference in bulk density between the rows of the row and inter-row treatment and a significant difference between the row and inter-row of each respective treatment (Fig 6).

Soil strength changed significantly in the row after all treatments at both sites (Fig 7). With subsequent reapplication of treatments the strength continued to increase in the surface (0-20 cm) under the row treatment. The degree of change in the row was less
under the near-row and inter-row treatments at both sites, with significant differences occurring in the 0-15 and 0-10 cm depths at Tully and Ingham, respectively.

Figure 5: Change in soil bulk density in the row due to traffic at Tully and Ingham
Figure 6: Comparison of soil density in the row (r) and inter-row (ir) due to traffic over the row and down the inter-row

Tully Traffic Trial
1994

Bulk Density (g/cm$^3$)
Figure 7: Change in soil resistance in the row due to traffic at Tully and Ingham

Tully Traffic Trial
Cone resistance (MPa)

Ingham Traffic Trial
Cone resistance (MPa)

- ● before first traffic
- ○ after first traffic
- □ after final traffic

(a) R
(b) NR
(c) IR
(d) R
(e) NR
(f) IR
4.3.2 Crop yield parameters

Stalk populations (data presented for Q138, Tully site) differed between treatments at various times through the season (Fig 8). However, there was usually no difference in stalk populations before harvest.

Figure 8: Stalk population (no/m²) for Q138 for each ratoon
Significant differences between treatments for tonnes cane per hectare were measured at both sites (Table 3).

There were few differences in yield parameters measured at both sites, especially for CCS (Table 4) and tonnes sugar per hectare (Table 5). Varieties seemed to respond differently to treatments at the sites, with one variety tending to yield higher than the other.

The trend was for the inter-row treatment to have the highest yields with the near-row treatment being slightly higher or lower and the row treatment having the lowest yield.

### Table 3: Cane yield (tonnes/ha) for each variety at each trial site

<table>
<thead>
<tr>
<th>Site</th>
<th>Variety</th>
<th>Equipment</th>
<th>Crop Class</th>
<th>R</th>
<th>NR</th>
<th>IR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tully</td>
<td>Q117</td>
<td>High flotation HBM 4t 1 axle</td>
<td>1R</td>
<td>108.5</td>
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<td>85.1</td>
<td>85.1</td>
<td>76.5</td>
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<td></td>
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<td>4R</td>
<td>93.6a</td>
<td>77.2b</td>
<td>64.6b</td>
</tr>
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<td>Q138</td>
<td></td>
<td>1R</td>
<td>115.7</td>
<td>115.0</td>
<td>113.6</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2R</td>
<td>105.4a</td>
<td>121.1b</td>
<td>114.8b</td>
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<td></td>
<td></td>
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<td>108.2ab</td>
<td>117.2b</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>4R</td>
<td>105.8a</td>
<td>120.4ab</td>
<td>122.4b</td>
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<td>Q115</td>
<td>Conventional Rollon/Rolloff 2 by 4t bins Dual tyres Dual axle trailer</td>
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<td>75.3</td>
<td>71.1</td>
<td>82.3</td>
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<td>79.4</td>
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<td>3R</td>
<td>81.5a</td>
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<td></td>
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<td>61.4</td>
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<td>Q124</td>
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<td>72.6b</td>
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<td>83.7a</td>
<td>88.4b</td>
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<td>3R</td>
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<td>88.5ab</td>
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<td></td>
<td>4R</td>
<td>74.4</td>
<td>80.9</td>
<td>77.5</td>
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<td></td>
<td>5R</td>
<td>66.2a</td>
<td>68.6a</td>
<td>80.9b</td>
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_Treatments in the same row with the same superscript are not significantly different (P<0.05)_
Table 4: CCS for both varieties at each trial site

<table>
<thead>
<tr>
<th>Site</th>
<th>Variety</th>
<th>Equipment</th>
<th>Crop Class</th>
<th>Treatment</th>
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</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>R</td>
</tr>
<tr>
<td>Tully</td>
<td>Q117</td>
<td>High flotation</td>
<td>1R</td>
<td>13.1</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HBM 4t 1 axle</td>
<td>2R</td>
<td>13.8</td>
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<td></td>
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<td>3R</td>
<td>13.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4R</td>
<td>13.2</td>
</tr>
<tr>
<td></td>
<td>Q138</td>
<td></td>
<td>1R</td>
<td>10.5a</td>
</tr>
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<tr>
<td></td>
<td></td>
<td></td>
<td>4R</td>
<td>13.5</td>
</tr>
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<td>Ingham</td>
<td>Q115</td>
<td>Conventional</td>
<td>1R</td>
<td>17.2</td>
</tr>
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<td></td>
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<td>Rollon/Rolloff</td>
<td>2R</td>
<td>11.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 by 4t bins</td>
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<td>15.7</td>
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<tr>
<td></td>
<td></td>
<td>Dual tyres</td>
<td>4R</td>
<td>16.1</td>
</tr>
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<td></td>
<td></td>
<td>Dual axle trailer</td>
<td>5R</td>
<td>14.3</td>
</tr>
<tr>
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<td>Q124</td>
<td></td>
<td>1R</td>
<td>16.8</td>
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<td>4R</td>
<td>15.9</td>
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<td></td>
<td></td>
<td></td>
<td>5R</td>
<td>13.8a</td>
</tr>
</tbody>
</table>

Treatments in the same row with the same superscript are not significantly different (P<0.05)

There was no significant difference in CCS between treatments with the exception of Q138 first ratoon at Tully and Q124 fifth ratoon at Ingham (Table 4).

As a result of few differences in CCS, there were few significant differences in the tonnes sugar per hectare (Table 5). The trend was similar to tonnes cane per hectare, with the inter-row treatment having the highest sugar yield compared with the other two treatments. The row treatment tended to have the lowest sugar yields.

Table 5: Sugar yield (tonnes/ha) for both varieties at each trial site

<table>
<thead>
<tr>
<th>Site</th>
<th>Variety</th>
<th>Equipment</th>
<th>Crop Class</th>
<th>Treatment</th>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>R</td>
</tr>
<tr>
<td>Tully</td>
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<td>High flotation</td>
<td>1R</td>
<td>14.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td>HBM 4t 1 axle</td>
<td>2R</td>
<td>12.1a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3R</td>
<td>11.5</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4R</td>
<td>12.2a</td>
</tr>
<tr>
<td></td>
<td>Q138</td>
<td></td>
<td>1R</td>
<td>12.2</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2R</td>
<td>13.4a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>3R</td>
<td>10.0a</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>4R</td>
<td>14.2</td>
</tr>
<tr>
<td>Ingham</td>
<td>Q115</td>
<td>Conventional</td>
<td>1R</td>
<td>12.3</td>
</tr>
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<td>Rollon/Rolloff</td>
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<td>2 by 4t bins</td>
<td>3R</td>
<td>12.8</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dual tyres</td>
<td>4R</td>
<td>10.4</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Dual axle trailer</td>
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<td>9.6a</td>
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<tr>
<td></td>
<td>Q124</td>
<td></td>
<td>1R</td>
<td>10.9a</td>
</tr>
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<td></td>
<td></td>
<td></td>
<td>5R</td>
<td>9.1a</td>
</tr>
</tbody>
</table>

Treatments in the same row with the same superscript are not significantly different (P<0.05)
There were significant differences in gappiness between treatments as the trial progressed at Tully (Table 6). There was an increase in gaps under the inter-row treatments, and this was largely under one variety (Q117).

### Table 6: Effect of treatments on gaps (%) at each trial site

<table>
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<tr>
<th></th>
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<th></th>
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</tr>
</thead>
<tbody>
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<td>Row</td>
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<td>7.8a</td>
<td>6.4a</td>
<td>3.0a</td>
<td>19.0a</td>
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<tr>
<td></td>
<td>Near-row</td>
<td></td>
<td>7.8</td>
<td>10.8ab</td>
<td>8.1ab</td>
<td>8.1ab</td>
<td>34.4ab</td>
</tr>
<tr>
<td></td>
<td>Inter-row</td>
<td></td>
<td>8.6</td>
<td>11.3b</td>
<td>8.8b</td>
<td>12.1b</td>
<td>45.9b</td>
</tr>
<tr>
<td></td>
<td>1.5m single</td>
<td></td>
<td>6.4a</td>
<td>8.1ab</td>
<td>8.8b</td>
<td>12.1b</td>
<td>45.9b</td>
</tr>
<tr>
<td></td>
<td>1.8m dual</td>
<td></td>
<td>6.4a</td>
<td>8.1ab</td>
<td>8.8b</td>
<td>12.1b</td>
<td>45.9b</td>
</tr>
</tbody>
</table>

| Ingham | Row       |               | 11.9 | 8.3 | 9.0 |
|        | Near-row  |               | 14.2 | 8.7 | 9.6 |
|        | Inter-Row |               | 15.3 | 8.6 | 7.9 |
|        | 1.5m single|               | 15.0a| 11.3a| 9.2a|
|        | 1.8m dual |               | 4.6b | 2.9b | 2.3b|

*Numbers in the same year followed by the same letter are not significantly different (P<0.05)*

#### 4.3.3 Discussion

The soil physical data demonstrate that over time traffic over-the-row increases soil bulk density of the row. There were changes in soil bulk density in the row position for the other treatments as well. Although all traffic in these treatments nominally occurred in the designated positions of near-row and inter-row, some encroachment of traffic has occurred into the row zone. A difficulty encountered throughout the trial was the ability to traffic the same area each year and to apply traffic treatments at the same soil moisture content. This influences the spread of traffic and the change in soil properties. It is appreciated that this situation occurs in commercial harvesting as well. One way to ensure the same area is trafficked would be to utilise guidance systems. This would restrict the spread of traffic and be appropriate in a controlled traffic system. It would also be necessary to ensure that when planting, the crop rows are parallel and at the appropriate spacing.

The encroachment of traffic was more evident for the near-row treatment than for the inter-row treatment. This was due to the proximity of the traffic to the row in the former compared with the latter treatment.

Soil cone resistance values reached values of 2MPa, which have been shown in the literature (Greacen et al. 1969) to restrict root growth, under all treatments. However, these values were approached close to the surface after traffic over-the-row. This would restrict root development and uptake of water and nutrients in the surface layers. If fertiliser is placed in the shallow surface layers or broadcast on the surface, high soil strength may be a limited factor in utilising the applied nutrients. However, when rainfall occurs or irrigation applied, the high strength layers in the soil disappear and water and nutrients become available. This is perhaps why sugarcane is less sensitive to soil compaction per se than other crop species, especially those with tap roots. The fact that sugarcane is a long growing crop also assists in its lack of sensitivity to soil compaction.
The crop has an opportunity to grow through or out of compacted soil as rainfall or irrigation occurs. Problems may arise if rainfall does not occur or rainfall occurs after an irrigation event.

Stalk counts and gap measurement were used as surrogates for stool damage due to harvest. It was not possible to evaluate stool damage by excavation, without compromising the trial. Sugarcane has the ability to shoot from multiple points after harvest (Moore, 1987), so it is difficult to know what the potential number of stalks that would germinate and emerge is or what effect harvesting traffic has. For example, if there are twenty potential eyes to shoot and only five fail, it is difficult to determine whether the failed eyes did so due to physical damage or they were not going to germinate anyway. Stalk population is not a good indicator of stool damage. It is presumed that gaps can occur in one of two ways, the sett is physically removed during the harvesting operation, due to stool tipping, or all the potential ratooning points are physically damaged resulting in stool death. Again it is difficult to distinguish between the two mechanisms, without excavation and physical examination.

There were fewer gaps in the row treatment compared with the near-row and inter-row treatments. With an increasing number of ratoons the number of gaps tended to increase in the inter-row treatment at Tully, especially with the variety Q117. This variety developed an open sprawling habit which contributed to harvester damage and yield losses. There were no differences between traffic treatments with respect to gaps at Ingham throughout the trial.

The data shows that under the conditions of the trial that minimal stool damage occurred. This contrasts with work from South America where 40% yield loss was attributed to compaction and stool damage (Torres and Villegas, 1993). However, they impacted the soil at considerably higher water contents than the completed study, and they also did not make any crop assessment other than yield.

Ratooning was affected by traffic over-the-row since yields tended to be lower than for the other two treatments. There was no consistent trend in ratoon yield with respect to ratoon age, this variability probably reflects seasonal conditions. At Tully yields for Q117 were below mill average at third ratoon and would in all probability have been ploughed out. This was confirmed from fourth ratoon yields which were considerably lower than the mill average. It is thought that the low yield for the inter-row treatment was due to the fact that the wide, single rows (1.9 m) formed an open sprawling growth habit. This resulted in cane losses at harvest due to knockdown in adjacent rows and poor pick-up by the harvester. Where traffic occurred over and near-the-row a less open sprawling habit was noted. This was not the case for Q138, which yielded higher than mill average for all ratoon crops. This crop could have been successfully ratooned for a fifth ratoon and possibly a sixth ratoon, although the yield drop-off was greatest for the traffic over-the-row compared with the other two traffic treatments.

Ratoon yields at Ingham were below mill average for both varieties for all treatments. However, this may be due to the fact that the crop was ploughout-replant which was necessitated by poor establishment under dry conditions of the first planting of the trial. Ratoon yields dropped-off more rapidly for the row traffic treatment compared with the
other two treatments. As a consequence this crop (traffic treatment) would have been ploughed-out and replanted earlier than the other two, thus shortening the ratoon cycle.

It should be noted that these yield losses occurred after one pass by a haulout in each designated position under ideal soil conditions for harvesting. Under a commercial harvesting operation many more passes occur, increasing the potential for traffic over-the-row and harvesting often occurs under less favourable soil moisture conditions, resulting in greater changes in soil conditions than these measured under the trial conditions reported here.

Objective 3 has been achieved.

4.4 Objective 4

Develop a decision support model to manage the effect of soil compaction and yield.

The fourth objective was to provide the basis of a subsequent project that was foreshadowed in earlier progress reports to develop an extension and demonstration package based on CD-ROM technology.

A finite element model was to be used by the student from USQ to enable changes in soil properties to be simulated under different harvesting equipment used by the industry. The model was to be validated from trials being conducted in the course of the project and measurements made on an opportunistic basis. A PPP was submitted to SRDC for consideration for funding in the financial year 1997/1998, but was unsuccessful in gaining funds. (A decision support package for machinery management in sugarcane).

This objective has been achieved with details to be reported in a Master's Thesis to be submitted to the University of Southern Queensland.

5.0 RECOMMENDATIONS

To maintain the soil resource and reduce or restrict soil degradation, through soil compaction, it is recommended that the sugar industry adopt a system of controlled traffic. The configuration of such a system will depend on the individual grower. A system of controlled traffic in conjunction with different crop spatial arrangements may offer the industry an opportunity for vertical expansion, thereby reducing the need for horizontal expansion onto marginal areas.

To ensure that traffic occurs in the same location each time crop rows need to be parallel and guidance systems developed for both planting and harvesting equipment.

To further explore the benefits of controlled traffic some work needs to be conducted in a drier environment than the area where this work was undertaken. It is thought that better soil physical conditions may be more important under dry conditions through an improvement in water availability and root growth. This issue was not able to be tested in the Wet Tropics since there were very few dry periods during the trial.
To reduce yield losses all harvesting traffic should be restricted to the inter-row. This will
minimise soil degradation in the row, reduce direct stool damage and maintain
productivity.

An education program needs to be instigated to increase industry awareness of the
consequences of harvesting traffic over the row, since it results in economic loss to the
whole industry.

The benefit of different running gear on haulout equipment in reducing soil compaction
needs to be investigated. High flotation tyres and rubber tracks offer potential to improve
mobility under wet soil conditions, but the effect on subsoil compaction is unknown. This
was beyond the scope of the reported project. Subsoil compaction maybe a hidden,
permanent limitation to productivity.

The use of long term controlled traffic in conjunction with strategic tillage for planting
should be investigated with respect to ratoon length and on changes in soil biology and
associated changes in soil insect populations and soil-borne diseases.

6.0 PUBLICATIONS ARISING FROM THE PROJECT


2nd national Controlled Traffic Conference, 26-27 August, 1998. University of
Queensland, Gatton, p155-162.


sugarcane harvesting. Proc. National Controlled Traffic Conference, 13-14


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8.0 REFERENCES


