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ECONOMIC COST OF SOIL COMPACTION

by

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SD00008

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SUMMARY

The cost of soil compaction to the Australian sugar industry is unknown. The main problem in estimating the cost of soil compaction is the difficulty in being able to relate crop response to a change in a soil physical property applicable across all soil types. To overcome this, the concept of degree of soil compactness was developed in Sweden, which is a field bulk density expressed as a percentage of the maximum bulk density of that soil determined in a standard test. It has been found that the degree of soil compactness is independent of soil type for a wide range of mineral soils.

A Scandinavian compaction model has been modified for the sugar industry. The model uses a crop response curve based on the degree of soil compactness. Using data from current trials and a historical trial, a response curve has been constructed for sugarcane. The model estimates yield loss, based on equipment parameters and the various operations involved in the production of a crop, and calculates the economic value of that loss based on the current price for the crop. This enables different scenarios to be examined with respect to potential yield loss. Such things as using different running gear, changing the number of passes or reducing the weight of equipment may be examined at different soil moistures to determine the effect on crop yield of the following crop. This will aid in making informed management decisions to minimise the effect of soil compaction and reduce potential yield losses.

The cost of soil compaction to the sugar industry in Queensland depends on the region and reduction in yields which may be anticipated. This will vary according to conditions at harvest. It has been estimated that the loss to growers is in the order of $116 per hectare at a 5% yield loss in the northern region to $500 per hectare at 15% yield loss in the Herbert-Burdekin region. Averaged over the state, the loss to growers is $145 to $431 per hectare at a 5% and 15% yield loss, respectively.

The economic loss to the Queensland industry, as a whole, has been estimated as ranging between $54m and $164m at a yield reduction of 5% and 15%, respectively (Table 3).

It is recommended that to reduce these losses to the individual growers and the industry as a whole, matching crop row spacing with equipment track widths be undertaken to minimise the effect of harvesting traffic.

It is recommended that during harvest, the number of passes down each row be kept to a minimum, and that harvesting be undertaken under as dry conditions as possible. Also, contractors should use the lightest equipment available to reduce the effect of subsoil compaction. Subsoil compaction was illustrated as a problem when the weight of equipment was increased in model simulations.

It is recommended that research be conducted into the effect of harvesting equipment on subsoil compaction and whether it is a limitation to productivity. Also, research is required into the efficacy and longevity of operations undertaken to remove subsoil compaction, since this is an expensive operation.

1.0 BACKGROUND

The economic cost of soil compaction in the Australian sugar industry is unknown. Since the complete adoption of mechanical harvesting in the mid 1970s, the industry has experienced a yield plateau. Soil compaction, as a result of increased infield traffic by heavier equipment, may be a contributing factor (Figure 1). The industry is inexorably moving to bigger and heavier harvesting and haulout equipment. To reduce the effect of traffic on soil compaction, wider tyres and an increasing number of axles are used.

Figure 1: Large haulout equipment used in the sugar industry. What is the cost due to soil compaction?

Yield losses of between 5% and 14% have been attributed to the effect of harvesting traffic (Braunack, 1995). It is estimated that for every 1% loss in yield, there is a loss of approximately $10m to the industry, so losses of 10% represent a potential loss to the industry of around $100m and a significant proportion of this may be prevented.

Soil compaction generally has an adverse effect on crop growth, but it is difficult to relate crop response to a single soil parameter which is applicable over a wide range of soil types. Håkansson (1990) developed the concept of the degree of compactness of the plough layer, which is defined as the dry bulk density of the soil as a percentage of the maximum bulk density of the same soil after a standardised uniaxial compression test. The optimal degree of compactness was found to be largely independent of soil type for a range of soils (Lipiec, *et al* 1991). The degree of compactness may differ between crop species and tended to vary with season, being high under dry conditions and lower under wet conditions.

Sugarcane is unique in that the crop grows in the same soil zone for a period of up to six years and is subject to intensive infield traffic during harvest. To assess the consequences of harvesting traffic, a Swedish compaction model (Arvidsson and Håkansson, 1991) was used to predict likely yield reductions and the economic value of the yield loss.

This project was developed as a result of a study tour undertaken by Dr Braunack (Braunack, 1994) where the concept of the degree of compactness was thought to be applicable to the Australian sugar industry.

The overall aim of the project was to assess the economic cost of soil compaction and the benefits from reducing soil compaction for the Australian sugar industry.

2.0 OBJECTIVES

1. Adapt a Scandinavian model to determine the effect of soil compaction on crop yield for the Australian sugar industry.

2. Relate crop response to degree of compactness by examining current and previous trials on soil compaction.

3. Estimate the economic value of reducing soil compaction.

4. Provide software and preliminary training to extension officers.

5. Subject to the successful completion of this project, apply for further funding to support a planned extension program.

3.0 METHODOLOGY

To adapt a compaction model developed for Scandinavian conditions to Australian conditions, one of the model authors, Dr Inge Håkansson, visited Australia (based at Tully) on two occasions. The first visit (12-24 November, 1995) was to familiarise Dr Håkansson with the production and harvesting system for sugarcane and to hold discussions regarding potential changes to the model and availability of data for model validation. Prior to the first visit, Dr Håkansson arranged for the model to be translated from Swedish to English. During the second visit (2 May – 7 June 1996) available trial data was worked up to calculate degree of compactness and crop response, to begin development of a response curve for sugarcane. Dr Håkansson also provided an English translation for documentation for the software.

Changes to the model were necessary since the Scandinavian model was developed for broadacre cropping and assumes soil loosening each year. Also, traffic in broadacre cropping was considered to be random, in contrast to sugarcane where the traffic position is fixed for the crop cycle.

Changes to be incorporated consisted of assuming cumulative effects on the degree of compactness of all traffic throughout the crop cycle since no annual cultivation occurs. The importance of position of traffic relative to the row and how this effect could be portioned was another consideration. The ability to increase the number of passes by haulout equipment needed to be incorporated as well.

A load frame was fabricated to enable the standardised uniaxial compression test (Håkansson, 1990) to be undertaken for a range of soils from current field trials and one historical site.

A field trial was established on Tully Experiment Station to assess the response of sugarcane to varying degrees of compactness. The area was conventionally cultivated and, prior to planting, traffic treatments were applied using a 7 tonne tractor. The treatments consisted of zero, one, three and nine passes over the entire plot surface. The crop was planted two days after treatment application. Seedbed conditions were assessed and the degree of compactness was determined (Håkansson, 1990).

4.0 RESULTS AND DISCUSSION

Objective 1: ***Adapt a Scandinavian model to determine the effect of soil compaction on crop yield for the Australian Sugar Industry.***

Changes to the Scandinavian model have been successfully incorporated. Runs with the model prior to modification indicated yield losses of 8%, which agree reasonably with experimentally measured losses of between 5% and 14%. However, in some years, experimental yield losses of 20% and 24% were measured. The model predicts losses of this order of magnitude as the soil moisture content at harvest increases, or the number of passes increases.

Only limited data were available for model validation under Australian conditions. This is due to the fact that only two trials have been conducted specifically to quantify the effect of harvesting traffic on soil physical properties and crop response (BS106, Assessing linkages between machine traffic, soil conditions and productivity).

Equipment parameters were available for the Tully haulout since it was included in the cane industry transport survey and parameters from similarly configured equipment to that used at Ingham was extracted from the same survey. This was used for model validation, since crop yield was also available from these trials.

The simulation assumed two passes by the loaded haulout directly over-the-row, near-the-row and in the middle of the inter-row at two soil moisture contents. The crop yield after the same number of passes in the field experiment are presented in Table 1. The predicted losses tend to be higher than the measured loss. The trials were harvested under conditions that left a tyre imprint on the surface, which would be equivalent to a soil moisture 2. There is reasonable agreement between the measured and predicted yield loss at this moisture content, and it is seen that, as the soil moisture increases, so does the predicted yield loss. This situation has been observed in the field, especially after wet harvesting conditions. Although there are only limited data available for validation, there is reasonable agreement between measured and predicted yield losses. The model can be used to provide indicative yield loss due to soil compaction as a result of using specified haulout equipment under defined soil conditions. The predicted losses may or may not reflect the real word, since the final yield will depend on environmental conditions during the growing season, and the model does not consider this. Also, direct damage to the stool is probably more important in the resultant yield, again the model does not take this into account. Not withstanding this, the model provides an estimate of yield loss due to soil compaction and the ability to compare the effect of different haulout units under defined harvesting conditions.

Table 1 Comparison between measured and predicted yield loss – model validation

Site	Equipment	Position of traffic	Yield loss (%) Measured	Predicted	
				2[+]	3
Tully	4t flotation	row	9.4	10.7	14.1
		near-row	3.8	5.7	8.7
		inter-row	0.0	3.8	6.9
Ingham	2 x 4t rollon-rolloff	row	7.4	10.4	13.4
		near-row	5.0	4.5	6.7
		inter-row	0.0	2.5	4.4

[+] Subective soil moisture scale: 2 = tyre imprint, 3 = tyre sinkage

The changes to the model enable the nomination of equipment used during harvest to tailor to individual growers, thereby making the predicted losses more pertinent to that particular grower or harvesting group. The number of passes allowable has been increased to account for the differences in row lengths in the various growing districts. This also enables passes to be made with haulouts full, empty or partially filled. It is also possible to include the various tillage operations involved in cane production.

The operation of the model is described in detail in the manual enclosed as Appendix 1. The model also gives an indication as to yield losses due to subsoil compaction (at depths>40 cm). Compaction at depth may be considered to result in a permanent loss in productivity over time. This is because subsoil compaction is very difficult to alleviate. The model indicates that subsoil compaction may be contributing, in the order of up to a 1% loss in productivity.

This is of concern as the industry moves to bigger harvesting and haulout equipment for economic efficiency. A loss of 1% productivity represents an economic loss of approximately $10 m to the industry.

Objective 1 has been achieved.

Objective 2: ***Relate crop response to degree of compactness by examining current and previous trials on soil compaction.***

There is a lack of soil physical data with respect to the Australian sugar industry, especially soil bulk density in relation to yield. Also, it is difficult to relate crop response to a single soil physical property for all soils. In response to this, Håkansson (1990) developed the concept of degree of compactness, where a field density is compared with the maximum density for the same soil determined in a standard manner. This enables comparisons across soil types, since the degree of compactness has been shown to be largely independent of soil type. If the row bulk densities are known and the maximum bulk density determined for each soil type of interest, sugarcane response can be compared across soil types and hence regions.

Data from current trails being conducted and from a trial conducted by Hurney (1975) have been used to construct a response curve for sugarcane. A major problem with using historical trials was being able to collect soil from the same site for the determination of the maximum bulk density; it was usually not possible to do this. Notwithstanding this limitation, the use of current trial data has provided a reasonable response curve of sugarcane to the degree of soil compactness (Figure 2).

The plotted data represent all treatments for the plant, first, second and third ratoon crops (meaned across replicates) for the trials conducted at Tully and Ingham as part of BS106. Treatments consisted of traffic over-the-row, traffic-near-the-row and traffic down the inter-row. All treatments were used to get a wide range of degree of compactness as possible. Data from Hurney (1975) are also included, since soil bulk density and yield information were available. The trend line presented is not statistically significant. These data represent the only information relating the degree of compactness of soil and yield for the Australian sugar industry. Further soil data needs to be collected from trials to more rigorously develop this relationship as they provide a means to compare crop response to soil compaction.

The trend line indicates that there is an optimum degree of soil compactness of around 90% for sugarcane. This is slightly higher compared with other grasses (wheat, barley etc), which probably reflects the physiological differences between species. The response curve shows that when the degree of compactness is low (75-80%), which indicates soil in a loose condition, yield is reduced. At the other end of the spectrum, when the soil has a high degree of compactness (>100%) yield is again reduced. This is when the soil is too compact. In the first instance, slight compaction of the soil would be of benefit, as in using a press-wheel at the time of planting. In the second instance, loosening of the soil would reduce the degree of compactness. This condition may have resulted from rolling with heavy equipment at planting, or ineffectual cultivation in removing soil compaction from the previous crop cycle.

The trial conducted at Tully to establish varying degrees of compaction showed that there was an optimum number of passes, which gave the greatest yield (Figure 3). There was, however, no significant difference in yield between the number of passes. Also, the corresponding degree of soil compactness tended to be relatively low and with little difference between treatments. This was due to the fact that the soil was dry at the time of impact and at planting. The net effect of the high number of tractor passes was pulverisation of the surface soil with little compaction. There was, however, a response even under dry soil conditions, which suggests that a greater response would occur under wetter soil conditions.

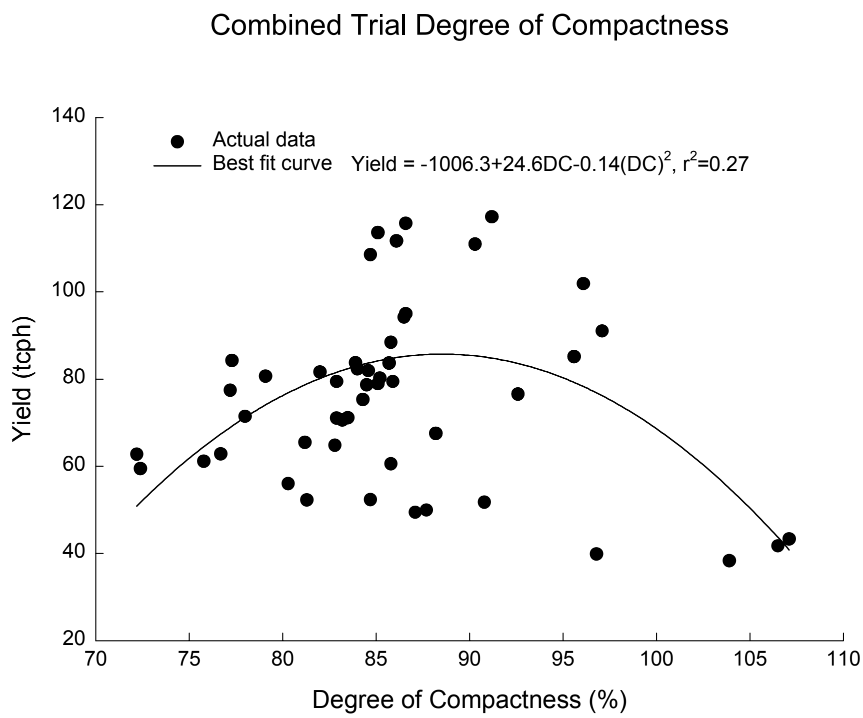

Figure 2 Yield response of sugarcane to degree of soil compactness

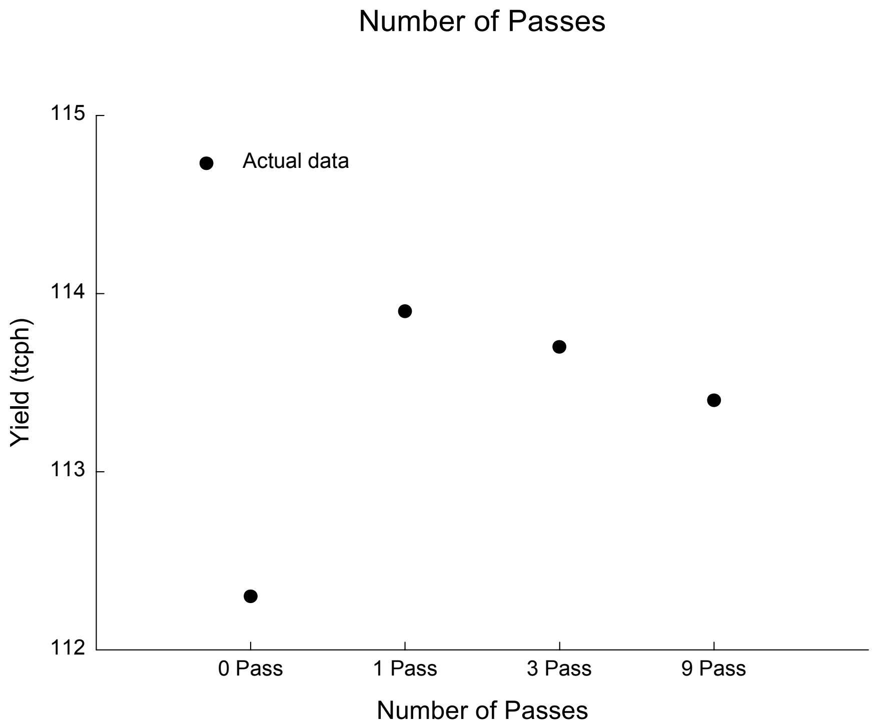

Figure 3 Yield of sugarcane after a varying number of tractor passes before planting

A response curve of sugarcane to the degree of soil compactness has been established.

Objective 2 has been achieved.

Objective 3: ***Estimate the economic value of reducing soil compaction.***

To estimate the economic value of reducing soil compaction, it is at best just that - an estimate. There are many interacting factors that the crop integrates over the season, which result in the final harvestable yield. The model is designed to be used by individual growers in conjunction with extension officers to assess the effect of various operations involved in the production of sugarcane. By providing an estimate of potential yield loss and calculating the economic value for that loss, a series of scenarios may be tested to determine the effect of changing tyres, weight of equipment, harvesting when the soil is dry, the number of tillage operations and the number of haulout passes. This will aid in decision making for the following harvest to reduce the effect of harvesting traffic, thereby minimising yield losses. This will improve ratoon longevity, enhancing the profitability of growers.

To gain an idea as to the benefit in reducing soil compaction, there is a need to estimate the cost of soil compaction in lost returns to growers and the industry as a whole. Statistics have been taken from the Australian Sugar Year Book 1998, pertaining to the 1996 season for Queensland.

Potential losses ($ per ha) to growers vary depending on the district and the level of yield loss (Table 1). The range of potential loss is from $116 per hectare to $500 per hectare in the Northern and Herbert/Burdekin districts at a 5% and 15% yield reduction, respectively. Measured experimental losses attributed to soil compaction range from 2% to 20%, and the model predicts a similar range of loss depending on initial parameters.

Table 2 Potential loss to growers due to soil compaction ($/ha)

Region	**Average Yield (tcph)**	**$Return/ha**	**Potential loss due to soil compaction ($/ha)**		
			5% yield loss	**10 % yield loss**	**15% yield loss**
Northern	90.97	2325.86	116.29	232.59	348.88
Herbert-Burdekin	108.54	3337.26	166.86	333.73	500.59
Mackay-Proserpine	99.00	2972.32	148.62	297.24	445.86
Southern	84.68	2583.24	129.16	258.32	387.49
State	**97.65**	**2875.98**	**143.80**	**287.60**	**431.40**

(Price of Cane = Price of sugar x 0.009 x (ccs – 4) + 0.328 + 0.125, where price of sugar = $334.59, and ccs = district average for 1996 per Aust. Sugar Year Book, 1998).

The overall industry perspective is presented in Table 2, again using statistics for the 1996 season in Queensland. If 5% yield loss can be ascribed to soil compaction, this represents a loss to the industry of $54m, and this increases to $164m if the yield loss increases to 15%. It can be seen that appreciable losses can potentially occur both to individual growers and the industry as a whole.

Table 3 Potential economic loss to the Queensland industry due to soil compaction

Region	Potential Loss ($ million) due to Soil Compaction		
	5% Yield Loss	10% Yield Loss	15% Yield Loss
Northern	9.4	18.9	28.4
Herbert-Burdekin	19.7	39.3	59.0
Mackay-Proserpine	16.7	33.5	50.2
Southern	8.9	17.8	26.7
State	**54.7**	**109.5**	**164.2**

The reverse of this situation is what is the value in minimising the effect of soil compaction? For example, if yield losses can be reduced by 5%, there is a potential extra $54m available to the industry. This translates into each individual grower getting an extra $142 per hectare for the increased yield.

Current research shows that by matching crop row spacing with equipment track widths and planting dual rows, it is possible to achieve yield increases of 5% or more compared with the current commercial row spacing. Strategies are being developed to minimise the effect of harvesting traffic, which will result in significant economic return to the industry.

The economic benefit of reducing or minimising soil compaction is estimated to be in the order of $54m if yield losses can be reduced by on average 5%. Greater benefits will accrue if yield losses can be reduced by greater amounts.

Objective 3 has been achieved.

Objective 4: ***Provide software and preliminary training to extension officers.***

Extension officers are aware of the work and that software is being developed for use in relation to the production system for sugarcane. No exposure to the program or training has been provided to date. The software and user manual are available.

One problem when collaborating with workers at overseas institutions is the long line of communication and the fact that the collaborators have other commitments as well. This tends to prolong the turn around time in effecting changes and testing these changes.

Objective 4 has been achieved, with the exception of preliminary training for extension officers. This may be undertaken at the next extension meeting to be held during 1999.

Objective 5: ***Subject to the successful completion of this project, apply for further funding to support a planned extension program.***

When the modified software is available and some preliminary training has been given to extension officers, following feedback from this, a proposal will be made to SRDC for funding to train extension officers throughout the sugar industry. This will enable growers to assess the effect of various harvesting scenarios and make better management decisions to minimise the effect of soil compaction.

Objective 5 has not been achieved, but will be the subject of a PPP to SRDC for the financial year 2000/2001.

5.0 CONCLUSIONS

The modified Scandinavian compaction model provides a valuable tool to aid in management decisions to minimise the effect of soil compaction. This will result in the maintenance of productivity to individual growers and the industry as a whole.

The model provides an indication of potential losses to individual growers and the reverse - the potential gains to growers through better 'management' of soil compaction. This then illustrates potential losses and gains to the industry as a whole. When crop yield is plotted against the degree of compactness there is an optimum degree of soil compactness for sugarcane. This shows the effect of soil being too loose or too compact, where yield tends to be reduced. This demonstrates that soil compaction is affecting sugarcane yields and is the first attempt to estimate the economic cost to the industry.

6.0 RECOMMENDATIONS FOR FURTHER RESEARCH

Results from simulation runs using the compaction model show that, with increasing weight of harvesters and haulouts, a loss of productivity due to subsoil compaction. This loss may be considered to be permanent due to the difficulty and expense of removing subsoil compaction.

There is a need to verify this effect and determine whether it is a real threat to the sugar industry's productivity in the future. Research needs to be conducted to determine how effective high flotation tyres and tracks have been in reducing or minimising the perceived soil compaction problems. It is thought that by using such equipment soil compaction is reduced. However, the model suggests otherwise.

Research also needs to be undertaken to assess the effectiveness and longevity of subsoiling to remove subsoil compaction.

7.0 PUBLICATIONS ARISING (APPENDIX 2)

Braunack, M. V. and Håkansson I., 1997. The response of sugarcane to harvesting traffic. Proceeding 14th ISTRO Conference, July 27 – August 1, 1997, Pulway, Poland. 2A p.95-98.

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9.0 ACKNOWLEDGMENTS

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The input from Dr Johan Arvidsson and Dr Inge Håkansson, Swedish Agricultural University, in making model changes is gratefully acknowledged. Jim Page provided stimulating observations and comment on the economics.

Technical support was ably provided by Lyn Crees.

APPENDIX 1

USER MANUAL FOR COMPACT$

A model to calculate yield loss due to soil compaction when harvesting sugarcane

INTRODUCTION

The model to estimate yield losses due to harvesting sugarcane has been adapted from a Swedish model developed by Arvidsson and Håkansson (1991). The Scandinavian model was developed from the results of a large number of field trials conducted over many years investigating soil compaction in annual crops.

The model has been adapted for conditions applying to the Australian sugar industry, and validated using data from trials conducted to quantify the effect of harvesting traffic on sugarcane response (Braunack, 1994; Braunack & Håkansson, 1997).

Yield losses are calculated using simple input parameters which are generally available at the grower level. The output from the model estimates the following: (1) yield loss (as a %) in the following crop due to topsoil compaction; and (2) yield loss due to subsoil compaction.

Model input

The model has been set-up in an Excel spreadsheet (Table 1) and runs in Excel 97.

Input data are as follows:

At the top of the spreadsheet basic information is entered.

- Crop value in $ per hectare, usually the $ value of cane per hectare (Row 2).
- This could be based on the average yield for the block or farm, and before or after costs have been deducted, for example $2,400.00, based on 80 tonne cane @ $30.00 per tonne.
- Area harvested in hectares (Row 1).
- This could be the area of a particular block or the area of a farm.
- Clay content of the soil (Row 2).
- Estimated from a field texture determination.
- Specific information about operations and equipment is entered in rows 3 to 20 of the spreadsheet, as follows:

Row 3: Can be used to distinguish between harvesting and haulout operations, by entering specific data for the harvester in the first column and the haulout in the second column.

Row 4: The number of operations is entered, usually two for the harvester since it travels over each inter-row twice, the number of haulout passes varies, but usually there is a minimum of two passes.

Row 5: Crop row spacing (in metres) is entered here depending on the row spacing in the block. See Attachment 1.

Row 6. 7: Soil moisture classes of the topsoil and subsoil are entered using a subjective scale of 1 (very dry) to 5 (very wet). This is the soil moisture in the block at the time of harvesting. This is explained in Attachment 2.

Row 8: Extra driving is the turning at the end of the rows. This should be 1, since no turning occurs in the cropped area, it all occurs on the headland.

Row 9, 10: Weight (kg) loaded and unloaded of the front axle of a harvester or haulout or tractor.

Row 11, 12: Weight (kg) loaded and unloaded for the rear axle of harvester or haulout or tractor.

Row 13,14: Weight (kg) loaded and unloaded of trailed bin, or the mean values for multiple axles of trailed bins or trucks or articulated units.

Row 15-17: Tyre inflation pressure for the corresponding axles given in rows 10, 12 and 14 or track ground pressure for tracked units.

Row 18: Number of rear axles - 1 for single axle units, 2 for dual axle units and 3 for tri-axle units.

Row 19,20: An estimate of the proportion of the area where traffic occurs over the row (line 19) and near-the-row (line 20). Yield losses are greater when traffic occurs over the row compared with traffic in the inter-row. See Attachment 3.

TABLE 1

	CALCULATION OF YIELD LOSSES CAUSED BY COMPACTION				Hectares:			
		Crop value/ha:		Clay, %:	Alternative:			
	Operation							Sum
1	Number of operations							
2	Working width							
3	Soil moisture class, topsoil							
4	Soil moisture class, subsoil							
5	Extra driving							
6	Weight first axle, loaded							
7	Weight first axle, no load							
8	Weight second axle, loaded							
9	Weight second axle, no load							
10	Weight rear axle(s) loaded							
11	Weight rear axle(s), no load							
12	Inflation pressure, first							
13	Inflation pressure, second							
14	Inflation pressure, rear							
15	Number of rear axles							
16	Driven in-row, %							
17	Driven near-row, %							
18	Driven between-rows, %	100	100	100	100	100	100	
19	*Topsoil, tonkm/ha*							
20	First axle	0.00	0.00	0.00	0.00	0.00	0.00	0.00
21	Second axle	0.00	0.00	0.00	0.00	0.00	0.00	0.00
22	Rear axle(s)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
23	In-row	0.00	0.00	0.00	0.00	0.00	0.00	0.00
24	Near-row	0.00	0.00	0.00	0.00	0.00	0.00	0.00
25	Between rows	0.00	0.00	0.00	0.00	0.00	0.00	0.00
26	Total	0.00	0.00	0.00	0.00	0.00	0.00	0.00
27	*Topsoil, yield loss (%)*							
28	First axle	0.00	0.00	0.00	0.00	0.00	0.00	0.00
29	Second axle	0.00	0.00	0.00	0.00	0.00	0.00	0.00
30	Rear axle(s)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
31	In-row	0.00	0.00	0.00	0.00	0.00	0.00	0.00
32	Near-row	0.00	0.00	0.00	0.00	0.00	0.00	0.00
33	Between rows	0.00	0.00	0.00	0.00	0.00	0.00	0.00
34	Total	0.00	0.00	0.00	0.00	0.00	0.00	0.00
35	*Subsoil, 20-40 cm, tonkm*							
36	First axle	0.00	0.00	0.00	0.00	0.00	0.00	0.00
37	Second axle	0.00	0.00	0.00	0.00	0.00	0.00	0.00
38	Rear axle(s)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
39	Total vehicle	0.00	0.00	0.00	0.00	0.00	0.00	0.00
40	*Subsoil, 20-40 cm, yield loss*							
41	First axle	0.00	0.00	0.00	0.00	0.00	0.00	0.00
42	Second axle	0.00	0.00	0.00	0.00	0.00	0.00	0.00
43	Rear axle(s)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
44	Total vehicle	0.00	0.00	0.00	0.00	0.00	0.00	0.00
45	*Subsoil, >40 cm, tonkm*							
46	First axle	0.00	0.00	0.00	0.00	0.00	0.00	0.00
47	Second axle	0.00	0.00	0.00	0.00	0.00	0.00	0.00
48	Rear axle(s)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
49	Total vehicle	0.00	0.00	0.00	0.00	0.00	0.00	0.00
50	*>40 cm, per mille yearly loss*							
51	First axle	0.00	0.00	0.00	0.00	0.00	0.00	0.00
52	Second axle	0.00	0.00	0.00	0.00	0.00	0.00	0.00
53	Rear axle(s)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
54	Total vehicle	0.00	0.00	0.00	0.00	0.00	0.00	0.00
55	*Total cost, Aust. $*							
56	In-row	0.00	0.00	0.00	0.00	0.00	0.00	0.00
57	Near-row	0.00	0.00	0.00	0.00	0.00	0.00	0.00
58	Between rows	0.00	0.00	0.00	0.00	0.00	0.00	0.00
59	20-40 cm	0.00	0.00	0.00	0.00	0.00	0.00	0.00
60	<40 cm in 50 years	0.00	0.00	0.00	0.00	0.00	0.00	0.00
61	Total	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Model output

Model output occurs in rows 23 to 64.

The first output is an estimate of traffic intensity for the topsoil (ton km/ha) for the operation and an estimate of traffic in the row, near-the-row and in the inter-row, with the total traffic intensity given in row 29.

The estimated yield loss (%) in the topsoil due to soil compaction is given in row 37.

These same outputs are provided for estimated yield loss to subsoil compaction in rows 47 and 57. Losses estimated for deeper layers (>40cm) are considered to be a permanent loss to productivity.

The estimated economic loss for the harvesting equipment used, under the soil conditions defined for a particular operation or circumstance, is given in row 64 as $ over the area nominated. The $ value per hectare is calculated by dividing this $ value by the area nominated.

The model provides an estimate of traffic intensity for the given equipment inputs and an estimate of yield loss (%) for the following crop due to soil compaction in the soil surface and in the subsoil due to that traffic under the conditions stipulated. The model also provides an estimated economic value ($) of that loss, depending on the price input of the product. This estimate can be for a specific block or can apply to the whole farm depending on the area input.

Model computations

1) Yield loss in the following crop due to topsoil compaction at harvest

Yield losses due to topsoil compaction will depend on where the harvesting traffic occurs relative to the row. Traffic over-the-row will result in greater losses than traffic near-the-row and the least loss will occur when traffic is in the inter-row. Therefore position of traffic is divided into three categories, traffic in-row, near-row and between-rows. Yield loss is assumed to be a function of traffic intensity (ton-km, the weight of vehicle times the distance travelled in the field), corrected for soil moisture and tyre inflation (or track ground pressure) pressure. Traffic intensity is calculated as follows:

Corrected Ton-km = (uncorrected ton-km)(log (tyre pressure)-1.2) (soil moisture x 0.2675 – 0.056). (1)

The yield loss is calculated separately for traffic in-row, near-row and between-rows. Yield loss is linearly correlated with traffic intensity. This is done in steps, because at high traffic intensities the yield loss due to additional traffic is less. This is because the largest change occurs with the first pass of traffic and less change occurs with each additional pass.

2) Yield loss due to subsoil compaction

Yield loss due to subsoil compaction is also based on traffic intensity, and correlated to the number of ton-km. Because subsoil compaction persists through time, no distinction is made between the in-row and between-row areas. The subsoil is also divided into two layers: 20 to 40 cm and >40 cm.

Losses for the 20 to 40 cm layer are considered over a 10 year period; the figure given in the spreadsheet (Row 47) is the total loss for that period as a percentage of one year's yield. Only axle loads greater than 4 tonnes are considered to influence this layer, so a correction of 4 tonnes is made when calculating the traffic intensity (ton-km):

Corrected ton-km = (uncorrected ton-km)(log (tyre pressure) – 0.53)((soil moisture – 2) x 0.326) (2)

and yield loss is calculated as,

Yield loss (%) = corrected ton-km/40 (3)

Yield losses for the layer > 40 cm are considered permanent and are given as a permanent loss to productivity. This is due to expense and effort required to remove deep subsoil compaction. The economic cost of this loss is calculated over a 50 yr period.

Yield loss is assumed proportional to the corrected traffic intensity, but only axle loads greater than 6 tonnes are considered in calculating the traffic intensity:

Corrected ton-km = (uncorrected ton-km)(log(tyre pressure) – 0.27)((soil moisture – 2) x 0.272) (4)

with yield loss being calculated as,

Yield loss (per mille) = corrected ton-km/40 (5)

An example of the Compaction Model output is set out in Attachment 4.

Database

A second sheet has been included containing a database of haulout equipment commonly used throughout the industry. Data can be copied into the calculation sheet to generate output for various situations. The data can be manipulated to generate specific equipment used by individual growers, if this information is not readily available from the grower or contractor.

References

Arvidson, J. and Håkansson, I. 1991. A model for estimating crop yield losses caused by soil compaction. Soil & Tillage Res., 20:319-332.

Braunack, M.V. 1994. Tillage and traffic for sustainable sugarcane production. Proc. 13th ISTRO Conference, Aalborg, Denmark, Vol.2, p.769-775.

Braunack, M.V. and Håkansson, I. 1997. The response of sugarcane to harvesting traffic. Proc. 14th ISTRO Conference, Putawy, Poland. Vol. 2A, p.95-98.

Attachment 1

Working width metric equivalents of imperial row spacings.

Metric	**Imperial**
1.5 m	4'11"
1.65 m	5'5"
1.8 m	5'11"
1.83 m	6'0"
2.0 m	6'6"
2.2 m	7'2"

This table can be used to estimate the working width in metres if the distance is provided in imperial measurement.

Attachment 2

Subjective soil moisture scale for use in COMPACT$.

Class 1 – Very Dry
Soil is very dry and hard both at the surface and at depth. No wheel ruts are formed except in recently tilled, loose soil.

Example: Harvest after a long dry period. Too dry for tillage operations.

Class 2 – Dry
Soil is dry and firm. No wheel ruts are formed except in recently cultivated, loose soil or when using wheels with extremely high ground pressure. In previously trafficked areas, tyre lugs make little or no imprint.

Example: Harvesting after 2-3 weeks dry weather. Minimum soil moisture for tillage.

Class 3 – Intermediate
Soil is drained and further drying of the surface by evaporation has occurred. Tyre lugs imprint to the full depth of lugs, but usually no imprint of the tyre is made, unless the soil has been recently loosened and is soft. The optimal soil moisture for most tillage operations (just below the lower plastic limit of the soil).

Example: The most common soil moisture encountered at harvest.

Class 4 – Moist
Soil in not completely drained. Wheel ruts (5-10 cm deep) formed by nearly all vehicles. Traffickability is reduced for heavy vehicles with conventional wheels. Wheel slip occurs.
Example: Wettest condition for harvest with conventional wheels. Some wet spots (hollows) may have moisture class of 4.5.

Class 5 – Wet
Soil is very wet, with surface ponding occurring. Generally the upper limit for vehicular field traffic. Deep ruts are formed (10-20 cm) even by vehicles with low ground pressure. Vehicles bog if not equipped with low-ground-pressure tyres. Large amount of wheel slip.
Example: Deep rut formation due to harvest traffic.

Attachment 3

Row Spacing (m)	Total length (m/ha)	Length (m) trafficked at various percentages												
		0	**5**	**10**	**15**	**20**	**30**	**40**	**50**	**60**	**70**	**80**	**90**	**100**
1.5	**6667**	0	333	667	1000	1333	2000	2667	3334	4000	4667	5334	6000	6667
1.65	**6061**	0	303	606	909	1212	1818	2424	3031	3637	4243	4849	5455	6061
1.8	**5555**	0	278	556	833	1111	1667	2222	2778	3333	3889	4444	5000	5555
1.85	**5465**	0	273	547	820	1093	1640	2186	2733	3279	3826	4372	4919	5465
2	**5000**	0	250	500	750	1000	1500	2000	2500	3000	3500	4000	4500	5000
2.2	**4545**	0	227	455	682	909	1364	1818	2273	2727	3182	3636	4091	4545

This table can be used to estimate the percent driven in each position by estimating the length of row per hectare driven over or alongside by field observation.

For example, if there is no visual evidence of traffic over the row (in-row) 0 is assigned for driven in-row, 50 is assigned for driven near-row %. The amount for driven between-rows % is automatically entered.

Attachment 4

An example of the compaction model output

This example illustrates the results of a simulation using data from the attached database. The haulout unit is a 12 t Carta bin articulated with a John Deere 7710 Tractor. The simulation consists of three (3) passes of the fully laden haulout under moist soil conditions (Class 4) in the surface and slightly wetter soil conditions (Class 4.2) in the subsoil. Row spacing is 1.5 m and it has been designated that 10% of the traffic occurred over the row with 45% of the traffic occurring near-the-row and 45% in the middle of the interspace.

As a result, the model predicts potential yield losses for the next ratoon crop to be 13.2% due to compaction in the surface soil, 4.4% due to compaction in the upper subsoil and 1.4% due to compaction in the lower subsoil.

Therefore, the potential economic cost due to this soil compaction, as a result of harvesting under moist soil conditions, is $597.00 per hectare.

CALCULATION OF YIELD LOSSES CAUSED BY COMPACTION					Hectares:	20	
	Crop value/ha:	2,400	Clay, %:	20	Alternative:		
Operation	Carta 12t Dual Conveyor Elevator with John Deere 7710 Articulated (Self Propelled)						Sum
Number of operations	1		2				
Working width	1.5		1.5				
Soil moisture class, topsoil	4		4				
Soil moisture class, subsoil	4.2		4.2				
Extra driving	1.1		1.1				
Weight first axle, loaded	0		0				
Weight first axle, no load	0		0				
Weight second axle, loaded	8590		8590				
Weight second axle, no load	7850		7850				
Weight rear axle(s) loaded	14060		14060				
Weight rear axle(s), no load	6190		6190				
Inflation pressure, first	0		0				
Inflation pressure, second	176		176				
Inflation pressure, rear	267		267				
Number of rear axles	2		2				
Driven in-row, %	10		10				
Driven near-row, %	45		45				
Driven between-rows, %	45	100	45	100	100	100	
Topsoil, tonkm/ha							
First axle	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Second axle	62.62	0.00	125.24	0.00	0.00	0.00	187.86
Rear axle(s)	90.54	0.00	181.09	0.00	0.00	0.00	271.63
In-row	15.32	0.00	30.63	0.00	0.00	0.00	45.95
Near-row	68.92	0.00	137.85	0.00	0.00	0.00	206.77
Between rows	68.92	0.00	137.85	0.00	0.00	0.00	206.77
Total	153.16	0.00	306.33	0.00	0.00	0.00	459.49
Topsoil, yield loss (%)							
First axle	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Second axle	1.80	0.00	3.61	0.00	0.00	0.00	5.41
Rear axle(s)	2.61	0.00	5.21	0.00	0.00	0.00	7.82
In-row	2.20	0.00	4.40	0.00	0.00	0.00	6.59
Near-row	1.53	0.00	3.07	0.00	0.00	0.00	4.60
Between rows	0.68	0.00	1.36	0.00	0.00	0.00	2.03
Total	4.41	0.00	8.82	0.00	0.00	0.00	13.23
Subsoil, 20-40 cm, tonkm							
First axle	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Second axle	38.07	0.00	76.13	0.00	0.00	0.00	114.20
Rear axle(s)	21.20	0.00	42.40	0.00	0.00	0.00	63.60
Total vehicle	59.27	0.00	118.53	0.00	0.00	0.00	177.80
Subsoil, 20-40 cm, yield loss							
First axle	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Second axle	0.95	0.00	1.90	0.00	0.00	0.00	2.85
Rear axle(s)	0.53	0.00	1.06	0.00	0.00	0.00	1.59
Total vehicle	1.48	0.00	2.96	0.00	0.00	0.00	4.44
Subsoil, >40 cm, tonkm							
First axle	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Second axle	19.24	0.00	38.48	0.00	0.00	0.00	0.00
Rear axle(s)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total vehicle	19.24	0.00	38.48	0.00	0.00	0.00	57.72
>40 cm, per mille yearly loss							
First axle	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Second axle	0.48	0.00	0.96	0.00	0.00	0.00	1.44
Rear axle(s)	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Total vehicle	0.48	0.00	0.96	0.00	0.00	0.00	1.44
Total cost, Aust. $							
In-row	1055.18	0.00	2110.36	0.00	0.00	0.00	3165.55
Near-row	736.25	0.00	1472.50	0.00	0.00	0.00	2208.74
Between rows	345.42	0.00	650.83	0.00	0.00	0.00	976.25
20-40 cm	711.18	0.00	1422.37	0.00	0.00	0.00	2133.55
<40 cm in 50 years	1154.46	0.00	2308.93	0.00	0.00	0.00	3463.39
Total	3982.50	0.00	7964.99	0.00	0.00	0.00	11947.49