TECHNICAL NOTE
21/98

SHORT ROTATION COPPICE HARVESTING: GROUND DAMAGE AND YIELD EFFECTS

Summary

Ground damage caused by Short Rotation Coppice harvesting machinery may affect crop yields over the c 25 year life span of the stools. Fieldwork has shown that machines will cause soil compaction and rutting within the crop area. Damage is influenced by both the weight of machinery and the number of passes made over the ground. Limited growth monitoring 1 year after harvesting has shown no direct relationship between ground damage and crop yield.

To minimise ground damage good working practicefollows the following principles:

- Use optimum weight machinery.
- Limited the number of passes over the ground.
- Use tracked machinery where possible.

Future work should concentrate on establishing whether ground damage has an effect on coppice yield. It should also determine the optimum weight of machines in relation to the number of passes over the ground.

Introduction

Short Rotation Coppice (SRC) is a perennial woody crop, usually willow or poplar, potentially suitable as a wood energy fuel or wood fibre source. The crop is grown in the farming environment on a 2 year or 3 year cycle, with a total expected stool life of 20 to 30 years.

Research on SRC has been underway since the early 1970s under the Department of Trade and Industry (DTI) 'Renewable Energy Programme'. This work included a 3 year contract to investigate the mechanisation of harvesting SRC. The work was jointly funded by ETSU, on behalf of the DTI and the Forestry Commission and was carried out by Technical Development Branch (TDB) between July 1993 and June 1996.

Plate 1

Ground Damage Occurring During Extraction

Results from the preliminary investigation and the 3 field trials are published in a series of TDB reports[1].

During the early field trials it became apparent that ground damage caused during the winter harvesting operations would be an important issue (Plate 1). Site damage was likely to have an effect on both machine effectiveness and future crop yields.

The issues of machine trafficability and efficiency are dealt with in the main trial reports. This report concerns ground damage caused by harvesting machinery and its effect on crop yield.

1 Details are provided at the end of this Technical Note.

Crop yields could be affected by ground damage, root/stool damage or a combination of both. Little data were available on the scale of these factors or their effect on yield. Therefore, investigations into machine trafficking, compaction and yield were carried out with the co-operation of Silsoe Research Institute.

Assessment Techniques

Data was collected from 4 main trials as shown in Table 1.

Table 1

Compaction Trial Details

	Assessment Techniques				
	CPR	RDM	SPR	CYA	VA
1. **Second SRC Harvesting Trial**. December 1994: Investigated the effect of machine trafficking on crop yields.					
	✓			✓	✓
2. **Silsoe Trial**. February 1995: Measured soil compaction in a dedicated 'ground damage' experiment.					
	✓	✓	✓	✓	
3. **Tracked Trailer Trials**. April 1995: Assessed the advantages of using tracked equipment.					
	✓	✓			
4. **Third SRC Harvesting Trial**. November 1995: Included tracked equipment in the main Harvesting Trials allowing "wheel versus tracks" ground compaction comparisons.					
	✓	✓			✓

CPR - Cone Penetrometer Readings
RDM - Rut Depth Measurement
SPR - Soil Pressure Readings @ 30 cm Depth
CYA - Crop Yield Assessment
VA - Visual Assessment

Cone Penetrometer: A Bush Recording Soil Penetrometer (Mk I Model) was used at all sites to collect data on soil compaction. A small steel cone of known size is forced down through the soil to a maximum depth of 56 cm. The pressure required to force the cone through the soil is recorded at intervals of 37.5 mm, giving up to 15 readings for each penetration. Very compact layers of soil or stones inhibit the progression of the cone through the soil and limit the number of readings. Measurements can be recorded on a data logger or 'played back' and manually recorded. A minimum of 20 penetrations per treatment is generally required, although if the site shows a lot of variability more may be necessary.

Pre-treatment readings were taken in order to provide a base line of background compaction. Post-treatment readings were taken following harvesting. All data were loaded into a computer for analysis. The readings for the various depths were averaged and the data plotted as line graphs for comparison and interpretation. Where necessary scatter diagrams were produced to test the validity of the lines. Soil samples were taken and analysed to provide a description of the soil.

Rut Depth Measurements: Detailed measurements were taken during the Silsoe experiment (Trial 2) using a bespoke machine designed and built by Silsoe Research Institute. This machine recorded depths across the full width of the rut and allowed visual profiles to be plotted. A simple measure of the mean depth was acquired in Trials 3 and 4 using a cross member and ruler.

Soil Pressure Readings: Readings were obtained by Silsoe Research Institute in Trial 2 by burying a series of pressure transducers in the soil, under the line of travel of the machines. Pressure was recorded over a predetermined time period as each wheel or track travelled over the transducers. Data was stored on computer and later analysed. Graphs were plotted which showed a trace of machine wheeling during passage over the transducers.

Crop Yield Assessments: Destructive sampling was used to assess yield before and following treatments in Trials 1 and 2. Samples were weighed and moisture content assessed to provide a measure of oven dried tonnes (ODT) per unit area.

Visual Assessment: This was carried out during 2 SRC main harvesting trials using a method developed by the Forestry Commission Research Division. Classification is based on a combination of visual interpretation and measurement of rut depth (Table 2).

Table 2

Classification of Damage by Visual Assessment

Classification	Visual Assessment
• Clear undamaged	Untrafficked
• Rutting class 0	Obvious trafficking but no damage
• Rutting class 1	Rutting to a depth of 0 to 5 cm
• Rutting class 2	Rutting to a depth of 5 to 15 cm
• Rutting class 3	Rutting to a depth of >15 cm

The rutting assessment was carried out during stool damage assessments, with sample rows selected at random. The number of rows sampled depended largely on the size of the treatment area. Sample points were taken in the trackway between rows and adjacent to every 4th stool. Although most areas assessed had been trafficked by 1 or more machines, there was occasionally no evidence of machine travel.

Trial 1: Second SRC Harvesting Trials

Cone penetrometer readings from the 4 sites were inconclusive except for particular data sets from Swanbourne and Buckfast.

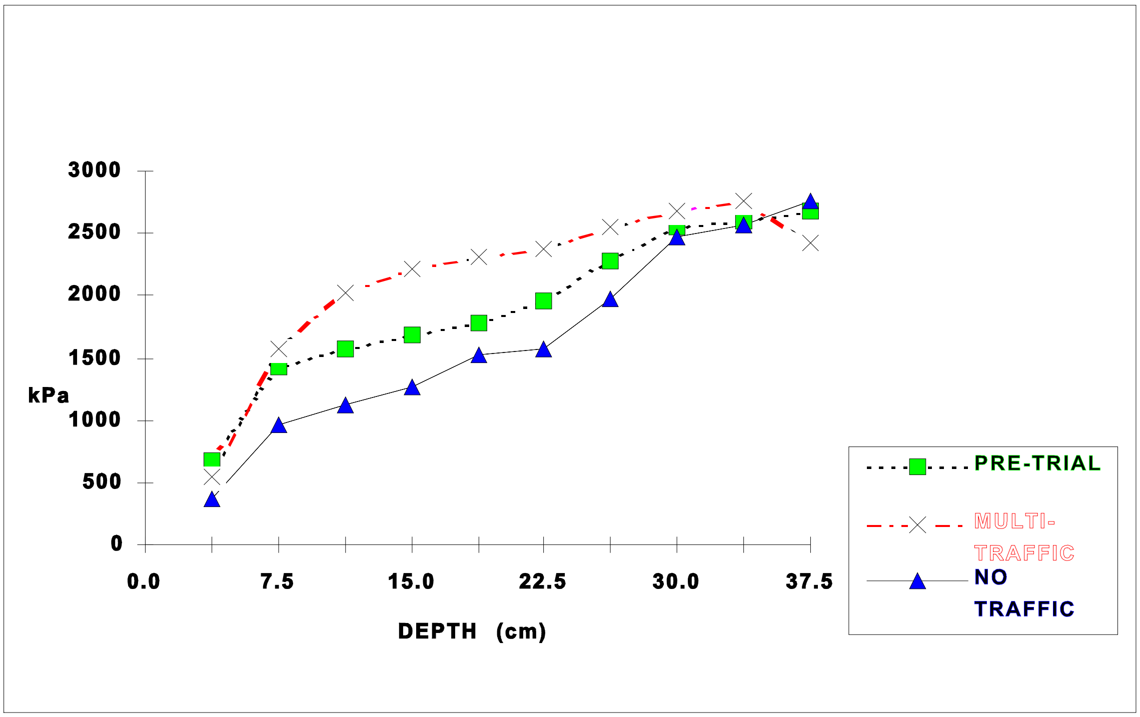
Swanbourne: As part of the trial a 'rack' was cut through the poplar coppice. This was repeatedly used by harvesters and tractor/trailer units to reach a corner of the site, travelling parallel to the rows. There was an adjacent block of coppice of the same age, planted as a research screening trial and which had always been hand cut. As far as could be ascertained no machines had travelled travel over this block since ground preparation.

Three harvesters, from 6 tonnes to 14.7 tonnes, passed over the track a total of 7 times and a tractor/trailer combination passed over the ground 11 times. The trailer weights ranged from 6.3 tonnes empty to 9.4 tonnes fully loaded.

Penetrometer readings were taken on the 'multi-trafficked track' before and after harvesting. Readings were also taken on the adjacent untrafficked block. Soil samples were taken across the site and analysed for moisture content and physical characteristics. The results (Figure 1) show that, within the crop area, the machines caused ground compaction. This was increased by repeated trafficking.

Figure 1

Swanbourne Ground Compaction



Sandy clay loam. Moisture content (wet basis) from 23% in the surface horizon (0 to15 cm) to 17% in the lower horizon (30-45 cm)

Buckfast: The concept of 'planted headlands' was investigated at 1 end of a block of 3 year willow coppice. The harvesting and carting machines turned on the existing *unplanted* headland and at the other end in the crop on the *planted* 'headland'. The planted headland consisted of a 10 m wide strip cut off the end of the coppice block, prior to the main harvesting, by a John Deere forage harvester. Harvesting was carried out by the Claas forage harvester chipping into tractor/trailer units.

The block consisted of 5 clones of willow planted in monoclonal sections and 1 randomly mixed block of all 5 clones. As each section had 4 rows there were 24 rows in the block. Plant spacing was 1.0 m x 1.0 m and row lengths were 175 m including the planted headland.

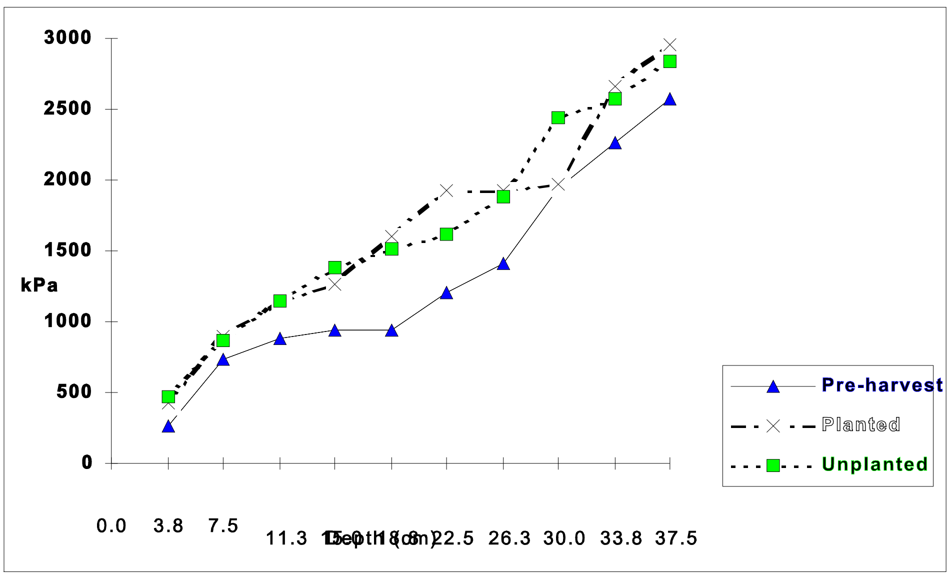
During harvesting details were recorded of the travel of machinery over the planted headland. A 'decreasing lands' system of harvesting gave minimum travel at the outside edges with a concentration of travel at the centre of the headland plot.

Cone penetrometer readings were taken before and after harvesting to determine the levels of compaction. Pre-readings were taken at random over 10 m headland and post readings along 3 transects 1 m, 4 m, and 7 m from the outer end, at 0.5 m intervals across each transect. Crop yield data was collected prior to harvest and after 1 growing season.

The pre harvesting readings from the 2 headlands were very similar and the data was combined. The post harvest data of the 3 transects was also combined and compared for comparison with the pre harvest 'base line' (Figure 2). Both headlands were more compact following harvest but there was little difference between planted and unplanted headlands.

Figure 2

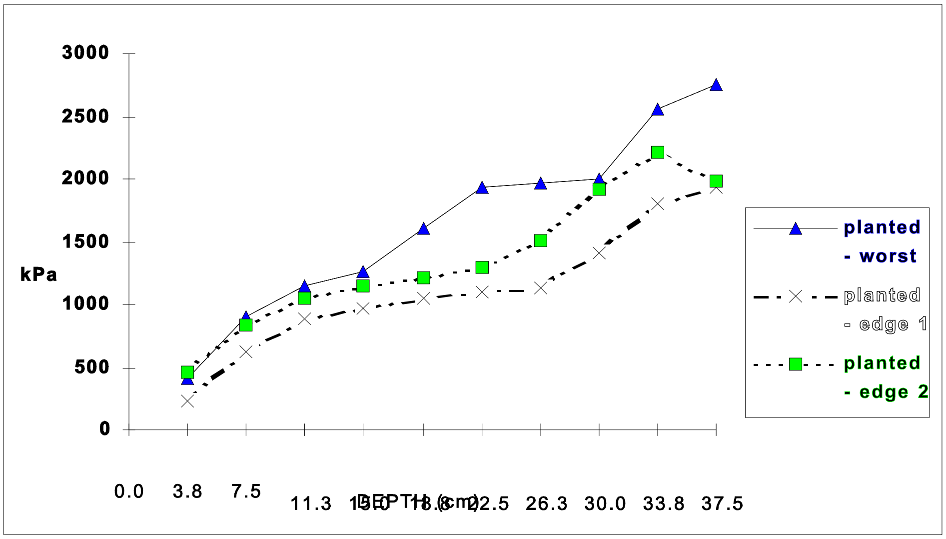
Planted and Unplanted Headlands
Before and After Harvesting



Further analysis was carried out to investigate the effect of multi-trafficking on planted coppice. The centre section of the headlands received the most traffic, and the outside edges the least. The result confirms that the greater the number of passes over the ground the greater the compaction (Figure 3).

Figure 3

Comparison Between Light and Heavy Trafficking



Growth data (Table 3) were collected in January 1996 one year after harvesting by the Wood Supply Research Group of Aberdeen University. Growth on the planted headland was compared to that in the adjacent main crop. No differences were detected for the 4 clones sampled either in the data or from visual assessment.

Table 3

Comparison of Crop Yields 1 Year After Harvest

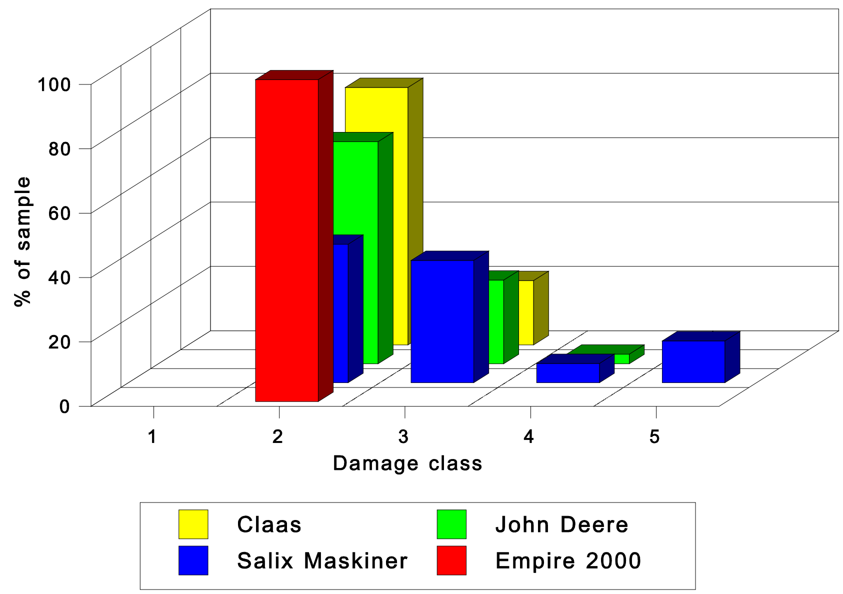
	Salix Clone (oven dry kg / stool)			
	S. x dasyclados	*S. burjatica* Germany	*S. viminalis* Mullatin	*S. viminalis* Bowles
Planted Headland	1.490	1.290	1.288	1.709
Main Crop	1.472	1.207	1.295	1.786
Difference (%)	-1.22	-6.65	0.54	4.41

During the trial no extra effort was made to avoid stools when turning on the planted headland. As stools were continually run over by relatively heavy machines it is surprising that this does not appear to have had a consistent effect on yield. The limited evidence collected during this trial indicates that willow SRC is capable of withstanding considerable physical damage and high levels of soil compaction without affecting overall crop yield. This may not be the case after a number of harvests when the effects of both types of damage have been compounded.

All Sites: A visual assessment was made of ground damage from all machine systems at the 4 harvesting sites at Castle Archdale, Parbold, Swanbourne and Buckfast (Figure 4).

Figure 4

Ground Damage Visual Assessment of Rut Depth



The majority of readings fell in the 'no damage' or minimum (0 to 5 cm) rutting classes. The use of low ground pressure tyres at Parbold fitted to a tractor/silage trailers[2] improved ground working capabilities and there was a visual reduction in the depth of rutting compared to that of standard machinery. The worst results were recorded on the wet silty clay loam soil at Castle Archdale in N. Ireland. If the wheeled machines had been fitted with low ground pressure tyres, the severe rutting might have been reduced.

Trial 2: Silsoe Compaction Experiment

Following the 2nd SRC field trials a specific trial was instigated to investigate the effects of a range of harvesting systems on soil compaction and ultimately on SRC yields. Sites at Silsoe Research Institute (SRI), although not ideal, were chosen as being the most suitable, and a joint trial took place in February 1995.

Two sites were at the Institute, representing different soil types:

- Pavillion Site - Sandy loam. Block A - Willow, Block B - Poplar.
- Clover Hill Site - Clay. Block C - Willow.

Six treatments were applied to simulate various harvesting machines (Figure 5).

2 The Valmet 8000 tractor with 480 mm (front) and 540 mm (rear) Michelin XM 108 tyres at 12 psi. Tandem axle silage trailer with 4 of 335 mm Michelin XP27 tyres also at 12 psi.

Figure 5

Trial 2 Treatments

T1 - *Light Harvester*: Massey Ferguson 699 tractor weighing 5040 kg.

T2 - *Heavy Harvester*: Ford 8700 tractor ballasted to weigh 8477 kg.

T3 - *Tracked Heavy Harvester*: Track Marshal 75 weighing 8232 kg.

T4 - *Standard Tractor/Trailer*: Massey Ferguson 699 (5040 kg) and loaded grain trailer (7942 kg) weighing in total 13 002 kg.

T5 - *Tractor/LGP Trailer*: Massey Ferguson 699 and loaded slurry tanker (8027 kg) with 'low ground pressure tyres', giving a total weight of 13 067 kg.

T6 - *Heavy Harvester and Standard Tractor/trailer*: i.e. T2 followed by T4.

Each machine or combination of machines traversed the ground twice. This involved driving one way forwards and the other in reverse. This simulated normal harvesting practice as a wheel 'run' would normally have 2 passes as the machinery moves across the site.

A number of field measurements were taken to assess the effect of machinery travelling through the coppice, on both bare ground and crop.

These were:

- Soil moisture content.
- Soil pressure readings from transducers at 30 cm depth.
- Rut profiles following machine travel.
- Cone penetrometer readings - before and after travel.
- Growth assessments.

A summary of results is given in Table 4.

Table 4

Summary of Silsoe Trial Results

Block Details	Assessment Type	Treatment					
		T1	T2	T3	T4	T5	T6
Block A Willow Sandy loam soil c 20% m.c.	Pressure - Tractor (kPa)	69-104	74-169	25	64 - 96	53 - 125	134 - 209
	Pressure - Trailer (kPa)				150 - 202	105 - 118	350 - 351
	Rut depth (mm)	19	17	14	46	29	32
	Penetrometer	6	8	0	25	27	13
Block B Poplar Sandy loam soil c 15% m.c.	Pressure (kPa)		74 - 103				
	Rut depth (mm)	8	21	2	21	28	22
	Penetrometer	1	6	-11	5	12	15
Block C Willow Clay soil c 38% m.c.	Pressure (kPa)		103 - 143				
	Rut depth (mm)	28	30	8	26	37	54
	Penetrometer	-28	-26	-32	-15	-18	-16

The cone penetrometer readings were plotted to produce a scatter diagram of results (Figure 6). This information allowed lines of best fit to be obtained for pre and post treatments (Figure 7). All the results have been plotted in this way.

Figure 6

Scatter Diagram Ground Compaction
(Cone Penetrometer)

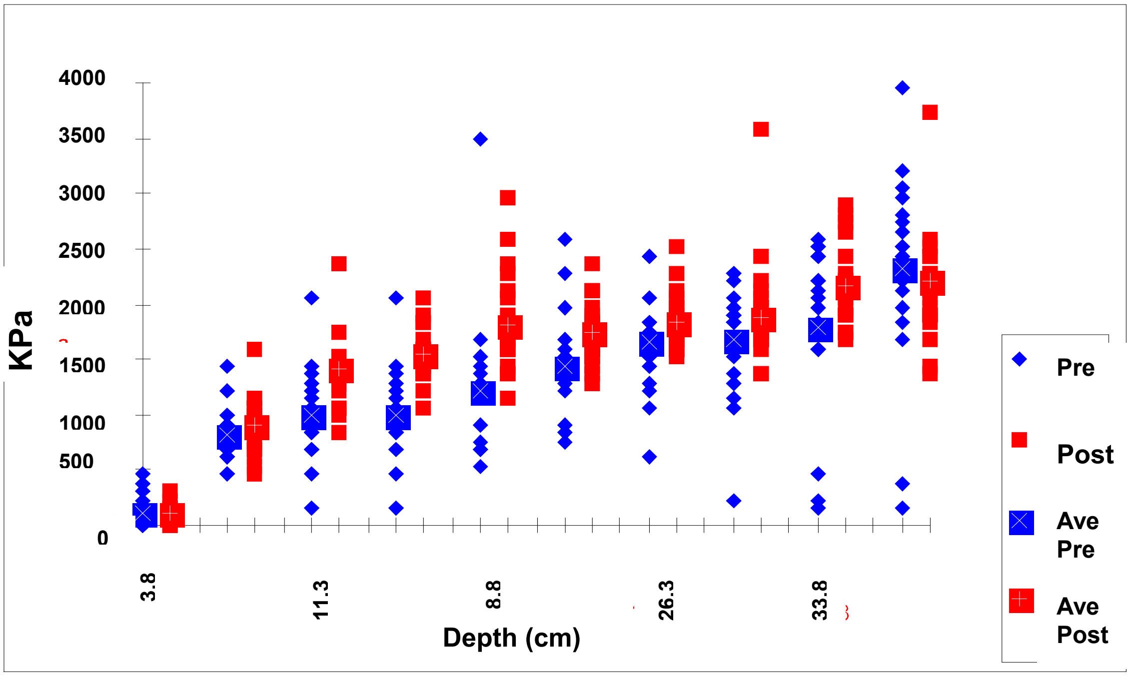
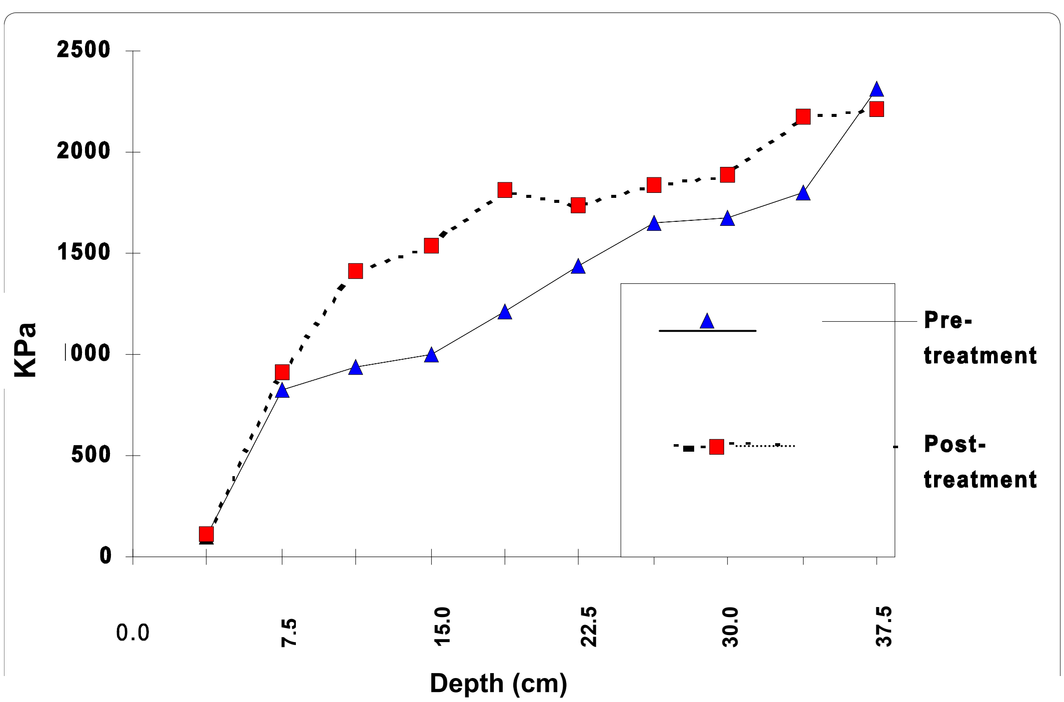


Figure 7

Average Ground Compaction



This was a very comprehensive trial involving a large number of assessments. The main points which can be drawn from the data are as follows:

- Pressure changes were noted as machinery passed over the sensors. Loaded trailers gave significantly higher readings than the towing tractors.

- The tracked machine caused significantly lower pressure readings than a wheeled machine of similar weight.

- All machines created ruts on all soil types, with the heavier units creating the deepest ruts. Rutting was deeper for all machines on the clay soil. The tracked machine created the least disturbance on all sites.

- On the loam sites there was evidence that the heavier equipment (loaded trailers) caused more compaction than the lighter equipment (harvesters). The use of low ground pressure tyres did not appear to reduce the compaction.

- On the clay site there was no evidence to suggest that the equipment compacted the site. Taking into account the deep rutting on this site it is probable that the soil was 'pushed' to the side rather than compacted. This is a feature of the plastic nature of wet clay soils. This movement can be just as damaging to the soil as compaction and it is probable that deep rutting will damage coppice root systems.

The Silsoe experiment highlighted 2 main features of SRC harvesting connected with soil damage and its potential effect on crop yield:

- The greatest damage is caused by the heavier equipment. In all cut/chip systems this was the trailer collecting the chips.

- Tracked units reduce compaction in the upper soil horizons and cause less rutting. The obvious conclusion is that a tracked trailer should be used to collect the produce from the coppice.

Trial 3: Tracked Trailer Trials

Tracked trailers are not commonly used in agriculture in the UK. However, the Richard Larrington Limited trailer (Plate 2) designed to haul carrots from the fields during very wet periods was identified and a trial organised to test it. The rubber tracks and associated components used on the trailer were imported from North America. These units were very expensive, and added £18 000 to the cost of the trailer.

Plate 2

The Larrington Tracked Carrot Trailer

The main objective was to compare a tracked trailer with a wheeled trailer carrying similar loads. Ground damage would be assessed using penetrometer readings and rut depth measurement. Details of the trailers are shown in Table 5.

Table 5

Trailer Details

Trailer	Tracked	Wheeled
Cost approx. (£)	35 000	17 000
Weight (tonnes)	10.01	4.65
Body length (m)	7.75	6.70
Overall length (m)	9.45	8.10
Body width (m)	2.30	2.30
Total width (m)	2.70	2.30
Trailer height (m)	1.30	1.56
Track centres (m)	2.00	
Inside track (m)	1.30	1.45
Outside track (m)		2.20
Track bogie centre (m)	1.78	
Track width (m)	0.70	
Track length (m)	2.83	
Track height (m)	1.02	
Tyres - Michelin X		18R 19.5 XYi

The trial took place in April 1995, and involved running the 2 trailers across a field and back (c 400 m) in their own tracks, to simulate the effect of SRC harvesting.

The site had a deeply cultivated sandy soil. Walking over the area caused deep footprints, an indication of the very 'soft' nature of the site.

Both trailers were loaded with carrots to give a gross trailer weight of 13.2 tonnes. In addition, the tracked trailer was also fully loaded to provide a gross trailer weight of 21.74 tonnes.

Cone Penetrometer readings and rut depths were taken before and after treatments:

- Tr 1 - Wheeled trailer; empty.
- Tr 2 - Tracked trailer; empty.
- Tr 3 - Wheeled trailer; gross trailer weight = 13.20 tonnes
- Tr 4 - Tracked trailer; gross trailer weight = 13.20 tonnes.
- Tr 5 - Tracked trailer; gross trailer weight = 21.74 tonnes.
- Tr 6 - Tracked trailer; as Tr5 but reverse in.

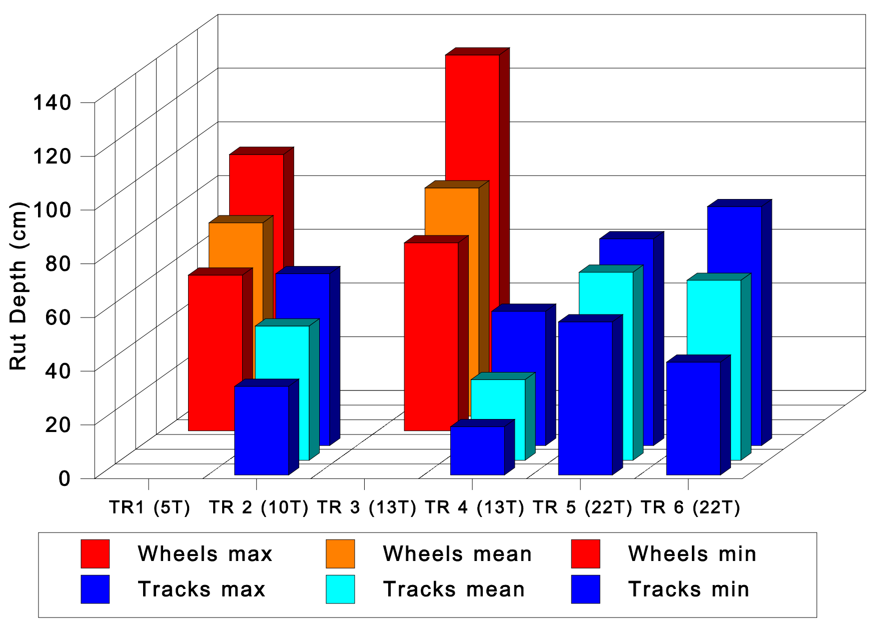
The **results** show that:

- **'Empty' Trailers**: Both units successfully travelled across the field and back again with no great difficulty. The units compacted the soil to a similar level. However, the tracked trailer weighed c 5.3 tonnes or 115% more.
- **'Loaded' Trailers - Gross Weight 13.2 tonnes**: The tracked trailer crossed the field and returned with no difficulty. The wheeled trailer bogged after c 30 m. Comparing the data with the individual pre-treatment readings, both trailers compacted the soil. The tracked unit indicated only a slight increase in compaction.
- **Fully Loaded Tracked Trailer - Gross Weight 21.7 tonnes**: This failed after c 25 m due to a build up of soil in front of the tractor tyres. A successful attempt was made to reverse into the field and drive out forward. Compaction was greater than that resulting from the gross weight of 13.2 tonnes.

Rut depth measurements showed that the tracked trailer caused considerably less rutting than the wheeled trailer (Figure 8). Even the fully loaded tracked trailer caused less rutting than the empty wheeled unit which was some 17 tonnes lighter.

Figure 8

Rut Depths: Tracked and Wheeled Trailers



Trial 4: 3rd SRC Harvesting Trial

The success of the Larrington tracked trailer trials resulted in further tests during the Third Harvesting Trial in November 1995.

The high cost of the tracks had led Mr Larrington to develop his own, cheaper, versions. The Larrington *high dump tracked peat trailer* (Plate 3) was used at Castle Archdale in Northern Ireland. The Larrington *high tip tracked trailer* was used at both of the English **sites. High Dump Tracked Peat Trailer**: A section of the Castle Archdale harvested site was selected as the trial area. The main features of the area were:

- 8% up/down slope and 10% side slope (resulting in 'upper' and 'lower' track readings').
- Minimum ground damage from previous operations.
- Large enough to run 2 trailers 'side by side'.

Plate 3

The Larrington Tracked Peat Trailer

Pre-treatment penetrometer readings were taken in each proposed wheel/track run at 20 per row. Run lengths were c 100 m with assessments made in a c 20 m centre section. The equipment used for this trial is detailed in Table 6.

Table 6

Equipment Details

Unit	Fiat 160.9 4WD Tractor	4 Wheel Utility Trailer	Tracked Trailer
Tyres / Tracks	Tayrus Safety radial HT 14.9R28	Avon 12.5/80 x 15.3	Rubber with wooden cleats
Track Widths (m)			
Centre	1.90	1.72	1.72
O/all	2.27	2.06	2.06
Inside	1.52	1.38	1.38

The 2 trailers were loaded to give a similar gross weight of c 5.3 tonnes. Post treatment penetrometer readings and rut depth measurements were taken after 2 passes. Rut depth measurements were recorded after a further 8 passes. Finally a further 10 passes (making 20 in total) were run before final assessment of rut depth and by penetrometer (Table 7).

Table 7

Rut Depths: Castle Archdale (mm)

		2 Passes		10 Passes		20 Passes	
		Upper	Lower	Upper	Lower	Upper	Lower
Wheeled Unit	Range	0 - 10 *	0 - 10*	20 - 40	35 - 65	45 - 50	55 - 80
	Mean	**5.0***	**5.0***	**33.75**	**47.5**	**46.3**	**67.5**
Tracked Unit	Range	0 - 10	0 - 15	10 - 55	30 - 65	30 - 80	40 - 105
	Mean	**5.0***	**7.5***	**36.3**	**51.3**	**48.8**	**66.3**

* Nominal

The main conclusions from the **rut depth** data are:

- Rut depth increased with the number of passes.
- There was very little difference between the 2 treatments. The well established root system of the willow coppice may have limited the extent of rutting.
- Rutting on the down hill side was greater than that on the uphill side.

Lower depth **penetrometer** readings were affected by stones and it was only possible to plot graphs of means for the first 8 readings (top 30 cm of soil horizon), which show:

- For both treatments, the greater the number of passes the greater the compaction.
- No evidence of more compaction on the lower side than the upper side, despite rut depth differences.
- That the tracked unit appeared to cause less compaction.

Conclusions

The main harvesters and towing tractors generally caused very little ground damage except in extremely wet conditions although some damage was observed on the headlands where trafficking was intense.

Extraction tractors and trailers caused the most damage and traction problems can limit the harvestable area.

The main points which can be drawn from the **cone penetrometer and rut depth results** are:

- *Machines generally cause ground compaction*. During the Silsoe trials no evidence of compaction was found on the clay site. This is likely to be due to the soil being pushed away to the side, as opposed to being compacted. The same may have occurred on the sandy tracked trailer trial site.
- *Lower soil pressure readings were recorded using tracked machinery* compared to wheeled machinery of the same weight.
- *Tracked machinery caused less rutting* than wheeled machinery.
- On loam sites there was evidence that *heavier equipment caused more compaction* than lighter equipment.
- Wheeled and tracked units gave *similar levels of compaction*.
- The level of *compaction was increased with an increase in trafficking*.
- There was *no difference in ground compaction between planted and unplanted headlands* following trafficking.
- Growth data assessments 1 season after harvest *did not show a willow yield effect* of compaction at the test site concerned.

Although no direct link has been established between rutting/compaction and a reduction in crop yield, it is generally considered good practice to keep damage to a minimum.

Recommendations

To minimise ground damage:

- Use the lightest possible equipment.
- Optimise load sizes.
- Use tracked equipment where possible.
- Avoid harvesting during excessively wet periods of weather.

Further work should be carried out to assess and quantify the long term effect of mechanised harvesting on crop yield. The ultimate aim should be to provide growers and contractors with recommendations on optimum machinery systems.

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Technical Development Branch Publications on Short Rotation Coppice

Information currently available from TDB includes:

Reports

- 1/94 (1993), Harvesting and Comminution of Short Rotation Coppice: Selection of Equipment for Initial Testing.
- 11/94 (1994), First Field Evaluation of Short Rotation Coppice Harvesters.
- 1/95 (1995), Second Field Trials of Short Rotation Coppice Harvesters.
- 5/95 (1996), Further Evaluations of Planting Machines for Short Rotation Coppice.
- 10/96 (in press) 3rd Field Evaluations of Short Rotation Coppice Harvesters.

Technical Notes

- 7/94 (1994), Short Rotation Coppice Planting Machines.
- 2/95 (1995), Layout of Short Rotation Coppice for Harvesting.
- 11/95 (1995), Harvesting Short Rotation Coppice Transport Options.
- 12/95 (1995), Small to Medium Scale Comminution Machinery.
- 3/96 (1996), Initial Tests of Comminution Machinery in Short Rotation Coppice.
- 28/96 (1997), Harvesting and Comminution of Sweet Chestnut Coppice for use as a Fuel Stock for Electricity Production.
- 21/98 (1998) Short Rotation Coppice Ground Damage
- 8/98 (1998) Harvesting and Comminution of Short Rotation Coppice.

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