

HARVESTING AND COMMINATION OF SHORT ROTATION COPPICE

Summary

Field trials in a range of generally poor ground and crop conditions have shown that machines are available from abroad which can successfully harvest Short Rotation Coppice. These include modified sugar cane or forage harvesters as capital expensive "contractor" machines and at least 1 tractor towed stick harvester, suitable for an individual or small group of farmers. A fast, "large scale" stick harvester has also been demonstrated, so there is a real choice of whether to stick or chip harvest at the large commercial scale. There is less choice at the small scale, with no truly small scale chip harvester but a medium scale tractor mounted system (Plate 1) with a novel cutting mechanism is available. To a greater or lesser extent all machines require some modification for successful use in UK crops, which should themselves be of a stem size, form and spacing appropriate to the harvesters.

Sloping and soft ground can be a major constraint on harvesting operations, with the high risk of bogging by collection machinery if drainage is poor or key routes are badly sited. Good site planning before planting is essential, to plan out side slopes, soft areas and allow for machine turning.

Chip harvesting returns lower direct harvesting costs but requires chip storage, under cover and with a degree of artificial ventilation. Chippers are available for use in stick harvesting systems but costs are relatively high even when grapple feeding is used.

Growers should ensure that the moisture content and chip size fraction which they can produce given their machinery and systems choice will be acceptable to end user plant, because there are a range of possibilities.

Technical Development Branch (TDB) of the Forestry Commission was engaged on the harvesting and chipping

Plate 1

Salix Maskiner MkIII on JCB Fastrac Box



Introduction

In the early 1990s there was less than 100 ha of Short Rotation Coppice (SRC) planted in the UK, mostly on lower quality arable farm land. With approvals for 3 gasification plants under the Non Fossil Fuels Obligation (NFFO) Third Tranche and a further 7 gasification or pyrolysis plants

(68 MWe) under the Fourth Tranche, it is likely that this figure will rise considerably within 2 to 3 years.

Following this the Energy Technology Support Unit (ETSU) of the DTI introduced a 3 year programme of shared cost research on the mechanisation of harvesting and comminution (chipping) of short rotation coppice, paralleled by work on storage and drying.

aspects of the programme while Silsoe Research Institute carried out the work on storage and drying.

Poplar and willow are suitable for use in the UK as SRC for renewable energy production. Species of the 2 genera have different growth characteristics, the most notable being the number and diameter of coppice shoots. The larger diameter poplar stems may be more difficult to harvest with some machines than willow, for which equipment has been under development in Sweden and elsewhere. Conversely, the greater tendency to straight growth habit of poplar can be an advantage.

Good site planning for SRC harvesting requires an appreciation of the systems that may be used and the limitations of current machinery. There may be a trade off between landscape and harvesting efficiency in terms of size, shape and scale of planting, but this will not necessarily significantly affect overall harvesting costs.

SRC will be harvested in the winter period of November to March after leaf fall and before leaf set. This tends to be a slack time in agriculture with bad ground conditions stopping many activities. Some farmers and agricultural contractors have under utilised machinery and labour at this time of year. SRC cropping would complement the agricultural timetable, increase the utilisation of farm machinery suitable for SRC work and promote winter employment.

Harvesting Systems

There are 2 main systems for harvesting SRC:

- Combined cut and chip, followed by on-site storage and delivery, or delivery direct to plant (Plate 2).

Plate 2

Austoft Harvester in 2 Year Poplar, Swanbourne



- Cut/bundle or cut/accumulate loose, store in field, chip before delivery then deliver to plant (Plate 3).



Plate 3

Frobesta Bundles Lying Infield Prior to Extraction to Headland

Although harvesting equipment continues to be developed and demonstrated abroad, especially in Sweden, conditions differ from those in the UK. Most of the machines have been developed to work in twin row plantations where the rows are planted at 0.75 m between rows with 1.5 m between pairs of rows. This permits the use of wider machines and tyres to enable working in wet conditions and reduce ground damage.

Harvesting Trials

Extensive trials were carried out over the period of the contract. All available machines were considered and the most appropriate included in the field trials.

Harvesting: Harvesting trials were carried out over 3 seasons on 9 harvesters.

- Cut and chip harvesters:
 - Austoft modified sugar cane harvester (Plate 2).
 - Claas self propelled forage harvester with specialist header (Plate 4).

Plate 4

Claas Harvester in 2 Year Poplar, Devon



- John Deere self propelled forage harvester with Kemper header.
- Salix Maskiner MK II & MK III tractor mounted harvesters (Plate 5).

Plate 5

Salix Maskiner MkIII, Using Continuous Saw Chain, in Willow



- New Holland unmodified trailed forage harvester (Plate 6).

Plate 8

Nicholson Basket Willow Harvester

Plate 6

Short Test of New Holland 719 in Low Yield Willow



- Stick harvesters:
 - Frobbesta trailed stick harvester (Plate 7).

Plate 7

Frobbesta Harvesting 2 Year Single Row Poplar



- Loughry trailed stick harvester.
- Nicholson trailed basket willow harvester (Plate 8).



- Empire 2000 self propelled stick harvester (Plate 9).

Plate 9

Seggerslaat Empire 2000 Stick Harvester



The harvesting trials covered a wide range of sites and crop types ranging from willow at Castle Archdale, in Northern Ireland, to poplar at Buckfast, in Devon and Ashmans Farm in Essex. Different methods and systems were tested and refined in order to find the most appropriate machines, methods and systems for UK conditions (Table 1).

Table 1

Summary of Machine Performance

Machine	Comment
Cut and chip harvesters	
Austoft	Coped with all crops and ground conditions encountered. Main chip fraction 50 mm to 100 mm. Some longer 'tips'.
Claas	Limited by wet slopes >10% and bushy crops with swept bases. Coped with straight crops. Very even 15 mm to 35 mm chip.
Kemper Header	Header unsuitable. High and fractured stools. Header could only cut lighter crops.
Salix Maskiner Mk III	Modifications allowed novel cutting mechanism to work despite blockages and cutting chain derailment due to vegetation and stool sweep. Even 15 mm to 35 mm chip.
New Holland	Cutting and 'transport' mechanism unsuitable but drum chipper worked well. Extensive modification required.
Stick harvesters	
Frobbesta	Single row cutting and larger stick size of poplar caused blockages. Principles appeared to work well. Off loading process frequent.
Loughry	Worked better uphill but blockages still a severe problem.
Nicholson	Not suitable for 2 or 3 year SRC crops as designed for smaller stems.
Empire 2000	Fast and effective prototype.

Both cut and chip harvesters and stick harvesters are likely to be used in SRC production in the UK. Cut and chip systems involve capital expensive equipment and are derived from existing forage and sugar cane harvesters. Forage harvesters have a dual forage and coppice harvesting role in the UK which will help to reduce costs. Cut and chip systems are more suited to contractors and large scale enterprises. Such systems may require provision of expensive storage facilities.

Stick harvesting systems may utilise existing farm equipment with specialised towed or mounted harvesting attachments. Specialised self propelled machines will give lower costs for large scale harvesting. Stick harvesting systems mainly involve a lower capital outlay and are more suited to smaller growers than higher output cut and chip systems, which will require large programmes to be cost effective. The exception is that the Empire is a large scale stick harvester. Sticks can be stored and partly dried outside. This may further increase the attractiveness of the system where capital is not available to construct specialised chip storage facilities. Sticks will probably need to be comminuted (chipped) for use and this will add to the cost of this system.

Comminution: Although comminution machinery has been developed for use in conventional forestry and arboriculture little was known of its use within SRC.

TDB identified the need to investigate comminution machinery to determine outputs, costs and quality of chips and to assess its potential within SRC.

The following machines were evaluated using hand and grapple feeding methods:

- Sasmo HP-21 with small screw chucker (Plate 10).

Plate 10

Green Poplar Comminution Trial at Silsoe Research Institute



- 1).

Plate 11

Chipping Dry Poplar at Swanbourne with a Sasmo HP25

- Vermere 935 disc chipper (Plate 12).



Plate 12

Vermere 935 Disc Chipper



- Haybuster HD-10 tub grinder (PLate 13).

Plate 14

Plate 13

Dry Poplar Chipping with a Large Siba Drum Chipper

Tub Grinder: Compressing the Sticks onto the Fails
Proved Difficult



- Sasmo HP-30 with L-screw chunker.
- Bandit 250 disc chipper.
- Patu DC100 disc chipper.
- Siba 745 RCX 240 HP Drum Chipper (Plate 14).

Ground Damage: Crop yields may be affected by either ground damage or root/stool damage, or a combination of both. Little work has been done to date to measure the results of this damage and the effect on yield. An attempt was made during the contract to quantify the impact of machinery trafficking on soil compaction and crop yield.

Data were collected from 4 main trials (Table 2).

Table 2

Ground Damage Summary of Sites and Methods of Assessment

Trial	Trial Details	Assessment Techniques				
		CPR	RDM	SPR	CYA	VA
1	2nd SRC Harvesting Trial Investigation into the possible problems of machine trafficking on crop yields December 1994.	✓	-	-	✓	✓
2	Silsoe Trial: Measurement of Soil Compaction In February 1995 a specific 'ground damage' trial was instigated at Silsoe Research Institute in Bedfordshire.	✓	✓	✓	✓	-
3	Larrington Tracked Trailer Trials In April 1995 a 3rd trial was arranged to assess the advantages of using tracked equipment.	✓	✓	-	-	-
4	3rd SRC Harvesting Trial Tracked equipment was included in the 3rd SRC Harvesting Trial in November 1995. During these trials the opportunity was taken to compare wheels and tracks in ground compaction tests (Plate 15).	✓	✓	-	-	✓

CPR - Cone Penetrometer Readings
CYA - Crop Yield Assessment

RDM - Rut Depth Measurements
VA - Visual Assessment

SPR - Soil Pressure Readings @ 30 cm Depth

Plate 15

Recording Cone Penetrometer Used to Measure Compaction in Wheel Ruts

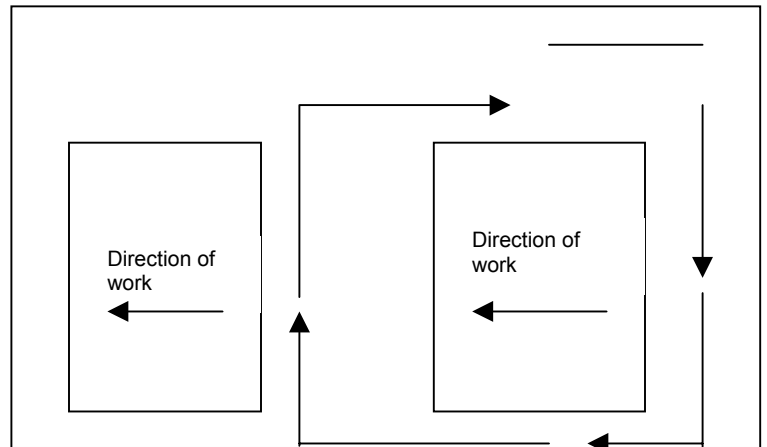


Harvesting Method

The simplest method of harvesting is to work up 1 row or pair of rows and back down the next. However, this approach involves the delay and ground damage caused by 3 point turns on the headland, especially by trailers.

Therefore, where possible SRC was worked in blocks or 'lands'. Two lands would be opened with the distance between faces of c 50 m to minimise unproductive travel (Figure 1).

Figure 1



Results

Harvesting **outputs and costs** (Table 3) vary according to the crop density, spacing, form, working method and row length. Operator skill also has an effect on the output of the harvester.

The crop spacing during the trials was not ideal for the machines but system outputs and costs have been modelled to reflect the current ETSU recommended twin row spacing of 1.5 m + 0.75 m.

Table 3

Outputs and Costs

System	Harvester	Range of Output (ha/shr)★	Range of Cost (£/odt)
Cut and Chip Harvesting	Austoft	0.28 - 0.56	7.48 - 15.91
	Claas	0.34 - 0.52	7.10 - 11.16
	John Deere	0.21 - 0.36	7.98 - 15.86
	Salix Maskiner	0.16 - 0.22	7.76 - 15.00
Stick Harvesting with separate chipping @ £8.22/odt	Empire 2000	0.16 - 0.22	16.26 - 24.84
	Frobbesta	0.09	28.17 - 33.54
	Loughry	0.13	30.35 - 36.55
	Nicholson	0.10	30.45 - 36.69

★ Outputs are shown per standard hour (shr) which includes allowances for operator Rest (22%) and miscellaneous Other Work during the day onsite (15%).

These figures exclude blockages and are based on crop yields of between 26 and 36 oven dried tonnes (odt/ha) and

the actual row lengths studied.

Intermediate haulage of chips may not be necessary if the storage area can be accessed by road haulage vehicles.

However, a secondary haulage element cost is included to allow for transport, of comminuted sticks stored on the headland, using a 15.5 m³ silage trailer.

Weed infestation at some sites and row spacings of either 1 m + 1 m or 1.5 m + 1.5 m caused difficulties with all harvesters. Blockage time within the trials accounted for from c 20% of productive time for the Austoft to c 412% for the Loughry.

Costs include fuel, operator, repair and maintenance with

100 m extraction infield and 500 m extraction on road.

In the stick harvesting systems chipping is a secondary operation.

A summary of the results of chipper trials is shown in Tables 4 and 5. The Sasmu produced chips for the lowest cost at c £8.22/odt.

Table 4

Comminution Machinery Study Results

Chipper Unit	Sasmu HP-25	Vermeer 935	Haybuster HD10	Sasmu HP-30	Bandit 250	Patu DC100	Siba 745 RCX
Feed method	Hand	Hand	Grapple	Grapple	Grapple	Grapple	Grapple
Coppice mc ¹ (%)	26	26	26	21	21	21	38
Allowances ²	1.28	1.28	1.4	1.23	1.23	1.23	1.4
Output (odt/shr)	0.91	0.87	3.30	2.95	2.21	1.13	1.44
Cost/hour (£)	30.81	21.13	40.32	24.65	20.35	18.8	55.89
Cost/odt (£)	33.56	24.29	12.22	8.36	9.21	16.64	38.81

1. Moisture content on wet basis.
2. Factor to allow for Rest and Other Work.

Table 5

Comminution Machinery Fractions of Poplar
(% in each Size Class)

	Sasmu HP-25	Vermeer 935	Haybuster HD10	Sasmu HP-30	Bandit 250	Patu DC100	Siba 745 RCX
Classes	Dry	Dry	Dry	Dry	Dry	Dry	Dry
> 150 mm		-	-	-	-	-	-
> 100 mm	12.6	-	36.3	47.5	-	-	-
> 50 mm	79.3	14.6	30.7	46	9	12	24
> 35 mm	5.1	6.9	14.5	2	10	12	16
> 15 mm	1.7	69.2	13.5	3	60	54	40
>2 mm	0.9	8.8	3.1	1	20	21	16
Fines < 2 mm	0.4	0.5	1.9	0.5	1	1	4

Main Conclusions of Trials

Harvesters: In general, the harvesters appeared to cause minimal **site damage**. However, chip tractor/trailer units

caused significant rutting at the wettest locations. Harvester unit traction, particularly of the Austoft, was good but chip collection equipment was unable to follow on the steeper, wetter slopes.

The Austoft harvested uphill on wet slopes up to c 20% **slope** (Plate 16). A side slope limit of 20% was indicated. Wheeled harvesters have lower slope capabilities with steep side slopes making driving difficult. Harvester outputs fall if one way harvesting is dictated by slope.

Plate 16

Austoft on c 20% Slope. The tractor Unit is Unable to Climb this Slope



Both the **Austoft** and the **Claas** harvesters are possible contractor machines for large scale cut and chip harvesting. The Austoft produces chunks of material with up to 90% between 50 mm and 100 mm (Plate 17). The Claas produces much smaller more fragmented material with up to 72% between 15 mm and 35 mm with a cross sectional diameter between 4 mm and 6 mm.

The John Deere forage harvester is an alternative to the Claas base machine, although it would have to be fitted with a Claas header. The **Kemper header** is not recommended for use in 2 to 3 year old SRC as damage to the stools is unacceptable.

The **Empire 2000** was the only large scale stick harvester tested. The unit could offroad at headland or into accompanying tractor/trailer unit. Various modifications were proposed by the designer to improve traction, stability, tank capacity etc.

Plate 17

Comminution machinery should be grapple fed at all times to ease operator fatigue, maximise outputs and minimise costs.

When comminuting dry material most consistent chip

Austoft Willow Billets in Northern Ireland. Set on Shorter Crop Length of c 50 mm to 60 mm



For the growers' co-operative and small contractor the **Salix Maskiner** provides an alternative to the larger self propelled machines. The harvester is designed to be fitted to the front 3-point linkage of an agricultural tractor which may facilitate the use of existing machinery during the winter.

For the individual "farmer" type operator, the **Frobbesta** stick harvester is a possible alternative to contract harvesting. Some difficulties were caused by the 1 m row spacing encountered in the trials and twin row planting is recommended for this machine. Relatively simple modifications are required, including changes for use in poplar.

Further modification could be made to the harvester to enable direct loading of trailers. This would remove the costly extraction operation.

Brief testing of the **New Holland** trailed forage harvester indicated that development of this type of machine could offer the "farmer" operator a small scale cut and chip harvester.

Both the **Loughry and Nicholson** machines require major modification to work in a safe and economical manner in SRC.

Comminution Machinery: The range of chippers tested gave a range of chip size fractions from the larger "chunks" of the Sasmo cone screw machines to finer chips of the disc chippers. Only the cone screw chippers could produce a larger chip of 60 mm to 70 mm or more, depending on the size of cone screw used. The material produced by the Haybuster was of a stringy and variable nature and is unlikely to be suitable for most generating plants.

fractions were produced with the disc chippers, with most chips falling into the 15 mm to 35 mm classification.

Green stems tended to produce a larger percentage of material >50 mm, made up mainly of long thin branches.

Results from the Silsoe Research Institute storage and drying research showed that 50 mm to 60 mm and greater Austoft type billets and Sasmo type chunks required far less ventilation in storage than more conventional finer chip material.

Ground Damage: Extraction tractors and trailers caused most ground damage and traction problems limited the harvestable area. The use of tracked tractors and trailers would reduce these problems (Plate 18).

Plate 18

Rubber Tracked CAT Challenger with Larrington Trailer and Sled Tracked Austoft



The main points from the ground damage work were:

- Machine trafficking causes ground compaction. During the Silsoe trials no evidence of compaction was found on the clay site. This was due to the soil being pushed away to the side.
- There was no difference in ground compaction between planted and unplanted headlands.
- Growth data assessments, 1 season after harvest, indicate that increased ground compaction had no initial effect on crop yield.

- Lower ground pressure readings were recorded using tracked machinery compared to wheeled machines of the same weight.
- On loam sites there was evidence that heavier equipment caused more compaction than lighter equipment.
- Tracked machinery caused less rutting than wheeled machinery.
- Wheeled and tracked units gave similar levels of compaction.
- The level of compaction was increased with increased trafficking.

Main Recommendations of Trials

Further work should be carried out on:

- **Small scale** Stick and Cut and Chip Harvesters and modified existing machinery.
- **Extraction** equipment, especially in relation to traction and site damage.
- The **interaction** of on-farm and off-farm elements.
- The **site effects** of machinery on stool regrowth and ground compaction.
- Testing **large scale chippers** for output and chip characteristics to ensure that market specifications can be achieved.

A **risk zone** should be determined and displayed on the machines by the harvester manufacturers. Unprotected personnel should be excluded from this zone.

Side guards should be fitted on all harvesters to cover sections of the saw periphery not used for actual cutting. This will reduce the risk of 'chain shot' from chain saws and 'fly off' of teeth from the circular saws.

Reversing sounders should be fitted to all machines.

A **chip collection** system should be developed to reduce site and crop damage. This might involve modification to machines to enable them to tow and operate their own trailer units.

Operators should be fully **trained**, and training should include changing blades and the use of props.

Individual machine recommendations are as follows:

Austoft: The Austoft can be used to harvest 2 to 3 year

old poplar and willow SRC at single row (1.0 m + 1.0 m) or, preferably, at twin row spacing (0.75 m + 1.5 m), providing that the consumer will accept the larger chip produced with minor modifications the harvester would work successfully in the UK.

Claas: The Claas can be used to harvest 2 to 3 year old poplar and willow SRC, either at single or twin row spacing. The harvester will operate at its best in twin row spacing with minor modifications the harvester should work successfully in the UK.

John Deere with Kemper Header: The John Deere 6910 base unit is suitable for harvesting 2 to 3 year old willow and poplar SRC. The Kemper header requires major modifications to the cutting and gathering system.

If user interest justifies the cost, the John Deere base unit should be retested using a Claas header to determine the full potential of the forager in SRC harvesting.

Salix Maskiner: The Salix Maskiner is capable of harvesting 2 to 3 year old poplar and willow at twin row spacing. The following modifications would need to be made to allow the harvester to work in the UK:

- Provision of an audible reverse warning and agreed safe working practice.
- Provision of a new chip collection bin to reduce stability problems.
- Improved guarding of the saw mechanism to reduce the risk of chainshot and derailment.

New Holland: Modifications to allow successful SRC harvesting would cost several thousand pounds. This would include modifying the cutting and crop feeding mechanisms to produce a better quality of stump cut. It could be more cost effective to develop a new machine based on known principles and available components.

Empire 2000: The Empire 2000 can be used to harvest 2 to 3 year old poplar and willow sticks at twin row spacing, although some modifications are advisable.

Frobbesta: The Frobbesta is recommended for use in twin row as opposed to single row crops in the UK, providing minor modifications are made.

Loughry: The Loughry coppice harvester cannot be recommended for harvesting SRC until the feed and cutting systems have been modified, to prevent blockage and improve crop flow.

Nicholson: Not recommended for use in SRC.

More detailed information on Harvesting and Comminution of Short Rotation Coppice can be found in the following TDB Reports available from the Forestry Commission, Technical Development Branch, Ae Village, Dumfries DG1 1QB. Tel: 01387 860264. Fax: 013487 860386

Reports

- 1/94 Selection of Equipment for Initial Testing.
- 11/94 First Field Evaluations of Short Rotation Coppice Harvesters.
- 1/95 Second Field Trials of Short Rotation Coppice Harvesters.
- 10/96 Third Field Evaluations of Short Rotation Coppice Harvesters.
- *11/96 Harvesting and Comminution of Short Rotation Coppice: Field Trials.
- *12/96 Harvesting and Comminution of Short Rotation Coppice: Appendices.
- *13/96 Guidance on SRC harvesting Operations.
- 21/98 Ground Damage caused by SRC Harvesters.

Technical Notes

- 2/95 Layout of Short Rotation Coppice for Harvesting.
- 11/95 Harvesting Short Rotation Coppice Transport Options.
- 3/96 Initial Tests of Comminution Machinery.
- 7/96 Second Field Trial of Comminution Machinery.
- 13/96 Large Scale Comminution of Short Rotation Coppice.
- * ETSU Publication B/W2/00262/REP
'Harvesting and Comminution of Short Rotation Coppice 1996.
Forestry Commission, Technical Development Branch'

Further Information

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