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HARVESTER DEVELOPMENT FOR NEW HIGH YIELDING SRC CROPS AND MARKETS

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EXECUTIVE SUMMARY

Objectives of the Work

Higher Yielding Crops

- To develop harvester drive chain and feeding systems to cope with larger higher yielding modern crops.

Harvesting Cycles

- To assess by harvesting sites of different ages of the most recently planted varieties the most economic harvesting cycle for SRC crops. Focus on maximising machinery and crop output thus minimising delivered cost per tonne whilst still maximising grower return.

Co-firing fuel production

- To produce in one pass fuel that can be directly fired with coal in pulverised fuel systems.

Gasification fuel production

- To produce in one pass large grade fuel suitable for gasification.

Overall

- To achieve a harvesting cost of ANY fuel specification of £10-£11/oven dried tonne (odt).

Background and the need for the work

Short rotation coppice (SRC) is an under developed industry in the UK. Currently there are around 2,000Ha of crops planted many of which are not allocated to a specific end use. Large-scale markets have emerged mainly driven by co-firing. For example, one 2,000MW coal station has an annual demand of up to 300,000 odt biomass, () based on 5% thermal load. This is equivalent to 30,000 planted Ha of SRC. Most UK coal-fired generators have co-fired significant quantities of biomass and continue to do so. There are seven UK plants to date that have biomass handling facilities. This creates pressure in the capability of harvesting SRC to a market specification (detailed below) required at an economic price of between £45 and £80/ODT depending upon the format that it is presented in (particle size, moisture content). In all cases the major concern of the generator has switched from being price of fuel to being security of supply. They are investing heavily in their coal fired generation plant to enable the introduction of biomass and need a high degree of confidence that the SRC fuel supply industry can deliver those significant tonnages required.

The latest information from crop breeders and field trials shows that a mix planted in the year 2000 compared to the late 1990's has a yield increase of 30%. The only way that the crop can achieve this is by growing more stems, and thicker stems that grow taller. This means that an SRC harvester has to be able to gather, feed, cut and chip this larger material.

There are also market sectors that have very different requirements for fuel specification. Trials work that CRL has been involved in to co-fire large coal-fired power stations has shown that the generators' requirement is for particles of fuel that are 6mm x 3mm x 3mm in size. At the other end of the scale, the gasification industry require a lump of wood that is 50-75mm long and as thick as the crop stem allows – ie retaining harvested stems whole as against splitting stems.

The goal of this project was to develop a harvesting system for SRC that can, in one pass, produce material to the required specification of an end user at a cost that enables the grower to be profitable and the end user to purchase fuel at a price that he can afford to pay. The developed technology could then be disseminated by CRL and mainstream machinery manufacturers to meet the needs of the expanding willow harvesting and fuel market.

Summary of work carried out

The project has consisted of a number of engineering and field trials. Key amongst these has been development of robust harvester drive mechanisms that are able to withstand the larger crops that the UK now produces and the modification of the chipping system to allow different fuels specifications to be produced. Throughout a method of research into the specific area has been followed by engineering adaptations that have then been field tested and reviewed. Clearly with cost objectives, trials involving the assessment of cost of production through workrate and expense have been necessary and these have been incorporated. Finally consolidation of the knowledge and results gained has been made and incorporated in guidance notes and recommendations for further work.

Summary of main results

Key results that have been achieved are as follows:

- Drive chain has been developed to be robust enough to cope with new larger , higher yielding crops
- Guidance notes have been developed around harvest cycles – intervals and crop size/specification – that produce the most efficient and therefore cost effective harvesting of SRC crops
- Fuel has been produced in a single pass that is suitable for co-firing – particularly where direct injection techniques are employed. The economics of producing this fuel are complex as there are multiple stages involved, and the processing stages impact upon other factors such as the logistics. For example “standard” chip direct from the field at 15mm can be processed into final “dust” fuel at the farm site (by drying and milling) but this then impacts on the haulage cost and on the cost of handling equipment at the power station. The alternative of delivering “standard” chip for processing at the power station has impact on capital spend and in siting and integrating processing equipment into the power station’s existing plant and equipment. Finally there is an increasing perception in the market that pellets are the most attractive fuel type for co-firing and this adds a further energy intensive process which again can be sited at the growing crop or at the power station or at a fuel aggregation site. The scenario where production of co-firing chip in a single pass looks most attractive is where the power station has adopted direct injection technology, the crop is grown within a relatively tight radius of around 15 miles and material can be delivered directly to the power station for storage and/or intermediate drying as required.
- Fuel has been produced in a single pass that is suitable for use in gasification based energy generation equipment and has been produced at an economically viable cost.

- A harvesting cost of £10-£11/odt for conventional fuel specification (15mm-30mm) and of gasification fuels (57mm-75mm) has been achieved. Production of fuel specification for co-firing has been more costly at £12-£20/odt.

Conclusions

- Harvesting of SRC crops using the technology developed as part of this project is technically robust.
- Fuel specification can be altered to suit the requirements of different markets and can be produced economically.
- In production of fuel for co-firing in large coal combustion plant using pulverised fuel there are a series of complex economics involving secondary processing and haulage that will dictate the most cost effective method of delivering product.
- As the scale of market grows the ability to harvest SRC over the majority of the year is essential to the economic viability of the crop as a fuel source in order to meet the desired tonnages of end users and to maintain a continual level of supply on a year round basis.
- Harvesting of crops that have grown beyond the normal scale is extremely costly (may be over three times the normal cost at £35/odt) and not recommended.

Recommendations

- Key recommendation is that in order to harvest effectively the crop must be within the following size criteria:
  - Maximum stem base diameter 100mm
  - Maximum crop height 8 metres

- In general age terms this can be expressed as:
  - Interval to 1st harvest is no more than 3 years from planting or from cutback
  - Interval from 1st to 2nd harvest should be 2 years with a maximum of 30 months

- Large single stem crops that exceed these dimensions should be left until economic to harvest using conventional forestry techniques.

- Further work should be targeted towards:

1. R&D/Technical
   - Assessing the technical viability of harvesting all year round. Harvesting in summer months – July/August – has been described as having issues in sugar return to stools for re-growth. This requires validation in commercial crop situations.
   - Assessing the biomass fuel specification that can be co-fired in large coal plant – note as more experience is gained of the burning properties (full burn required to avoid ash contamination) of SRC/biomass in coal fired systems the current limits on moisture and particle size may be extended.

2. Commercial
    - Modelling the economics of fuel supply to specific co-firing projects with regard to the balance between producing final fuel specification in the field, or reprocessing on/off site from larger SRC particles.
    - Developing models of the co-firing market in relation to trends in ROC values, fossil fuel prices and the value of "captured carbon". This will help to develop understanding in the marketplace for growers/fuel suppliers in terms of price and demand thus ensuring that the supply industry is able to negotiate with large end users on a more equal footing.
    - Long term work into embedded distributed generation will be vital to the industry following the end of the co-firing period in 2016 and in reducing the economic impact of fuel costs on haulage of biomass fuels to end users.
    - Assessing the haulage cost relationship with the specification of fuel produced. The different sizes of fuel produced will have different bulk densities and so the dry weight that can be carried in vehicles will vary and so the cost. In certain circumstances it may be more effective to chip initially at the most appropriate density for haulage and then to reprocess to the final specification for use.

1. MANUFACTURE AND INSTALLATION OF NEW COMPONENTS FOR LARGE CROP HARVESTING

The modifications carried out to the harvesting head were numerous. In order to transfer power more effectively from the harvester to the head, number of bands driving from the main drum to the cutting head was increased from four to six. The path of these belts was altered to create a smoother "S" shaped path for belts to follow and the pulleys and gear boxes that the drive belts run on were strengthened. The blade carriers of the head itself were strengthened and all surfaces were smoothed off to direct larger stems more effectively to the feed rollers. In addition a gathering reel and supporting arms to front of head were added to direct stems into the centre of the head and again increase ease of crop flow. Safety clutches were added into drive system to prevent damage from crop surges which in previous work had shown that they could cause power to be fed in the working direction along the drive belts which resulted in belt failure. Finally additional under body protection was added to counter large stumps and the depth control disks on the head were strengthened.

The alterations are best illustrated in the following series of photographs Figs 1 to 14

Fig 1 - The Starting Point

Fig 2 – the head stripped down

Fig 3 Triple band drive chain added

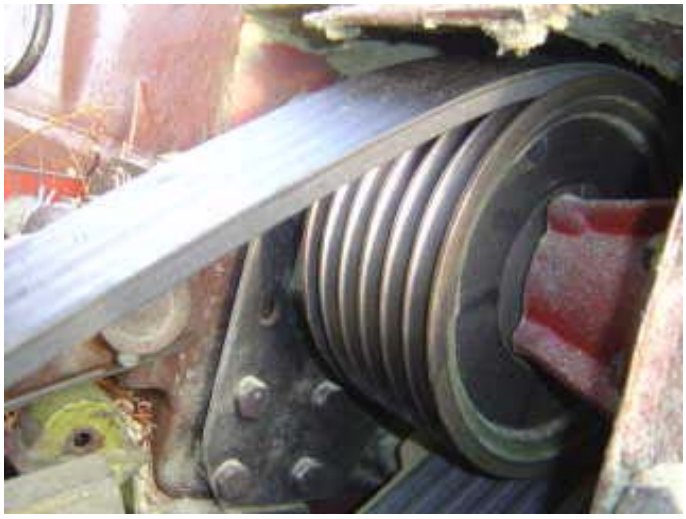

Fig 4 Six groove pulley and powerband

Fig 5 Uprated Gearbox and shafts

Fig 6 Pulley Lock Outer

Fig 7 Pulley Lock Steel Inner

Fig 8 The smoothed out “S” Drive configuration

Fig 9 S Drive (Top View)

Fig 10 Main Drive Pulley with Clutch Insert

Fig 11 spiral reel and gathering arms

Fig 12 Blade holder assembly

Fig 13 Smoothed cutting head surfaces

Fig 14 In situ for field testing

2. ACTIVITY SUMMARY AND RESULTS OF INITIAL FIELD TESTING ON SRC CROPS

Field Trials were carried out over a period of five days in a crop three years old that on measurement yielded seven odt/ha/annum. The crop structure was 100mm average stem base diameter and a height of approaching 8 metres.

Setting up of the machine and modifications to newly constructed/installed items took the whole of day one and half of day two. The main areas that needed attention were in tightening drives and clutches plus regular inspection were carried out (hourly) of drive belts, idler pulleys and front feed roller.

Over the period 9 Ha was harvested with peak work rates of 25odt/hour achieved. At this output the cost/odt of harvesting (on a commercial basis assuming full employment of a harvesting team on an annual basis) was £10.31/odt.


Fig 15(L) and 16 (R) SRC Crops prior to harvesting

Fig 17 Setting into opened out SRC rows

Fig 18 Cut stools (ragged edge from blunted blades – sharpened blades (the norm) produce a clean cut)

3. ACTIVITY SUMMARY AND RESULTS OF FIELD TESTING AND YIELDS OF DIFFERENT AGES OF CROPS

3. 1 Key points summary

The trials showed a number of clear physical stages of the SRC crop that can be used to set guidance at which harvesting operations and fuel produced are cost effective. These are centred on the growth years two to four where the crop develops rapidly as it utilises the majority of its energy in producing stem rather than in setting the initial root base from which the crop later grows. This effect is seen even more clearly in the second harvest rotation where the effect occurs between years 2 and 3 of growth.

In essence the following rules apply:

- Crop structure at 2-4 years undergoes large change
    - At two years crops are even in structure, multi stemmed and varietal differences are minimised.
    - At three years apical dominance is starting to show as stools lose side shoots and the main stem grows dominant. This is particularly exhibited by the variety Tora – the highest yielding type in commercial plots.
    - At four years old apical dominance is complete and Tora dominates the crop stand with other varieties losing out due to shading and competition for resources.
- Second harvest shows greater than expected growth in the size of crop and so yields increase.

These are reflected in the ability to harvest the crop effectively because harvesting costs increase disproportionately as the crop size exceeds 100mm stem base diameter and 8m in height. At the extreme of the largest crops harvested where stem base diameters of 170mm and heights of 12m were present harvesting costs have more than doubled. This is entirely due to the physical structure of the crop which is able to be cut effectively but felling the stem to the horizontal and directing it into the feed rollers is extremely difficult and much slower to feed.

This information is summarised in table 1 below and illustrated in figures 19 - 22

Table 1 – Annual dry weight yield and harvesting cost summary

Crop Age	Yield (av) Odt/ha/yr	Maximum Diameter	Maximum Height	Average Cost/Odt	Notes
2	10.9	75mm	7m	£8.12	2nd harvest
3	7.64	90mm	10m	£10.05	Average of all sites
4	8.62	170mm	12.5m	£20.95	Average of all sites*
5	6.88	90mm	10m	£13.16	Low yielding site

*There is a lot of variation in 4 year old sites. Those with largest crop growth show yields of 11odt/Ha/annum and maximum harvesting cost of £40.72/odt.

3.2 Illustration of harvesting at various crop stages

Fig 19 Harvesting 2 year Old SRC at 2nd Harvest Cycle

Fig 20 Harvesting 3 year old SRC 1st Harvest Cycle

Fig 21 Harvesting 4 year old SRC

Fig 22 Opening out in 4 year old SRC

Figs 23 – 26 Illustration of stump and stem sizes

Fig 23

Fig 24

Fig 25

Fig 26

3.3 Harvester Damage from large SRC crops

3.3.1 Key Points:

In normal operation the harvester is cutting stems that are up to 75mm in diameter and are 6-7 metres tall. Where the size exceeds this as illustrated above, damages above and beyond normal wear and tear are the result. Damage is predominantly caused by the physical size (girth and height) of main stems. In essence it is the feeding and chipping system that has been damaged most.

The major damages are listed below

1. Front hydraulic feed roller – drive shaft sheared from mounts due to excess weight/pressure on the roller
2. Harvester Feed Rollers – damage to teeth and roller centres, return springs, bearings and shafts from forcing large single stems through a gap smaller than their diameter
3. Drive shafts/clutches – excess force required to drive and chip large stems through the drum
4. Chipping drum – stress cracks from cutting large thick stems.

5. Blades – cracked off at corners due to excess force from cutting large thick stems
6. Long term stress damage to drum drive shafts causing failure resulting in whole chipping system failure.

3.3.2 Illustration of damages

Fig 27 Damage to feed rollers (depression in grooves)

Fig 28 New vs. “worn” drive shaft.

Fig 29 Broken blade corner (left blade)

Fig 30 Cracked main chipping drum

3.4 General Harvesting Recommendations

From the trials carried out the following recommendations should be adhered to:

1. Interval to 1st harvest is no more than 3 years from planting or from cutback
2. Interval from 1st to 2nd harvest should be 2 years with a maximum of 30 months
3. Large single stem crops of 4 years or more in age should be left to grow until economic to harvest using Forestry techniques

4. REMANUFACTURE OF CHIPPING DRUM AND PRODUCTION OF MARKET CHIP SAMPLES

4.1 "Gasification/Co-firing Reprocessing" Fuel

4.1.1 Key Targets

The aim was to produce an elongated chip/mini billet of 57 -85mm in length.
Fuel of this size is suitable for gasification in test units currently being operated in the UK.
Fuel of this grade is also attracting interest from coal-fired power stations with the intention to process to final fuel specification on site.*

*In discussion with co-firers over fuel specification it has been brought to our attention that this may be useful for storage prior to secondary processing for co-firing end use. Billets of larger size (200mm) can dry out to lower moisture contents than chipped products – estimates at 22%. They are however more difficult to handle and to chip/mill when supplied in this form. There may be a compromise at 50mm-100mm that allows drying and storage of a "mini billet" that is also able to be readily processed down to final specification for firing in the pulverised fuel boilers.

The economics of production of this initial fuel for reprocessing for co-firing and direct use in gasification are contained in Section 5.

4.1.2 Drum remanufacture

The length of chip produced from the harvester is a function of speed of feeding into the drum and the number of blades that the drum contains. The following table shows the settings required to be achieved for large chip/mini billets.

Table 2 – drum and blade configurations

BASE: 20 Blade Drum 2 x 10

Feed roller drive setting	No Drum Blades	Blades per side	Chip Length	Possible?
17	20	10	17.00	Y
17	10	5	34.00	Y
17	8	4	42.50	N
17	6	3	56.67	N
17	4	2	85.00	Y

BASE: 24 Blade Drum 2 x 12

Feed roller drive setting	No Drum Blades	Blades per side	Chip Length	Possible?
17	*20*	10	*17.00*	*Base 20B*
17	24	12	14.17	Y
17	12	6	28.33	Y
17	8	4	42.50	Y
17	**6**	**3**	**56.67**	**Y**
17	**4**	**2**	**85.00**	**Y**

Blade Combinations tested: (in bold above)
57mm spec - 24BD 6 blades (3 per side) feed roller drive at 17mm
85mm spec - 24BD 4 blades (2 per side) feed roller drive at 17mm

Notes
Drum centre clearance 120mm (edge of blade to drum carcass)
Point to point of consecutive knife holders 180mm

In order to maintain balance in drum weighting it was decided that we should operate the drum that can carry 24 blades and remove blades as specified in the chart above. The blade mount clearance established at 120mm to the main drum wall and 180mm to the following blade mount allows space for production of a chip of up to 85mm in length without distortion.

4.1.3 Photo illustration of the drum specifications

Figures 35 and 36 illustrate the chipping drums showing distances between blade points and drum centres. Also note strengthening plates.

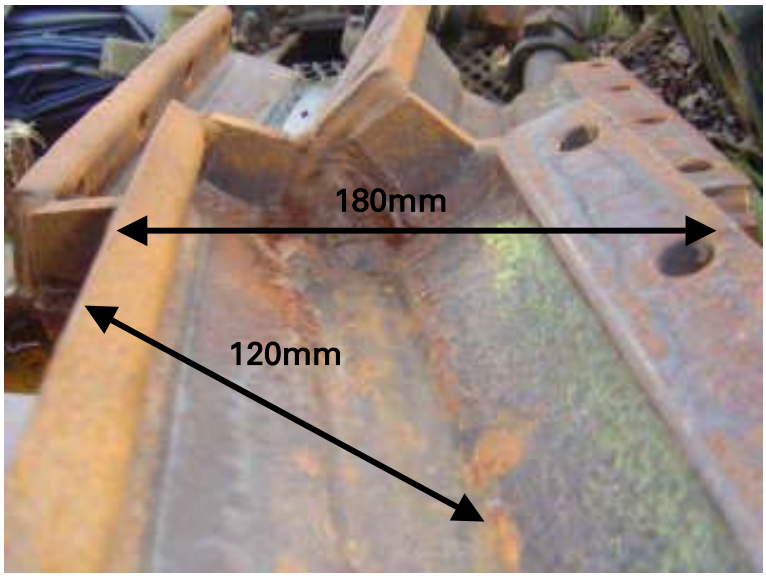

Fig 35 Drum clearances

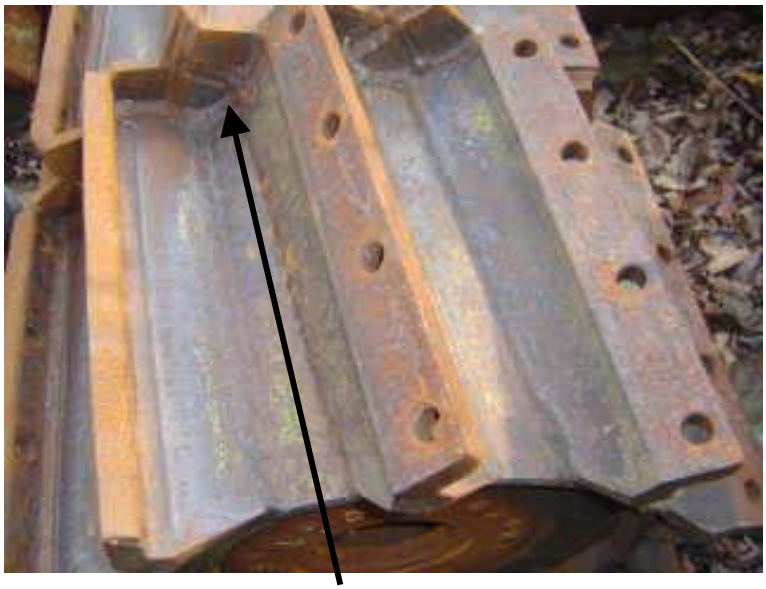

Fig 36 Central spine strengthening plates

4.1.4 Field Trials Summary and Analysis

- Harvester operation was not affected by production of mini billets.
- Forward speed maintained was as appropriate to crop conditions and unaffected by the change in chip size being produced.
- There were no power gains in chipping less frequently which matches our view that the limiting factor on harvesting is felling the crop to horizontal and feeding it into the drum. (Also seen in previous work when chipping fuel at 36mm)
- We do not know but suspect there may be increased wear on the accelerator unit (the fan that blows chip up and out of the spout) from passing larger chips through it.
- At this point therefore expected outputs and harvesting costs therefore match those of standard chip production as summarised in table 3 below.

Table 3 Cost analysis for mini billet production

Crop Age	Yield (average*)	Maximum Diameter	Maximum Height	Average Cost/odt
2	10.9	75mm	7m	£8.12
3	7.64	90mm	10m	£10.05
4	8.62	170mm	12.5m	£20.95
5	6.88	90mm	10m	£13.16

* odt/ha/yr

4.1.5 Fuel specification analysis

Tables 4 and 5 summarise the results of fuel analysis vs the market specification required

Table 4 Fuel Analysis – 57mm target size

Size	%age	
55mm+	3.00%	In specification
45-55mm	48.00%	In specification
35-45mm	42.00%	In specification
<35mm	7.00%	
	100.00%	

Table 5 Fuel Analysis – 85mm target size

Size	%age	
85mm+	4.50%	In specification
65-75mm	46.00%	In specification
55-65mm	42.50%	In specification
<55mm	7.00%	Possibly in spec
	100.00%	

Fuel Notes
1. Fuel dimension in 3 planes is critical to this. Requires "chunks" for most efficient production
2. SRC planted on standard row widths will always produce greater amounts of "thin" chips due to the growth habit of the crop being multi stemmed and thin compared to conventional forestry.
3. SRC can produce thicker stems by planting at lower densities and harvesting one year longer than the norm
4. "Flowability" of the mini billet fuels is questionable. Bulk density likely to be low (lots of voids)

Harvesting Notes
1. Trial samples produced were at artificially slowed drum speeds (through engine management).
2. Shatter induced in the shorter lengths may be transferred to the longer length specification when the harvester drum is operating at full speed

4.1.6 Photographic record of fuel produced
Figs 37-40


Fig 37 (left) and Fig 38 (right) 57mm target size


Fig 39 (left) and Fig 40 (right) 85mm target size

4.2 Harvester Drum reconfiguration for Co-firing chip specification

4.2.1 Key Targets:

All coal-fired power stations run on pulverised fuel. Prior to combustion, fuel particle size is reduced in pulverising mills to a fine powder that is conveyed to the boiler for burning. Any alternative/biomass fuels that are to be supplied need to be of the same particle sizes (dust) to pass through feed systems or similar sizes if introduced by direct injection into the boiler. In both cases it is vital that full burn out of the wood particles is achieved in the boiler otherwise carbon-in-ash levels might be adversely effected, which could have implications in the 'fly ash' being not saleable for utilisation in other industries, such as concrete block manufacture.

4.2.2 Fuel Specifications

The current specifications that CRL work to are as follows:
Co-milling (traditional feed system): 6mm x 3mm x 3mm
Direct Injection: 7mm x 4mm x 4mm

4.2.3 Stage 1 - Key adaptations made to the harvester:

The mechanical feed roller drive was replaced with hydraulic drive pack allowing greater variation (slowing down) of speed of feed rollers. (Slower the feed the smaller the chip produced).

4.2.3.1 Issues and solutions:

The slow speed of feed rollers caused the forage harvester control computer to believe that the machine was stalling and so reversed the feed rollers automatically to "spit out" excess material being fed into the drum. This was overcome by isolating the feed roller sensor.

Collection of material in trailers was also difficult with the very fine particles (<1mm) being particularly susceptible to blowing away in even moderate winds. This may not cause an issue as the end users find the very fine particles hard to handle and in our case they are a very small proportion of output.

4.2.3.2 Illustration of adaptations *(Drive exposed for viewing)*

Fig 31 front ¾ view of hydraulic drive

Fig 32 Top view of hydraulic drive

4.2.3.3 – Illustration of samples produced vs "market standards"

Fig 33 Fuel produced direct from harvester

Fig 34 Fuel from secondary processing

Photo Notes – fuel from harvesting (drum blade chipper) tends to be more granular than secondary processed fuel that has been pulverised in a hammer mill.

4.2.4 Full Mechanical Drive Drum configurations

The length of chip produced from the harvester is a function of speed of feeding into the drum and the number of blades that the drum contains. The following table shows the settings required to be achieved for large chip/mini billets. Table 6 below shows the settings required for co-firing fuels

Table 6 – Drum settings for co-firing

20 blade Drum

Feed roller drive setting	No Drum Blades	Blades per side	Chip Length	Possible?
4	**20**	**10**	**4.00**	**Y**
4	10	5	8.00	Y

24 Blade Drum

Feed roller drive setting	No Drum Blades	Blades per side	Chip Length
4	*20*	10	*17.00*
4	24	12	3.33
5	**24**	**12**	**3.99**

Blade combinations tested (in bold above):
4mm Spec - 20BD - full blades, gearbox at 4mm
4mm Spec - 24BD - full blades, gearbox at 5mm

4.2.4.1 Field Output Results

Output Results are summarised below in table 7

Table 7 Maximum and minimum operating results and costs

Output	Drum	Drive Setting	Speed m/hr	Ha/hr	Hrs/day	Ha/day	ODT/Ha	ODT/day	£/ODT
Min	20	4	1000	0.23	10	2.27	28	64	£19.64
Max	20	4	1400	0.32	10	3.18	28	89	£14.03
Min	24	5	1200	0.27	10	2.73	28	76	£16.37
Max	24	5	1680	0.38	10	3.82	28	107	£11.69

Notes on table 7:

1. 20 blade drum and drive setting 4 included for comparison from earlier field trial with hydraulic drive system
2. Addition of four extra blades to the drum increased forward speed by 20% (in direct proportion to number of blades)
3. Costs are for ***total*** Oven Dry Tonnes produced.

4.2.4.2 Fuel Analysis and Market Specification

Table 8 Analysis vs traditional (via coal mill) specification

Tgt size 3mm x 3mm x 6mm

Size	%age	
5mm+	11.00%	Out of spec – requires milling
3-5mm	33.00%	Possibly in spec
1-3mm	52.00%	In specification
<1mm	4.00%	In specification
	100.00%	

Table 9 Analysis vs specification direct injection into boiler

Tgt size 4mm x 4mm x 7mm (estimated)

Size	%age	
5mm+	11.00%	Partially in spec
3-5mm	33.00%	In specification
1-3mm	52.00%	In specification
<1mm	4.00%	In specification
	100.00%	

Overall Range: Minimum in specification 56% - Maximum in specification 89%

FUEL NOTES

1. Direct Injection specification may change on moisture level of fuel.
2. Drier fuel (<17% moisture) will probably allow larger sizes as it will maintain burn out completely
3. Fuel also needs to be light for conveying by air into the boiler
4. Fuel produced from the harvester tends to be "fluffy" - cf cotton wool from the willow fibres. This can be taken out by mechanical sieving leaving the samples as photographed
5. Fuel should have low drying costs due to large surface area: volume ratio
6. Fuel will require immediate artificial drying as "composts" in outdoor drying piles

HARVESTING NOTES:

1. Trial speed of operation was extremely slow. Forward speed of 1 - 1.4km/Hour
2. This is limited by the speed that feed rollers pushed material into the drum. It is possible to improve this by adding more blades into the drum but we are close to the limits that Claas have tested

Full economic analysis of harvesting costs and fuel values are contained in Section 5.

The indications are that with the addition of extra drum blades enabling increased forward speed then it will probably be economic to harvest directly to this size. Drying of the fuel at this specification may be achievable in conventional farm grain driers – although this is yet to be confirmed as technically or economically possible.

4.2.4.3 Cost of fuel production

Based on the range of fuel produced in specification the following table 10 summarises the costs of material that has been produced within the required specifications

Table 10 Cost/odt of fuel produced in specification

Output	Drum	Drive Setting	Speed m/hr	ODT/day	£/ODT	Min % in spec	£/odt in spec	Max % in spec	£/odt in spec
Min	20	4	1000	64	£19.64	56%	£35.08	89%	£22.07
Max	20	4	1400	89	£14.03	56%	£25.05	89%	£15.76
Min	24	5	1200	76	£16.37	56%	£29.23	89%	**£18.39**
Max	24	5	1680	107	£11.69	56%	**£20.88**	89%	**£13.14**

4.2.5 Discussion of results:

The cost of milling in an integrated processing unit is in the order of £3/odt. However an integrated processing unit is centrally located and so requires transport from field where the SRC crop is grown to point of process. If on farm drying using grain driers can be operated and a mobile screening system with small mobile mill made available to deal with the oversize chip so transport cost can be reduced. There will be a site by site element to this between individual haulage distances and costs but direct chip harvesting will be more economic in many cases and can also offer growers the opportunity to "value add" by drying the product.

With a finished delivered product value of £75/odt so 3 of the 4 outputs Max speed + Min%; Min speed + Max %; and Max speed + Max % all produce fuel within an acceptable cost ceiling of £20/odt based on the results achieved here.

In relation to the project objective which was to be able to harvest any fuel specification at £10-£11/odt then the criteria have not been met for producing fuel for co-firing. The best result we have had is to create fuel at £13.14/odt which represents a premium of £2.14/odt or 19.5%. The reference above to an acceptable cost ceiling of £20/odt is based upon the fact that the current market for co-firing fuels is in under supply and the predictions are that this trend will continue. Therefore market price has risen and we expect further increases in 2009 when energy crop supply is required under the current regulations. We have experienced rises in SRC value in contracts we are discussing of 20% where the generator is purchasing fuel ex farm and where fuel is being delivered in to the end user increases of over 33% are being negotiated.

Further discussion and results are incorporated in Section 5 – economic modelling.

5. ECONOMIC ANALYSIS AND HARVESTING GUIDANCE

This section brings together the economics of operating harvesting and support machinery.
A number of options are modelled and discussed including:

1. Period of operation
2. Drum configuration
3. Type of forage harvester platform employed
4. Owning vs contract hiring of support machinery

Daily output also has a strong influence however in this study machinery of a similar size has been compared thus giving standard daily output in order to compare effectively the other factors.

These costs are summarised in section 5.1 with full details of the individual costs and their makeup attached in Appendix A.

5.1 Summary of results

Table 11 Cost/odt production summary

Claas 480 Jaguar Harvester

Mechanical Head Drive	**Standard Drum**				**Modified Drum**			
	Annual Cost	Harvest Days	ODT/Day	Total	Annual Cost	Harvest Days	ODT/Day	Total
All Owned Winter Harvest	£144,450	90	150	£10.70	£146,388	90	150	£10.84
All Owned 9 month Harvest	£234,450	180	150	£8.68	£234,450	180	150	£8.68
Harvester owned Trailers Contract Hired Winter Harvest	£159,100	90	150	£11.79	£161,038	90	150	£11.93
Harvester owned Trailers Contract Hired 9 month Harvest	£257,200	180	150	£9.53	£259,138	180	150	£9.60

CNH FX Harvester

Hydraulic Head Drive	**Standard Drum**				**Modified Drum**			
	Annual Cost	Harvest Days	ODT/Day	Total	Annual Cost	Harvest Days	ODT/Day	Total
All Owned Winter Harvest	£145,450	90	150	£10.77	£147,388	90	150	£10.92
All Owned 9 month Harvest	£235,450	180	150	£8.72	£237,388	180	150	£8.79
Harvester owned Trailers Contract Hired Winter Harvest	£160,100	90	150	£11.86	£162,038	90	150	£12.00
Harvester owned Trailers Contract Hired 9 month Harvest	£258,200	180	150	£9.56	£260,138	180	150	£9.63

5.2 Assumptions

Harvesting periods are defined as follows:

- Winter harvest period is the months October to February inclusive. The total days in this period are 152 and standard agricultural working days (based on 5.5 day average week) are 120. Due to adverse weather and breakdowns we expect only operate 75% of these available days which reduces the actual working days to 90.
- Nine-month harvest is based on harvesting the months October to June inclusive. The total days in this period are 273 and standard agricultural working days (based on 5.5 day average week) are 214. Due to adverse weather (which is reduced compared to winter alone harvesting) and breakdowns we expect to operate 85% of these available days which reduces the actual working days to 180.
- ODT/day – ie the daily output is based upon current output achieved in crop that is in specification for harvesting. An average operating day of 8 hours with an hourly output of 18.75 odt gives 150 odt/day. This capacity is directly limited by the speed at which crop can be fed crop into the harvester.
- Capital and operating costs are derived from current standards in agriculture based upon a professional contracting business or professional main dealer for machinery sales/hire. Full details of these costs are included in appendix A.

5.3 Discussion of Economics

There are a number of key messages from the economic analysis that harvesting of SRC that should be noted:

1. The single most critical factor is the number of days over the period that the machinery operates. By operating for 180 days rather than 90 there is on average a reduction of 37% in the cost per dry tonne of material produced.
2. The next factor is the ownership or hiring of support machinery. In all cases where the harvest period is over 90 days/annum it is more economic to own and operate support machinery. There average reduction is just over 9%
3. Whether a standard or remanufactured drum is utilised there is little effect on cost of production.
4. The type of forage harvester used as a base platform has little effect on the cost of production.

The cost of harvesting encountered here ranges from £8.68/odt to £12.00/odt. All of these results are economically viable within a commodity market value (co-firing) of £35/odt ex farm. They leave sustainable returns for growers whilst allowing harvesting contractors/operators to effectively run and maintain machinery whilst investing against machinery replacement.

In comparison to our objective of harvesting material for any market at £10-£11/odt then we have a number of the scenarios that meet this requirement and the most expensive harvesting solution here at a premium of only £1/odt or 9% which is acceptable given the current market's price rises of 20% and above.

The most cost effective system is to harvest 180 days/annum with all machinery being owned.

5.4 Harvesting Guidance

5.4.1 Market Specification Notes

Co-Firing	Ultimate fuel particle size of 8x4x4mm (6x3x3 where no direct boiler feed) Requires drying - natural air drying where possible Can be produced direct from harvester with modified drums Alternative is to harvest at larger chip size and re process Some generators have issues with harvesting crop in leaf (high chlorine perception)
Grate Burn Heat Boilers/ Power/CHP	Fuel particle size 15x 5 x 10mm to 50 x 50 x 50mm Moisture content up to 50% (30 - 35% preferred) Produce direct from harvest on standard drum Naturally air dry to lower moisture to preferred range
Gasification	Longer particles - 58 - 75mm Retain chip in the stem "round" - ie whole chunk - desirable Air dried product at 35% preferred

5.4.2 Harvesting Guidance

Age of crop is of minimal relevance to harvest timings
The Key factor is the size of crop in terms of:

1. Height
2. Stem Base Diameter
3. Number of stems per stool

Production of chip for co-firing and grate burning allows best harvesting economics
Production of chip of gasification LENGTH ONLY also allows best harvesting economics

5.4.2.1 Co-firing and Grate Burning

Target Crop specifications at harvest are as follows:

Height	6-7m
Stem Base Diameter	50-65mm
Number of stems per stool	4-5

5.4.2.2 Gasification

Production of "High Grade" chip for gasification will increase harvest cost
This is because to achieve the ***THREE*** dimension specification will mean harvesting at larger stem sizes
Target Crop specifications are as follows;

Height	7-8m
Stem Base Diameter	75-100mm
Number of stems per stool	2-3

Crops exceeding diameter this will incur significantly higher harvesting costs irrespective of stem numbers

5.4.2.3 Cut Off Points
Crops should not be allowed to exceed stem bases of 100mm under any circumstances

5.4.2.4 Relationship with other crop factors;
Planting density will affect ultimate crop specification

5.4.2.4.1 Co-firing and Grate Burning
Co-firing and Grate burning allow more flexibility and current density of 15,000/Ha is suitable
Site selection will be important where end users specify out of leaf harvesting

5.4.2.4.2 Gasification
Plantations dedicated for gasification should be planted at lower density (10-12,000/Ha)
Varieties should be selected for single stem growth habit
Wherever possible cutback should NOT be carried out

Note
All information is based on current machinery, markets, SRC varieties and growth habits
Changes in these base factors will affect harvest guidelines

6. CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER WORK

Key conclusions reached are as follows:

- Harvesting of SRC crops using the technology developed as part of this project is technically robust.
- Fuel specification can be altered to suit the requirements of different markets and can be produced economically.
- In production of fuel for co-firing in large coal combustion plant using pulverised fuel there are a series of complex economics involving secondary processing and haulage that will dictate the most cost effective method of delivering product.
- As the scale of market grows the ability to harvest SRC over the majority of the year is essential to the economic viability of the crop as a fuel source.
- Harvesting of crops that have grown beyond the normal scale is extremely costly and not viable at current market prices for fuels.
- The current rising costs of fossil fuels employed in operating the harvesting and support machinery will have an impact on cost/odt.

Further work should be targeted towards:

- Assessing the technical viability of harvesting all year round.
- Modelling the economics of fuel supply to specific co-firing projects.
- Assessing the biomass fuel specification that can be co-fired in large coal plant.
- Assessing the haulage cost relationship with the specification of fuel produced.
- Developing models of the co-firing market in relation to trends in ROC values, fossil fuel prices and the value of "captured carbon".
- Long term work into embedded distributed generation will be vital to the industry in following on from the end of the co-firing period in 2016 and in reducing the economic impact of fuel costs on haulage of biomass fuels to end users.

APPENDIX A

Full economic analysis of harvesting systems

Mechanical Drive Tractors & Trailers Contract hired Winter harvest Remanufactured Drum

Harvester Costs

CAPITAL	Capital Cost	Depreciation	Residual	Annual	Operating	Cost	Output	Cost
		Period	Value	Cost	Days/yr	/Day	/Day	/tonne
	£	Years	£	£		£	ODT	£/odt
Harvester	115000	5	25000	18000	90	£200.00	150	£1.33
Head	72750	5	10000	12550	90	£139.44	150	£0.93
Total	187750		35000	30550		£339.44		£2.26

	Annual	Operating	Cost	Output	Cost
	Cost	Days/yr	/Day	/Day	/tonne
Operating	£		£	ODT	£/odt
Driver	£16,200	90	£180	150	£1.20
Fuel & Oils	£12,150	90	£135	150	£0.90
Repairs	£13,500	90	£150	150	£1.00
Servicing	£2,250	90	£25	150	£0.17
Finance Charges	9387.5	90	£104	150	£0.70
	£53,488				£3.96

Fuel Cost Breakdown			
Lt/Hr	Hr/day	£/lt	Total
45	10	£0.30	£135.00

Total	£/odt
Capital	£2.26
Operating	£3.96
	£6.23

Mechanical Drive Tractors & Trailers Contract hired Winter harvest Remanufactured Drum

Tractor Trailer & Forklift Support

Contract Hire	Annual		Operating	Cost	Output	Cost
Charges	Cost	Number	Days/yr	/Day	/Day	/tonne
	£			£	ODT	£/odt
Tractor	£16,000	2	90	£88.89	150	£1.19
Trailer	£5,400	2	90	£30.00	150	£0.40
Forklift	£7,000	1	90	£77.78	150	£0.52
Total	£28,400			£118.89		£2.10
	Annual		Operating	Cost	Output	Cost
	Cost		Days/yr	/Day	/Day	/tonne
Operating	£			£	ODT	£/odt
Drivers	£40,500	3	90	£150	150	£3.00
Fuel & Oils	£8,100	3	90	£30	150	£0.60
	£48,600					£3.60

Total	£/odt
Capital	£2.10
Operating	£3.60
	£5.70

Fuel Cost Breakdown			
Lt/Hr	Hr/day	£/lt	Total
10	10	£0.30	£30.00

Totals Summary

Harvester	Annual Capital	£30,550
Harvester	Operating	£53,488
Support	Contract hire costs	£28,400
Support	Operating	£48,600
		£161,038

Mechanical Drive Tractor & trailers contract hired Winter Harvest Standard Drum

Harvester Costs

CAPITAL	Capital Cost	Depreciation	Residual	Annual	Operating	Cost	Output	Cost
		Period	Value	Cost	Days/yr	/Day	/Day	/tonne
	£	Years	£	£		£	ODT	£/odt
Harvester	115000	5	25000	18000	90	£200.00	150	£1.33
Head	65000	5	10000	11000	90	£122.22	150	£0.81
Total	180000		35000	29000		£322.22		£2.15

	Annual	Operating	Cost	Output	Cost
	Cost	Days/yr	/Day	/Day	/tonne
Operating	£		£	ODT	£/odt
Driver	£16,200	90	£180	150	£1.20
Fuel & Oils	£12,150	90	£135	150	£0.90
Repairs	£13,500	90	£150	150	£1.00
Servicing	£2,250	90	£25	150	£0.17
Finance Charges	9000	90	£100	150	£0.67
	£53,100				£3.93

Fuel Cost Breakdown			
Lt/Hr	Hr/day	£/lt	Total
45	10	£0.30	£135.00

Total	£/odt
Capital	£2.15
Operating	£3.93
	£6.08

Mechanical Drive Tractor & trailers contract hired Winter Harvest Standard Drum

Tractor Trailer & Forklift Support

Contract Hire Charges	Annual Cost £	Number	Operating Days/yr	Cost /Day £	Output /Day ODT	Cost /tonne £/odt
Tractor	£16,000	2	90	£88.89	150	£1.19
Trailer	£5,400	2	90	£30.00	150	£0.40
Forklift	£7,000	1	90	£77.78	150	£0.52
Total	£28,400			£118.89		£2.10
	Annual Cost		Operating Days/yr	Cost /Day	Output /Day	Cost /tonne
Operating	£			£	ODT	£/odt
Drivers	£40,500	3	90	£150	150	£3.00
Fuel & Oils	£8,100	3	90	£30	150	£0.60
	£48,600					£3.60

Total	£/odt
Capital	£2.10
Operating	£3.60
	£5.70

Fuel Cost Breakdown			
Lt/Hr	Hr/day	£/lt	Total
10	10	£0.30	£30.00

Totals Summary

Harvester	Annual Capital	£29,000
Harvester	Operating	£53,100
Support	Contract hire costs	£28,400
Support	Operating	£48,600
Harvester	Annual Capital	£159,100

Hydraulic Drive Tractor & trailers Contract Hired Winter harvest Remanufactured Drum

Harvester Costs

CAPITAL	Capital Cost	Depreciation	Residual	Annual	Operating	Cost	Output	Cost
		Period	Value	Cost	Days/yr	/Day	/Day	/tonne
	£	Years	£	£		£	ODT	£/odt
Harvester	115000	5	25000	18000	90	£200.00	150	£1.33
Head	76750	5	10000	13350	90	£148.33	150	£0.99
Total	191750		35000	31350		£348.33		£2.32

	Annual	Operating	Cost	Output	Cost
	Cost	Days/yr	/Day	/Day	/tonne
Operating	£		£	ODT	£/odt
Driver	£16,200	90	£180	150	£1.20
Fuel & Oils	£12,150	90	£135	150	£0.90
Repairs	£13,500	90	£150	150	£1.00
Servicing	£2,250	90	£25	150	£0.17
Finance Charges	9587.5	90	£107	150	£0.71
	£53,688				£3.98

Fuel Cost Breakdown			
Lt/Hr	Hr/day	£/lt	Total
45	10	£0.30	£135.00

Total	£/odt
Capital	£2.32
Operating	£3.98
	£6.30

Hydraulic Drive Tractor & trailers Contract Hired Winter harvest Remanufactured Drum

Tractor Trailer & Forklift Support

Contract Hire Charges	Annual Cost £	Number	Operating Days/yr	Cost /Day £	Output /Day ODT	Cost /tonne £/odt
Tractor	£16,000	2	90	£88.89	150	£1.19
Trailer	£5,400	2	90	£30.00	150	£0.40
Forklift	£7,000	1	90	£77.78	150	£0.52
Total	£28,400			£118.89		£2.10
	Annual Cost		Operating Days/yr	Cost /Day	Output /Day	Cost /tonne
Operating	£			£	ODT	£/odt
Drivers	£40,500	3	90	£150	150	£3.00
Fuel & Oils	£8,100	3	90	£30	150	£0.60
	£48,600					£3.60

Total	£/odt
Capital	£2.10
Operating	£3.60
	£5.70

Fuel Cost Breakdown			
Lt/Hr	Hr/day	£/lt	Total
10	10	£0.30	£30.00

Totals Summary		
Harvester	Annual Capital	£31,350
Harvester	Operating	£53,688
Support	Contract hire costs	£28,400
Support	Operating	£48,600
		£162,038

Hydraulic Drive Tractor & Trailers Contract Hired Winter harvest Standard Drum

Harvester Costs

CAPITAL	Capital Cost	Depreciation	Residual	Annual	Operating	Cost	Output	Cost
		Period	Value	Cost	Days/yr	/Day	/Day	/tonne
	£	Years	£	£	£		ODT	£/odt
Harvester	115000	5	25000	18000	90	£200.00	150	£1.33
Head	69000	5	10000	11800	90	£131.11	150	£0.87
Total	184000		35000	29800		£331.11		£2.21

	Annual	Operating	Cost	Output	Cost
	Cost	Days/yr	/Day	/Day	/tonne
Operating	£		£	ODT	£/odt
Driver	£16,200	90	£180	150	£1.20
Fuel & Oils	£12,150	90	£135	150	£0.90
Repairs	£13,500	90	£150	150	£1.00
Servicing	£2,250	90	£25	150	£0.17
Finance Charges	9200	90	£102	150	£0.68
	£53,300				£3.95

Fuel Cost Breakdown			
Lt/Hr	Hr/day	£/lt	Total
45	10	£0.30	£135.00

Total	£/odt
Capital	£2.21
Operating	£3.95
	£6.16

Hydraulic Drive Tractor & trailers Contract Hired Winter harvest Standard Drum

Tractor Trailer & Forklift Support

Contract Hire Charges	Annual Cost	Number	Operating Days/yr	Cost /Day	Output /Day	Cost /tonne
	£			£	ODT	£/odt
Tractor	£16,000	2	90	£88.89	150	£1.19
Trailer	£5,400	2	90	£30.00	150	£0.40
Forklift	£7,000	1	90	£77.78	150	£0.52
Total	£28,400			£118.89		£2.10
	Annual Cost		Operating Days/yr	Cost /Day	Output /Day	Cost /tonne
Operating	£			£	ODT	£/odt
Drivers	£40,500	3	90	£150	150	£3.00
Fuel & Oils	£8,100	3	90	£30	150	£0.60
	£48,600					£3.60

Total	£/odt
Capital	£2.10
Operating	£3.60
	£5.70

Fuel Cost Breakdown			
Lt/Hr	Hr/day	£/lt	Total
10	10	£0.30	£30.00

Totals Summary		
Harvester	Annual Capital	£29,800
Harvester	Operating	£53,300
Support	Contract hire costs	£28,400
Support	Operating	£48,600
		£160,100

Mechanical Drive Tractors & Trailers Contract hired All year harvest Remanufactured Drum

Harvester Costs

CAPITAL	Capital Cost	Depreciation	Residual	Annual	Operating	Cost	Output	Cost
		Period	Value	Cost	Days/yr	/Day	/Day	/tonne
	£	Years	£	£		£	ODT	£/odt
Harvester	115000	5	25000	18000	180	£100.00	150	£0.67
Head	72750	5	10000	12550	180	£69.72	150	£0.46
Total	187750		35000	30550		£169.72		£1.13

	Annual	Operating	Cost	Output	Cost
	Cost	Days/yr	/Day	/Day	/tonne
Operating	£		£	ODT	£/odt
Driver	£32,400	180	£180	150	£1.20
Fuel & Oils	£24,300	180	£135	150	£0.90
Repairs	£27,000	180	£150	150	£1.00
Servicing	£4,500	180	£25	150	£0.17
Finance Charges	9387.5	180	£52	150	£0.35
	£97,588				£3.61

Fuel Cost Breakdown			
Lt/Hr	Hr/day	£/lt	Total
45	10	£0.30	£135.00

Total	£/odt
Capital	£1.13
Operating	£3.61
	£4.75

Mechanical Drive Tractors & Trailers Contract hired All year harvest Remanufactured Drum

Tractor Trailer & Forklift Support

Contract Hire Charges	Annual Cost	Number	Operating Days/yr	Cost /Day	Output /Day	Cost /tonne
	£			£	ODT	£/odt
Tractor	£16,000	2	180	£88.89	150	£1.19
Trailer	£10,800	2	180	£30.00	150	£0.40
Forklift	£7,000	1	180	£38.89	150	£0.26
Total	£33,800			£118.89		£1.84
	Annual Cost		Operating Days/yr	Cost /Day	Output /Day	Cost /tonne
Operating	£			£	ODT	£/odt
Drivers	£81,000	3	180	£150	150	£3.00
Fuel & Oils	£16,200	3	180	£30	150	£0.60
	£97,200					£3.60

Total	£/odt
Capital	£1.84
Operating	£3.60
	£5.44

Fuel Cost Breakdown			
Lt/Hr	Hr/day	£/lt	Total
10	10	£0.30	£30.00

Totals Summary		
Harvester	Annual Capital	£30,550
Harvester	Operating	£97,588
Support	Contract hire costs	£33,800
Support	Operating	£97,200
		£259,138

Mechanical Drive Tractors & Trailers Contract hired All year harvest Standard Drum

Harvester Costs

CAPITAL	Capital Cost	Depreciation	Residual	Annual	Operating	Cost	Output	Cost
		Period	Value	Cost	Days/yr	/Day	/Day	/tonne
	£	Years	£	£		£	ODT	£/odt
Harvester	115000	5	25000	18000	180	£100.00	150	£0.67
Head	65000	5	10000	11000	180	£61.11	150	£0.41
Total	180000		35000	29000		£161.11		£1.07

	Annual	Operating	Cost	Output	Cost
	Cost	Days/yr	/Day	/Day	/tonne
Operating	£		£	ODT	£/odt
Driver	£32,400	180	£180	150	£1.20
Fuel & Oils	£24,300	180	£135	150	£0.90
Repairs	£27,000	180	£150	150	£1.00
Servicing	£4,500	180	£25	150	£0.17
Finance Charges	9000	180	£50	150	£0.33
	£97,200				£3.60

Fuel Cost Breakdown			
Lt/Hr	Hr/day	£/lt	Total
45	10	£0.30	£135.00

Total	£/odt
Capital	£1.07
Operating	£3.60
	£4.67

Mechanical Drive Tractors & Trailers Contract hired All year harvest Standard Drum

Tractor Trailer & Forklift Support

Contract Hire Charges	Annual Cost £	Number	Operating Days/yr	Cost /Day £	Output /Day ODT	Cost /tonne £/odt
Tractor	£16,000	2	180	£88.89	150	£1.19
Trailer	£10,800	2	180	£30.00	150	£0.40
Forklift	£7,000	1	180	£38.89	150	£0.26
Total	£33,800			£118.89		£1.84
	Annual Cost		Operating Days/yr	Cost /Day	Output /Day	Cost /tonne
Operating	£			£	ODT	£/odt
Drivers	£81,000	3	180	£150	150	£3.00
Fuel & Oils	£16,200	3	180	£30	150	£0.60
	£97,200					£3.60

Total	£/odt
Capital	£1.84
Operating	£3.60
	£5.44

Fuel Cost Breakdown			
Lt/Hr	Hr/day	£/lt	Total
10	10	£0.30	£30.00

Totals Summary		
Harvester	Annual Capital	£29,000
Harvester	Operating	£97,200
Support	Contract hire costs	£33,800
Support	Operating	£97,200
		£257,200

Hydraulic Drive Tractor & trailers Contract Hired All year Remanufactured Drum

Harvester Costs

CAPITAL	Capital Cost	Depreciation	Residual	Annual	Operating	Cost	Output	Cost
		Period	Value	Cost	Days/yr	/Day	/Day	/tonne
	£	Years	£	£		£	ODT	£/odt
Harvester	115000	5	25000	18000	180	£100.00	150	£0.67
Head	76750	5	10000	13350	180	£74.17	150	£0.49
Total	191750		35000	31350		£174.17		£1.16

	Annual	Operating	Cost	Output	Cost
	Cost	Days/yr	/Day	/Day	/tonne
Operating	£		£	ODT	£/odt
Driver	£32,400	180	£180	150	£1.20
Fuel & Oils	£24,300	180	£135	150	£0.90
Repairs	£27,000	180	£150	150	£1.00
Servicing	£4,500	180	£25	150	£0.17
Finance Charges	9587.5	180	£53	150	£0.36
	£97,788				£3.62

Fuel Cost Breakdown			
Lt/Hr	Hr/day	£/lt	Total
45	10	£0.30	£135.00

Total	£/odt
Capital	£1.16
Operating	£3.62
	£4.78

Hydraulic Drive Tractor & trailers Contract Hired All year Remanufactured Drum

Tractor Trailer & Forklift Support

Contract Hire Charges	Annual Cost	Number	Operating Days/yr	Cost /Day	Output /Day	Cost /tonne
	£			£	ODT	£/odt
Tractor	£16,000	2	180	£88.89	150	£1.19
Trailer	£10,800	2	180	£30.00	150	£0.40
Forklift	£7,000	1	180	£38.89	150	£0.26
Total	£33,800			£118.89		£1.84
	Annual Cost		Operating Days/yr	Cost /Day	Output /Day	Cost /tonne
Operating	£			£	ODT	£/odt
Drivers	£81,000	3	180	£150	150	£3.00
Fuel & Oils	£16,200	3	180	£30	150	£0.60
	£97,200					£3.60

Total	£/odt
Capital	£1.84
Operating	£3.60
	£5.44

Fuel Cost Breakdown			
Lt/Hr	Hr/day	£/lt	Total
10	10	£0.30	£30.00

Totals Summary		
Harvester	Annual Capital	£31,350
Harvester	Operating	£97,788
Support	Contract hire costs	£33,800
Support	Operating	£97,200
		£260,138

Hydraulic Drive Tractor & trailers Contract Hired All year Standard Drum

Harvester Costs

CAPITAL	Capital Cost	Depreciation	Residual	Annual	Operating	Cost	Output	Cost
		Period	Value	Cost	Days/yr	/Day	/Day	/tonne
	£	Years	£	£		£	ODT	£/odt
Harvester	115000	5	25000	18000	180	£100.00	150	£0.67
Head	69000	5	10000	11800	180	£65.56	150	£0.44
Total	184000		35000	29800		£165.56		£1.10

	Annual	Operating	Cost	Output	Cost
	Cost	Days/yr	/Day	/Day	/tonne
Operating	£		£	ODT	£/odt
Driver	£32,400	180	£180	150	£1.20
Fuel & Oils	£24,300	180	£135	150	£0.90
Repairs	£27,000	180	£150	150	£1.00
Servicing	£4,500	180	£25	150	£0.17
Finance Charges	9200	180	£51	150	£0.34
	£97,400				£3.61

Fuel Cost Breakdown			
Lt/Hr	Hr/day	£/lt	Total
45	10	£0.30	£135.00

Total	£/odt
Capital	£1.10
Operating	£3.61
	£4.71

Hydraulic Drive Tractor & trailers Contract Hired All year Standard Drum

Tractor Trailer & Forklift Support

Contract Hire Charges	Annual Cost	Number	Operating Days/yr	Cost /Day	Output /Day	Cost /tonne
	£			£	ODT	£/odt
Tractor	£16,000	2	180	£88.89	150	£1.19
Trailer	£10,800	2	180	£30.00	150	£0.40
Forklift	£7,000	1	180	£38.89	150	£0.26
Total	£33,800			£118.89		£1.84
	Annual Cost		Operating Days/yr	Cost /Day	Output /Day	Cost /tonne
Operating	£			£	ODT	£/odt
Drivers	£81,000	3	180	£150	150	£3.00
Fuel & Oils	£16,200	3	180	£30	150	£0.60
	£97,200					£3.60

Total	£/odt
Capital	£1.84
Operating	£3.60
	£5.44

Fuel Cost Breakdown			
Lt/Hr	Hr/day	£/lt	Total
10	10	£0.30	£30.00

Totals Summary		
Harvester	Annual Capital	£31,350
Harvester	Operating	£97,788
Support	Contract hire costs	£33,800
Support	Operating	£97,200
		£260,138

Hydraulic Drive All owned Winter Harvest Remanufactured Drum

Harvester Costs

CAPITAL	Capital Cost	Depreciation	Residual	Annual	Operating	Cost	Output	Cost
		Period	Value	Cost	Days/yr	/Day	/Day	/tonne
	£	Years	£	£		£	ODT	£/odt
Harvester	115000	5	25000	18000	90	£200.00	150	£1.33
Head	76750	5	10000	13350	90	£148.33	150	£0.99
Total	191750		35000	31350		£348.33		£2.32

	Annual	Operating	Cost	Output	Cost
	Cost	Days/yr	/Day	/Day	/tonne
Operating	£		£	ODT	£/odt
Driver	£16,200	90	£180	150	£1.20
Fuel & Oils	£12,150	90	£135	150	£0.90
Repairs	£13,500	90	£150	150	£1.00
Servicing	£2,250	90	£25	150	£0.17
Finance Charges	9587.5	90	£107	150	£0.71
	£53,688				£3.98

Fuel Cost Breakdown			
Lt/Hr	Hr/day	£/lt	Total
45	10	£0.30	£135.00

Total	£/odt
Capital	£2.32
Operating	£3.98
	£6.30

Hydraulic Drive All owned Winter Harvest Remanufactured Drum

Tractor & Trailer Support (per Unit)

CAPITAL	Capital Cost	Depreciation	Residual	Annual	Operating	Cost	Output	Cost
		Period	Value	Cost	Days/yr	/Day	/Day	/tonne
	£	Years	£	£		£	ODT	£/odt
Tractor	45000	5	20000	5000	90	£55.56	150	£0.37
Trailer	12000	5	4000	1600	90	£17.78	150	£0.12
Forklift	40000	5	15000	5000	90	£55.56	150	£0.37
Total	97000		39000	11600		£128.89		£0.86

	Annual	Operating	Cost	Output	Cost
	Cost	Days/yr	/Day	/Day	/tonne
Operating	£		£	ODT	£/odt
Driver	£40,500	90	£450	150	£3.00
Fuel & Oils	2700	90	£30	150	£0.20
Repairs	£1,350	90	£15	150	£0.10
Servicing	£1,350	90	£15	150	£0.10
Finance Charges	4850	90	£54	150	£0.36
	£50,750				£3.76

Total	£/odt
Capital	£0.86
Operating	£3.76
	£4.62

Fuel Cost Breakdown			
Lt/Hr	Hr/day	£/lt	Total
10	10	£0.30	£30.00

Totals Summary		
Harvester	Annual Cap	£31,350
Harvester	Operating	£53,688
Support	Annual Cap	£11,600
Support	Operating	£50,750
		£147,388

Hydraulic Drive All owned Winter Harvest Standard Drum

Harvester Costs

CAPITAL	Capital Cost	Depreciation	Residual	Annual	Operating	Cost	Output	Cost
		Period	Value	Cost	Days/yr	/Day	/Day	/tonne
	£	Years	£	£		£	ODT	£/odt
Harvester	115000	5	25000	18000	90	£200.00	150	£1.33
Head	69000	5	10000	11800	90	£131.11	150	£0.87
Total	184000		35000	29800		£331.11		£2.21

	Annual	Operating	Cost	Output	Cost
	Cost	Days/yr	/Day	/Day	/tonne
Operating	£		£	ODT	£/odt
Driver	£16,200	90	£180	150	£1.20
Fuel & Oils	£12,150	90	£135	150	£0.90
Repairs	£13,500	90	£150	150	£1.00
Servicing	£2,250	90	£25	150	£0.17
Finance Charges	9200	90	£102	150	£0.68
	£53,300				£3.95

Fuel Cost Breakdown			
Lt/Hr	Hr/day	£/lt	Total
45	10	£0.30	£135.00

Total	£/odt
Capital	£2.21
Operating	£3.95
	£6.16

Hydraulic Drive All owned Winter Harvest Standard Drum

Tractor & Trailer Support (per Unit)

CAPITAL	Capital Cost	Depreciation	Residual	Annual	Operating	Cost	Output	Cost
		Period	Value	Cost	Days/yr	/Day	/Day	/tonne
	£	Years	£	£		£	ODT	£/odt
Tractor	45000	5	20000	5000	90	£55.56	150	£0.37
Trailer	12000	5	4000	1600	90	£17.78	150	£0.12
Forklift	40000	5	15000	5000	90	£55.56	150	£0.37
Total	97000		39000	11600		£128.89		£0.86

	Annual	Operating	Cost	Output	Cost
	Cost	Days/yr	/Day	/Day	/tonne
Operating	£		£	ODT	£/odt
Driver	£40,500	90	£450	150	£3.00
Fuel & Oils	2700	90	£30	150	£0.20
Repairs	£1,350	90	£15	150	£0.10
Servicing	£1,350	90	£15	150	£0.10
Finance Charges	4850	90	£54	150	£0.36
	£50,750				£3.76

Total	£/odt
Capital	£0.86
Operating	£3.76
	£4.62

Fuel Cost Breakdown			
Lt/Hr	Hr/day	£/lt	Total
10	10	£0.30	£30.00

Totals Summary		
Harvester	Annual Cap	£29,800
Harvester	Operating	£53,300
Support	Annual Cap	£11,600
Support	Operating	£50,750
		£145,450

Mechanical Drive All owned Winter Harvest Remanufactured Drum

Harvester Costs

CAPITAL	Capital Cost	Depreciation	Residual	Annual	Operating	Cost	Output	Cost
		Period	Value	Cost	Days/yr	/Day	/Day	/tonne
	£	Years	£	£		£	ODT	£/odt
Harvester	115000	5	25000	18000	90	£200.00	150	£1.33
Head	72750	5	10000	12550	90	£139.44	150	£0.93
Total	187750		35000	30550		£339.44		£2.26

	Annual	Operating	Cost	Output	Cost
	Cost	Days/yr	/Day	/Day	/tonne
Operating	£		£	ODT	£/odt
Driver	£16,200	90	£180	150	£1.20
Fuel & Oils	£12,150	90	£135	150	£0.90
Repairs	£13,500	90	£150	150	£1.00
Servicing	£2,250	90	£25	150	£0.17
Finance Charges	9387.5	90	£104	150	£0.70
	£53,488				£3.96

Fuel Cost Breakdown			
Lt/Hr	Hr/day	£/lt	Total
45	10	£0.30	£135.00

Total	£/odt
Capital	£2.26
Operating	£3.96
	£6.23

Mechanical Drive All owned Winter Harvest Remanufactured Drum

Tractor & Trailer Support (per Unit)

CAPITAL	Capital Cost	Depreciation	Residual	Annual	Operating	Cost	Output	Cost
		Period	Value	Cost	Days/yr	/Day	/Day	/tonne
	£	Years	£	£		£	ODT	£/odt
Tractor	45000	5	20000	5000	90	£55.56	150	£0.37
Trailer	12000	5	4000	1600	90	£17.78	150	£0.12
Forklift	40000	5	15000	5000	90	£55.56	150	£0.37
Total	97000		39000	11600		£128.89		£0.86

	Annual	Operating	Cost	Output	Cost
	Cost	Days/yr	/Day	/Day	/tonne
Operating	£		£	ODT	£/odt
Driver	£40,500	90	£450	150	£3.00
Fuel & Oils	2700	90	£30	150	£0.20
Repairs	£1,350	90	£15	150	£0.10
Servicing	£1,350	90	£15	150	£0.10
Finance Charges	4850	90	£54	150	£0.36
	£50,750				£3.76

Total	£/odt
Capital	£0.86
Operating	£3.76
	£4.62

Fuel Cost Breakdown			
Lt/Hr	Hr/day	£/lt	Total
10	10	£0.30	£30.00

Totals Summary		
Harvester	Annual Cap	£30,550
Harvester	Operating	£53,488
Support	Annual Cap	£11,600
Support	Operating	£50,750
		£146,388

Mechanical Drive All owned Winter Harvest Standard Drum

Harvester Costs

CAPITAL	Capital Cost	Depreciation	Residual	Annual	Operating	Cost	Output	Cost
		Period	Value	Cost	Days/yr	/Day	/Day	/tonne
	£	Years	£	£		£	ODT	£/odt
Harvester	115000	5	25000	18000	90	£200.00	150	£1.33
Head	65000	5	10000	11000	90	£122.22	150	£0.81
Total	180000		35000	29000		£322.22		£2.15

	Annual	Operating	Cost	Output	Cost
	Cost	Days/yr	/Day	/Day	/tonne
Operating	£		£	ODT	£/odt
Driver	£16,200	90	£180	150	£1.20
Fuel & Oils	£12,150	90	£135	150	£0.90
Repairs	£13,500	90	£150	150	£1.00
Servicing	£2,250	90	£25	150	£0.17
Finance Charges	9000	90	£100	150	£0.67
	£53,100				£3.93

Fuel Cost Breakdown			
Lt/Hr	Hr/day	£/lt	Total
45	10	£0.30	£135.00

Total	£/odt
Capital	£2.15
Operating	£3.93
	£6.08

Mechanical Drive All owned Winter Harvest Standard Drum

Tractor & Trailer Support (per Unit)

CAPITAL	Capital Cost	Depreciation	Residual	Annual	Operating	Cost	Output	Cost
		Period	Value	Cost	Days/yr	/Day	/Day	/tonne
	£	Years	£	£		£	ODT	£/odt
Tractor	45000	5	20000	5000	90	£55.56	150	£0.37
Trailer	12000	5	4000	1600	90	£17.78	150	£0.12
Forklift	40000	5	15000	5000	90	£55.56	150	£0.37
Total	97000		39000	11600		£128.89		£0.86

	Annual	Operating	Cost	Output	Cost
	Cost	Days/yr	/Day	/Day	/tonne
Operating	£		£	ODT	£/odt
Driver	£40,500	90	£450	150	£3.00
Fuel & Oils	2700	90	£30	150	£0.20
Repairs	£1,350	90	£15	150	£0.10
Servicing	£1,350	90	£15	150	£0.10
Finance Charges	4850	90	£54	150	£0.36
	£50,750				£3.76

Total	£/odt
Capital	£0.86
Operating	£3.76
	£4.62

Fuel Cost Breakdown			
Lt/Hr	Hr/day	£/lt	Total
10	10	£0.30	£30.00

Totals Summary		
Harvester	Annual Cap	£29,000
Harvester	Operating	£53,100
Support	Annual Cap	£11,600
Support	Operating	£50,750
		£144,450

Hydraulic Drive All owned All year Harvest Remanufactured Drum

Harvester Costs

CAPITAL	Capital Cost	Depreciation	Residual	Annual	Operating	Cost	Output	Cost
		Period	Value	Cost	Days/yr	/Day	/Day	/tonne
	£	Years	£	£		£	ODT	£/odt
Harvester	115000	5	25000	18000	180	£100.00	150	£0.67
Head	76750	5	10000	13350	180	£74.17	150	£0.49
Total	191750		35000	31350		£174.17		£1.16

	Annual	Operating	Cost	Output	Cost
	Cost	Days/yr	/Day	/Day	/tonne
Operating	£		£	ODT	£/odt
Driver	£32,400	180	£180	150	£1.20
Fuel & Oils	£24,300	180	£135	150	£0.90
Repairs	£27,000	180	£150	150	£1.00
Servicing	£4,500	180	£25	150	£0.17
Finance Charges	9587.5	180	£53	150	£0.36
	£97,788				£3.62

Fuel Cost Breakdown			
Lt/Hr	Hr/day	£/lt	Total
45	10	£0.30	£135.00

Total	£/odt
Capital	£1.16
Operating	£3.62
	£4.78

Hydraulic Drive All owned All year Harvest Remanufactured Drum

Tractor & Trailer Support

CAPITAL	Capital Cost	Depreciation	Residual	Annual	Operating	Cost	Output	Cost
		Period	Value	Cost	Days/yr	/Day	/Day	/tonne
	£	Years	£	£		£	ODT	£/odt
Tractor	45000	5	20000	5000	180	£27.78	150	£0.19
Trailer	12000	5	4000	1600	180	£8.89	150	£0.06
Forklift	40000	5	15000	5000	180	£27.78	150	£0.19
Total	97000		39000	11600		£64.44		£0.43

	Annual	Operating	Cost	Output	Cost
	Cost	Days/yr	/Day	/Day	/tonne
Operating	£		£	ODT	£/odt
Driver	£81,000	180	£450	150	£3.00
Fuel & Oils	£5,400	180	£30	150	£0.20
Repairs	£2,700	180	£15	150	£0.10
Servicing	£2,700	180	£15	150	£0.10
Finance Charges	4850	180	£27	150	£0.18
	£96,650				£3.58

Total	£/odt
Capital	£0.43
Operating	£3.58
	£4.01

Fuel Cost Breakdown			
Lt/Hr	Hr/day	£/lt	Total
10	10	£0.30	£30.00

Totals Summary		
Harvester	Annual Cap	£31,350
Harvester	Operating	£97,788
Support	Annual Cap	£11,600
Support	Operating	£96,650
		£237,388

Hydraulic Drive All owned All year Harvest Standard Drum

Harvester Costs

CAPITAL	Capital Cost	Depreciation	Residual	Annual	Operating	Cost	Output	Cost
		Period	Value	Cost	Days/yr	/Day	/Day	/tonne
	£	Years	£	£		£	ODT	£/odt
Harvester	115000	5	25000	18000	180	£100.00	150	£0.67
Head	69000	5	10000	11800	180	£65.56	150	£0.44
Total	184000		35000	29800		£165.56		£1.10

	Annual	Operating	Cost	Output	Cost
	Cost	Days/yr	/Day	/Day	/tonne
Operating	£		£	ODT	£/odt
Driver	£32,400	180	£180	150	£1.20
Fuel & Oils	£24,300	180	£135	150	£0.90
Repairs	£27,000	180	£150	150	£1.00
Servicing	£4,500	180	£25	150	£0.17
Finance Charges	9200	180	£51	150	£0.34
	£97,400				£3.61

Fuel Cost Breakdown			
Lt/Hr	Hr/day	£/lt	Total
45	10	£0.30	£135.00

Total	£/odt
Capital	£1.10
Operating	£3.61
	£4.71

Hydraulic Drive All owned All year Harvest Standard Drum

Tractor & Trailer Support

CAPITAL	Capital Cost	Depreciation	Residual	Annual	Operating	Cost	Output	Cost
		Period	Value	Cost	Days/yr	/Day	/Day	/tonne
	£	Years	£	£		£	ODT	£/odt
Tractor	45000	5	20000	5000	180	£27.78	150	£0.19
Trailer	12000	5	4000	1600	180	£8.89	150	£0.06
Forklift	40000	5	15000	5000	180	£27.78	150	£0.19
Total	97000		39000	11600		£64.44		£0.43

	Annual	Operating	Cost	Output	Cost
	Cost	Days/yr	/Day	/Day	/tonne
Operating	£		£	ODT	£/odt
Driver	£81,000	180	£450	150	£3.00
Fuel & Oils	£5,400	180	£30	150	£0.20
Repairs	£2,700	180	£15	150	£0.10
Servicing	£2,700	180	£15	150	£0.10
Finance Charges	4850	180	£27	150	£0.18
	£96,650				£3.58

Total	£/odt
Capital	£0.43
Operating	£3.58
	£4.01

Fuel Cost Breakdown			
Lt/Hr	Hr/day	£/lt	Total
10	10	£0.30	£30.00

Totals Summary		
Harvester	Annual Cap	£29,800
Harvester	Operating	£97,400
Support	Annual Cap	£11,600
Support	Operating	£96,650
		£235,450

Mechanical Drive All owned All year Harvest Remanufactured Drum

Harvester Costs

CAPITAL	Capital Cost	Depreciation	Residual	Annual	Operating	Cost	Output	Cost
		Period	Value	Cost	Days/yr	/Day	/Day	/tonne
	£	Years	£	£		£	ODT	£/odt
Harvester	115000	5	25000	18000	180	£100.00	150	£0.67
Head	72750	5	10000	12550	180	£69.72	150	£0.46
Total	187750		35000	30550		£169.72		£1.13

	Annual	Operating	Cost	Output	Cost
	Cost	Days/yr	/Day	/Day	/tonne
Operating	£		£	ODT	£/odt
Driver	£32,400	180	£180	150	£1.20
Fuel & Oils	£24,300	180	£135	150	£0.90
Repairs	£27,000	180	£150	150	£1.00
Servicing	£4,500	180	£25	150	£0.17
Finance Charges	9387.5	180	£52	150	£0.35
	£97,588				£3.61

Fuel Cost Breakdown			
Lt/Hr	Hr/day	£/lt	Total
45	10	£0.30	£135.00

Total	£/odt
Capital	£1.13
Operating	£3.61
	£4.75

Mechanical Drive All owned All year Harvest Remanufactured Drum

Tractor & Trailer Support

CAPITAL	Capital Cost	Depreciation	Residual	Annual	Operating	Cost	Output	Cost
		Period	Value	Cost	Days/yr	/Day	/Day	/tonne
	£	Years	£	£		£	ODT	£/odt
Tractor	45000	5	20000	5000	180	£27.78	150	£0.19
Trailer	12000	5	4000	1600	180	£8.89	150	£0.06
Forklift	40000	5	15000	5000	180	£27.78	150	£0.19
Total	97000		39000	11600		£64.44		£0.43

	Annual	Operating	Cost	Output	Cost
	Cost	Days/yr	/Day	/Day	/tonne
Operating	£		£	ODT	£/odt
Driver	£81,000	180	£450	150	£3.00
Fuel & Oils	£5,400	180	£30	150	£0.20
Repairs	£2,700	180	£15	150	£0.10
Servicing	£2,700	180	£15	150	£0.10
Finance Charges	4850	180	£27	150	£0.18
	£96,650				£3.58

Total	£/odt
Capital	£0.43
Operating	£3.58
	£4.01

Fuel Cost Breakdown			
Lt/Hr	Hr/day	£/lt	Total
10	10	£0.30	£30.00

Totals Summary		
Harvester	Annual Cap	£30,550
Harvester	Operating	£97,588
Support	Annual Cap	£11,600
Support	Operating	£96,650
		£236,388

Mechanical Drive All owned All year Harvest Standard Drum

Harvester Costs

CAPITAL	Capital Cost	Depreciation	Residual	Annual	Operating	Cost	Output	Cost
		Period	Value	Cost	Days/yr	/Day	/Day	/tonne
	£	Years	£	£		£	ODT	£/odt
Harvester	115000	5	25000	18000	180	£100.00	150	£0.67
Head	65000	5	10000	11000	180	£61.11	150	£0.41
Total	180000		35000	29000		£161.11		£1.07

	Annual	Operating	Cost	Output	Cost
	Cost	Days/yr	/Day	/Day	/tonne
Operating	£		£	ODT	£/odt
Driver	£32,400	180	£180	150	£1.20
Fuel & Oils	£24,300	180	£135	150	£0.90
Repairs	£27,000	180	£150	150	£1.00
Servicing	£4,500	180	£25	150	£0.17
Finance Charges	9000	180	£50	150	£0.33
	£97,200				£3.60

Fuel Cost Breakdown			
Lt/Hr	Hr/day	£/lt	Total
45	10	£0.30	£135.00

Total	£/odt
Capital	£1.07
Operating	£3.60
	£4.67

Mechanical Drive All owned All year Harvest Standard Drum

Tractor & Trailer Support

CAPITAL	Capital Cost	Depreciation	Residual	Annual	Operating	Cost	Output	Cost
		Period	Value	Cost	Days/yr	/Day	/Day	/tonne
	£	Years	£	£		£	ODT	£/odt
Tractor	45000	5	20000	5000	180	£27.78	150	£0.19
Trailer	12000	5	4000	1600	180	£8.89	150	£0.06
Forklift	40000	5	15000	5000	180	£27.78	150	£0.19
Total	97000		39000	11600		£64.44		£0.43

	Annual	Operating	Cost	Output	Cost
	Cost	Days/yr	/Day	/Day	/tonne
Operating	£		£	ODT	£/odt
Driver	£81,000	180	£450	150	£3.00
Fuel & Oils	£5,400	180	£30	150	£0.20
Repairs	£2,700	180	£15	150	£0.10
Servicing	£2,700	180	£15	150	£0.10
Finance Charges	4850	180	£27	150	£0.18
	£96,650				£3.58

Total	£/odt
Capital	£0.43
Operating	£3.58
	£4.01

Fuel Cost Breakdown			
Lt/Hr	Hr/day	£/lt	Total
10	10	£0.30	£30.00

Totals Summary		
Harvester	Annual Cap	£29,000
Harvester	Operating	£97,200
Support	Annual Cap	£11,600
Support	Operating	£96,650
		£234,450