



Short Rotation Coppice Willow

Best Practice Guidelines

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Teagasc and AFBI staff will endeavour to update this publication based on research findings. Teagasc is the agriculture and food development authority in Ireland. Its mission is to support science-based innovation in the agri-food sector and the broader bio-economy that will underpin profitability, competitiveness and sustainability. Teagasc is funded by the Department of Agriculture Fisheries and Food.

Research carried out by the Agri-Food and Biosciences Institute (AFBI) on biomass crops is financially supported by the Department of Agriculture and Rural Development, Northern Ireland (DARD). The AFBI is a Non-Departmental Public Body sponsored by DARD.

This publication is supported by ARBOR. ARBOR is an Interreg IVB NWE project with 13 partners from six European regions dealing with the development of technological solutions and regional strategy development for improved sustainable biomass utilisation. The project is co-funded by local authorities from the United Kingdom, Flanders, Saarland, Luxemburg, the Netherlands, and Ireland.

ARBOR's mission is to foster and accelerate sustainable development and use of biomass in North West Europe, to facilitate the achievement of 2020 energy objectives and to make the EU a world-class centre for biomass utilisation. The authors wish to thank Mr Robert Dowdall and Professor Ravi Thampi from UCD for supporting the publication of the Best Practice Guidelines.

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February 2015



ISBN number 1-84170-610-8

Photos supplied by Teagasc, AFBI, Queen's University Belfast, Resourceful Organics, Winters Renewables

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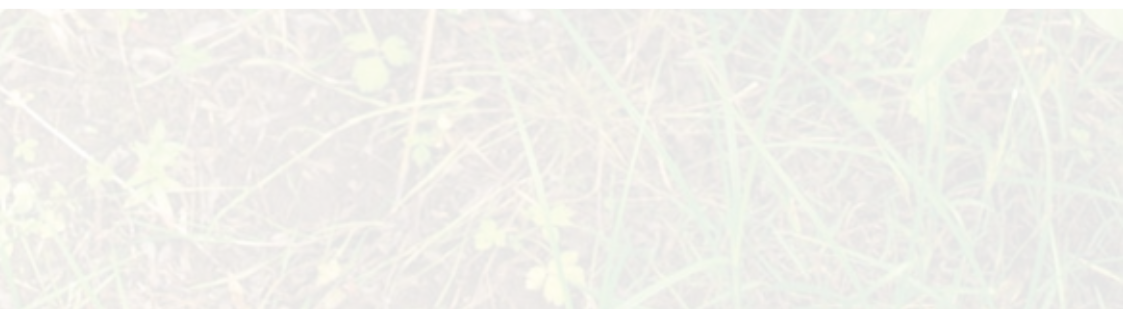
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1.0 Introduction

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1.0 Introduction

Ireland has limited fossil energy resources and as a result has to import in excess of 90% of the energy it uses. The total energy usage on the island is currently almost 20 million tonnes oil equivalent with an approximate value of €20 billion. This can be divided roughly into 37% electricity generation, 34% heat and 29% transport fuels. Hence there are huge incentives to reduce the island's dependency on imported energy, while at the same time exploiting renewable sources of energy generation.

The most promising renewable energy technologies which could be used in Ireland include energy from biomass (anaerobic digestion and combustion), wind, solar (photovoltaics and solar heat), hydro, wave, tidal and ground and air source heat pumps.



Two year old SRC willow

In the past twenty years woody biomass has been recognised as an important biomass source which can be used primarily for heat generation-combustion. More recent technologies such as gasification are being used for electricity production. Sources of woody biomass include conventional

forestry and purpose grown energy crops including Short Rotation Coppice (SRC) willow (*Salix spp.*). One hectare of willow produces approximately 13 tonnes of biomass (25% moisture content) every year.

One tonne of willow has an energy content of 13.2 Giga Joules (GJ) (at 20% moisture), so one hectare produces 172 GJ of energy per year. For comparison 1000 litres of home heating oil has an energy content of 38 GJ meaning that one hectare of willow wood chip at 20% moisture has the same energy content as 4,500 litres home heating oil. This figure will vary slightly depending on moisture content and annual yield. The ROI and the UK have challenging targets to increase energy production from renewable sources and to reduce the production of greenhouse gases (GHGs).

There is an EU target to reduce GHGs by 20% by 2020. In the UK this figure is 34% with an even more challenging target of 80% by 2050. In Northern Ireland the Department of Enterprise, Trade and Industry (DETI) have targets of 40% electricity from renewable sources by 2020 (currently at approximately 14%) and 10% heat from renewable sources (currently at approximately 1.8%). Technologies including wind, photovoltaics, tidal and anaerobic digestion all have potential to contribute to the electricity target. Energy from woody biomass is ideal for heat generation. Furthermore energy produced from woody biomass is regarded as being carbon neutral, in that any carbon dioxide (CO₂) which is released during combustion has first been captured through photosynthesis by the plant when it is growing. CO₂ contributes around 75% of all GHGs which in turn are responsible for climate change and global warming. Energy generation using woody biomass has therefore a significant contribution to make in reducing GHGs.

Total carbon budgets have been calculated for the generation of electricity from biomass, natural gas and coal: the CO₂ per kilo Watt Hour (kWh) is 60g, 400g and 1,000g respectively. The carbon balance of SRC willow (the ratio of energy used in cultivation and processing compared to energy produced) is excellent. From a number of studies, at minimum SRC willow will yield 14 times more energy than is needed in its production and in some situations may be as much as 30 times more.

Biomass

Biomass is biological material derived from living, or recently living organisms. In the context of biomass for energy this is often used to mean plant based material, but biomass can equally apply to both animal and vegetable derived material. Biomass for combustion (heat production) can include cereal grains, oil seeds or the stems of annually harvested energy grasses such as miscanthus (elephant grass), reed canary grass and switchgrass. However, for a variety of reasons in Ireland the most suitable renewable energy biomass crop is SRC willow, although other fast growing trees species such as poplar, paulownia and eucalyptus have been investigated.



Re-sprouting SRC willow coppice following harvest

SRC willow as an energy crop exploits the vigorous juvenile growth associated with *Salix spp.* and its ability to coppice, or re-sprout, from the stool that remains after harvesting. The crop does not need to be replanted after cut back. An SRC willow plantation is established from hard-wood cuttings prepared from one-year old stems produced by

specialist nurseries. Cuttings are fully inserted into the ground in the spring and at the end of the first growing season are cut back to approx. 10cm above ground level (coppiced) to encourage multi-stemmed stools. Growth is rapid after cut back and can be as much as 4 metres in the first year increasing to 6 – 8 metres at harvest in year three (short rotation) following cut back.

The willow can be coppiced six to eight times giving the plantation a life span of 19 – 25 years, allowing for the establishment year. Shorter (2 years) and longer (4 or 5 years) harvest cycles have been considered depending on the productivity of the sites and other end use factors.

1.1 Site Selection

Willow is not a demanding species in terms of its site requirements. It will flourish on a wide range of soil types and environmental conditions, and in common with other crops, productivity will be determined by soil fertility, temperature, and availability of water and light.



Willow Plantation

Soils

Most agricultural soils with pH in the range 5.6 -7.5 will produce satisfactory coppice growth. However, light sandy soils, particularly in drier areas, will have a problem with moisture availability and highly organic or peaty soils should be avoided as initial weed control, which is vital, will be extremely difficult. Medium to heavy clay-loams with good aeration and moisture retention are ideal, although they must have a capability of allowing a minimum cultivation depth of 200-250mm to facilitate mechanical planting.

Water Availability



Willow needs an annual rainfall of between 800-1,100mm
Sites prone to frequent water logging should be avoided

Willow coppice requires more water for its growth than any other conventional agricultural crop and hence requires a good moisture retentive soil. Areas with an annual rainfall of 800-1,100mm are best or areas where the crop has access to ground water.



Production sites should generally be below 100m above sea level

Temperature

Willow in its native environment is a northern temperate zone plant and consequently temperatures in Ireland are unlikely to be an issue. However, elevated sites can result in exposure problems and a reduction in the number of growing days per year. Therefore, production sites should generally be below 100m above sea level.

Access

Harvesting is carried out in winter in the period December to March and whilst the root system of the growing coppice will support the harvesting and extraction equipment on the coppice site, hard access is required to the site. Slopes in excess of 13% will provide difficulty for harvesting machinery, particularly in wet conditions, and should be avoided.

Area

For logistical reasons there is a recommended minimum sustainable planted area. In most situations a commitment of at least 5.0 ha is minimal and furthermore this should be in at least 2.0 ha blocks to facilitate the large harvesting machinery involved. Smaller and irregular shaped fields are also more difficult to manage, and where rabbit fencing is necessary, they will be more costly to fence on an area basis.



Willow at the end of a two year growth cycle will be up to 8m tall

Location in the Landscape

Willow has more similarities with arable cropping than conventional forestry – it has a regular harvest pattern, and its deciduous nature gives it a seasonal diversity of texture and colour.

SRC willow at the end of a two year growing cycle will be up to 8m tall, and therefore creates a three-dimensional mass in the landscape which arable crops do not. Poorly planned SRC plantations have the potential to adversely affect the rural landscape. However, well-designed and carefully sited plantations could bring small but important landscape improvements. In most cases with some thought, the establishment of SRC is likely to bring, at best, a significant improvement or, at worst, no detrimental effect to most mixed agricultural landscapes.

Because of the likely small-scale production and use patterns of SRC in Ireland, it is unlikely to be a dominant landscape feature in any particular area. A 1% uptake in a catchment area with a 20km radius (optimal delivery distance for coppice chip to a conversion plant) would provide 1,200 ha or 15,000 tonnes of dry matter, sufficient for 2 MW continuous generation.

Consideration should be given to blending new plantations with the existing landscape. Additionally, in a large landscape, SRC willow plantings should be in scale and link up if possible with existing woodland to give visual and environmental benefits.

SRC willow development is likely to be sited in landscapes which are already in agricultural use, and is unlikely that they would impinge on landscapes of species interest or scarcity.

SRC willow should not be planted on or adjacent to sites of historical importance or where they would obscure natural landscape features.

Sites with specific designations such as Areas of 'Outstanding Natural Beauty' or Areas of 'Special Scientific Interest' will also require consultation with the regulatory bodies concerned.



Overhead powerlines may pose a risk to anyone in the vicinity of machinery involved in site preparation or harvesting of SRC willow.

Overhead power lines may pose a risk to farmers, contractors or anyone in the vicinity of machinery involved in site preparation, planting or crop husbandry of SRC willow. The Health and Safety Authority has published a booklet, 'Guidelines for safe working near overhead electricity lines in Agriculture - Health and Safety Authority' to ensure safety when farming activity is carried out in the vicinity of overhead power lines.

In the 2-3 years prior to harvesting, SRC willow will reach a height that is very close to overhead power line heights. This can (1) create a serious electrical risk to anyone in the vicinity of machinery involved in harvesting; (2) interfere with the safe operation of the power line. Contact ESB / relevant networks at planting stage for advice if it is proposed to plant directly under an overhead power line.

Site Selection – Key Facts

- Know your land and soil types
- For logistical reasons a minimum of five hectares should be planted
- Aim to blend new plantations into the existing landscape
- Avoid sites with features of historical interest or designated natural habitat areas
- Overhead power lines may pose a risk

1.2 Pre-Planting Site Preparation

Since SRC willow will be in the ground for up to twenty five years, thorough site preparation is essential.

Pre-ploughing

It is important that this phase is carried out effectively, particularly on old pasture land where the presence of perennial weed such as docks and nettles is more likely. Ideally for a grass lea site a translocated herbicide such as **glyphosate** (e.g. **Roundup Biactive at 5-6 l/ha**) should be applied in September to actively growing vegetation. If not possible then the application of the herbicide should be in early spring when weeds are actively growing.

For the pre-ploughing herbicide application on grassland or set-aside sites an application of **chlorpyrifos** (e.g. **Dursban at 1.5l/ha**) will provide leatherjacket control. This should be included in the herbicide mix with **glyphosate**.



Spraying grass with **glyphosate** in advance of ploughing

For stubble ground a translocated herbicide such as **glyphosate** (e.g. **Roundup Biactive at 3l/ha**) should be applied in early spring, prior to ploughing.

Where sites have excessively heavy vegetation present, consideration should be given to cutting and removal of the vegetation to allow for effective weed control. If this is necessary, sufficient time should be allowed for re-growth to allow for active herbicide uptake.

A minimum of fourteen days after herbicide application is recommended before the site can be ploughed. Land which has been regularly shallow ploughed and land that has been intensively grazed can both suffer from compaction close to the surface. This will require deep ploughing and/or sub-soiling to allow full root development. Normally this would be carried out in the autumn and the ground allowed to weather over winter. However, compliance with the Nitrates Directive makes this impossible. Whatever the site, a minimum plough depth of 20-25cms will be required to allow for the insertion of the cuttings.

On suitable soils, the site can be ploughed and power harrowed, and a stale seedbed prepared in mid-March, six weeks before planting. The germinated weeds can then be sprayed off prior to planting using **glyphosate** (e.g. **Roundup Biactive at 2.0 l ha⁻¹**). On heavy clay soils, this approach is not practical and the site should be power harrowed as close to planting as possible. It may be necessary to lift stones after power harrowing as these can interfere with the use of mechanical planters.

If rabbits and hares are present in sufficient numbers, they can be very destructive in new and establishing coppice plantations and should be excluded with appropriate fencing. This is an expensive operation and where necessary, will represent the single largest cost in site preparation. The fencing may be temporary in nature as established coppice is less susceptible to economic damage. Netting is generally used, with the lower portion buried, or turned horizontally to deter rabbits from burrowing underneath. Machinery is now available to plough in wire netting, and this substantially reduces the cost. Electric mesh fencing has proved satisfactory but it must be kept weed free to prevent shorting out. The

cost of fencing to exclude deer is normally prohibitively expensive but in some situation may be necessary. Electric fencing can provide sufficient protection.

Pre-Planting and Site Preparation – Key Facts

- Spray off vegetation with **glyphosate**
- Erect rabbit / deer fencing only if necessary
- Plough to a minimum depth of 20 – 25cm
- Power-harrow as close as possible to planting
- Lift stones after power-harrowing
- Use **Chlorpyrifos** if required for leather jacket control

1.3 Planting Material



Newly bred varieties are more productive and have greater resistance against pests and disease

Salix (Willow) is the preferred genus for SRC in Ireland. It is native to northern temperate zones and therefore thrives in the cool wet conditions and largely heavy soils in Ireland. Other native genera such as **Alnus** (Alder), **Fraxinus** (Ash), and **Populus** (Poplar) have been investigated but have exhibited establishment or coppicing problems and generally have not been as productive. Willow is a pioneer species meaning that it is one of the first woody species to colonise disturbed ground. Pioneer species, among other properties, generally exhibit vigorous juvenile growth. This

property is exploited in the short harvesting cycles imposed on the system, willow can be coppiced regularly and repeatedly without losing vigour. SRC willow establishes easily and quickly from un-rooted cuttings. In favourable conditions, roots can be produced within ten days of planting, which is important in making the cuttings self-sustaining as quickly as possible.

Breeding Programmes

Willow genetic improvement programmes in Sweden and the UK have made significant progress in breeding short rotation coppice (SRC) willow. However, to expand production, cultivars suited to a wider range of European environments and future climates will be needed.

Willow breeding programmes were initiated in Sweden in 1987 and the UK in 1996. The primary aims of these programmes are to produce high yielding disease and pest-resistant varieties with a growth habit that facilitates mechanical harvesting. The majority of the crosses made by the Swedish breeding programme at Svalöf- Weibull AB have involved *S. viminalis*, *S. dasyclados* and *S. schwerinii*. The original parental material was based on Swedish and central European collections, later supplemented by collecting expeditions to central Russia and Siberia. The UK breeding programme based at IACR-Long Ashton (funded by the European Willow Breeding Partnership) utilised over twenty different species held at the UK National Willows Collection. These included exotic equivalents of *S. viminalis* and *S. caprea* such as *S. rehderiana*, *S. udensis*, *S. schwerinii*, *S. discolor* and *S. aegyptiaca*.

All new willow plantations now involve newly bred varieties, which are more productive and have greater resistance against pests and diseases. These factors will bring about more stable yield levels. Until recently there has been a lack of frost tolerant material for certain areas in Sweden. The varieties 'Gudrun' and to a lesser extent 'Tora' can be used in areas that have a high risk of frost. The choice of variety depends on the specific need of the grower and the climatic conditions of the site. It is also dependent of the availability of cuttings from the producers. Cutting producers need at least one year's lead time in order to be able to provide sufficient cuttings

of each variety. Once they know which varieties are required they can cut back their plantations to produce one-year old shoots for cutting production the following winter.

It takes approximately ten years to develop a new willow variety. There are presently 24 certified EU varieties available. There are only about ten of those in mainstream commercial use today. Approximately one – two new varieties are developed annually. Details of SRC willow suppliers and distributors are in the contact section.

Supplying Quality Willow Cuttings

The willow cuttings should be prepared from one-year-old wood, which has had the un-ripened wood at the tip of the harvested rod removed (planting rods). Generally, planting rods of 1.5- 2.5m will be supplied by the specialist producer. Cutting material is generally harvested in January – February period when the buds are fully dormant. It is important that this dormant state is maintained using refrigerated storage at -2 to -4°C up to the point of planting. Ideally, cold storage should also be provided on-site at planting. This is particularly important where delayed planting in the May-June period is anticipated. Dehydration is the most likely problem to be encountered in storage thus the cuttings and rods should be protected by wrapping in black 'polythene' film.



Planting rods 1.5m - 2.5m, will be supplied by a specialist producer

Cuttings should be a minimum of 200 mm in length with a minimum diameter of 9 mm. This will ensure an adequate carbohydrate reserve

to sustain the cutting before establishment. Shorter cuttings have been used successfully by planting operators, however it should be noted that weather and soil moisture levels may determine the success of using shorter cuttings.



SRC willow being planted with a step planter in double rows

The planting material should be sufficiently matured (lignified) to prevent deformation on insertion into the prepared ground; and should not show any discoloration or wrinkling of the surface, indicating dehydration.

All of these improved commercial varieties are protected by European plant breeders' rights. In practice, this means that it is illegal to produce propagation material for self-use or sale from protected varieties. Derogations are allowed by certain plant breeders which enables the gapping up of establishing crops with the material produced at cutback. It is recommended that your provider of planting material is consulted before doing this.

It is absolutely imperative that mixtures of willow genotypes are used when establishing a new plantation. These mixtures should contain at least six different genotypes drawn ideally from different breeding programmes, and having as great a genetic diversity as is practically possible.

Planting Material – Key Facts

- Willow thrives on heavy moisture retentive soils
- The main willow breeding programmes in Europe are in Sweden and England
- Cutting material should be maintained in a refrigerated unit at -2 to -4°C prior to planting
- Cutting material is harvested from one year old wood
- Willow varieties are protected by European plant breeders rights
- Initial planting density of approximately 15,000 cuttings per hectare
- Plant a mixture of at least six genetically diverse genotypes

1.4 Planting



Cuttings are inserted vertically into prepared seed bed

The planting season using cold stored planting material ideally extends from early April – mid May, when weather conditions allow soil preparation and cultivation. Planting has occurred from late May and even into June, however this would pose a risk to successful establishment. Early planting will give early establishment and a longer growing season for the establishing crop with a lower risk of water stress from a late spring dry period.

Over the years much information has been collected on a wide range of planting densities. To facilitate mechanical harvesting and machinery access, the crop is planted in double rows 0.75m apart with double rows spaced at 1.5m. An in-row spacing of 0.6m gives an initial planting density of approximately 15,000 cuttings per hectare. Establishment should, in good conditions, be in excess of 90%. This, together with a natural loss of stools in the early rotations, should produce a cropping density of 13,500 cuttings per hectare. Where possible, rows should be planted

parallel to the longest axis of the field to maximise machine efficiency. Avoid running rows across steeper slopes, as this will create difficulties in holding machinery in the row.



Planting using a Step planter - when completed the site should be rolled to consolidate the surface

Ireland's soil and climatic conditions can pose operational problems in the unplanted headlands during harvesting. Harvesting and extraction machinery requires the increased carrying capacity which the root system of the growing crop provides. Therefore, the sacrificial planting of marginal rides and headlands should be considered, in all but the lighter soils, accepting the reduced yield in these areas that the compaction and rutting caused by the harvesting and extraction will produce. If open unplanted areas in the coppice are required for environmental reasons, they are more easily managed as internal rides.

Several types of mechanical planters have been used but the dedicated Step Planter designed in Sweden by Salix Maskiner has become the industry standard in Ireland. This planter plants two double rows at a pass and automatically makes the cuttings from rods inserted into the planting

heads. In ideal conditions, it has a capability of 6-8ha per day. However, in the smaller field sizes that are likely to be encountered in Ireland this could be reduced to 4-5 ha per day.

After planting the site should be rolled to consolidate the surface. This provides the best possible conditions for the application of residual pre-emergence herbicides to be effective.



Cuttings will produce 1-3 shoots which grow to a maximum height of 2.0-3.0m in the first year

Planting – Key Facts

- Planting season extends from early April – late May/June
- Cutting material harvested during dormant period (January – February)
- Plant in double rows 0.75m apart, with double rows spaced at 1.5m and in-row spacing of 0.6m
- Roll site after planting prior to herbicide application

1.5 Post-Planting Establishment

Management of the crop post-planting for the first year is crucially important, particularly in terms of weed control. This cannot be over emphasised as newly-planted willow cannot effectively compete against most weeds. If adequate weed control is not achieved, then a successful coppice system will not be established.

Cutback

During the first growing season, the inserted cuttings will produce 1-3 shoots with a maximum height of 2.0 - 3.0m. Cutback (coppicing) after the first year of growth has been the standard practice in willow biomass production systems. The necessity of cutback and the decision made should be based a range of factors.



First year willow growth is cutback to within 10cm of ground level using a reciprocating type mower

Field conditions, plant size, number of stems per stool, degree of weed competition, stage of growth of plant and weather conditions can all affect the plant's response to coppicing. In Ireland where weed growth can continue throughout the year cutback gives a second opportunity for herbicide application. Advice should be sought if unsure whether cutback is required. Research has shown that there is little difference in yield between coppiced and uncoppiced plots after four years (four straight years of growth versus one year of growth, coppice and three years of re-growth).

Traditionally the first year growth is cutback to within 10cm of ground level using a reciprocating type mower, which should produce a clean cut. Other types of swathers or flail mowers can cause excessive damage. This cutback will encourage the established cutting to produce multiple shoots, often eight to ten depending on variety.

Following cutback, the coppice enters it's cropping cycle of between two and four years. Following each harvest operation the crop will regrow. At harvest, the coppice will have attained a maximum height of seven to eight metres, and only the most vigorous of the shoots produced at cutback will survive to this point with the weaker ones being shaded out.



One year old growth of stems following first harvest of willow crop

Weed Control

Weed control can be divided into four distinct phases in total. The first phase is preploughing which has already been covered in section 1.2.

Post-Planting

It essential to spray the site before any growth begins. An insecticide such as *chlorpyrifos* (e.g. **Dursban at 1.5l/ha**) to control leatherjackets, the larval stage of the crane fly or 'daddy-long-legs' (*Tipula paludosa*), should be included with this herbicide application. An application of a pre-emergent residual herbicide mix to keep the crop clean during the establishment phase is required.



SRC willow is very fast growing but needs minimal competition from weeds in the establishment year



Weeds can become a problem during establishment if site is not effectively managed

There are a number of residual herbicides which can be used but a mixture of **pendimethalin** (e.g. **Stomp Aqua at 3.3l/ha**) and **isoxaben** (e.g. **Flexidor 125 at 2.0l/ha**) has been found to be an effective mix on a range of sites.

During Establishment

During establishment if weeds become a problem, as can be the case particularly on ex-grassland sites where the seed bank in the soil is greater than on ex-arable sites, there is only a very limited range of contact herbicides available for over-spraying the established crop. Additionally, these are highly specific herbicides with a limited weed spectrum. Effectively, there is only **clopyralid** (e.g. **Dow Shield 100 at 0.25 – 0.5l/ha**) for thistle control and **fluazifop-p-butyl** (e.g. **Fusilade Max at 1.5l/ha**), **cycloxydim** (e.g. **Laser at 2.25l/ha**) or **propaquizafop** (e.g. **Falcon 1.5l/ha**) for grass control. Other herbicides can be applied as directed sprays using an inter-row guarded sprayer. However, this is a skilled operation and should only be undertaken with advice as the crop is highly susceptible to the herbicides used. Spot treatment of small areas of troublesome perennial weed (docks and nettles) can be undertaken with appropriate herbicides using guarded knapsack sprayers or weed wipes.



Canopy closure usually occurs by midsummer in the second growing season

Following Establishment and after Cutback

Following establishment and after cutback, a further herbicide application will be necessary to keep the crop weed free until it achieves canopy closure, usually in midsummer of the second growing season. The use of the contact herbicide **amitrole** (e.g. **Weedazol at 20l/ha in NI**) or **glufosinate-ammonium** (e.g. **Basta at 3.75l/ha in ROI**) together with an additional application of residual herbicide **pendimethalin** (e.g. **Stomp Aqua at 3.3l/ha**), will provide the necessary control and should be applied before bud burst, but delayed sufficiently after cutback to allow for wound sealing. SRC willow coppice has shown tolerance to **amitrole /glufosinate-ammonium** before bud burst which can vary from mid-February – early April depending on local climatic conditions. If weed cover is significant, a later cutback of the established crop in mid-March will delay bud burst and will ensure that the weeds are actively growing, when they will take up the **amitrole /glufosinate-ammonium** more effectively.

Mechanical weed control using inter-row cultivators is also an option but less likely to be effective in the climatic conditions in Ireland where the moist growing conditions do not favour the dehydration of the disturbed

weed cover. The use of herbicides should be avoided if the crop is under any stress, particularly moisture stress, as crop damage is likely. There will be an increased emphasis on mechanical weed control in terms of sustainability and the high cost of chemical herbicide weed control. Some companies have now developed their own inter row cultivators /sprayers.

Pesticides used to protect plant/crops from pests and diseases or control unwanted plants (weeds) are known as plant protection products. The law requires that only plant protection products authorised by Ministers shall be sold, supplied, used, stored or advertised. For the UK the responsible departments are the Department for Environment, Food and Rural Affairs (DEFRA), Department of Health, the Scottish Government, the Welsh Government and Department of Agriculture and Rural Development, Northern Ireland (DARDNI). The Chemicals Regulation Directorate (CRD) of Health and Safety Executive (HSE) acts as the delivery body for regulating plant protection products authorised for sale, supply, use and storage in the UK. The HSE website has a Pesticides Register of UK Approved Products where information on Plant Protection Products with On-Label Authorisations is available.

The Pesticide Registration and Control Divisions and the Pesticide Control Laboratory of the Department of Agriculture, Food and the Marine (DAFM) are responsible for implementing the regulatory system for plant protection and biocidal products in ROI. Product approval can be checked via the DAFM site product database which contains details of registered plant protection products and is updated on a regular basis.

It is important to read product labels prior to use and to follow the manufacturer's instructions carefully. Many pesticides are being continuously removed from the market making the weed control challenge even greater. Products should not be applied if they are not approved by the appropriate authority.

Post – Planting Establishment – Key Facts

- Weed control post planting is critical for successful coppice establishment
- Make crop management decision regarding necessity for cutback at end of first year
- Cutback with reciprocating type mower at the end of first growing season to within 10cm of ground level to encourage development of multi-stemmed coppice
- Apply herbicides post cutback prior to bud burst
- Re-growth following cutback is rapid with ground cover/canopy closure by midsummer
- Coppice enters cropping cycle of between two and four years

1.6 Nutrition and Fertilisation

Background

Many soils have excess levels of phosphorus (P). In Ireland, over 50% of soils tested had high levels of P (index higher than 2), with significant potential to create surface water quality problems. With the relatively low levels of P removal in the harvested SRC willow the P status of the soil may well be adequate in most circumstances. The risk of nitrogen (N) leaching from SRC willow plantations is relatively low compared with normal arable situations given the long term perennial nature of the crop and the absence of soil disturbance through cultivation. The production of mineral fertilisers is heavily dependent on the input of fossil fuels and when these are used on SRC willow plantations the energy balance (energy in versus energy out) is adversely affected and actual GHG emissions may be increased.



Willows thrive on nutrition. Applying organic fertilisers can boost yields up by 35%



SRC willow can be fertilised with many organic wastes, sludges and effluents

Potassium (K) can be relatively stable in soils and so unavailable for easy plant uptake. There is the potential for balancing most of the K exported from the site at harvest by returning the ash to the site, after conversion of the wood chip to energy.

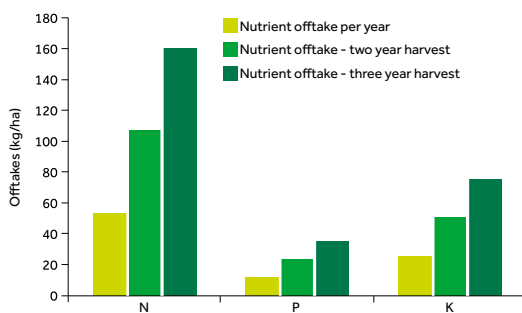


Foliar rust (*Melampsora*) on willow

Two other important observations have been made over numerous years of growing SRC willow. Firstly, after the onset of serious rust (*Melampsora spp.*) infections on plantations in 1986, it was obvious that those stools in least competition for nutrients and light were

those which were least affected by rust. In particular the problems of stool death caused by entry of secondary dieback organisms into the stem tips following defoliation by the rust infection were less obvious. Secondly it is also evident that in a plantation where vigour had declined through poor nutrition it was difficult if not impossible to recover that vigour, raising the necessity of maintaining the nutrient capital of the soil by balancing off-takes.

As with any crop, fertiliser, from whatever source, should only be applied as the result of formal soil analysis and the consideration of other inputs in perennial crops such as internal recycling of nutrients in the leaf litter. In the case of SRC willow, current available research and data suggest a level of nutrient off-take in the harvested crop and this should be used in calculating fertiliser requirement.



Nutrient removal when willow is harvested
Based on results from willow harvests at Teagasc, Oak Park

There is evidence that on moderate to fertile soils, particularly in the early rotations, there is not necessarily a positive response to fertiliser applications. However sites with a naturally poorer nutrient capital may need these early applications to maintain productivity. Fertiliser application is not recommended on most sites in the first growing season because the nutrient capital is generally adequate for establishment and the crop will not have developed the necessary root system for effective uptake. Additionally it is in the establishment year that weed control is likely to be most difficult and fertiliser application may well exacerbate the problem.

Significant amounts of nutrients are taken-up by willow crops over the course of a two or three year harvest cycle. At the end of each growing season, approximately 21% of the dry weight of the willow crop will consist of leaf material and 79% as stem material. However, a substantial percentage of the mass of nutrients in the crop will be in the leaf component of the crop, between 44% and 64% depending on the nutrient. Most of this nutrient mass is recycled as leaf material falls to ground before harvesting and the nutrients are gradually worked into the soil and become available for uptake during subsequent growing seasons. All of the P and K can be expected to be available in due course to succeeding crops. The table below shows an example of total uptake of nutrients and the quantity of nutrients recycled before harvest in a three year old willow crop yielding 10 tonnes DM/ha/yr.

	N (kg/ha)	P (kg/ha)	K (kg/ha)	Ca (kg/ha)	Mg (kg/ha)
Total Nutrient Uptake	423	38	224	186	76
Nutrients Recycled	271	18	130	82	47

Nutrient uptake and recycling in SRC willow

Biofiltration and the UK Fertiliser Recommendations (DEFRA RB209)

Although The DEFRA Fertiliser Manual (RB209: 8th Edition) suggests what level of nutrients are required to provide the best financial return for the farm business, it should also be noted that the authors of the Manual acknowledge that the data presented in the table (N and P off-takes by willow) on page 175 of RB209 are based on fairly limited published information.

Unlike other crops described in the Fertiliser Manual (RB209: 8th Edition), SRC willow is officially recognised on page 175 as potentially being able to avail of higher rates of nutrient application in recognition of the low environmental risks associated with the management of the crop and in particular the method of waste recycling in comparison to other alternative methods of disposal. On page 176 it also recognises the need for willow to have nutrient in years two and three from a single application in year one, due to the difficulty in physically accessing the crop.



Willow being fertilised by an irrigation system

Current application regulations as agreed by NIEA (Northern Ireland)

The application of $180 \text{ kg N ha}^{-1} \text{ year}^{-1}$, based on off takes is currently agreeable.

If the N is applied in conjunction with phosphorus (unbalanced crop requirement ratio e.g. biosolids), this can result in an accumulation of P in the soil which needs to be monitored.

Solid organic fertiliser can be applied to P index 2 soils however this should cease when soils reach P index 3.

The rate of P application will depend on the source of organic waste and the regulatory instrument it falls under. $24 \text{ kg ha}^{-1} \text{ year}^{-1}$ is a current workable estimate.

When irrigating low nutrient waste waters to SRC willow, communication and in-depth discussion with the environmental regulator is essential to weigh up and mitigate environmental risks with environmental, community, practical and other associated benefits.

The on-going analysis of soil, soil-water and groundwater would normally be considered unnecessary, however in exceptional circumstances more detailed monitoring may be required.

The Northern Ireland Environmental Regulator has current published soil testing regimes for application of certain organic wastes and will review other environmental analysis requirements on a case by case basis.

Current Application Advice from Teagasc (Republic of Ireland)

Nutrient recommendations differ slightly between the Republic of Ireland and Northern Ireland, recommendations can be summarised as follows

Willow nutrient recommendations: Northern Ireland

Soil P index	N (kh/ha/year)	P (kh/ha/year)
1 to 2	180	24
3 to 4	180	0

Nitrogen 100% availability
Phosphorus 100% availability
The regulator may agree Phosphorus over addition for different organic wastes and on the basis of building up soil P reserves.

Willow nutrient recommendations: Republic of Ireland

Soil index	N (kh/ha/year)	P (kh/ha/year)	K (kh/ha/year)
1	130	34	155
2	100	24	135
3	75	0	120
4	40	0	0

Nitrogen 40% availability
Phosphorus 100% availability
Local authorities may stipulate differing Phosphorus availabilities for different organic wastes

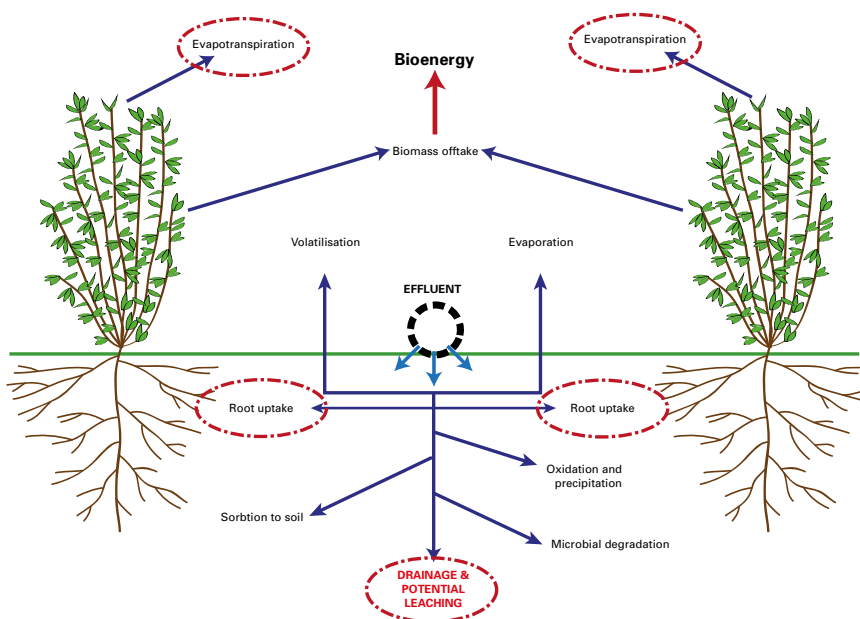
Nutrition and Fertilisation - Key Facts

- Fertiliser application is not recommended on most sites in the first growing season
- Fertiliser, from whatever source, should only be applied as the result of formal soil analysis
- The level of nutrient off-take in the harvested crop is the basis for calculating fertiliser requirement

1.7 BIOREMEDIATION

Bioremediation is defined as, “the use of living organisms to break down or remove toxins and harmful substances from soil and water.” SRC willow is an ideal crop for the bioremediation of dilute liquid wastes such as municipal effluent, industrial effluents and even landfill leachate. Willow has a significantly higher water uptake than many other woody or arable crops, using up to one million litres per tonne of dry matter produced annually. Coppiced willows produce a fine shallow root system of which 85% is in the top 50 cm of the soil profile. This significantly improves stability as well as providing an effective ‘filter’ for the reception of liquid wastes.

The leaf area of the plants is at a maximum early in the growing season, start of May or June, which provides the maximum ‘pull’ through the system by means of evapotranspiration. The guiding principle for all bioremediation systems is that the nutrient input into the system via the waste being recycled should be matched to the nutrient requirements of the crop. The actively growing willow plants take up nutrients including N and P which are then exported off-site in the wood when the crop is harvested. In this way the system is self-sustaining with no excessive build-up of nutrients in the soil reducing subsequent risks of nutrient leaching or run-off from the site.



Schematic diagram of processes involved in bioremediation of effluent by SRC willow

Once the crop has been well established, irrigation pipes are laid between the rows of the double row every third double row. In each pipe there is an outlet point for the effluent approximately every 10 metres. The effluent is pumped under pressure and is vented through each of the outlet points.

A plantation is divided into a series of zones with each zone being independently irrigated for a short set amount of time before the irrigation moves on to a subsequent zone. The irrigation will cycle through every zone before returning to the original zone to start the process again. The pipes are laid on the surface of the soil and the short irrigation periods gives time for the effluent to percolate into the soil and root zone. The level of irrigation will depend on the hydrology of the site, soil conditions, the nutrient status of the soil and nutrient content of the effluent.



Feed and irrigation pipe construction

When selecting a site with the potential for effluent irrigation it is highly desirable to have a relatively flat area which reduces the risk of surface run off. Irrigation can be controlled on sites with a slope although the risks of run-off will need to be carefully mitigated.

The application of effluents or leachates whether municipal, industrial, agricultural or land-fill is tightly regulated by the relevant environment agency (Environment Protection Agency/ Northern Ireland Environmental Agency).

Their regulation is based on the requirements set out by Europe in a number of directives including Nitrate Directive, Waste Framework Directive and the Water Framework Directive.

Other requirements may be put in place which are specific to a site and are needed to prevent contamination of soils, waterways or groundwater.

More details about the use of SRC willow for the bioremediation of effluents and leachates can be found in “Use of Short Rotation Coppice (SRC) willow for the bioremediation of effluents and leachates: current knowledge”, published by the ANSWER (Agricultural Need for Sustainable Willow Effluent Recycling) project.



A.N.S.W.E.R.
**(Agriculture Need for Sustainable
Willow Effluent Recycling)**

<http://www.afbini.gov.uk/index/research/hp-work-area-environment-land/answer/answer-events.htm>

1.8 Disease and Pests

Leaf Rust

Leaf Rust (*Melampsora spp.*) is the most important fungal pathogen of SRC willow and potentially the most limiting to sustainable cropping, particularly in the cooler maritime type of climate in Ireland, which favours the development of this disease. It is a heteroecious rust (has an alternate host) and is first seen on willow in late spring – early summer as small orange coloured rust pustules on the underside of the leaf. These initial infections classically develop from aeciospores which have been formed on the pathogen's alternate host – European Larch (*Larix decidua*).



Foliar rust (*Melampsora*) symptoms on SRC willow

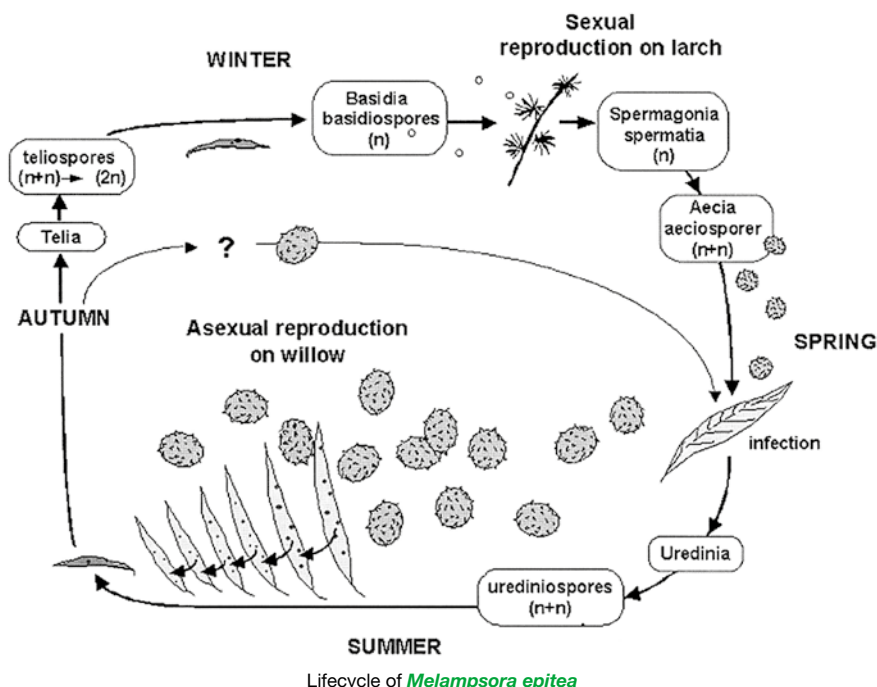
Development on the host willow is through repeated asexual cycling of urediniospores. This cycle can be as short as two weeks and consequently can lead to serious levels of infection very quickly on susceptible genotypes. High levels of infection result in premature defoliation, reducing growth, and more seriously enabling the entry of secondary dieback pathogens

through the unprotected leaf scars. These dieback organisms (*Fusarium sambucinum* and *Glomerella miyabeana*) can cause significant levels of damage to, and subsequent death of, shoots and stools. Yield losses in excess of 50% have been recorded.

Significantly, in the moist, relatively mild winters experienced in Ireland, it also believed that *Melampsora spp.* urediniospores can survive over-winter in the bud scales and leaf litter, without the need to go through the alternate host. This can lead to early infection and serious disease levels early in the growing season.

In common with most fungal diseases, control could be achieved using fungicides. However, in the case of SRC willow, this is not considered a practical solution for a number of reasons: (i) Economics - SRC willow is a high volume, low value crop and the necessary repeated fungicide applications could not be sustained economically; (ii) SRC willow is seen as an environmentally acceptable crop and the intensive use of fungicides would not be compatible; (iii) and practically, after the early stages of re-growth following coppicing, it is increasingly difficult to achieve the necessary chemical coverage of the plant to effect adequate disease control. As a result, an alternative non-chemical disease control strategy needed to be developed and this has been the subject of on-going research since the late 1980's.

Since the major contributing factor to the development of rust disease was the lack of genetic diversity in the single variety plantings used in the early plantations, it was argued that the introduction of diversity by planting mixed variety plantations would be effective in control. This has proved to be a successful approach, with mixtures delaying the onset of the disease and reducing its spread, so that at the end of the growing season, the disease, although still present, was not at levels where yield was affected. This is a more sustainable approach, and a number of recommendations can be made.



Evidence clearly indicates that where disease pressure is high, as it is in Ireland, the planting of single variety plantations even where the variety is less susceptible or resistant to rust, is a short term high risk strategy and not to be recommended. There are examples where previously resistant varieties have become susceptible as the natural rust population has evolved, resulting in severe losses in single variety plantations.

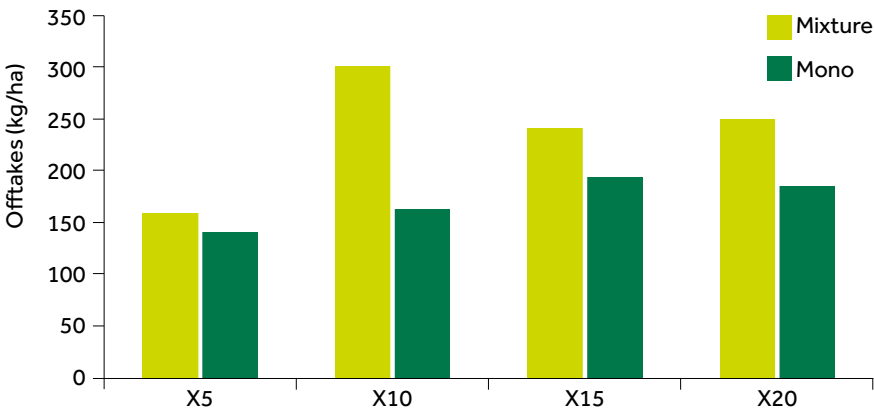
The yield of the improved varieties from the breeding programmes in Sweden and the UK, together with their superior rust resistance, means that only they should be used in commercial developments.

Yield from diverse mixtures is greater than the equivalent yield of the mixtures' components grown in monoculture even in the absence of the disease. Where less diverse mixtures have been planted e.g. mixtures of exclusively *Salix viminalis* varieties, these yield increases have not been recorded and the disease suppression aspects, whilst present, are not

as marked. This is an important aspect since many of the commercially available improved varieties are of *S. viminalis* origin.

Furthermore increasing diversity in mixtures can result in yield compensation, where individual components of the mixture become susceptible to the disease over time and make increasingly smaller contributions to yield. This yield compensation occurs as a result of the remaining varieties occupying the space left by those that have become disease susceptible.

Consequently, at least six to seven varieties (consult the Willow Variety Identification Guide for best composition of mixtures) should be included in commercial plantations. With the step planting machinery used, short run random mixtures are achieved which are as effective as completely random mixtures. There are differences in how individual mixture components contribute to the overall yield of the mixture and provided that individual components do not have a significant negative effect, their inclusion is justified by the diversity they bring and the positive effect they have on improved sustainability.



Yield (kg) from 100^{m2} of mixtures and component genotypes grown in mono-plots

Rust – Key Facts

- Disease pressure is high in Ireland
- Seen on willow in late spring or early summer as small orange coloured pustules
- Lack of genetic diversity in single variety plantations
- Non-chemical disease control strategy needed
- A mix of six to seven varieties should be planted in commercial plantations

Pests

Willow beetles (*Chrysomelids*)

This group of beetles represents the major economic pest problem in SRC in Ireland.

There are three species of willow beetle involved - brassy or green (*Phratora vitellinae*), blue (*Phratora vulgatissima*), and brown (*Galerucella lineola*). The blue and brown species are more prevalent. Overwintering adults emerge from hibernation in April and, after a short feeding period, begin to breed. Egg-laying takes place between early May and late June. Larval stages are found from mid-May into July and develop through three instars before pupating.



Willow leaf beetle (*Phratora vulgatissima*) and larvae

The new generation of adult beetles appear in July/August and feed until hibernating in the autumn. There can be two generations per year – the first emerging from the eggs laid by overwintering adults in May and a second generation in August. Adults feed on the upper leaf surface, whilst the larvae feed on the underside of the leaf which eventually is skeletonised and turns brown.

Unlike rust infections, skeletonised leaves usually remain attached. Economic damage has been recorded in the UK. However, damage may visually appear severe but defoliation experiments have shown if <30% leaf surface is damaged the effect on yield will be minimal. However, the willow plant has been shown to have increased sensitivity to beetle attack during the initial stages of re-growth following harvest, with significant effects recorded on both root and shoot growth.

Beetle populations vary considerably from year to year, and just because there may be a heavy infestation in a particular year, this does not mean that the following year will be equally affected. The overwintering adults

often hibernate off-site and this provides the only economic opportunity for control. If population numbers are large, they can be reduced by target spraying the borders of the plantation with insecticide when the beetles are re-colonising the plantation from their overwintering sites in early spring.

However, this is a one-off operation and routine spraying is NOT recommended for both economic and ecological reasons. Mixtures have also been found to be effective in limiting damage as there is a variation in feeding preference of the beetles between the different varieties. The modern improved varieties also have increased resistance to insect damage.

Other Pests



Giant willow aphid (*Pterocomma salicis*)

There is a range of other potential pest species feeding on willow and the most obvious of these are the various aphid species. There are two large species which form extensive colonies on the stems in late summer/autumn - the giant willow aphid, (*Tuberolachnus salignus*), and the black willow aphid, (*Pterocomma salicis*).

These aggressive aphid species can grow to 6mm long, and can form large colonies on the woody stems of some willow varieties. Both have

been shown to have significant negative effects on above ground biomass yield and root systems.

However, as with other aphid species, control with insecticides is not desirable either environmentally or economically, and nor is it possible practically. There are also various midges (*Dasyneura spp.*) which can result in the death of the terminal bud or can cause rolling of the leaf margins. Their effect on yield is uncertain and control is not practical.

Pests – Key Facts

- There are three species of willow beetles
- Beetle populations vary considerably from year to year
- Adult populations appear in July / August
- Aphids can have negative effects on above ground biomass
- Control with insecticides is not desirable

1.9 HARVESTING

The harvesting window for the SRC willow is from leaf fall to bud burst, or flushing in the spring. In normal conditions, this gives a three to three and a half month period from December to mid-March. In Irish conditions, soil trafficability is often at its worst in this period and hence there is a need for hard access to the cropping site. Where earlier bud burst can be expected because of favourable site conditions, harvesting time should take account of this. Bud burst results from the mobilisation of a significant proportion of the reserves stored in the roots and stems and their transport to the developing shoots. Their removal in harvested material could weaken the stool, delay flushing, and lead to increased weed competition.



Ideally, the harvested crop, chips, billets or sticks should be stored under cover in order to stop re-wetting from rain



It is important that the harvester's blades are set correctly to make sure that the crop is cut low down. This is where the stems are thickest and are of greater mass, reflected in better yields

Consequently, harvesting should be carried out on dormant stools. SRC willow does not fall under the remit of the 1946 Forestry Act in the Republic of Ireland, and is therefore not subject to its felling and replanting requirements. There are a number of approaches to harvesting: direct chip, whole rod, billet and bale harvesting, and each has its own advantages and disadvantages. Harvesting is seen as a co-operative or contractor's operation because of the specialised nature of the machines and the justification of their cost on relatively small individual holdings. It is unlikely that any single harvesting option will be the correct choice across the board. Various factors including the availability drying and/or storage facilities, the requirements of the supply chain and site conditions will determine choice.

Direct Chip Harvesting

In this option, the crop is cut and chipped in a single pass and the resulting material must be either used immediately in suitable applications or artificially dried immediately following harvest to prevent deterioration. Most of the machinery developed for this type of operation has been designed to harvest the double row in a single pass, and essentially have modified harvesting heads fixed to standard forage harvesters.



Direct Chip Harvesting is an effective harvesting operation but will require dedicated drying facilities if the chips are not being used directly after the harvest

These cut the standing crop, which is then chipped and blown into trailers for removal.

Where, initially at least, it is envisaged that in Ireland end users will be mid-to small scale, conventional silage type trailers can be used to transport this chip from the field for drying and storage and then to the end user. As the harvested crop is chipped fresh, the quality of the chip will be maximised and the power requirement for the chipping operation minimised.



Chip produced from Class Harvester



In certain regions it may be possible to dry woodchip outside, in which case it should be stored in long windrows up to 5m high using a telehandler

This is an efficient harvesting operation but will require dedicated drying facilities if the chip is not being used immediately as the harvested chip will self-heat quickly due to natural degradation similar to composting. This leads to a deterioration of the chip with resulting loss of calorific value, and the production of mould growth with potential health and safety implications.

Ventilated grain drying floors have been used efficiently for this operation and since harvesting is carried out after the grain drying season has been completed, maximum use can be made of these expensive facilities. This type of harvesting machine has a capacity of 5-6 ha/day. However, in Irish conditions where field sizes are potentially smaller with restricted row lengths, actual capacity is likely to be 3-4 ha/day.

Whole Stem Harvesters

This method harvests the crop as entire rods, and whilst in some circumstances it maybe the harvesting method of choice, a number of points should be taken into consideration. These machines produce loose rods which have to be collected and removed to the storage area as separate operations. The whole stem harvester pictured above weighs 7.5 tonnes empty and can carry up to 4.5 tonnes of willow on the trailer before having to slide it off. Its work rate is approximately 2 ha of 4 year old willow per day.

The handling of loose rods with a length of 6-8m can be difficult. No fully successful bundling and tying operation has been developed yet although forestry bundlers have been used to bundle and tie stems. The harvested rods will have to be handled a second time when they are ultimately chipped prior to use.

Where possible the harvested rods are stacked on a hard standing area and when there is adequate natural ventilation, they will dry over a period of time without any deterioration. For this methodology, the specialised



Willow being harvested with a Whole Stem harvester. Ideally harvesting should occur between December and early March when no leaves are present



Whole Stem rods should ideally be stored off the ground to allow optimum drying conditions to occur



Harvested whole stem rods are stored on a hard standing area and, since there is adequate ventilation, will dry naturally over a period of time

drying facilities which may be required for the direct chip harvest operations are not required. In Irish conditions, because of temperature and humidity, limited drying of the harvested rods takes place until early spring. Over the following 8-12 weeks, moisture levels will drop to approximately 30% and depending on climatic conditions can drop to 25% during the summer months. The rods require chipping prior to use.



Chipping willow stems

The chip produced from this dried material may have a wider range of particle size and increased dust fraction than that produced from the direct chip harvesting method. There is also a higher power requirement for the chipping operation. In Irish conditions, where individual coppice plantations may be small and isolated, with limited field size and lack of access to sophisticated drying facilities, this system may be the harvesting method of choice, even if it is a more expensive operation. The ‘Stemster’ whole rod harvester is a well proven design and has been operating in Ireland for a number of years.

Billet Harvesters

This method of harvesting sits somewhere between the chip and whole stem harvesters. They were developed for sugar cane harvesting and produce short portions of entire stem, 5-20cm in length which, in a similar way to direct chip harvesting, are blown into trailers for removal. These harvesters are tracked and can therefore cope quite well with wet conditions. They can also harvest thick stems up to 10cm in diameter. In this case, because of the larger entire stem pieces and improved air circulation, natural drying can occur in much the same way as the whole rod system. Billets will also need to be chipped prior to use to maximise combustion efficiency, but they can, unlike the whole rods, be easily handled mechanically.

Again, chip quality can be poorer because the material being chipped is relatively dry (30% moisture).

Biobaler

The Biobaler from the Anderson Group in Canada is a revolutionary machine which was developed to allow foresters to harvest biomass from woody weeds in between the rows of the plantations. It also affords the effective harvesting of troublesome regrowth. The Biobaler Harvesting System is a simple concept which has also been used to harvest SRC willow. In a single pass, with only one operator, the Biobaler cuts and compacts the biomass into a dense round bale. Bales can then be collected on site at any time after harvest prior to re-growth of the willow.



Research has shown that the moisture content of the bales will fall rapidly and can typically be below 20% moisture by the summer after harvest

The philosophy behind the Biobaler Harvesting System is to use a small dimension harvester to collect and densify the biomass in the field to reduce the ecological footprint. The shape and density of the bales allow for more cost-efficient transportation from the field to the processing facility with conventional equipment. At this point, the biomass can be processed according to the facility's specifications with more efficient equipment. Bales can be delivered directly to the plant or stored in the field for future use. Bales of biomass are not expected to deteriorate during the storage process over a long period, even if they are harvested in very wet conditions. An advantage of this technology is that biomass bales dry out naturally without risk of self heating and loss of calorific value. In this aspect they are dissimilar to a pile of woodchips which may indeed self heat and lead to a loss in calorific value. Research has shown that the moisture content of the bales from the Biobaler falls rapidly in the months after harvest and will typically be below 20% by the summer after harvest.

Harvesting Data

Data relating to each of the harvesters described in the text is provided in the table below. Harvesting is the greatest single cost in the management of SRC plantations. Costs include essential estimates for breaks for machine operators and 100m in field transport and 500m to storage. Additional costs may be necessary when harvesting with the forager/austoft if tractor/trailer combinations need to be hired to transport the chips and billets from the field.

Harvester	Weight (tonnes)	Material Produced (length)	Output (oven dry tonne/hr)	Cost* (€/ha)	Output (ha/hr) @ 10 odt/ha
Forage Harvester	12-13	2.5-7cm chips	12	€300	0.6-0.8
Billet Harvester	12-18	5-20cm billets	18	€300-€350	0.5-1
Whole Stem Harvester	12*	7m rods	10-12	€350	0.20-0.53
Baler	10*	1.2m by 1.2m Bales	<10	-	<1
*Harvester plus full load, does not include weight of tractor					

Harvesting Logistics

Harvesters cause minimal site damage apart from where vehicle use is intense, such as on the headlands. In particular the tractor and trailer used for chip removal can cause significant rutting on the wettest ground. In these situations it would be advisable to use tracked vehicles instead of wheeled vehicles. Compaction still occurs but this doesn't seem to cause particular yield disadvantage.

Comparison of willow products

Harvester Material	Drying Ability	Requires Reprocessing	Moisture Content after Storage	Density (kg dry matter/m3)	Dry matter loss during storage
Chips	More expensive to dry	No	<35% after 2-3 months	140-165	Covered < 10%
					Uncovered up to 25%
Billets	Easier to dry	Yes	Covered bins 18%* after 9 months	90	Covered 5.7%
			Outdoor heaps 25% in 4-5 months		UncoveredNot Measured
Whole Rods	Easier to Dry	Yes	Covered bins 21%* after 9 months	100	Covered 4.3%
			Outdoor heaps 25-30% after 3-4 months		UncoveredNot Measured

* Based on Rothamstead Research

Harvesting - Key Facts:

- Willow can be harvested by a number of different methods
Harvesting methods produce either chips, billets, whole stems or bales of whole stems
- Choice of method should consider the end use of the crop and drying cost if applicable

1.10 YIELD

The principle on which crop yield is based is the conversion of light energy through the normal growth processes into chemically bound energy in the economically important part of the crop. In the case of SRC willow, it is the above ground woody stems. It has been estimated that this represents 60% of the total biological yield, with 10% allocated to the leaves, and 30% to the stool/root system. The leaves and fine root system are recycled on an annual basis.

For SRC willow, yield is normally quoted as tonnes of dry matter (DM) per hectare per year. Dry matter (all moisture removed) weights are used because they standardise the figures where fresh weights (including moisture) vary. To maximise economic yield, the crop canopy must be maximised as early as possible in the rotation and maintained for as long as possible throughout the growing season. This ensures efficient interception of solar energy, thereby maximising yield potential.

On suitable sites, canopy closure or complete site capture usually happens in the second year of the first cropping cycle. However, it may be delayed to the third year on poorer sites with resultant loss of yield. This can be exacerbated with light penetration to the soil allowing weed development to compete with the coppice crop.



Loading a walking floor trailer with willow chips. A 100m³ walking floor trailer will contain approx. 25 tonne of freshly harvested willow wood chip

Harvesting is normally carried out on a three year cycle. However, due to other considerations such as the use of sewage sludge for optimising yield on poorer sites, cycles of two years may also be considered. This is particularly the case when high yielding hybrids are grown in mixtures where individual stool size could cause problems with harvesting options in longer rotations.

A wide range of yield data has been published and much of it needs to be considered in the knowledge that the yields quoted come from small experimental plots. Yields in excess of 30 tonnes DM/ha/yr have been obtained where crop nutrient and water requirements have been supplied artificially. However, this should be considered as the theoretical maximum for the species and not a commercial reality.



Loading willow chip

Much of the yield data published comes from varieties that have now been outclassed in terms of their productivity. Trials have shown that the most recently available improved varieties have productivity levels significantly above these earlier choices.

Improvement in the planting material in terms of both its productivity and its disease resistance could give sustainable yields of 10 – 12 tonnes DM ha⁻¹ yr⁻¹. However when factors such as soil, fertility, light, exposure, or water availability are sub-optimal, significantly lower yields of 6 – 10 tonnes DM ha⁻¹ yr⁻¹ may be expected.

Yields from the first cropping cycle can be expected to be lower than subsequent cycles because complete site capture is not achieved until the

middle of the second year of the first cycle. Thereafter, yields will reach a plateau with the normal seasonal variations, due to the prevailing weather conditions etc.

There is still uncertainty over the yields that can be expected from different soil types although, in general, better yields can be expected from better soils. Extended cropping cycles have shown that yields can be sustained over 8-10 cycles at which point improvement in the available planting material could, on its own, justify replanting.

Yield - Key Facts

- Willow is typically harvested either every two or three years and can yield up to 10-12 tonnes of dry matter per hectare per year depending on soil type, management and growing conditions.

1.11 Drying and Storage

As a fuel supply is required almost continuously through the year, depending on the end user, some form of drying and storage will be required. This is the part of the supply chain that has been least studied but there is ongoing work to identify and address the problems experienced. Freshly harvested chip will have a moisture content in excess of 50% and the need for drying will be determined by the harvesting system used. Generally, it is only the direct harvested chip that requires immediate drying and dedicated active drying facilities. Harvested whole rods and billets do not have the same self-heating potential and will dry naturally. Artificial drying is a costly operation as in Irish conditions heat will need to be used. Estimates of £8-12 per tonne have been calculated to bring the moisture content below 25%, at which point the chips will become stable for the long-term storage necessary to provide a continuity of supply to the end user.

Chip with a moisture content in excess of 50% at harvest and with the chipping operation making nutrients in the wood more accessible to the fungi and bacteria (which cause decomposition), make it more liable to



Ventilated floor drying willow chip



Willow Drying Shed

heat up to temperatures in excess of 60°C within a short period of time. This results in a loss of calorific value and a general degrading and loss of quality in the fuel. Spore production from the fungi involved, in particular *Aspergillus spp.*, will also cause a health and safety risk.

The level of moisture reduction necessary will depend on the storage time required. Long term storage will need moisture levels below 20%. Where whole rods and billets are harvested and natural drying employed, moisture levels of 30%, and exceptionally in Ireland in dry conditions, 25% can be obtained. This is adequate where short-term storage by the end user is required, as the rods/billets are chipped on demand.

Generally, whilst large-scale combustion facilities will accept chipped material directly from harvest (50% moisture content), the smaller facilities will work more efficiently with drier material. Dried wood has an energy content of approximately 14MJ/kg of usable energy because of the need to use a portion of its own energy to remove the water before combustion can take place.

Ventilated grain floors have been used successfully to dry wood chip from SRC willow. They can achieve the required moisture contents for storage relatively quickly (3-6 weeks). Heated air (6-10°C) above ambient to increase its water holding capacity is circulated. This drying operation for direct harvested chip must begin immediately after harvest, as self heating begins very quickly.

There is a need to develop simple low cost drying systems that can be deployed in small scale operations, utilizing perforated ducts and low rate ventilation from small fans. The practicalities of doing this and using conventional on-farm facilities could be provided and operated on a co-operative basis linked to the contract harvesting of the crop.



Farmyard clamp for drying willow chips

A low-cost, simple approach for drying willow chips has been developed and successfully demonstrated. The system employs a single phase fan which blows air through a perforated duct. A clamp is constructed around the ducting into which fresh chips are loaded and the clamp is covered

once complete. An air flow rate of 150m³/tonne of wet chips for twelve hours a day over a period of three months was used to dry chips from a moisture content of >50% to <20%. The cost, primarily electricity, was less than €5 / wet tonne.

Whatever drying system is used, it is vital to provide a continuity of supply of a consistent, high quality fuel source to the end user, not only to optimise boiler operation but to provide a dry matter base on which to price the fuel. Where the more advanced systems of utilisation are envisaged e.g. for gasification, a lower moisture content of 10% is required due to the requirements of the process involved.

1.12 SITE RESTORATION

When a willow coppice has reached the end of its life, the site will have to be restored to either grass or arable production or indeed replanted again with willow. In many of the heavy wet sites considered suitable for coppice, the root system of the crop will have improved soil structure and its mechanical removal may well cause significant damage.



Land disced after the removal of willow



Using a heavy rotovator or forestry mulcher, the willow stools and surface layer of the soil are incorporated to form a shallow tilth layer into which the grass or arable crop is sown

Site Restoration - Key Facts

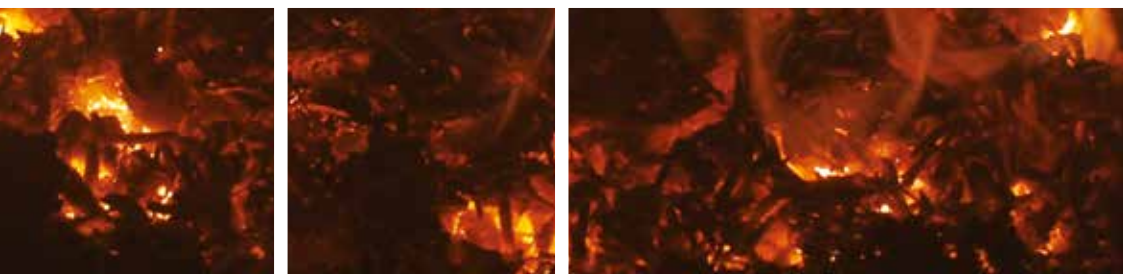
- After last harvest, allow stools to re-sprout until they are 30-50cm tall (mid-May)
- Willow is extremely susceptible to herbicide, so a single application of a translocated herbicide **glyphosate (e.g. 5l/ha Roundup)** is sufficient to kill off the actively growing crop. The crop should be left for at least two weeks after spraying to allow full absorption and translocation of the herbicide
- Using a heavy rotovator or forestry mulcher, the stools and surface layer of the soil are incorporated to form a shallow tilth layer into which the grass is sown. This leaves the majority of the root system in place without damaging the soil structure
- The return to grass production will take a full season. Returning to arable will take a longer grass break to allow roots to decay, otherwise, a much more involved and costly mechanical removal and collection of the stools and roots will be required



2.0 Combustion and Other Uses

SHORT ROTATION COPPICE WILLOW

Best Practice Guidelines



2.0 Combustion and Other Uses

Total energy use in Ireland is divided approximately equally between electricity generation and distribution, transport, and heat generation. It is therefore difficult to understand why most of the incentives for the production of renewable energy have been directed towards electricity production. Additionally, the technologies for heat generation are the most advanced. Therefore, they are of the most immediate interest for deployment at the scale of operation applicable to the structure of the agricultural industry in Ireland. The logistics of supplying large multi-megawatt generation facilities from a large number of small producers is likely to present serious problems.

However, supplying relatively small (<1.0MW) dispersed heat only installations from individual or co-operative groups of growers is a more sustainable and immediate way forward. This approach also raises the opportunity of supplying heat to an end user through an Energy Service Company (ESCO), thereby gaining the advantage of selling the added value product (heat) rather than the raw material (wood chip).

2.1 Combustion

There are three thermo chemical processes, which can be used to convert energy stored in the willow chip to usable energy – heat, and/or electricity; Combustion, Gasification and Pyrolysis. At the small to medium scale (as envisaged as practical in Ireland for best financial returns for the grower) the direct combustion technologies are largely available ‘off the shelf’. There is a wide range of biomass combustion equipment available ranging in size from a few kilowatts to multi-megawatts. The generated heat can be used directly to produce hot water or air or it can be used to raise steam to drive a turbine to produce electricity.

Small-scale gasification technologies have yet to complete their commercial development and pyrolysis is still at the research and development stage. The following discussion will concentrate on combustion.



Biokompakt 120kW AFBI Hillsborough boiler system showing chip bunker external combustion



Froling (320kW) Biomass boiler utilising woodchip at AFBI Hillsborough

Combustion

Generally this is the most efficient way to produce heat from wood chip. It is an established technology with many systems from many manufacturers available. In the combustion process, the combustible elements in willow chip (carbon and hydrogen) are converted to CO₂ and water in the presence of sufficient oxygen. Heat is released during this process.

Willow chip substitutes readily for wood chip and can be used as a feedstock for the generation of heat and/or electricity in a variety of combustion technologies from small grate boilers (> 30kW) to large combustion plants using fluidised bed technology (> 1MW). Willow chip, however will typically have a higher ash content compared to wood chips so greater quantities of ash will be produced when willow chips are burnt.

Willow chip can also be manufactured into pellets and used to fuel specifically designed pellet stoves. However, this process requires the further drying of the chips to below 10% moisture and their reduction in a hammer mill and final extrusion in a pellet mill, all of which are highly energy intensive. This has a major negative influence on the energy balance of chip production in SRC and largely cancels out their cost advantage over oil. Pellet production from specifically grown energy crops is therefore unlikely to be sustainable economically.

Combustion to produce Heat in small-medium Scale Boilers

Generally the more suitable systems have a chip store with the boiler's combustion chamber fed by a thermostatically controlled auger with the necessary safety systems to prevent burn-back. The wood chips supplied from forestry and the agricultural production of SRC willow will normally contain 20% to 30% moisture (approximately 16 to 14MJ/kg energy value).

Most systems have two combustion chambers, a primary combustion chamber in which initial combustion of the fuel takes places and a secondary combustion chamber in which volatile gases released in the primary combustion chamber are subsequently combusted. Combustion

air is added to both combustion chambers using one or more fans. Combustion systems in this size range often differ in the design of grate utilised by the system, common designs include stepped grates, moving grates, rotary grates and tilting grates.

Sizing & Installation

Chip boilers are available in a wide range of sizes, the capacity of a boiler to produce heat is defined by its kilowatt (kW) output. It is critically important that the boiler is sized correctly to deliver the heat required. Suitably sized boilers should deliver efficiencies of over 80%. Boilers should never be oversized (output greater than heat demand). Oversized boilers operate under part-load conditions where the efficiency of fuel conversion to heat is often reduced and emissions are increased. Water storage buffer tanks are often used to ensure that the operation of the boiler at any time is not dependent on heat demand. Combustion efficiency decreases during boiler start-up, shut-down and during periods of part-load operations. Consequently, daily operation of boilers should ensure that such periods are minimised.

Chip boiler installations typically consist of a reception/unloading area, a chip storage area and a boiler room. The reception area should be big enough to allow the vehicles which deliver the chip to manoeuvre and unload their chips. For large boiler's, chips may be delivered by an articulated vehicle which may disgorge its load into a reception pit. For smaller systems, a tractor and trailer may tip a load of chips directly into a storage area. Alternatively, the chips may be blown into the storage area.



Walking floor chip delivery



Willow has a fresh bulk density of 250kg per m^3 at harvest. When dried to 30% moisture content the bulk density changes to approx. 170kg per m^3

Storage

The storage volume for wood chip will be approximately nine times the volume required to store light fuel oil with the same energy content and is an important issue when designing installations (1.0m³ of oil will provide an equivalent amount of energy as approximately 9m³ of wood at 30% moisture content). Storage systems should be sized to provide at least a week of fuel supply and the storage capacity should be larger than the volume of a typical delivery to avoid the necessity of emptying the storage area before the next load can be delivered or the requirement to receive part deliveries.

There should be adequate space in the storage area to permit cleaning and blockage clearance. Adequate ventilation of storage areas is important, storage areas should be cleaned out at least once a year to avoid the accumulation of dust and micro-organisms but care should be taken during these operations particularly in underground storage areas or silos where oxygen levels can be low and dust levels high. A fresh air supply may be required when such storage areas are being cleaned. Such operations should never be carried out by one person on their own.



Willow chip is dried from +50% moisture at harvest to less than 30% moisture to prevent dry matter losses through biological composting and physical degradation of the willow chip

Emissions from Willow Wood Chip



Combustion

CO₂ and water vapour are released during the combustion process. Other gases released during combustion include carbon monoxide (CO), oxides of nitrogen (nitric oxide (NO) and nitrogen dioxide (NO₂)), sulphur dioxide (SO₂) together with various hydrocarbons. When fuels are burned in air, the nitrogen and oxygen combine together forming oxides of nitrogen - NO, NO₂ which are commonly known as NO_x. Nitrogen oxides are emitted as NO which rapidly reacts with ozone or radicals in the atmosphere forming NO₂ and the main anthropogenic origin of NO_x is the combustion of energy generation and transportation fuels.

Particulate matter is also released during combustion. Some of the particles released can be relatively large such as soot particles (unburnt carbon) while other particles are very small and cannot be seen by the naked eye. The smaller particles (often referred to as PM₁₀, PM_{2.5} and PM₁ depending on their diameter) are mostly formed from the release of inorganic elements such as potassium.

High concentrations of particulate matter, particularly small particles, and gases such as CO, SO₂ and NO₂ are harmful to human health and should be minimised during biomass combustion. Emissions of CO and unburnt carbon (soot) can and should be minimised by setting the boiler to operate as efficiently as possible. Concentrations of sulphur in biomass are low and consequently emissions of SO₂ are typically small. Thus, emissions of NO_x and particulate matter are essentially the most significant emissions from biomass combustion. Such emissions are characteristically higher during the combustion of willow chips compared to the combustion of wood chips because of higher levels of N and inorganic elements in willow; in particular in the bark.

Oxides of nitrogen can contribute to acid rain and smog and can react with ammonia, moisture and other compounds to form nitric acid vapour and related particles. Gaseous pollutants and these small particles can penetrate into sensitive lung tissue causing damage, exacerbation of respiratory diseases, such as emphysema or bronchitis or may also aggravate existing heart disease.

The effects of inhaling particulate matter can include asthma, lung cancer, cardiovascular issues, respiratory diseases, birth defects, and premature death. The particle size is the main determinant of where in the respiratory tract the particle will come to rest.

Particle Sizes - Key Facts

- Particulate matter >10 µm are generally filtered in the nose and throat via cilia and mucus. (The 10 µm size does not represent a strict boundary)
- Particulate matter <10 µm (PM₁₀) can penetrate the deepest part of the lungs such as the bronchioles or alveoli
- Particulate matter <2.5 µm (PM_{2.5}), tend to penetrate into the gas exchange regions of the lung

Typical Emission Values from Willow Chips (grams per GJ)

PM ₁₀	NO _x	SO ₂
70-99	119-241	6.7-8.1

Emissions from Biomass Combustion are directly related to the chemical composition of the fuel. Average values for harvested willow biomass are given below (concentration ranges are provided in brackets).

Average SRC willow biomass chemical composition

Ash (%)	N (%)	S (%)	Si (mg/kg)	Ca (mg/kg)	K(mg/kg)	P(mg/kg)
1.4 (1.0-2.3)	0.6 (0.4-1.0)	0.1 (0-0.1)	262.3 (88-861)	3931 (2738-5716)	993 (520-1787)	285 (166-382)

Emission abatement

Emissions from willow chip combustion can be minimised by careful boiler control of combustion and temperature. The moisture content of the willow chips should be within the range specified by the boiler manufacturer for efficient combustion. Emissions will increase if the moisture content of the chips is either too wet or too dry.

The ash content of willow can be reduced by not harvesting when any leaf is present and also by, where possible, harvesting willow grown in longer rotations. Emissions of NO_x can be reduced by optimising the amount of air used in the primary combustion chamber. Particulate emissions may be reduced by fitting filters to the flue from the boiler to remove particles from the flue gases before they exit to the atmosphere. However this may add significantly to the cost of biomass heat system installation.



Combustion test bed at Teagasc, Oak Park fitted with electrostatic precipitator to reduce particle emissions during combustion

Emissions in a NI Context

Results from AFBI emissions testing have indicated that emissions from pure SRC willow chip in an experimental 120kW Biokompakt boiler are likely to miss the proposed RHI emissions limits. Particulate levels (PM_{10}) range between 70.3 and 99.2 g/GJ with reference to a target of 30 g/GJ and NO_x emissions range between 119 to 241 g/GJ with reference to a target of 150g/GJ for nitric oxide/nitrogen dioxide (NO_x).

It is important that we maintain good air quality in NI but it is also important that the air quality regulatory drivers with regards to emissions from biomass combustion should be seriously considered within an appropriate context relative to the particular EU member state. It would seem logical to examine an overall picture of the energy usage backdrop and current dependence on oil and coal for heat and power. The majority of the

biomass boilers which are currently, and will be, installed which utilise an amount of SRC willow for fuel, will be installed in areas that are off the gas grid and therefore replacing oil fired heating rather than gas heating. The smaller domestic boilers referred to earlier will almost without exception be burning pellets and currently there are no moves or plans to produce pellets from SRC willow for the reasons outlined in this document.

Other emissions of NO_x and particulates in NI should also be taken into consideration e.g. NO_x emissions from diesel cars is known to be high and would dwarf the effect of the SRC willow currently being sustainable farmed and burned in NI each year. The biomass supply chain contributes about 10,000 tonnes of SRC willow and 200,000+ tonnes forestry (not including imports) so the proportion of SRC willow is relatively insignificant (<5%). As the supply chain consists of a mixture of SRC willow and other timber products, the overall particulate and NO_x emissions from a biomass heat system will be unrepresentative of emissions from pure SRC willow; this whole aspect of mixed biomass fuel sourcing should also be taken into consideration.

Biomass Uptake in NI and the Renewable Heat Incentive (RHI)

The uptake of biomass heating has been slow over the last number of years. However, the recently launched Renewable Heat Incentive (RHI) implemented by the Department of Enterprise, Trade and Industry (DETI) is facilitating inroads into the extremely challenging target of obtaining 10% of heat from renewable sources set within the Strategic Energy Framework for Northern Ireland.

Currently this level stands at about 3% (500 GWh) with an extra 1200 GWh still to be obtained. The increasing numbers of biomass heat systems currently being installed are of a smaller scale and use pelletised fuel. Pelletised fuel is generally manufactured from saw mill residues which have purity and a cleaner burn than other biomass sources might; agricultural and otherwise.

Phase two of the RHI is likely to increase the uptake of biomass use for

heating as a result of certain inclusions such as the introduction of support for boilers >1MW and possibly an uplift for district heating system. These larger scale biomass heat systems are often capable of realising better economics when using wood chip rather than wood pellets so this extra uptake might now be more skewed to the supply of good quality wood chip which is likely to come from a mixture of sources including energy crops such as SRC willow and agriculture waste products.

Biomass Boiler Systems - Key Facts

- Have feed systems capable of handling chip and pellets
- Are capable of handling a higher %MC (moisture content) in the fuel
- Are often sited where space for storage and large scale delivery of fuel chip is available
- Require significant wood fuel quantities

Emissions

There is good potential for the expansion of the production of renewable heat from wood chip and the recent introduction of the RHI (in NI) is likely to provide an important and vital boost to the industry as outlined above. However, during early discussions on the introduction of a RHI to NI it was suggested that the emission standards limits be set at 30g/GJ for particulate matter (PM₁₀), and 150g/GJ for nitric oxide/nitrogen dioxide (NO_x), in its requirements for the forthcoming scheme to ensure compliance with air quality EU limit values for which all NI Departments are statutorily required to achieve under the Air Quality Standards (NI) 2010 Regulations. These figures would align with those recommended by DEFRA/DECC in rolling out the equivalent RHI scheme in England, Wales and Scotland and would apply to new biomass boilers.

A full list of the proposed tariffs, including existing tariffs, are detailed below

Tariff Name	Equipment Size	Tariff Duration	Northern Ireland levels (pence per kWh)
Biomass (heat only)	Less than 20kWth	20 Years	6.3
	20kWth and above but less than 100 kWth		6.1
	100kWth and above but less than 1000 kWth		1.5
	1000kWth and above		0.6
Biomass Direct Air	Less than 1000kWth	20 years	5.1
	100kWth and above but less than 1000kWth		1.4
District Heating*	200kWth and above. (1314 yearly peak load hours)	20 years	7.0 (uplift)

*At the consultation stage of Phase 2 of the DETI Northern Ireland Renewable Heat Incentive, an uplift for district heating of £0.07 / kWh for community heating or district heating schemes are being considered. There will be stringent eligibility requirements to prevent potential applicants constructing ineffectual district heating schemes. Due to the potential increase in installation of larger biomass heat systems, where wood chip may be financially preferable over pelletised fuel, this addition to the renewable heat incentive structure should help grow the market for wood chip including that produced from agriculturally grown SRC willow

Combustion - Key Facts

- Willow chips readily substitute for forestry wood chips to produce heat or electricity from a wide range of combustion technologies ranging from relatively small domestic boilers which produce heat to very large combustion plants which produce heat and/or electricity
- Boilers should be sized and installed correctly to deliver the heat required
- Wood fuel storage systems should be designed to be easily accessible and should be sized to provide at least a week's supply of fuel
- Emissions of NO_x and particulate matter from willow combustion can be expected to be greater than those from virgin forestry wood or clean pellet combustion



3.0 Economic Evaluation

SHORT ROTATION COPPICE WILLOW Best Practice Guidelines



3.0 Economic Evaluation

SRC willow is a difficult crop to evaluate economically compared with more conventional farming enterprises, as it is planted only once and is harvested only every two or three years in a 20-year plus cycle.

There are numerous assumptions which can be made. However, the following figures are used in calculations to assess the economic case for willow.

Teagasc has developed a spread sheet which can determine the annual net cash flow based on various assumptions. This can be accessed through your local advisor. The table below shows typical values from which payback calculations are made for investment in SRC willow. These figures can be changed depending on the economic or policy environment.

- Bank interest rate 6%
- General inflation rate 3%
- Energy inflation rate 3%
- Not VAT registered
- Initial establishment costs borrowed over 20 years
- No willow or miscanthus gate fee for sludge
- No carbon premium
- 50% of the establishment costs covered by grant aid
- Annual Land Opportunity Cost (OC) €250/ha

Establishment Costs

Willow is an expensive crop to establish. A breakdown of operational and materials costs involved in the establishment of a willow crop is shown in the following table. The approximate cost per hectare is estimated at €2,730, taking operational and material costs into account in Year 1. With further developments in crop knowledge and advances in machinery efficiency, it could be expected that establishment costs related to planting, management, and harvesting, will fall in the next few years.

VAT

Farmers who are not registered for VAT will have to pay the VAT on the willow cuttings at 13.5%, which can add an extra €257 per hectare. VAT on other materials at 23% would add an additional €59 per hectare. VAT on operational costs is charged at 13.5%, which would add €75 per hectare if employing a contractor for all the work. The total VAT could therefore potentially amount to about €390 per hectare, if a grower is not registered for VAT.

Harvest Cycle

Traditionally, SRC willow has been harvested on a three year cycle. For example, a crop planted in April will be cutback with a reciprocating type (ideally an old finger-bar) of mower in January or February of the following year. This will allow more tillers (shoots) to form. The cost of cutback is approximately €30 per hectare. The first harvest of this three year cycle will be three years from cutback and the crop will be about four years in the ground at the time of harvest (Dec – March). Ireland's maritime climate is suitable for two years harvests when the crop is grown in the correct soil type and managed adequately.

Two Year Cycle

Some willow growers and contractors are recommending a two year harvest interval rather than three. The main reasons given are the ease on machinery in getting through a two-year-old crop as opposed to a three-year crop. Furthermore, the potential to apply sewage sludge to suitable sites is possible more frequently on a two-year-old harvested crop because the sludge is applied after harvest on suitable plots.

Harvesting Method

The moisture content of willow at harvest will be between 50 – 60%. There are two main methods of harvesting used in Ireland. Harvesting is generally carried out from December to March. This provides an opportunity for contractors to have their machinery in use at a time of the year when machines would normally be idle.

SRC willow establishment costs /ha

Operational Costs	€/ha
Spray 1	20
Plough	75
Power Harrow/Cultivate	80
Plant	350
Roll	10
Spray 2	20
Total Operational Costs	€555
Material Costs	€/ha
glyphosate herbicide (4 l/ha)	40
Weed killer / Insecticide	25
Residual Herbicide	60
Management Fee	150
Cuttings	1,900
Total Material Costs	€2,175
Total Establishments Costs	€2,730

Whole Stem Harvesting

Whole stem harvesting costs approximately €30 per dry tonne harvested but there are no artificial drying costs. Chipping and transport of the material will be extra. It costs approximately €10 per fresh tonne for chipping the whole stem rods, which then have to be transported in chipped form to the end user.

Direct Chip Harvesting

Artificial drying is costly and the estimated cost of force drying is €30 per dry tonne to bring the moisture content below 20%, at which point wood chips are normally stable for long-term storage. The cost of direct-chip harvesting is approximately €25 per dry tonne.

Harvest Yields

SRC willow yield is normally quoted in tonnes of dry matter (DM) per hectare per year. Harvesting is normally carried out on a three year cycle. Newer high yielding hybrid varieties which cycle outside the norm may cause machinery harvesting problems for the three year harvest rotation.

Yields of 10-12 tonnes DM/ha/yr can be achieved on better sites. A lot more research needs to be done in order to determine the yields achievable on various soil types. Yields from the first cropping cycle (3-year harvest) can be expected to be lower than subsequent cycles.

The yield from the first harvest cycle would be expected to achieve 23 tonne DM/ ha, which would be equivalent to 51 tonnes of fresh material at 55% moisture. The yield from subsequent harvests on a 3-year cycle should be 30 tonnes DM/ha, equivalent to a fresh harvest weight of 67 tonnes at 55% moisture content.

Markets for Willow

Willow can potentially be used in power stations, as well as district heating and commercial heating projects. It will mainly be supplied in chipped form at a moisture content suitable to its recipient boiler. It is difficult to give a common price for willow as markets are currently in their infancy.



Whole Stem willow bundles naturally drying prior to processing

The following table compares the various feedstock's to that of oil, which essentially will be the main commodity displaced from the market by biomass. Rural Ireland is mainly oil dependent because of the absence in rural areas of a gas pipeline. Therefore, the price of oil is a good barometer in terms of evaluating the value of willow chip.

Cost of Oil

The price of oil can fluctuate widely, depending largely on demand and other global market factors. However, it is possible to benchmark the price of biomass to that of the well-established supply chain of home heating oil. Assuming 1,000 litres of home heating oil contains approximately 38 GJ, its energy value at €0.90 per litre is €23.70 per GJ of energy. The table below illustrates the relative value of oil in energy terms at various costs per litre.

Fuel Cost Comparison

Fuel	Price Per Unit	kWh Per Unit	Cent Per kWh
Willow Chips (30% MC)	€130 per tonne	3,369 kWh/t	€0.039
Miscanthus Chips (20% MC)	€130 per tonne	3,805 kWh/t	€0.034
Wood Pellets (10% MC)	€230 per tonne	4,800 kWh/t	€0.048
Natural Gas	€0.051 cent/kWh	1	€0.051
Home Heating Oil	€0.90 per litre	10.5 kWh/t	€0.086
Electricity	€0.14 cent/kWh	1	€0.140

If we take the value of wood chip at €100 per tonne to the farmer the average net margin per Hectare over a 20 year period is €888.

Cost of oil in energy terms

Cost Per Litre	Cent/kWh	Value per GJ
1.30	€0.123	€34.23
1.20	€0.114	€31.60
1.10	€0.104	€28.96
1.00	€0.095	€26.33
0.90	€0.085	€23.70
0.80	€0.076	€21.06
0.70	€0.066	€18.43

Payback on biomass installation

Before deciding on converting from oil or gas to biomass, most businesses e.g. hotels, nursing homes, hospitals, leisure centres, Office of Public Works (OPW) buildings etc, will carry out an economic analysis on the potential payback from the system. Using the figures presented in the table above, it is possible to evaluate the potential payback period. For

example, a nursing home which currently consumes 30,000 litres of home heating oil per annum is effectively consuming 315,000 kWh ($30,000 \times 10.5$) per annum. This is equivalent to 93.5 tonnes ($315,000 / 3,369$) of woodchip, which would cost the nursing home €12,155 per annum based on a delivered price of €130 per tonne.

In contrast, the home heating oil would cost €27,000 ($30,000 \times 0.9$) based on a delivered price of €0.90 cent per litre. Consequently, using wood chip would give an annual saving of €14,845 on energy costs compared with using oil. However, it must be remembered that a biomass installation is more expensive than an oil or gas boiler installation, and therefore, the annual saving in fuel costs must cover the additional annual capital cost of the biomass installation, over the payback period.

No mechanism to pay for Carbon abated

Willow and miscanthus are carbon neutral energy crops, and could be used to abate CO₂ emissions from peat burning power stations. The combustion of one tonne of peat releases approximately 0.856 tonnes of CO₂. To put this in context, if a power station had reported CO₂ emissions of 846,352 tonnes, under the National Allocation Plan (NAP) administered by the EPA, and it had an allowance of only 627,676 tonnes of CO₂, then its excess emissions would have been 218,676 tonnes of CO₂, equivalent to 255,462 tonnes of peat. The power station is now faced with the option of purchasing carbon credits or using a carbon neutral fuel such as biomass.

One carbon credit represents the reduction of one metric tonne of carbon dioxide. Carbon is currently trading at just over €5 per tonne but is expected to increase as further pressure is exerted by Government on various emission sources and sectors to possibly €40 per tonne. On an energy basis, --143,371 tonnes of willow at 20% moisture is equivalent to the 255,462 tonnes of peat at 55% moisture. If we assume a future value on carbon of €25 per tonne, this would give a saving in carbon costs to a power station of almost €5.5 million ($218,676t \times €25$), which equates to €38 per tonne of willow supplied. However, there is currently no mechanism in place for a power station to pay the farmer for supplying a carbon neutral crop, which eliminates the need for the power station to purchase the carbon credits. This may change in the future.

Payback to the farmer

The price paid to the farmer should track the price of fossil fuel alternatives i.e. oil and gas.

There may be a number of other third party involvements in the supply chain which will add additional costs for transport and quality control, and possibly chipping / drying costs.

Opportunity Cost (OC)

Opportunity cost measures the cost of any economic choice in terms of the next best alternative foregone. The opportunity cost of deciding not to work is the lost wages foregone. The opportunity cost of using arable farm land to produce willow is that the land cannot be used in that production period to harvest potatoes or wheat, for example. When considering the opportunity costs of decisions, the highest-valued alternative that has had to be sacrificed for the option chosen, needs to be used.

A simple guide figure to use is the potential rental value of the land on the open market. If estimated correctly, this will allow for land type and quality to be taken into account. It will also give an indication of what the alternative enterprises available may return to the farmer. While it may be possible to estimate the opportunity cost for the first few years, the longer the investment, say 20 years, the more difficult it becomes to make an accurate estimate.

Net Present Value (NPV)

The Net Present Value (NPV) is the difference between the present value of future cash inflows and the present value of future cash outflows. NPV is used in capital budgeting to analyse the potential returns of an investment or project. NPV takes the effect of inflation on the future returns into account.

For example, one euro in your pocket today is worth more than the euro in your pocket in 10 years' time, so there is a time value for money. The NPV calculation takes this into account, discounting future values and putting them into the value of today's money. All the future cash inflows and cash

outflows are added to give a positive or negative figure. If the NPV of a project is positive, it should be accepted. However, if NPV is negative, the project should be rejected, unless there is some compelling non-financial reason for proceeding with it. If the current interest rate is used for the discounting process, then the calculation allows for a comparison of returns between the proposal and the interest rate.

Internal Rate of Return (IRR)

The Internal Rate of Return (IRR) is a capital budgeting method used to decide whether one should make an investment, including an appropriate risk premium. Mathematically, the IRR is defined as any discount rate that results in a net present value of zero of a series of cash flows. It is an indicator of the efficiency of an investment (as opposed to NPV, which indicates value or magnitude). The IRR is the annualised effective compounded return rate which can be earned on the invested capital, i.e. the yield on the investment. A project is a good investment proposition if its IRR is greater than the rate of return that could be earned by alternative investments (investing in other projects, buying bonds, even putting the money in a bank account). Thus, the IRR should be compared to an alternative cost of capital, including an appropriate risk premium.

Potential Returns

The potential returns from an SRC willow crop will vary hugely depending on the assumptions made. In the comparison of two different types of harvesting in the table below, whole stem appears to leave the greater return in all cases. The overall return will depend on the price received for the crop. For example, if willow is direct chipped and dried by the farmer and no opportunity cost for the land is assumed, and we assume a cost on borrowed money of 6%, the NPV will range from €624 to €6,520 as the willow price rises from €60 to €100 per tonne at 25% moisture content. These figures will improve if the cost of drying direct chip harvested willow is removed. Power stations can take chip direct from the field without any drying requirement. The drying of direct chip harvested will be required for most commercial and all domestic boilers.

Please note that figures will vary depending on soil type and management procedures. The figures in the table below assume average yields based on good management practices.

Teagasc has developed an Excel Calculator which calculates the net cash flow over a 20 year investment period in willow.

Potential returns per hectare on two year harvests

Returns from Willow Whole Stem Harvest			
Price received per tonne @ 25% moisture - No Opportunity Cost	€60	€60	€60
Net Present Value (NPV)	€742	€3,690	€6,638
Internal Rate of Return (IRR)	10.4%	22.3%	30.6%
Price received per tonne @ 25% moisture - Opportunity Cost €250/ha	€60	€80	€100
Net Present Value (NPV)	€2,126	€823	€3,771
Internal Rate of Return (IRR)	-9.7%	9.4%	18.6%

Returns from Willow Direct Stem Harvest			
Price received per t 25% mc no opportunity	€60	€80	€100
(NPV)	€624	€3,572	€6,520
(IRR)	9.8%	21.9%	30.3%
Price received per tonne @ 25% moisture - Opportunity Cost £250/ha	€60	€80	€100
(NPV)	€2,243	€705	€3,653
(IRR)	-	9.0%	18.3%

Economics - Key Facts

- Before deciding on converting from oil or gas to biomass, most businesses will carry out an economic analysis on the potential payback from the system
- SRC Willow is a carbon neutral energy crop, and could be used to abate CO2 emissions from peat burning power stations
- There may be a number of other third party involvements in the supply chain which will add additional costs for transport and quality control, and possibly chipping / drying costs
- The overall return will depend on the price received for the crop and the type of harvesting and drying method.
- SRC willow destined for power stations will not require drying before combustion
- SRC willow destined for the heat market will require drying in most end-use situations



4.0 Environmental Impact of SRC willow

SHORT ROTATION COPPICE WILLOW

Best Practice Guidelines



4.0 Environmental Impact of SRC willow



Long tailed tit *Aegithalos caudatus*, a widespread bird species throughout the UK and Ireland, very common in SRC willow plantations

One of the biodiversity benefits of SRC willow is that it requires minimal chemical intervention as, once established, it outcompetes most weeds. Any change in land use from arable or grassland to SRC willow will inevitably result in changes in the ecology/biodiversity of at least those fields directly concerned. They may also have measurable affects on the surrounding area, particularly if the location of the crop links it up with other woodland areas or intercepts run-off from intensively farmed areas. The willow crop can stabilise fragile soils and reduce erosion on slopes and near watercourses. The nature and extent of the change and to what degree it would be beneficial, will not be totally clear until the area of coppice expands and significantly older plantations are available for study. These changes will be modified by the use of herbicides and

other pesticides, inorganic and organic manures and fertilisers, and other effluents, and frequency of harvesting. In general, the overall effect on wildlife values, where SRC replaces intensive agricultural production, is likely to be positive but where it replaces improved grassland, it will have little overall effect.

SRC willow plantations and their surrounding areas have been shown to increase the biodiversity of an area over previous land uses, including sheep grazed pastures and arable crops where a low biodiversity predominates. Ecological studies of the large areas of SRC willow planted in Yorkshire for the ARBRE project clearly demonstrated that willow plantations never displace species from an area and that the overall biodiversity, including ground vegetation, birds, butterflies and invertebrates, is improved (Rich and Sage, 2001). The crop provides habitats for a diverse community of birds, small mammals, flying insects, phytophagous insects, arthropod predators and soil micro-organisms. Many of these insects are predators and could be highly beneficial in controlling pests in adjacent food crops.

SRC willow provides crucial pollen and other nectar sources during the late winter to early spring period when there are few other sources. This early pollen derived protein is key to building up insect population numbers including bee and other pollinator populations. This influences the level of pollination in both agricultural and wild plant populations later in the season.

Environmental Impact of SRC willow – Key Facts

- SRC willow plantations and surrounding areas have been shown to increase farm biodiversity
- For wildlife values the likely overall effect of SRC willow replacing intensive agriculture is positive with little overall effect for grassland replacement
- SRC willow provides crucial pollen and other nectar sources thereby rebuilding bee and other pollinator populations

4.1 Flora



Coppice established on ex-grassland sites will have a more diverse flora with a higher percentage of long lived perennials than ex-arable sites

Plant species diversity is high in SRC willow plantations, higher than estimates for all British lowland farms with 151 species of plant having been recorded growing in SRC willow at sites across in England. These provide, both directly and indirectly, food for butterflies and many other insects and their predators. This diversity of ground flora is also important in regulating weed control by providing competition for resources and preventing domination of individual plant species. Floral diversity also increases the habitat complexity which will encourage a wider diversity of beneficial predatory invertebrates important for controlling pest species. Design and locations of SRC sites should, where possible, include the provision of headlands and rides to help maximise species diversity although this may not be practical on heavy wet sites, where headlands should be planted to improve machine trafficability.

Conversion from grassland or arable use to a woody perennial crop with a regular harvesting pattern will result in changes to the ground flora. The species composition of the plant community below an area of SRC willow will develop at first rapidly but then more slowly as a succession, until a fairly stable community is established. The starting point for these changes and the rate of change will depend on soil type, previous land use, and management factors such as herbicide and fertiliser use and frequency of harvesting. A pattern of succession has been established with annuals germinating from the seed bank after planting. This is followed by short lived perennials which are often aggressive weed species and finally by long lived perennials of a higher nature conservation value and stress tolerant. Coppice established on ex-grassland sites will have a more diverse flora with higher percentage of long lived perennials than ex arable sites which would have had a previous history of herbicide usage.

Flora – Key Facts

- Plant species diversity in SRC willow is higher than estimates for all lowland farms
- Species composition of plant community in SRC willow changes with time with a reduction in invasive weed species and increase in shade tolerant perennial flora
- Where possible, design SRC willow site to provide headlands and rides to help maximise species diversity

4.2 INVERTEBRATES

The abundance and diversity of insects in SRC willow is high compared with other crops. Species of conservation importance recorded in SRC willow include beetles, spiders, flies, moths and butterflies. Chrysomelid beetles are the main pest species with sawflies, terminal midges, and stem and leaf aphids identified as potential problem species. This combined with the existence of potentially beneficial insect species, means that the environmental cost of overall insecticide applications would be very high even if, on economic grounds, they could be justified. In the case

of insecticide use, as with herbicides, only highly specific targeted spot applications in established coppice can be justified.

At least three times the number of plant-eating species spend part of their life cycle in the canopy of SRC willow compared to conventionally grown barley and wheat (Sage & Tucker, 1998). Over 135 invertebrate species have been found in the canopies of willow, and almost as many ground dwelling and subterranean species have also been recorded. Between 70-80% of all of these species were found to be non-pest species and many of which were beneficial to the crop by predating on pests and therefore acting as a natural control.

The species diversity of invertebrates on the coppice floor and their population sizes will be heavily dependent on the nature of the ground flora. Intensively managed coppices are unlikely to provide botanically rich sites and consequently are unlikely to be of great value as habitats for ground dwelling invertebrates. As with the flora, the opening up of coppice sites after harvest, could lead to a rapid increase in diversity and number of invertebrate species but this is likely to be transient, invertebrate communities change with SRC willow age since harvest. The invertebrate fauna of coppice is more diverse than that of arable crops and will be encouraged by the presence on a single site of the various stages of the crop through phased planting and consequently harvesting. It is recommended that harvesting is staggered over three years to support the highest diversity of invertebrates.

Invertebrate communities in SRC willow resemble those of forest habitats suggesting SRC willow could provide a potential surrogate habitat for forest invertebrates. Semi-natural field margins between SRC willow and grass support high levels of invertebrate diversity, highlighting the importance of retaining hedgerows and increasing habitat heterogeneity for invertebrate communities.

Invertebrates – Key Facts

- Abundance and diversity of insects in SRC willow is high compared to other crops
- Species of conservation importance in SRC willow include beetles, spiders, flies, moths and butterflies
- Invertebrate communities in SRC willow resemble those of forest habitats.
- Important to retain hedgerows to increase habitat heterogeneity for invertebrate communities
- Recommended that harvesting is staggered over three years to support the highest diversity of invertebrates

4.3 Birds



SRC willow supports a relatively large number of bird species and individuals when compared to agricultural crops. Above is a Song Thrush nest in a willow plantation

Extensive surveys have shown that SRC willow supports a relatively large number of species and individuals, when compared with the agricultural crops it tends to replace. This can be attributed to the structural diversity provided by the coppice, the perennial nature of the crop, the fact that

sites are often weedy, and the attractiveness of SRC willow because of the increased insect diversity and number. The edge zone of the crop appears to be particularly attractive to most species studied, the interior of large SRC willow plantations containing fewer birds than the edge zone (<50m). Birds were more abundant in hedgerows next to SRC than in those adjoining arable or grass areas (Sage et al 2006). The abundance and diversity of birds in a SRC system has more than ecological significance. It has significance in the public perception of the environmental state of a site, whether or not the site has actual ecological importance.

Many species of birds that would benefit from SRC willow plantations are on national conservation / action plans including skylark, reed bunting, linnet, willow warbler, fieldfare, snipe, song thrush, yellowhammer, goldcrest, redwing, woodcock and lapwing. Included in the list are a variety of migrant and resident species whose numbers have declined steeply in recent decades.

Species richness and diversity increase with crop age since harvest and there remains considerable species turnover between years of growth. Planting schemes need to be carefully planned to maximise the wildlife and biodiversity benefits. Staggering planting and therefore harvest between years is recommended in order to maintain multiple stages of SRC willow growth at any one time to increase avian diversity. It is preferable to have and maintain the various stages of SRC rotation in one location rather than a single stage. This gives a continuity of the different habitats provided by coppice in its various developmental stages and increases species diversity. Interface habitats that include a combination of SRC willow and hedgerows have been shown to support a higher diversity of birds than SRC willow alone. It is likely that, whilst SRC willow provides a valuable food resource during the energy intensive period for breeding birds, hedgerows are necessary as they provide suitable nesting sites.

Birds – Key Facts

- SRC willow holds relatively large numbers of species and individuals compared to agricultural crops it typically replaces
- Species of birds (on national conservation / action plans) that would benefit from SRC willow plantations include skylark, reed bunting, linnet, willow warbler, fieldfare, snipe, song thrush, yellowhammer, goldcrest, redwing, woodcock and lapwing
- Staggering harvest between years is recommended in order to maintain multiple stages of SRC willow growth at any one time to increase avian diversity
- The edge zone of the crop appears to be particularly attractive to most species studied

4.4 Mammals

SRC willow could provide valuable habitats for small mammals, if a similar structural mosaic to that of traditional coppice is allowed to develop. A minimum of ten species have been observed in SRC willow including the brown hare, stoat, mice, vole, shrew, fox and rabbit. These include important food resources for larger carnivores. However, SRC is unlikely to provide an optimal habitat for small mammals because of the lack of seasonally important food items, such as berries as well as insufficient ground cover and nest sites.

Larger mammals such as deer, hare and rabbit can all cause considerable damage through browsing, particularly to establishing crops or those re-growing after coppicing or harvest. However, since they are likely to be excluded from plantations wherever they pose a threat, they cannot be considered as a 'game benefit'. Squirrels are unlikely to be attracted to SRC because of a lack of a suitable food source. Hare numbers could decline further if planting of SRC were to become widespread. This species favours mixed farmland and is unlikely to thrive in densely planted coppice stands. This is less of an issue in Ireland with the small scale planting envisaged.

Studies have indicated that linear features in SRC willow farms promote bat activity. Therefore it is important to retain existing hedgerows in farm landscape when designing future plantations. These field boundaries create excellent, semi-natural habitats for bats. Increased abundance and diversity of insects in SRC willow habitats combined with hedgerows, may play an important role in ecosystem services by sustaining bat populations.

Mammals – Key Facts

- SRC willow unlikely to provide an optimal habitat for small mammals due to lack of seasonally important food items
- Large mammals (deer, hare, rabbit) can cause considerable damage and are likely to be excluded
- Squirrels are unlikely to be attracted to SRC willow due to a lack of a suitable food source
- Linear features (such as hedgerows) in SRC willow promote bat activity

4.5 SRC Willow and Water

Water Use

SRC willow is a temperate plant well suited to a maritime climate and to wet soils. It has a long growing season and is easily coppiced (i.e. can be cut back regularly to ground level) for biomass as a fuel for wood-fired boilers producing renewable heat. The fact that willow has a higher water demand than almost any other agricultural crop means that significant volumes of effluent and rainfall can be applied. SRC willow uses an average of 35% to 45% more water than a similar agricultural area growing potatoes or cereals. The type of willow used in coppice plantations generally has a fine shallow root system with 85% situated in the top 50 cm of the soil profile. This not only improves stability but also provides an excellent receptive surface for the uptake of soil moisture resulting from rainfall or the application of wastewater. SRC willow uses large quantities of water because of its rapid juvenile growth rates and a more rapid transfer of water through the stomata. Total water use (evapo-

transpiration) is a combination of transpiration (the largest component of water use determined by soil availability and rainfall) and interception and evaporation. On a clay site with 700mm rainfall, SRC willow will use 600mm compared to 400mm for barley and 650mm for pine forest.

Water use will vary. In the first year after harvest, it will be less than in subsequent years due to the developing canopy. However, this would largely be made more consistent by sequential harvesting operations which should be encouraged. Average rainfall required over the growing season to fully meet the needs of SRC willow to produce an annual yield of 12 t DM ha⁻¹, is in the region of 550 – 600 mm. If rainfall during the period of active growth is significantly lower than this level, then either yield may be reduced or deficits of soil water will result in deeper soils. Interception losses (evaporation) are equivalent to 20% of rainfall in the third year of coppice growth. In comparison, most arable crops have interception levels of 15% or less. During the dormant period, these losses are reduced to 10-12%.

The growth and subsequent biomass yield of SRC willow will be better if there is sufficient water available which will largely be the case in Ireland. During periods of relatively prolonged drought however, it has been noticed in certain plantations that growth can slow. However once the rain returns, the growth will catch up quickly affording good subsequent yields. The presence of irrigation schemes applying waste water will not only supply nutrient but also ensure continued fast growth during periods of low rainfall.

Environmental Water Protection

As a result of the high water demand of SRC willow and indeed its dense establishment and introduction of land surface roughness, the crop has the potential to form effective defences against erosion caused by water movement. The slowing of water movement again aids the soil absorption and percolation of water and associated nutrients / pollutants allowing the rhizosphere associated activities to continue and perform effective nutrient recycling and water uptake. Areas of willow planted intentionally to reduce diffuse pollution into environmental water bodies such as rivers,

lakes and streams, are known as riparian strips and can help facilitate agriculture to reduce polluting discharges.

SRC willow and water – Key Facts

- In Ireland water shortage will seldom be a limiting factor for SRC willow growth
- Calculations indicate that a growing season annual precipitation level of 550 – 600 mm is required for optimum growth
- SRC willow's high water uptake makes it a suitable crop for sustainable waste water management – Reference EU ANSWER project publications
- SRC willow can help reduce agricultural diffuse pollution run-off

4.6 Carbon Mitigation Potential

One of the major drivers for growing SRC willow is its potential for the reduction of Green House Gas (GHG) emissions. There are potential two ways in which growing willow as a source of renewable energy can off-set carbon emissions.

Carbon Mitigation

The energy content of dry willow wood chip is approximately 19 MJkg⁻¹. One hectare of SRC willow produces the equivalent energy of 3,300 – 5,700 litres of light heating oil and an average medium sized house will burn around 3000 litres of oil per year, which releases 8 tonnes CO₂. SRC willow wood is a carbon neutral fuel, where carbon that is released during its combustion has been absorbed by the crop whilst growing. For every GJ of energy produced from wood chip around 7 kg CO₂ is released compared to 79 kg CO₂ released when the same amount of energy is produced from oil, resulting in greater than 90% reduction in emissions.

Carbon Sequestration

Growing SRC willow has the potential to sequester (capture) carbon, thus preventing its release as GHG. After the above ground biomass has been harvested for wood chip carbon can be stored in three ways: in the non-harvested above-ground biomass (stumps); the below-ground biomass in the form of coarse and fine roots; and the input of the carbon onto the soil organic matter. SRC willow can sequester around 0.12 t of carbon/ha/yr.

There are a number of factors which will determine the rate of change as well as the total amount of soil carbon sequestered by SRC willow. These include the carbon inputs to the system – i.e. during the net primary production phase; decomposition of the major carbon pools – which is affected by soil moisture and temperature; the initial carbon content of the soil – there is an inverse relationship with the sequestration rate; crop management – e.g. harvest intervals, re-plantation; depth of soil influenced by the willow – which will influence the total amount of carbon sequestered. The amount of carbon captured by SRC willow can be further enhanced if plantations are used for the bioremediation of effluents and sludges.

Carbon Mitigation Potential – Key Facts

- SRC willow is considered to be a carbon neutral fuel
- The energy content of dry willow wood chip is approximately 19 MJkg⁻¹
- One hectare of SRC willow produces the equivalent energy of 3,300 – 5,700 litres of light heating oil
- 90% reduction in emissions from woodchip compared to oil
- 1 GJ of energy from wood chip releases 7 kg CO₂ compared to 79 kg CO₂ for oil
- SRC willow can sequester around 0.12 t of carbon/ha/yr

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Appendices

SHORT ROTATION COPPICE WILLOW

Best Practice Guidelines



APPENDIX 1 – Waste Legislation

It should be noted that whilst these are the main articles of legislation involved in recycling wastes to Short Rotation Coppice willow their implementing legislation may differ in detail between member states and always should be referred to before application.

There are other significant areas of legislation such as The Ground Water Regulations, The Urban Wastewater Treatment Regulations, Environment impact - uncultivated semi-natural areas regulations, Shellfish and bathing waters Directives which are involved but relate more directly to specific situations.

The application of sewage sludge and other wastes to land is specifically controlled by the following legislation:

EU

1. Waste Framework Directive (75/442/EEC) (as amended)
2. Sludge Directive (86/278/EEC)

Republic of Ireland (RoI)

1. S.I. No. 148/1998 – Waste Management (Use of Sewage Sludge in Agriculture) Regulations., 1998
2. S.I. No. 86 of 2008 – Waste Management (Facility Permit and Registration) (Amendment) Regulations 2008
3. For effluent irrigation - Article8(1) of the Planning and Development Regulations, 2001 (S.I. No. 600 of 2001)

UK (Northern Ireland)

1. Environmental Protection Act (1990)
2. 1990 No. 245 - The Sludge (Use in Agriculture) Regulations (Northern Ireland)
3. The Waste Management Licensing Regulations (Northern Ireland) 2003
4. Code of Practice for Agriculture Use of Sewage Sludge (to complement the sludge regs)

5. 2002 No. 271 - The Controlled Waste (Duty of Care) Regulations (Northern Ireland)
6. For effluent irrigation - Consent to the discharges of waste water to the environment in accordance with the Water (Northern Ireland) Order 1999.

The application of sewage sludge to land must have regard to the following codes of practice which are currently non-statutory:

1. The code of good practise for the agricultural use of sewage sludge (DoE 1989, amended 1996)
2. Code of Good Practice for the Prevention of Environmental Pollution from Agricultural Activity (PEPFAA Code) (Scotland)
3. The Code of Good Agricultural Practise for the Protection of Water (MAFF 1998) (The Water Code);
4. The Code of Good Agricultural Practise for the Protection of Soil (MAFF 1998b) (The Soil Code);
5. Safe Sludge Matrix (ADAS 2001);

The Nitrates Directive

Requires Member States to:

- Apply agricultural Action Programme measures throughout their whole territory or;
- Apply agricultural Action Programme measures within discrete Nitrate Vulnerable Zones.

An Action Programme consists of statutory measures of good agricultural practice, including:

- Limiting nitrogen fertiliser use to crop requirement only;
- Limiting organic manure use (170kg N/ha annually across the agricultural area);
- Controlling the spreading period of nitrogen fertiliser and organic manure;

- Keeping adequate farm records; and
- Having sufficient slurry storage to comply with annual closed periods for spreading manure.

The Wastes Framework Directive (WFD)

The WFD states that any establishment, or undertaking, which carries out waste disposal or recovery operations, must have a permit (e.g. a waste management licence) or be registered as exempt from the need for a permit. The Waste Management Licensing Regulations 2003 provide limited exemptions from licensing for the treatment of certain types of waste by spreading it on or injecting into land, where this results in benefits to agriculture or ecological improvement. This might remove the need for a licence but would still involve registration and would be subject to other constraints e.g. quantity and quality of waste spread per hectare. Agricultural benefit is assessed by reference to whether the application of sludge will result in an improvement of the soil for the purpose of growing crops and the relevant criteria for assessment will be:

- That the addition of total nitrogen is carried out in accordance with any requirements imposed in the implementation of an action programme under the Nitrates Directive.
- That the addition of nitrogen, phosphorus, and other plant nutrients in the waste takes account of the soil nutrient status, other sources of nutrient supply and is matched to the needs of the planned crop rotation.
- That the addition of organic matter which improves the moisture holding capacity of the soil is a benefit.

Sludge Directive

- Sewage sludge may be used in agriculture, provided that Member States regulate its use.
- The Directive lays down limit values for concentrations of heavy metals in the soil (Annex IA), in sludge (Annex IB), and for the maximum annual quantities of heavy metals which may be introduced into the soil (Annex IC).
- The use of sewage sludge is prohibited if the concentration of one or

more heavy metals in the soil exceeds the limit values laid down in accordance with Annex IA. The Member States must take the measures necessary to ensure that these limit values are not exceeded through the use of sludge.

- Sludge must be treated before being used in agriculture but the Member States may authorise the use of untreated sludge if it is injected or worked into the soil.
- The use of sludge is prohibited: on grassland or forage crops, if the grassland is to be grazed or the forage crops to be harvested before a certain period has elapsed (this period, fixed by the Member States, may not be less than three weeks); on soil in which fruit and vegetable crops are growing, with the exception of fruit trees; and on ground intended for the cultivation of fruit and vegetable crops which are in direct contact with the soil and normally eaten raw. This applies for a period of ten months preceding the harvest of the crops and during the harvest itself. The sludge and the soil on which it is used must be sampled and analysed.

The Member States must keep records registering the following:

- the quantities of sludge produced and the quantities supplied for use in agriculture;
- the composition and properties of the sludge;
- the type of treatment carried out; and
- the names and addresses of the recipients of the sludge and the places where the sludge is to be used.

APPENDIX 2 – Crop Management

PRESCRIPTION FOR WILLOW GROWING		
1	Pre -ploughing perennial weed control and leatherjacket control when weeds are actively growing. For grass lea preferably September / October before growth stops, if not mid -March / early April when growth starts. For stubble ground March / April when growth starts.	
	Glyphosate (e.g. Roundup Biactive)	3 - 6 litres/ha
	Chlorpyrifos (e.g. Dursban)	1.5 litres/ha
	Water	One sprayer application (200l/ha)
2	Rabbit fence where necessary.	
3	Plough at least 14 days after spraying.	
4	Power harrow, lift stones & level ground as soon as conditions allow, preferably before the end of April to make a stale seed bed. In heavy soils, stale seedbed not needed and planting can take place immediately. In this case go straight to item 7 on the prescription.	
5	Leave stale seedbed for 6 weeks to allow weeds to germinate	
6	Within 48 hours before planting, burn off germinated weeds with	
	Glyphosate (e.g. Roundup Biactive)	2 litres/ha
	Water	One sprayer application (200l/ha)
7	Plant willows with step planter keeping soil disturbance to a minimum at a willow population density of 15,000 per ha. NB: ALL WILLOW CUTTINGS MUST BE KEPT IN COLD STORE (-2 TO -4°C) UNTIL DAY OF PLANTING	
8	Roll site keeping soil disturbance to a minimum	
9	Prior to any growth emergence, spray onto a moist soil a pre -emergence weed killer & pesticide for leatherjackets. Best results are obtained when rain follows treatment. It is essential that this is done prior to any signs of growth.	
	Pendimethalin (e.g. Stomp Aqua)	3.3 litres/ha
	Isoxaben (e.g. Flexidor 125)	2 litres/ha
	Chlorpyrifos (e.g. Dursban)	1.5 litres/ha
	Water	One sprayer application (200l/ha)
10	May - August	Walk fields on weekly basis.
		Check for rabbit, slug, leatherjacket & beetle damage.
		Monitor weed populations.
		Take remedial action as required (refer to worst case scenarios section)

11	February	Make crop management decision regarding requirement for cutback.
12	February	Cut back willows not higher than 10cm using reciprocating type mower.
13	Mid March - early April	Before the willow buds start to burst open, spray with weed killer mix in dry weather.
	Glufosinate - ammonium (e.g. Basta in R.o.I.)	3.75 litres/ha
	Amitrole (e.g. Weedazol in NI)	20 litres/ha
	Pendimethalin (e.g. Stomp Aqua)	3.3 litres/ha
	Water	One sprayer application (200l/ha)

WORST CASE SCENARIOS

1	For a bad thistle infestation	
	Clopyralid (e.g. Dow Shield 100 or Cliophar 100)	0.25 - 0.5 litres/ha
	Water	One sprayer application (200l/ha)
2	For a bad perennial grass infestation	
	Fluazifop -p -butyl (e.g. Fusilade Max), Cycloxdim (e.g. Laser) Propaquizafop (e.g. Falcon)	1.5litres/ha 2.25 litres/ha 1.5 litres/ha
	Water	One sprayer application (200l/ha)
3	For slug infestation	
	Metaldehyde (e.g. Axcela , TDS Major)	7kg/ha
	Application of pellets	

FOR ALL SPRAY ACTIVITIES ALWAYS READ PRODUCT LABEL PRIOR TO USE AND FOLLOW THE MANUFACTURER'S INSTRUCTIONS CAREFULLY

APPENDIX 3 – Further Reading

Crop Production

- Energy from Biomass – summaries of projects carried out in the Energy from Biomass project area of the DTI's New and Renewable Energy Programme 1998 – 2004, URN No. 05/1110
- www.dti.gov.uk/publications
- DEFRA Best Practice Guidelines Growing Short Rotation Coppice. DEFRA publications, Admail 6000, London 2002
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APPENDIX 4 – Energy Calculations

Bulk Density and Storage of various fuels		
Material	Typical Bulk Density	Storage Space Requirements
	Metric	Metric
	t/m ³	m ³ /t
Wheat	0.78	1.28
Barley	0.7	1.43
Oats	0.56	1.78
Softwood chip (Sitka Spruce) 45% moisture	0.28	3.57
Hardwood chip (Beech) 45% moisture	0.35	2.86
Softwood chip (Sitka Spruce) Dry Weight	0.15	6.66
Hardwood chip (Beech) Dryweight	0.19	5.26
Miscanthus bale (8x4x3)	0.13	7.69
Miscanthus chip	0.09	11.1
Willow Chip (25% moisture)	0.15	6.66
Wood pellets	0.65	1.54

Fuel cost comparison			
Fuel	Price per unit	kWh per unit	Cent per kWh
Wood chips (30% MC)	€120 per tonne	3,500 kWh/t	3.4 cent/kWh
Wood pellets	€200 per tonne	4,800 kWh/t	4.2 cent/kWh
Natural gas	4.6 cent/kWh	1	4.6 cent/kWh
Heating oil	€0.70 per litre	10.2 kWh/ltr	6.8 cent/kWh
Electricity	€0.14 cent/kWh	1	14 cent/kWh

Energy Conversion Table					
	MJ	GJ	kWh	toe	Btu
MJ	1	0.001	0.278	24 x 10 ⁻⁶	948
GJ	1000	1	278	0.024	948,000
kWh	3.6	0.0036	1	86 x 10 ⁻⁶	3,400
toe	42,000	42	11,700	1	39.5 x 10 ⁶
Btu	1.055 x 10 ⁻³	1.055 x 10 ⁻⁶	295 x 10 ⁻⁶	25.3 x 10 ⁻⁹	1

General conversion factor for energy				
From/to	1 MJ	1kWh	1 kg oe	Mcal
1 MJ	1	0.278	0.024	0.239
1kWh	3.6	1	0.086	0.86
1 kg oe	41.868	11.63	1	10
Mcal	4.187	1.163	0.1	1

Decimal Prefixes

10 ¹	Deca (da)	10 ⁻¹	Deci (d)
10 ²	Hecto (h)	10 ⁻²	Centi (c)
10 ³	Kilo (k)	10 ⁻³	Milli (m)
10 ⁶	Mega (M)	10 ⁻⁶	Micro (u)
10 ⁹	Giga (G)	10 ⁻⁹	Nano (n)
10 ¹²	Tera (T)	10 ⁻¹²	Pico (p)
10 ¹⁵	Peta (P)	10 ⁻¹⁵	Femto (f)
10 ¹⁸	Exa (E)	10 ⁻¹⁸	Atto (a)

Energy Content of Different Biomass Fuels at 0% M.C.

NCV	NCV		GCV	
	(GJ/t)	kWh/t	(GJ/t)	kWh/t
Soft Wood (spruce)	18.8	5,222	20.2	5,611
Hard wood (beech)	18.4	5,111	19.8	5,500
Willow (short rotation coppice)	18.4	5,111	19.7	5,472
Straw of cereals	17.2	4,778	18.5	5,139
Straw of corn	17.7	4,917	18.9	5,250
Cereals, seeds	17	4,722	18.4	5,111
Rape.Seeds	26.5	7,361	28.1	7,806
Rape, cake	20	5,556	21.8	6,056
Cereals, whole plant	17.1	4,750	18.4	5,111
Miscanthus	17.7	4,917	18.9	5,247
Hay	17.1	4,750	18.4	5,111

Typical Moisture Content of Biomass Fuels And Corresponding Calorific Values As Received

The GCV is only calculated for fuels with high moisture content.

	GCV				NCV		
	Moisture content %	kWh/kg	GJ/t	toe/t	kWh/kg	GJ/t	toe/t
Green Wood direct from the forest, freshly harvested	60%	2	7.2	0.17	1.6	5.76	0.14
Chips from short rotation coppices after harvest	50-55%	2.5	9	0.21	2.1	7.56	0.18

Recently harvested wood	50%	2.6	9.36	0.22	2.2	7.92	0.19
Saw mill residues, chips etc	40%	3.1	11.16	0.27	2.9	10.44	0.25
Wood, dried one summer in open air, demolition timber	30%				3.4	12.24	0.29
Wood, dried several years in open air	20%				3.4	12.24	0.29
Pellets	8-9%				4	16.92	0.4
Wood, dry matter	0%				4.7		0.45
Silomaize	30%				4	14.4	
Rape seed	9%				7.1	25.6	0.61
To compare with:							
Heating oil					11.41	42	1.00
Peat	55%				2.16	7.77	0.185

Examples For Weight and Energy Content (Ncv) For 1 M3 Wood at Different Water Contents, Species and Shape of the Wood

Species	Shape	m.c in %	t/m ³	GJ/m ³	kWh/m ³
Spruce	Solid wood	0	0.41	7.7	2,130
Spruce	Solid wood	40	0.64	6.6	1,828
Spruce	Stapled wood	25	0.33	4.5	1,245
Spruce	Chips	40	0.22	2.3	640
Beech	Solid wood	0	0.68	12.6	3,500
Solid wood	40	0.96	9.2	2,547	
Beech	Stapled wood	25	0.5	6.3	1,739
Beech	Chips	40	0.34	3.2	892
	Pellets	9	0.69	10.8	3,300
Average figures					
Average figures for different species	Solid wood	35	0.75	7.2	2,000
Average figures for different species	Chips	35	0.3	2.9	800

	t CO ₂ /TJ (NCV)	g CO ₂ /kWh (NCV)
Liquid Fuels		
Motor Spirit (Gasoline)	70.0	251.9
Jet Kerosene	71.4	257.0
Other Kerosene	71.4	257.0
Gas/Diesel Oil	73.3	263.9
Residual Oil	76.0	273.6
LPG	63.7	229.3
Naphta	73.3	264.0
Petroleum Coke	100.80	362.9
Solid Fuels and Derivatives		
Coal	94.60	340. 6
Milled Peat	116.7	420.0
Sod Peat	104	374.4
Peat Briquettes	98.9	355.9
Gas		
Natural Gas	57.1	205.6
Electricity (2008)	153.6	553.0

Note: CO₂ emission factors for electricity vary from year to year depending on the fuel mix used in power generation.

APPENDIX 5 – Willow Payback Calculations

Willow Payback Calculations

Bank Interest (%)	6.0%	1st Harvest		Moisture %	55			
General Inflation (%)	2.00%	Weight in DM / t per ha =		14.00				
Energy Inflation (%)	2.00%	Weight @		55.00 % moisture	31.11 tonnes			
Gate Fee (€/tonne)	0	Compare to price of oil at		0.50	cent/litre			
Price Per Tonne	€38.15	€13.62		per GJ				
Price (€/GJ)	€5.51							
VAT Registered	No							
Bank Borrowings €/ha	1,734	over	5	years =	6.00%			
Costs per ha:	2012	2013	2014	2015	2016	2017	2018	2019
Operations	1	2	3	4	5	6	7	8
Plough	75							
Cultivate / Roll	91							
Spray1	20	20		22		23		23
Spray2	20							
Plant	400							
Spread Sludge	0							
Harvest	0	30		€379		€563		€563
Chipping	0							
Drying	0			€0		€0		€0
VAT (13.5%)	81.81	6.75	0	€54	€0	€79	0	€80
Sub-total	688	57	0	457	0	667	0	69
Annual land opportunity cost	0	0	0	0	0	0	0	0
Materials								
Round-up (4 l/ha)	40							
Weed Killer / insecticide/ beetle Ctrl	25			€163		€170		€170
Selective herbicide (Stomp 5l/ha)	58	40						
Management Fee								
Cuttings	1650							
Fertiliser	0					€50		€50
VAT (21%)	25.83	8.4	€0	€34	€0	€36	€0	€36
VAT cuttings (13.5%)	222.75	0						
Sub-total	2022	48	0	197	0	255	0	26
Total	2709	105	0	654	0	922	0	95
Income:								
Est. grant	975	325						
Fuel sale		0	0	1,285	0	1,909	0	1,909
Gate fee	0	0	0	0	0	0	0	0
EU Energy Payment	0	0	0	0	0	0	0	0
Carbon premium	0	0	0	0	0	0	0	0
Total	975	325	0	1,285	0	1,909	0	1,909
Start up loan	1,734							
Loan Principle		308	326	346	366	388	0	0
Loan Interest		104	86	66	45	23	0	0
Total Repayment		412	412	412	412	412	0	0
Net cash flow	0	-192	-412	219	-412	576	0	1,007
Profit/loss	0	116	-86	565	-45	964	0	102
Cum. disc. profit/loss	0	116	30	595	550	1514	1514	254
Mean annual profit/loss	0	58	10	149	110	252	216	31
Cum. Cash Flow	0	-192	-604	-385	-796	-221	-221	80
Annual discount rate	5.0%							
Annual land opportunity cost	0							
NPV (using int rate as disc)	€3,416							
Internal Rate of Return	21.4%							

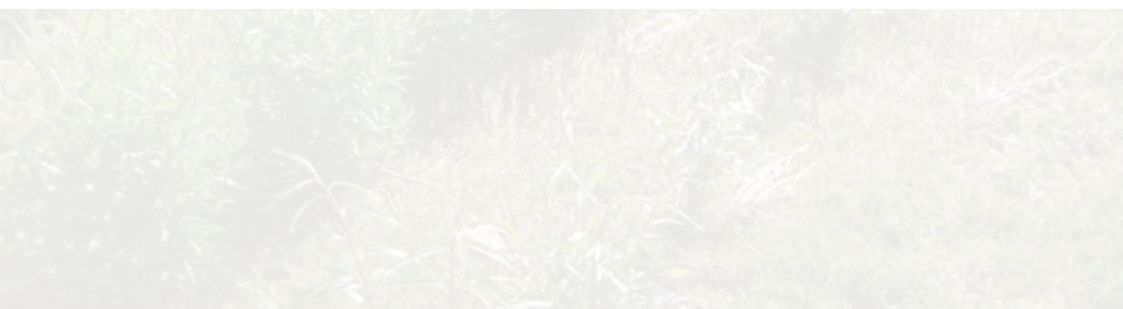
Note: The higher the NPV (Net Present Value) the more viable the investment, negative NPV should not be entertained. If the annual land opportunity cost is 0 and the discount rate is equal to the borrowing rate of interest available then the NPV is what could be paid for land purchased /ha over this time scale.



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SHORT ROTATION COPPICE WILLOW

Best Practice Guidelines



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