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Miscanthus

Best Practice Guidelines

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Prepared by Teagasc and the Agri-Food and Bioscience Institute

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Introduction

These guidelines are designed to introduce farmers to a new crop. They give guidance on the most appropriate location, land preparation, planting techniques and crop management required to grow miscanthus as a crop destined for energy use (or for other uses). These guidelines summarises on-going current research and best practice. As further experience is gained, these guidelines will be modified.

Why Grow Energy Crops?

Both Republic of Ireland (ROI) and UK governments are keen to encourage sustainable and responsible growth in the energy crop market in response to the need foratmospheric carbon dioxide (CO_2) abatement. ROI energy targets, aspirations and long-term energy policy were contained in the Energy White Paper published in 2007.

Miscanthus can be used to produce heat, CHP or electricity power on a range of scales from large power stations (30MW+) requiring hundreds of thousands of tonnes of biomass annually, to small-scale systems (on-farm or single building) requiring just a few dozen tonnes during winter months. There is no planting grant for miscanthus in Northern Ireland. The Department of Agriculture and Rural Development is, however, taking forward a Renewable Energy Action Plan (2010) which includes measures to encourage the development of the biomass supply chains and the utilisation of biomass for heat.

What is Miscanthus?


Miscanthus Giganteus

Miscanthus species originate in Asia and they are perennial, rhizomatous grasses with lignified stems resembling bamboo. Once the plants are established (typically requires 3-4 years) Miscanthus has the potential for very high rates of growth, growing stems that are >3m within a single growing season. While there are many miscanthus species ‘Miscanthus Giganteus’ is the only one of value for biomass production. Miscanthus is planted in spring and once planted can remain in situ for at least fifteen years. The miscanthus leaves fall off in the winter, contributing to the development of soil humus and nutrient cycling. Miscanthus produces bamboo-like canes during late spring and summer which are harvested in late winter or early spring.

This growth pattern is repeated every year for the lifetime of the crop. Miscanthus differs from short rotation coppice willow (the alternative energy crop funded under the bioenergy scheme) in that it gives an annual harvest and thus an annual income to the farmer. Miscanthus spreads naturally by means of underground storage organs known as rhizomes. However, their spread is slow and there is little risk of uncontrolled invasion of hedges or fields. These rhizomes can be split and the pieces re-planted to produce new plants. All propagation, maintenance and harvest operations can done with conventional farm machinery. In Ireland, including trials, in Northern Ireland long-term average harvestable yields from a mature crop (i.e. excluding the first 3 years – have exceeded 10 dry tonnes per hectare per year (t/ha/yr) at the most productive commercial sites). These yields suggest that the crop has the potential to make an important contribution to Ireland’s commitment to energy generation from renewables.

1.0 Crop Production

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1.1 Annual Growing Cycle

The growth pattern of the crop is simple. From the underground rhizomes new shoots are produced annually. These shoots develop into erect, robust stems, which reach 0.5 – 1m in height by late August of the first year of planting, with a diameter of up to 10mm. The stems, which have an appearance similar to bamboo canes, are usually unbranched and contain spongy pith. From the third season onwards the crop can be expected to achieve a maximum height of 2.5 - 3.5m.

From late July the lower leaves senescence as canopy closure prevents sufficient light penetration. Following the first air frost in autumn senescence accelerates and nutrients move back to the rhizome. Leaves then fall and a deep leaf litter develops. Any remaining foliage dies and the stems dry to relatively low moisture content (30-50%) during winter. By February, free standing, almost leafless, canes remain and it is these which are harvested mechanically. This growth cycle is repeated once spring-time temperatures increase again.

Miscanthus growing cycle

In year 1 miscanthus grows to approximately waist height producing 2 or 3 canes. In year 2 it grows to approximately head height with probably 15 canes and in year 3 it grows to about 2.4 metre height with about 50 canes. Miscanthus is on a yield building phase over the first 3 years.

Miscanthus is a C4 plant similar to maize and it likes the warmer climate. Growth potential is dependant on temperature, the water capacity within soil and the rainfall levels. Therefore sunlight and moisture are important.

1.2 Site Selection

Crop Requirements

Soils

Miscanthus has been reported growing, and producing high or reasonable yields on a wide range of soils, from sands to high organic matter soils. It is also tolerant of a wide range of pH, but the optimum is between pH 5.5 and 7.5. Miscanthus is harvested in the winter or early spring and therefore it is essential that the site does not get excessively waterlogged during this period, as this may limit accessibility for harvesting machinery and cause damage to the soil structure. Growing miscanthus on heavy clay soils in certain circumstances should therefore be avoided.

Miscanthus loses its leaves and frost speeds up the senescence process

Temperature

The potential cropping zones for miscanthus are quite widespread. Miscanthus does not grow at low temperatures below a threshold of 6°C. This is considerably lower than for maize and therefore the potential growing season is longer. Late spring frosts which destroy early spring foliage and effectively reduce the duration of the growing season can be a constraint to long season growth in M. x Giganteus. The commercially available clones of Giganteus can survive low winter temperatures of -14°C based on recent years' experience.

Water Availability

Annual rainfall and soil water retention will strongly influence the yield of miscanthus at any site. Miscanthus possesses good water use efficiency when considered on the basis of the amount of water required per unit of biomass and miscanthus roots can penetrate and extract water to a depth of around 2m. However, to achieve high yields the crop may need more water than the crops that it may replace. In addition, research at Teagasc, Oak Park has shown that up to 50% of rainfall can be intercepted by a dense canopy and evaporates off the leaves without reaching and infiltrating into the soil. Limited soil water availability during a growing season will prevent the crop from reaching full potential yield in that year; a loss of 90 kg of biomass per ha for each millimetre of soil water deficiency has been calculated. Irrigation is not justified by the value of increased biomass obtained. In times of severe drought, the foliage of miscanthus will first show leaf rolling and then die back from the leaf tip. This will reduce yield in the year of drought but in all cases experienced in Ireland and the UK to date the crop will survive and re-grow the following year.

Site Selection

Since miscanthus will exist on site for at least 15 years and can reach up to 3.5m in height, its impact on the local landscape particularly if the site is close to a footpath or a favourite view needs to be considered. Impacts on wildlife, archaeology and public access must also be addressed prior to

Its important to grub or power harrow the ground in advance of planting in order to ensure an adequate soil tilth.

Mature miscanthus can reach a maximum height of 2.5 – 3.5m by August of the third growing cycle cropping. In addition, the impact of harvesting machinery on the soil should be considered. Soil diffuse pollution should be prevented by ensuring soil compaction is minimised and soils retain good structure.

From November miscanthus starts to lose its leaves and goes into senescence

Up to 10% of eligible land for the bioenergy scheme in the ROI can remain un-cropped with miscanthus in order to accommodate landscape and access issues, with no impact on the amount of grant awarded and including any phased planting under that agreement. The positioning of these spaces also needs to be considered in terms of sympathetic landscape views whilst enhancing wildlife and minimising soil compaction. Miscanthus has the potential to encourage a greater diversity of wildlife than some agricultural crops, particularly if located in an area of low conservation value or as a link between existing habitats. It may also provide an area of sheltering habitat. Care must be taken to prevent this new habitat from adversely affecting existing conservation areas.

1.3 Pre-Planting Site Preparation

Thorough site preparation is essential for good establishment, ease of subsequent crop management and high yields. As the crop has the potential to be in the ground for at least 15 years, it is important that it is established correctly to avoid future problems.

If it's a grassland site, the first step, before planting, is to spray the site with an appropriate broad spectrum herbicide (e.g. glyphosate) for controlling perennial weeds. The site should be sprayed and then ploughed from January 15th to control perennial weeds. This will allow frost activity to break down the soil further. This may also help prevent 'ley' pests such as the larvae of two moths; the common rustic moth and the ghost moth attacking the newly established plants, as any larvae or eggs already in the soil from the previous crop will have insufficient food over the winter to survive. Later in the spring from March to April the site should be rotovated or power harrowed immediately prior to planting. This will not only improve establishment by aiding good root development, good soil root contact and improved soil aeration but will also improve the effectiveness of any residual herbicides, applied after planting.

1.4 Planting Material

Using vigorous and healthy planting material is vital. For phytosanitary reasons, miscanthus rhizomes should only be sourced from European or Mediterranean countries. There is currently no rhizome certification or quality standards protocol available anywhere.

In an extensive study by ADAS researchers in the UK, commissioned by the DTI, methods to improve the establishment of Miscanthus and to reduce establishment costs were examined. The main objective of the study was to identify storage and pre-planting treatments likely to result in the highest rates of rhizome establishment in the field.

Storage temperature Period of Weeks	Ambient	3-5°C
0	94	94
2	67	94
4	17	72
6	6	89

***Table 1** Effect of storage at ambient temperature or in a cold store on percentage establishment of Miscanthus rhizomes*
Source UK – Department of Trade & Industry – www.dti.gov.uk/files/file37692.pdf

The conclusions drawn from this study were:-

- Rhizomes will not establish at soil moisture contents below 40%
- Rhizomes should ideally be planted fresh within 4 hours of harvesting
- Exposure of rhizomes to ambient conditions, even for a few hours, can lead to a reduction in viability and vigour
- Storage at 3-5°C can maintain the viability of rhizomes for several weeks
- Rhizomes to be stored should be placed in cold storage within 4 hours of harvesting and planted within 4 hours of coming out of cold storage
- The use of a moisture retaining gel to coat the rhizomes or of watering treatments prior to planting were of little or no practical benefit.

Researchers at the University of Illinois examined Miscanthus in trials and also identified that storage temperature was the critical factor to consider when establishing Miscanthus rather than rhizome size, with the ideal storage temperature being 4°C, at which temperature rhizomes could be stored for up to 4 months with less than a 20% reduction in viability.

(http://Miscanthus.uiuc.edu/index.php/symposium/2007-symposium symposiumpresentations/Miscanthus-x-giganteus-establishment-studies/)

Methods of Propagation

There are two methods of miscanthus propagation i.e. rhizome division and micropropagation. Rhizome division is favoured because it is less expensive and generally produces more vigorous plants. To produce new planting material, two or three-year old rhizomes in the ground are split whilst dormant, using a rotary cultivator, and the rhizome pieces collected for re-planting. The mechanically cut rhizomes of 20 -100g units must be stored as quickly as possible post-harvest to prevent drying out. A 30-40 fold increase in plants can be achieved this way. Rhizome pieces must have at least 2 to 3 shoot initials, (buds with sharp points)' and must be kept moist before re-planting. This is best achieved by keeping rhizomes under cold-storage conditions (<4°C), but they will remain viable in the field for a short period of time, if stored in a heap and covered with moist soil.

Rhizome Size

Miscanthus is planted from a rhizome from the size of your thumb to the size of your fist.

Rhizomes will vary from the size of your thumb to the size of your fist. Chopping rhizomes in the field is not a precision job. A lot of buyers don't like the little rhizomes as they feel there is less of a chance of establishing them. Germination tests carried out by Teagasc have shown germination rates of over 90% with viable rhizomes (2-3 buds).

Rhizomes have to be kept moist from the time they are lifted from the soil. During the rhizome harvesting operation, rhizomes should not be left exposed on top of the soil for a period of three hours or more especially if you want to replant the field with miscanthus. The viability and vigour of the rhizome will be challenged if it desiccates.

Planting Density

A planting rate of 16,000 rhizomes/ha is recommended to give an emergence of 10-15,000 plants/ha. This rate allows for some establishment losses while still providing the plant density required to achieve optimal yields


Oak Park crops sown in March 2010.
Picture taken in August 2010.

from year three onwards and effective weed suppression through competition. Recent improvements in rhizome extraction and selection have resulted in much higher establishment rates (typically >80%) of the rhizomes planted becoming miscanthus plants. Rhizomes need to be planted at a depth of 5-10 cm. Where soil is inadequately prepared certain areas of the field will show open-spaces with poor establishment. The optimal planting time for rhizomes is from March to April but planting can continue into May and even early June and still be successful. Early planting takes advantage of spring-time soil moisture and allows an extended first season of growth. This is important, because it enables larger rhizome systems to develop. These crops are more robust in future years, and allow the crop to tolerate drought and frost better. Miscanthus rhizomes are not as simple to plant as potato tubers. The rhizomes tend to get tangled up. Some planting equipment is set up at 1 metre spacing's between the rows. ADAS in the UK plant at 1m wide rows at 67 cm spacing's.

Calculating planting density

A planting density of 16,000 rhizomes/ha is recommended to give an emergence of 10-15,000 plants/ha and avoid the cost coming back to patch plant a crop for areas where establishment did not occur. 16,000 rhizomes per hectare allows for some rhizome losses during the establishment phase. Some miscanthus crops are planted at 0.8m x 0.8m between every rhizome set. One hectare is 100m x 100m and if the miscanthus is planted at 0.8m x 0.8m wide spacing – you are planting 100 ÷ 0.8 = 125 rhizomes per 100m. Therefore 125 rhizomes per 100m x 125 per 100m (100 x 100 x 125 ÷ 80) = 15,625 rhizomes per hectare.

Its important to grub or power harrow the ground in advance of planting to ensure the rhizome is buried adequately.

AFBI Research

Effects of rhizome size and planting rate: AFBI have found that provided rhizomes have viable buds that breaking the rhizome into smaller pieces (25 to 30g) rather than larger pieces (70-80g) generates more shoots per kilogram of rhizome planted. Therefore planting the same amount of rhizome, but broken into smaller pieces planted more closely together should give greater shoot numbers and a more uniform stand over the field, reducing the risk of large gaps in the crop stand.

Effects of degradable plastic mulch applied at planting

Miscanthus, like forage maize, is a plant originating from a warm climate and which responds to higher temperatures. Although not available as a commercial system for miscanthus, AFBI trials have shown that when the plastic system used for forage maize is applied to miscanthus it will accelerate the development of the crop and increase the number of shoots it generates in the first year. Although the plastic mulch breaks down during the first season the increased shoot numbers and higher DM per year continue into the 2nd and 3rd seasons, but with diminishing effect as internal competition within the crop itself becomes the main limiting factor.

1.5 Planting Machinery

Specialist Planters

Wexgen Planter requires five operators and the driver.

A number of specialist companies have developed, or are developing, bespoke planting machines. Wexgen have developed a planter which worked very successfully. The planter was used at Oak Park for 2010 trials and establishment was very good at over 80%. The machine is a modified corn drill with five people standing on the back manually dropping the varying shaped rhizomes through a pipe which fall to the ground and are buried. It plants at 0.8 m spacing's. The modified corn drill which has a workrate of 1 ha per hour. Wexgen manufactures this planter and their contact details are at the back of this booklet.

Another automatic planting machine was designed in 2004 and has successfully planted Numerous crops ever since. Minor alterations have been made year on year resulting in optimum performance levels. The automatic planter requires one operator and plants 1.5 ha of Miscanthus per hour. A machine has been designed specifically for planting miscanthus by Nordic Biomass in Denmark. This machine works by planting two rows of rhizomes into a shallow furrow opened by shares. Once planted, the soil is moved back to cover the rhizomes, and is then rolled. The machine can be adjusted to achieve different planting densities, if required.

Automatic two and four row planters have been developed for use in the UK. These are based on automatic potato planters but have been modified to provide accurate flow of rhizomes into coulters to achieve accuracy of depth and within-row placement.

Modular Potato Planter

For rhizomes destined for use in the potato planter, grading is required to remove rhizomes which will not pass down the planting tube or have less than 2-3 'buds'. Once graded, the operator of the potato planter places rhizomes into a cup or drops them down a planting tube. The distance between plants is governed by the speed of a land wheel.

As the rhizomes enter a furrow opened by a share, the soil is ridged over the rhizomes.

The potato planter should be followed by a heavy roller, to aid soil consolidation. The work rate achieved is low (0.3 ha/hr.) but might still be suitable for planting small areas.
This technique ensures accurate placement and good depth control, both of which are important for good establishment success. Where gaps occur in miscanthus it is normal practice to stitch-in miscanthus rhizomes to fill

Ground should be rolled directly after planting.

the gapped areas. This practice occurs the following year after planting, usually from early April until mid-May. The practice of stitching-in rhizomes is very costly and through good crop management, suitable site selection and the procurement of rhizomes which have been stored in the correct environment prior to planting – the requirement for stitching-in rhizomes should be reduced.

Irrespective of the planting machinery used, planted ground should be rolled immediately after planting in order to consolidate the seedbed.

1.6 Weed Control

Background


Grass and weeds competes with the miscanthus plant for available nutrients.

Weeds if not controlled, will compete with the crop for light, water and nutrients and thus reduce yields. The level of weed interference will depend on the stage of maturity of the crop (i.e. its ability to out-compete weeds), the degree of weed infestation at the site and the diversity of the weed species (affected by location, season, climate and previous land use). Weed control is essential in the establishment phase of the crop because the slow initial growth of miscanthus reduces its ability to compete. The planting process causes soil disturbance which promotes seed germination. Furthermore, the low planting densities which are used result in large unoccupied spaces where weed growth can occur.

At this stage the young miscanthus plantlets can easily become overwhelmed by weeds. As the Miscanthus crop becomes more established, a range of selective herbicides can be used for weed control. Table 3 gives a list of herbicides which have been successfully used for weed control in miscanthus with notes made beside herbicides which can only be used pre-emergence. Any active ingredient which is appropriate for cereals should also be suitable for miscanthus (with the possible exception of some graminicides) and some C4 specific herbicides can also be used. Off-label approval has been given for the use of many cereal herbicides in miscanthus.

Active ingredient(s)	Example Product(s)*	Notes
Bromoxynil/ioxynil/ Diflufenican	Capture	1.1 l/ha
Bromoxynil/ioxynil	Oxytril CM	2 l/ha
Bromoxynil/ Mecroprop-P/ioxynil	Swipe	5 l/ha
Diflufenican/isoproturon	Panther or Cougar	2 l/ha
Isoxaben	Flexidor 125	2 l/ha Isoxaben is used within 14 days of planting i.e. pre emergence
Fluroxypyr	Starane 2,Floxy, Tomahawk,Tandus, Hurler, Binder	2 l/ha
Glyphosate	Roundup or touchdown quattro	6 l/ha. Glyphosate is applied prior to establishment and see note below on its careful use to control grass weeds.
Isoproturon	Tolkan Liquid	5 l/ha
Metsulfuron-methyl	Ally SX	30 g/ha
Metsulfuron methyl/ Tribenuron-methyl	Ally Max SX	42 g/ha
Tribenuron-methyl	Cameo SX	30 g/ha
Metsulfuron- methyl/fluroxpyr	Ally	20 g/ha
MCPA	Mortone	5 l/ha
	M50, Mastercrop, MCPA amine 500, Agroxone or Agritox 50	3.5 l/ha
Mecoprop-P	Duplosan New Syst	2.3 l/ha
Mecoprop-P/Dicamba	Foundation	1.25 l/ha
Pendimethalin	PDM 330	3.3 l/ha 4 l/ha. Pendimethalin is only applied within 14 days of planting i.e. pre-emergence of crop.

***Table 2** Weed Control Herbicides Approved For Off-label Use on Miscanthus*

* Refers to ROI product names

Once the full canopy develops, the germination of new weed seedlings is dramatically reduced, and only shade tolerant varieties such as black-bindweed and chickweed or particularly mature individuals will survive. Autumn germinating species such as Annual Meadow Grass may present problems after crop senescence has occurred in the establishment year.

Weed control in the establishment phase of the crop is essential, because poor control can severely check the development of the crop. It is vital that proposed sites should be cleared of perennial weeds before any planting takes place. The Department of Agriculture Fisheries & Food Pesticides Control Service has given off-label approval for some herbicides used for cereals, grass and maize to be used on miscanthus. Visit: http://www.pcs.agriculture.gov.ie/. To see UK off-label approvals visit www.pesticides.gov.uk/offlabels/offlabellist.asp

Pre-Planting Weed Control

It is important that this operation is carried out effectively particularly on old pasture land where the presence of perennial weeds such as docks and nettles is more likely. A translocated (systemic) herbicide (e.g Glyphosate at 4-6 l/ha) should be applied to actively growing vegetation from January 15th. To allow the herbicide to fully translocate, a period of ten days post herbicide application should be allowed before ploughing.

Miscanthus is sprayed with glyphosate to eliminate grass weed while the miscanthus is dormant.

Miscanthus is topped 24 hours after applying the glyphosate. Teagasc Oak Park.

Weed Control Post Planting

Within 14 days of planting, spray a pre-emergence weed killer and if necessary an insecticide onto a moist soil. The insecticide is only necessary if following a grass ley and thresholds of leatherjackets are found to be high. A high water volume of 500 litres per hectare is essential to give a good coverage of chemical on the soil. For example apply the 500 litres of water together with 3.3 litres of Pendimethalin (Stomp) together with 1.5 litres of Isoxaben (Flexidor 125) and 1.5 litres of Chlorpyrifos (Dursban 4) insecticide.

Post Emergence Year 1

Year 1 miscanthus crop. Planted in April and picture is taken the following January. Teagasc Oak Park

Once miscanthus shoots have emerged, selective herbicides may be used for the control of vigorous annual dicotyledonous weeds. A weed wiper may be used to apply post-emergence roundup to the taller, more persistent weeds such as thistles.

From May to August walk the fields on a weekly basis. Check for rabbit and leatherjacket damage. Monitor weed populations and take remedial action in worst case scenarios. Spring cereal broad leaf weed herbicides can generally be used on miscanthus. Sulphonylureas such as Metsulfuron – Methyl can be used for general broad leaf weed control, as can hormone herbicides, such as MCPA, CMPP, and HBN. Mecroprop P + Dicamba (Foundation or Swift) at 1.25 l/ha, has worked very well at the Teagasc Kildalton miscanthus site.

Weed Control towards end of Year One

Miscanthus crops while dormant have only very small amounts of green material present in the Miscanthus leaf or stem. Growth will only re-commence in late March or early April.

Patch-planting or infilling should be carried out during March/April where significant gaps appear in the crop – typically those gaps that amount to the size of a small car in area. In order for those patch-planted rhizomes to have a chance to survive, grass growth will have to be suppressed or killed in those areas particularly.

Glyphosate (e.g. roundup) being a systemic herbicide will kill or check the plant if there is green material in the plant. Some first year crops do not lose all their green leaf so in order to spray glyphosate in such circumstances the crop should be topped within 48 hours after the application of glyphosate. This will prevent any glyphosate taken in by any green matter in the plant from trans-locating down to the rhizome.

Glyphosate (4 litres/ha.) should be sprayed across the entire crop normally from mid- February onwards where grass weeds are present. If there are little or no grasses present, there should be no requirement for roundup. Spraying of glyphosate should normally be completed by Mid-March. Note this is a very delicate and time critical operation and only if carried out correctly will eliminate the grass weeds which otherwise cannot be treated as miscanthus itself is a grass species.

There also have been some reports of crops grown on high organic (peaty) soils where glyphosate persistence has been reported. IGER researchers in Wales adopted a management system from 2009 of topping (anytime from January 20th and spraying glyphosate ('Glyphosate 4 l/ha) as soon as possible after topping and applying a soil acting herbicide e.g. Calisto at 1.5 l/ha, 3 – 4 weeks later. This has proved very effective.

The control of grass weeds is a careful and delicate part of the management of miscanthus.

Weed Control in Older Crops

Ally Sx (Metsulfuron-S-Methyl) is completely safe up to one metre height of the Miscanthus crop, and can be safely tank mixed with either

Duplosan, MCPA, Starane, HBN, and have no side effects (obviously not all mixed together!).

Generally from year two onwards the crop will suppress weed growth and chemical control should no longer be required.

Second or Third Year

Once the crop is mature (i.e. from the summer of the second or third year, depending on site and climate), weed interference is effectively suppressed, initially by the leaf litter layer on the soil surface and subsequently by the closure of the crop canopy, which reduces the light penetrating into the under-storey. Weeds that do survive offer little competition to the crop. Since there are no label recommendations, all products are used at the users own risk.

Weed control is likely to be relatively intensive after planting and during the establishment phase. However once the crop has become established, the demand for weed control is low. The development of new weed fauna in long term plantations must be monitored in order to identify any 'new' weed species which will pose a threat to the crop.

Grass weed control during the second and subsequent years can be accomplished by spraying glyphosate well before shoot emergence while broadleaf weed control can be accomplished during the early groaing season using the broadleaf products described in Table 2.

1.7 Nutrition and Fertilisation

Nutrient Requirements

Miscanthus is very efficient in the way it uses nutrients. There are a number of reasons for this high level of efficiency.

- Miscanthus is deep rooted and can abstract nutrients from a large area of soil
- Miscanthus has a high nutrient efficiency compared to arable crops (wheat, barley) and native grasses (ryegrass). Less nutrients are needed for each kilogram or unit mass of biomass produced by the crop.

- Excess nutrients are exported from the above ground parts to the rhizome during the autumn as the leaves senesce (die). The nutrients are stored in the rhizome during the winter and are used to support early growth of shoots during the following spring.
- Leaves fall off the Miscanthus stems as winter progresses and accumulate as a litter layer on the surface of the soil. The litter layer is broken down over time and the nutrients find their way back into the soil where they can be once again absorbed by the root system. Additional nutrition is available to the crop through atmospheric deposition and soil mineralisation.

Nutrient movement from the rhizome to the above-ground crop goes through an annual cycle. Considerable quantities of nutrients are translocated from the rhizome network to the growing shoots after shoot emergence. Thus, nutrient stored in the rhizome supports the crop during its early growth. This translocation is essentially complete by early to mid July after which nutrients start to be remobilised back to the rhizome network. This remobilisation continues for the remainder of the summer. It has been shown that the nutrient content of the rhizome network is related to the subsequent growth and yield of the crop. Thus, it is important that nutrient reserves in the rhizome network are maintained. Nutrient uptake by the growing shoots depends on the nutrient content of the rhizome network and the surrounding soil as well as on the productivity of the crop. For productive crops, maximum nutrient uptake (typically around July) can fall within the following ranges.

N	P	K
100-280	10-33	280-410

Table 3

Nutrient uptake ranges for productive crops (> 10 t DM/ha). All values in kg/ha.

Uptake of potassium and nitrogen is broadly similar and considerably greater than phosphorus uptake. Some studies, however, have reported much higher uptake rates of potassium compared to nitrogen. Nutrient uptake rates for lower yielding crops will be lower and related to the yield of the crop.

Nutrient off-takes are confined to the amount of nutrients in the stems at harvest as nutrients in the leaves are returned to soil. Final harvest yields and consequent nutrient offtake will depend on crop productivity. Crop productivity will depend largely on rainfall and temperature in the case of Miscanthus. Research from experiments conducted throughout Europe have shown that nutrient off-takes from productive crops (> 10 t dm/ha) may fall in the following ranges.

N	P	K
35-100	5-17	35-230

***Table 4** Nutrient Offtake Ranges for Productive Crops. All values in kg/ha.*

A large number of nitrogen fertiliser trials have been conducted on Miscanthus. To date, approximately half of the trials have shown a response to nitrogen while a considerable number of trials have shown no response to nitrogen fertilizer. Generally speaking, the crops which have shown a response to nitrogen have been grown on less fertile soils. In Teagasc trials, older crops have not shown a response to nitrogen whereas younger crops have shown a response to Nitrogen application. Similarly, limited trials on Potassium application at Oak Park and elsewhere have shown no response to Potassium. Knowledge of the fertilization requirements of Miscanthus is still limited and many more fertilizer trials on a wide range of soil types will need to be conducted before definitive guidance can be given.

Some sources suggest that nutrient off-take at harvest can be balanced by the mineralisation of soil organic matter as well as by atmospheric deposition. However, crop nutrient requirements will ultimately depend on soil type, cropping history and nutrient off-take. Growers are advised to make use of regular soil tests to determine that sufficient levels of nutrients are available in the soil. Teagasc advice is based on the principal that, fertilization is necessary and the minimum requirement is for growers to replace nutrients removed at harvest. The following preliminary nutrient advice has been developed for miscanthus. This advice may change as additional information on the crop becomes available. The philosophy is based on replacing nutrient removal by the crop.

It is generally not recommended that any fertiliser be applied in the first two years as off-takes are low and there are generally sufficient nutrients in the soil. Typically, fertiliser application during these years will only promote weed growth which will compete with the growth of the young miscanthus plants and incur additional expenditure on herbicides. Fertiliser requirements for subsequent years are summarized in the tables below.

Soil Index	Nitrogen (N) kg/ha	Phosphorus (P) kg/ha	Potassium (K) kg/ha
1	100	23	120
2	80	13	75
3	50	0	40
4	30	0	0

***Table 5** Miscanthus nutrient guidance requirements*

Note: The use of muriate of Potash (Potassium Chloride) should be avoided as the resultant high levels of chloride can lead to corrosion in boilers.

Fertilization of Miscanthus, according to the above guidelines, can be carried out using a range of fertilizers including slurries, manure and sewage sludge in addition to chemical fertilizers.

Livestock manures on miscanthus

Livestock manures are also an option in terms of meeting the nutrient requirements of miscanthus. Livestock manures are governed by nutrient legislation (SI 610 of 2010, Nitrates Directive) in ROI and RB 209 in the UK. For example, cattle slurry can be used as an effective nutrient source for miscanthus and can be applied annually to satisfy crop nutrient requirements. Cattle slurry contains a total of 5Kg N/m^3, 0.8 kg P/m^3 and 4.3 kg K/m^3. Miscanthus grown on a soil P index of 1 requires approximately 28.75m^3/ha (2,492 gals/acre) cattle slurry (23/0.8) to satisfy its annual P requirement. The slurry would provide 57.5 kg N/ha and 123.6 kg/K/ha per application.

Nutrient uptake and rhizome development

AFBI have monitored rhizome development in plots which were planted with 0.5 t/ ha of fresh rhizome in pieces of about 25g. Over three seasons the rhizome biomass increased to 35 t/ha (Table 7) and had built up significant nutrient reserves of N, P and K. These reserves are present in the rhizomes at the start of each growing season and can contribute a substantial proportion of the crop's requirement over the season. The presence of these reserves explains why miscanthus is generally unresponsive to the application of fertilisers during the growing season. The nutrient off-takes from the AFBI crops during harvesting of the mature crops have been similar to the standard figures quoted earlier in this booklet.

	At planting	After 1 year	After 2 years	After 3 years
Rhizome fresh weight (t/ha)	0.5	8	25	35
Total N in rhizomes (kg/ha)	2	25	80	115
Total P in rhizomes (kg/ha)	0.2	4	11	16
Total K in rhizomes (kg/ha)	3	40	130	180

Table 6

Rhizome development and nutrient content over the first 3 seasons of growth.

1.8 Pests and Diseases

Miscanthus species are susceptible to pests and diseases in the areas to which they are native (Asia) but, as yet, none of these has been reported in the UK or Ireland. Stem basal diseases may infect stems in the autumn or winter, reducing stem strength. There are no reported insect pests in Europe that have significantly affected the production of miscanthus. However, two 'ley pests', the common rustic moth and ghost moth larvae feed on miscanthus and may cause problems in the future. Rabbits can also be a problem in establishing a new miscanthus crop as they like to feed on the fresh emerging leaf as the crop grows initially. Fencing may be required if rabbits pose a serious threat to establishment.

The Common Rustic Moth

The larvae feed from autumn until May on miscanthus roots and other grasses including cock's-foot. These larvae overwinter once before becoming adults which can be found resting in a wide variety of habitats. Concealed in ground vegetation by day, becoming active after dark. They are particularly attracted to flowers of the common ragwort and marsh grasses.

Common Rustic Moth Larvae

Common Rustic Moth Adult

The Ghost Moth Larvae

Ghost moth larvae are subterranean and rarely seen, feeding on roots of the miscanthus and other grasses. It takes two years to develop into a moth, thereby over-wintering twice. Ghost moth adults are often found in grassy embankments, fields and hillsides. The males can often be in flight at dusk on warm evenings swaying up and down amongst tall grassy vegetation.

Ghost Moth Larvae

Ghost Moth Adult

Wireworms

Wireworms are the larvae of click beetles. Yellow larvae with distinct legs at the front and two dark spots at the tail, bite into stems at the soil surface causing a hole with tattered edges. By the time this is evident, wireworms have usually moved along rows to attack further shoots.

Wireworm Larvae

Adult Click Beetle

Economic Importance

Wireworm damage has been suspected in some cases of lower yielding miscanthus.

Wireworms have become a more serious pest since the withdrawal of organochlorine insecticides and the increase of winter cropping of cereals. They can now affect all winter cereal or winter cereal/ley rotations. Heavy infestations can cause yield loss of up to 0.6 t/ha in cereals. Peas, linseed and flax are more tolerant of damage than other crops.

Cultural Controls

- Consolidate seedbeds to restrict movement
- Control grass weeds.

Risk Factors

Crops at highest risk are those sown within two years of ploughing out permanent pasture. However, any rotation with predominant winter cropping, particularly with grass weeds, is at risk. Populations can be very patchy so estimating numbers is difficult.

Examining soil cores in the field for larger wireworms or in the laboratory for smaller ones is costly and rarely justified. A seed treatment is recommended in potatoes if wireworms exceed the threshold of 750,000/ha is exceeded. Some residual damage is likely if numbers exceed 1.25 M/ha. The main natural enemies are fungi and parasitic wasps.

Life Cycle

Adult click beetles cause no economic damage. They live for about a year and lay eggs in grass fields. Larvae then feed for five years before pupating in the spring. Numbers increase over the years; highest populations occur in old permanent pastures. Wireworms feed in ploughed-down turf for about six months before moving to the surface to damage the next two crops.

Sampling Methodology

Oak Park experience with wireworms is that populations in most grassland are very low.

The only places where reasonable populations were encountered were those sites/fields that were neglected most notably where vegetation was allowed to accumulate throughout the growing season. The real problem with wireworms, is that low infestations can cause serious problems with some crops such as potatoes whereas cereal crops can harbour several multiples without causing much problem. The methodology used by Oak Park for wireworm sampling was to use a 10 cm diameter golf corer to a depth of 10-15 cm. One larva per 20 samples equated to 63,635 ha^{-1} which was the threshold for damage in potatoes. The advice to growers are advised that a spade can be used to sample wireworms. A 'standard' spade was 5" x 5", again Oak Park recommended that at least 20 samples be examined per field. In the latter case, finding one larva per 8 samples equated to 68,578 ha^{-1} (or 2.5 larvae per 20 samples being the same thing).

Various traps to estimate wireworm populations have been tried especially in the UK and USA but Oak Park has never tried them. Some of the various methods devised to estimate populations vary greatly depending on soil conditions such as soil moisture etc. Good old fashioned soil sampling and teasing your way through samples is the only reliable means of estimating populations. If miscanthus were to be sown in 'normally' managed grassland major problems would not be anticipated.

1.9 Harvesting

Miscanthus is harvested annually during spring, typically with conventional farm machinery.

Self propelled harvester with a Kemper header which is cutting and crimping miscanthus into a sward prior to baling.

Conditioner mower being used to cut Miscanthus

Timing

After growing vigorously during the summer, Miscanthus stops growing during Autumn. The leaves drop off the crop and the stems dry as the winter proceeds reaching a moisture content of approximately 30% the following spring. Harvested biomass with lower moisture content is easier to store and the calorific value of biomass increases with decreasing moisture content. Early harvesting of Miscanthus (January, February) can produce a product with high moisture and leaf content which will be unsuitable for many applications. In contrast, delayed harvesting (April) can damage the new growth of the emerging crop. The underground Miscanthus rhizome network starts to produce shoots when soil temperatures reach 10°C and research at Oak Park has shown that harvesting at any time after that point can cause permanent damage even if the shoots are not visible above the surface of the ground. Successive late harvests after new shoot growth has been initiated will result in more and more damage with each successive year.

Harvesting with a self-propelled forager

Consequently, the optimum time of harvest is after the crop has dried down sufficiently but before soil temperatures have reached the threshold value (10°C) for the initiation of new growth. Growers who find themselves in a position with no option other than to harvest late should ensure that all machinery used for harvesting operates at reduced tyre pressures as damage will reduce with reducing tyre pressures.

Machinery

Miscanthus can be harvested by mowing and baling. Alternatively, the crop can be cut and chipped using a forager equipped with a Kemper header.

Mowing and Baling

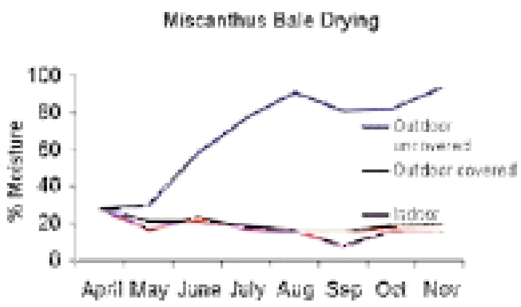


***Figure 1** Miscanthus Bale Drying*

The crop can be cut with a conditioner mower. Trailed mowers tend to work better than tractor mounted models. Conditioning breaks up the rigid stems, allowing accelerated moisture loss, and produces a light, rectangular windrow. This not only makes baling easier, but also helps in the drying of the material, by increasing the surface area and increasing air circulation in the windrow. Moisture content can reduce significantly if the crop is cut and left to dry in a windrow for several days if weather conditions permit.

The use of drum or disc mowers is not recommended as baler pick-up mechanisms will have difficulty with this material. An alternative to conditioner-mowers which has found favour in the UK and more recently in Ireland is that of mowing the crop with a forager equipped with a Kemper header and a drum which conditions the crop without chipping it.


Baling Miscanthus with a square baler

This method produces a windrow for subsequent baling, its advantages are a higher work rate and an enhanced capacity to deal with dense crops compared to conditioner mowers.

In all cases it should be noted that Miscanthus is a much harder material compared to grass and maize and higher rates of wear and tear can be expected.

There are a number of different types of balers, each producing different bales (e.g. rectangular, round and compact rolls), suitable for different scales of energy combustion. Large rectangular and round balers are capable of producing bales with a dry matter density of between 120 and 160 kg/m^3 and weighing between 250 and 600kg. These balers generally have a capacity of 1 ha/hr. Once harvested, bales should be stored inside a shed or outside under cover. Covered storage will ensure that bales will continue to dry whereas bales stored without cover will deteriorate particularly if conditions are poor (refer to Figure 1 drying graph).

Cutting and Chipping

Miscanthus can be cut and chipped in one operation using a forager equipped with a Kemper header. This method of harvesting involved one operation whereas two operations are involved when the crop is mowed and baled. Cutting and chipping produces a product in chip form which is suited for combustion in boilers and power stations. It is important to set the harvester to produce a chip size of less than 40mm, this can be achieved by adjusting the speed of the feed rollers and/or by reducing the number of knives on the drum. Smaller chip sizes have a greater tendency to heat during storage while larger chip sizes are likely to be unsuitable for the intake systems of boilers and power stations.

Harveting with a self-propelled forager

Heating risk can be considerably reduced by harvesting material that is as dry as possible as Miscanthus chips with significant moisture content (>30%) contain sufficient sugars to stimulate microbial activity. Microbial respiration can result in a sharp rise in temperature within chip piles. Microbial activity ceases at temperatures above 80°C but this initial rise in temperature can initiate chemical and physical processes within the chip pile which lead to further increases in temperature and ultimately to a risk of self – ignition under certain conditions. Research conducted at Teagasc Oak Park has shown that the risk of self-ignition can be minimised by keeping the height of the chip pile below a maximum height of 6m. Storage of Miscanthus chips with higher moisture contents (>30%) need not necessarily lead to self-ignition although over time the top layer of such piles may rot leading to the loss of some material and fungal growth in such piles stored for periods of more than a few weeks may reduce the attractiveness of the chips to an end-user.

Miscanthus is usually baled to densify the material for transport.

Growers should be mindful of harvest losses (material left behind in the field after harvest). Teagasc research has shown that harvest losses with mowing and baling systems can be significantly higher than for cut and chip systems. For both systems, cutting height should be set to be just above the leaf litter layer (see below), higher cutting heights will lead to further increases in harvest losses.

Quality

To ensure the best quality of product, it is important that miscanthus is harvested at the correct moisture and stored in a suitable manner to keep it dry. The leaf litter layer which gathers on the ground under the crop over the winter should not be harvested. This leaf material that sits on the ground is generally excessively wet as it is in direct contact with the soil. The leaf material will be decaying, mouldy, definitely wet and have a high probability of containing soil or small stones. Inclusion of this leaf material could lead to an increase in both moisture content and ash content, and could contribute to higher chlorine levels which is undesirable from a combustion viewpoint within the harvested material. Additionally, nutrients within this leaf layer provide nutrition for succeeding crops. Consequently, mowing height and the height of the baler pick-up should be set to avoid picking up this material. Additionally, it is important that mown windrows are not raked together as this will gather any decaying leaf material that will have fallen from the plants over the year and through the winter whilst drying.

AFBI Harvesting

Field harvesting of the FBI crops at two sites was carried out using a self-propelled forage harvester fitted with a 'Kemper' header. By varying the number of blades and the drum speed settings chop lengths of between

25mm and 50mm could be achieved which was found to be satisfactory for the delivery auger into the biomass boiler. The senesced crops were harvested at moisture contents of 28% and 24% at the two sites. The loose material was spread to a depth of one to two meters on a drying floor and dried intermittently with unheated air, bringing it down to about 12% MC over a two week period.

1.10 Yield

Yields will vary according to age of the crop and environmental factors specific to any one particular site. The crop will take three to four years to reach a mature yield (up to five years on marginal sites). After this initial yield-building phase, the crop will remain productive for many years (at least 15 years).

Yield as Plants Mature

The yield from the first season's growth, at 1-2 t/ha, is not worth harvesting. The stems do not need to be cut and so the stems may be left in the field until the following season.

However, if spring-time applications of translocated herbicides are planned then the miscanthus stems should be flailed in order to avoid any risk of crop uptake. From the second year onwards the crop is harvested annually. The second year harvestable yields may range from 4-10 t/ha, and those in the third year may achieve between 10-13 t/ha or more at 20% moisture content. Harvestable yields reach a plateau after 3-4 years.

The reasons for the variation in the yield building phase duration and yield in the plateau phase depends on planting density, soil type and climate. At sites where moisture supply or exposure limits yield, there may be a longer 'yield-building' phase.

1.11 Site Restoration

Miscanthus can easily be removed from an existing site by the application of a post-emergence non-selective herbicide such as glyphosate. This is followed by rotovation of the crop to eliminate the miscanthus rhizome.

Allow the miscanthus crop to green-up after harvest and before the miscanthus is 1 metre high (Mid - late May) spray with 5 litres of round-up per hectare. Plough and cultivate before the end of May. Grass will out-compete any surviving rhizomes. Another herbicide option you could also consider is 4.5 ltrs of cycloxydim (Stratos Ultra) plus wetter instead of glyphosate, as it is very effective at killing miscanthus.

Herbicide application can be followed by discing to break up the rhizomes. If the miscanthus was a failure there may not be any big rhizome stools to break up. Deep ploughing would bury rhizomes and they would struggle to re-emerge if they had any life left in them whereas shallow ploughing may not bury any surviving rhizomes and they might re-emerge. If rhizomes were left exposed on the top of the soil for a while they would dehydrate and die, before being buried. So there may be an option of not ploughing. When the new grass ley is mowed on a couple of occasions the energy store in any surviving rhizomes will deplete.

1.12 Rhizome Harvesting

The use of rhizome cuttings from fields of mature miscanthus (4-5 years) can represent a low cost propagule system. Miscanthus rhizomes can be harvested from year 4 after initial planting. Planted crop will have a rhizome multiplication factor of 15 after 4 years. Therefore a crop planted in 2010 (year 0) will produce approximately 150,000 rhizomes per hectare by 2013 (year 4). Planting the regenerated rhizomes at a rate of 15,000 per hectare should provide enough rhizomes to plant another 10 hectares.

Harvesting Operation

Rhizome harvesting needs to be carried out before new buds start to appear on the rhizomes which can be as early as March. As the process is similar to potato harvesting, the ideal soils for this operation are lighter soils with little or no stone content. The harvesting operation will be more difficult and slower on heavier and/or stony soils. There are several steps in rhizome harvesting.

Step 1 - Biomass Harvesting

It is necessary to harvest the above-ground biomass crop before rhizome harvesting can commence. In normal harvesting situations where a forage harvester or mower/baler are used, there is a considerable amount of stem and leaf litter remaining post harvest.

The loss of leaf is advantageous as it allows nutrients to be recycled while reducing the combustion ash produced by the harvested crop. However, for rhizome harvesting, it is beneficial if the leaf litter layer and the remaining stubble are removed so as to minimise interference with the subsequent harvest of the rhizomes. Some operators have reported that the biomass can be harvested in a two-step operation to deliver the bulk of the crop with a high quality and low ash content after which the remaining stubble and leaf can be removed in a separate mowing and baling step.


Sub-soiler with ripper bar

Step 2 – Undercutting

After the biomass is harvested, the rhizomes are separated from their deep roots using an under-cutter. While under-cutters are available for vegetable beds, some growers have used sub-soilers with a horizontal blade welded between the tines to act as an under-cutter (see picture). The under-cutter is operated at a depth of approximately 230mm (9inches). When the soil surface is wet it can be difficult to get traction with the sub-soiler.

It is not advisable to work too far ahead of the following machinery with the under-cutter, as the loosened soil will absorb water and make subsequent operations more difficult.

Step 3 – Rhizome Chopping

THe spike rotavator turns the rhizome

The next step is to break up the rhizome mat so as to produce rhizome pieces suitable for replanting. This operation is generally carried out with a rotovator preferably with either L shaped blades or straight blades.. Generally, a rotovator with round tine bars is considered too severe for this operation as it can bruise rather than cut the rhizome. Rotovation is generally carried out to a depth of approximately 200mm (8 inches) which is needed to cut through the rhizome mat. Two passes are often necessary to achieve this cultivation depth.

Rhizome chopping is typically followed by a ridging operation to set the soil/rhizome mix.up for the potato harvester or de-stoner. The rotavator can be fitted with ridging bodies or, alternatively, this can be done as a separate operation.

Step 4 – Rhizome Harvesting and sorting

Rhizomes need to be lifted from the ground, separated from the soil and any stones removed. Very large or small rhizome must be removed also. This operation can be carried out using a potato or bulb harvester. A picking table allows the rhizomes to be sorted before loading on to the trailer. This results in less soil being transported to the yard. However it is difficult to achieve complete rhizome removal with potato harvesters and a certain proportion are returned to the field even with the use of small web sizes.

Alternatively, an unmanned harvester or a de-stoner can be used if fitted with a rear elevator to transfer the rhizomes into a trailer for subsequent sorting. Higher efficiencies (more rhizomes recovered) are achievable with de-stoners. However, they require a seperate pass over a stationary sorting table in the yard.

Stone picker with elevator

Potato Harvester

Patience and flexibility are needed in the rhizome harvesting operation as the equipment used was not designed with this task in mind. Rhizomes can build up in front of the roller at the front of harvesters and de-stoners for example effectively preventing the roller from turning. Some users have found that this can be avoided by welding spikes onto the roller body.

Step 5 – Storage

Once sorted, the rhizomes need to be placed in a cold store as soon as possible if they are not being planted immediately.

Grading Line

Picking Table

Costs

Miscanthus production costs could be reduced if a proportion of the crop is used as a 'mother crop' for the production of rhizome cuttings. The reduction in stem harvest yield which occurs due to this will be compensated by the revenue obtained from the sale of the rhizome cuttings. As per table 7; the labour costs are based on two days to harvest one hectare, three labourers lifting, transporting and loading, three picking and sorting rhizomes and one shifting. The farmer is compensated for the opportunity cost of his land forgone at a rate of €0.025 cent per rhizome (150,000 x €0.025) = €3,750 per hectare. The cost per rhizome from regeneration of the mother crop is approximately €6,289 /150,000 rhizomes = 4.1 cent per rhizome. If we assume a 10% additional cost for gapping-up the crop and another 15% profit this would allow for a selling price per rhizome of 5.2 cent per rhizome.

It should be noted that a very high investment cost in harvesting machinery and suitable cold storage facilities with adequate space is required before these costs can be achieved.

Because of the seasonal nature of rhizome harvesting, a business plan for rhizome harvesting and storage sheds needs to allow for periods when machinery or sheds are not in use. The cost of this capital investment has not been included.

Cost Breakdown per hectare	
Number of Rhizomes harvested	150,000 rhizomes
Rotavating	€82
Harvesting	€850
Labour (5 men x two days)	€1100
Levelling	€36
Rolling	€21
Compensation to farmer (4 year landuse)	€3,750
Transport (€15/box)	€300
Storage	€150
Total Costs	€6,289

***Table 7** Cost Breakdown per hectare*

Planting

If we assume that 18,000 rhizomes will be planted per hectare the recommended retail price should be in the region of 18,000 x €0.052 = €936 per hectare. If the planting rate is 16,000 rhizomes per hectare the recommended retail price should not exceed (16,000 x €0.052) €832 ha. However it may take two years for us to be at this level of production and efficiency as crops and harvesting know how develop and improve. The above costs are based on ADAS experience who have developed this business model on a commercial basis. Ireland will be in a position to regenerate our own rhizomes and reduce the cost of miscanthus establishment in the not too distant future.

2.0 Utilization and Economics

MISCANTHUS
Best Practice Guidelines

The growth of miscanthus in Ireland has increased rapidly in recent years. This high uptake is a direct result of the bioenergy scheme in ROI which provided 50% funding towards miscanthus establishment. In Northern Ireland there has been no miscanthus uptake as no government planting support has been made available.

The bioenergy scheme was launched in 2007 and now many of those crops are mature.

The question is where can miscanthus be utilised and marketed. While a lot has been done to encourage planting very little has been done to help create markets for miscanthus.

Energy Harvested

The first crop of miscanthus is harvested two years after planting with a small yield of up to 7 tonnes at 20% moisture content per hectare rising to maximum yields of 9 to 13 tonnes per hectare at 20% depending on soil type, field slope, topography, soil nutrient status and pH. The vibrancy of the planted rhizome together with crop management including weed control is critical to successful establishment. If we assume an interim yield figure of harvested miscanthus at 12 tonnes per hectare at 20% moisture and the energy per tonne at 13.7 GJ, one hectare will produce approximately 164 GJ at this yield level.

2.1 Economics

Cost of Oil

1,000 litres of oil contains 36.68 GJ of energy. The price of oil continues to fluctuate, however it is possible to benchmark the price of biomass to that of the well-established supply chain of home heating oil. One litre of home heating oil contains approximately 10.5 kilo Watt hours (kWh) of energy. Table 2 shows that the value of home heating oil at €0.90 per litre is €23.61 per Giga Joule (GJ) of energy. To calculate the value per GJ, multiply the cent / kWh by 277.78.

Cost per litre €	Cent/kWh	Value per GJ
1.10	€0.104	€28.89
1.00	€0.095	€26.39
0.90	€0.085	€23.61
0.80	€0.076	€21.11
0.70	€0.066	€18.33
0.60	€0.056	€15.56
0.50	€0.047	€13.05

***Table 8** The value of oil in energy terms*

Market returns for miscanthus

Based on the best available data to date, miscanthus in its second year should yield up to 7 tonnes of dry matter per hectare per year. This is expected to increase to 10 tonnes dry matter per hectare from year 3 onwards. This will yield approximately 12 tonnes per hectare at 20% moisture content.
The following list summarises several of the potential applications for Miscanthus:

- Energy crop - woodchips and pellets - co-firing with coal or peat
- Animal bedding - production of horse bedding
- Construction - incorporation in manufacture of medium density fibre board (MDF)
- Thatching - as an alternative to straw as a roofing material
- Paper production - incorporation in the manufacture of paper
- Horticulture - raw material for the production of plant pots

The cost of the rhizomes (at 20,000 a hectare) is €1,925 (+VAT** if not registered) and planting costs an additional €485 per hectare (+VAT** if not registered). Cultivation costs (soil preparation) including, ploughing, power-harrowing, grubbing spraying and rolling costs approximately €185 per hectare. As the land is tied up for 20 years we have included an opportunity cost of €200 / hectare to cover the potential other income lost and some farm fixed costs (this may be substantially higher depending on the land quality and potential alternative uses). Over a 20 year period miscanthus could provide an average annual net cash flow before tax of €342 per hectare working at a price of €60 per tonne and €320 per hectare at a price of €65 per tonne (remember that you also have the €200 cash per hectare set aside to cover opportunity and some fixed costs),allowing for a bank interest rate of 6% and an annual average inflation rate of 3%. The above also assumes an energy inflation rate of 3%. The cash flow will not be positive until year three. The return is very sensitive to

- Site selection
- Soil fertility and crop establishment
- Crop yield
- Price per tonne of harvested miscanthus

Please refer to Appendix 8 to see an example of Miscanthus payback calculations.

Fuel – 20% MC	kWh/tonne	Price /tonne	Cent per kWh	Value per GJ
Miscanthus Chips	3,805	€60	€0.016	€4.36*

***Table 9** The value of Miscanthus*

*€4.36 per Giga Joule is equivalent to €0.16 cent per litre of home heating oil. Home heating oil at time of publication is €0.73 cent/litre.
** VAT rates ROI – 13.5% and 20% in NI for Rhizomes

2.2 Markets

Miscanthus pet bedding

The primary market for Miscanthus is the energy market although it can be used for other purposes such as animal bedding. At present, combustion provides the primary pathway for converting Miscanthus biomass into energy in the form of heat and/or electricity.

Second generation technologies are available for converting

Miscanthus into liquid biofuels, it is expected that these technologies will become commercially viable in the future.

Power Generation

Most of the miscanthus growing in Ireland and England is for power generation. Edenderry Power station have utilised considerable quantities of miscanthus. They have improved the feed in mechanism so there is no reason apart from price why the power stations cannot take thousands of tonnes of miscanthus annually. If the targets set by the energy white paper are to be achieved our three power stations should be replacing 900,000 tonnes of peat with approximately 600,000 tonnes of biomass annually from 2015. The power stations currently purchase peat at a very low price of €4.20 GJ. While some technical issues remain with burning miscanthus they are not insurmountable. This market will not fully develop until a price in excess of €10 per GJ is paid for purpose grown energy crops with the help of a renewable energy feed in tariff (REFIT). The peat stations in Ireland will be able to take 5-10% miscanthus. 4,000 ha per station per year. It currently works out at €88-90 tonne @20% moisture delivered in shredded form. This will need to improve when the REFIT details emerge.

Miscanthus Combustion

Peat burning power stations will provide a market for miscanthus

Miscanthus can be burnt in open fires, in stoves and boilers or in power stations to produce heat, electricity or both heat and electricity (combined heat and power). There are several forms in which miscanthus can be combusted.

Heat Market

Pellets

Oak Park Research has shown that pellets of acceptable quality can be made from miscanthus. However miscanthus has different chemical properties to that of ordinary wood pellets and requires specific boiler technologies to handle its alternative burning nature (see below –Issues associated with Miscanthus combustion). It's also expensive to convert from miscanthus chip to pellets circa €60 per tonne depending on economies of scale.

Chip

Miscanthus prior to combustion at AFBI in Hillsborough

Miscanthus can be harvested by cutting with a conditioner mower and baling in large Heston bales or round bales and then chipped out of the bales. It can also be chipped by a maize Kemper header on harvest. However the problem with this type of harvest is the crops low bulk density of approx 50 – 130 kg/m^3.

The crop is very bulky and will take up a lot of storage space on harvest. Additionally, storage of chips may be problematic if the chips are too small or too wet as heating may occur. The other potential problem with the miscanthus is due to its fluffy nature in chip form it can potentially bridge or get blocked while feeding into the boiler combustion zone. However a suitable auger feed in mechanism will overcome this issue.

Briquettes

Miscanthus is currently being sold in shops and garages across the country in the form of densified briquettes. While there are many boilers that can handle miscanthus,

Miscanthus Briquettes

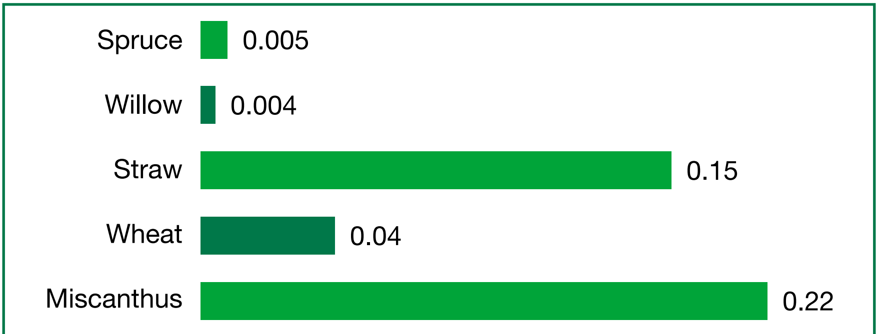
the manufactured briquettes are 50% wood and 50% miscanthus which will then be suitable for most stoves. It would be prudent to enquire with the stove manufacturer as to their endorsement of such a briquette in their stoves. The briquettes will also be very suitable for open fires but is a very limited market.

Whole Bale Boilers

There are boilers such as Passat and Farm 2000 which can take whole bales of miscanthus at once and combust from the bale. Other systems operate on a bale feed in mechanism whereby the large square bale is fed through along a conveying table into a slow moving shredder which shreds the bale prior to the miscanthus being auger fed into the combustion zone such as REKA and Linka who are both Danish manufacturers. The Danes have done a lot of work on combusting fuels such as straw for many years and the combustion of miscanthus is similar to straw. Demonstrations of such technologies are urgently required. Please refer to Appendix 6 for a list of boilers whose manufacturers claim that they are suitable for the combustion of Miscanthus.

UK Markets

ADAS supply their miscanthus to a straw fired power station at Ely which takes 220,000 t per annum. 70% of what they burn is wheaten straw with a lot of leaf present. Drax burns 36,000t of coal every day. They are co-firing miscanthus with coal with the Renewable Obligation Certificate policy supporting this effort.



Chlorine content of biomass materials per cent of dry weight

Technical Issues with Miscanthus Combustion

The combustion of Miscanthus differs somewhat from the combustion of woody biomass as Miscanthus is a grass species with a different chemical composition to that of wood (see Table 10).

Typical chemical composition of Miscanthus	
Ash Content (%)	2.6-3.5
Chlorine Content (%)	0.03-0.49
Sulphur Content (%)	0.07-0.19
Nitrogen Content (%)	0.33-0.61
Silicon Content (%)	0.5-1.6%
Potassium Content (%)	0.5-0.7%

Table 10 *Typical chemical composition of Miscanthus*

The most important difference between the combustion of Miscanthus,and that of other fuels,is that Miscanthus needs to be burned at a lower temperature as Miscanthus has a lower ash softening temperature at approximately 950°C compared to wood chip at >1260°C. The ash produced on combustion of the fuel effectively melts at temperatures above ~ 950°C.

Sintering or fusion of ash particles may first of all occur at higher temperatures before ash particles begin to melt on the combustion bed of the boiler. Subsequent ash melting and fusion once the ash melting temperature has been reached, in addition to sintering, can form quite large lumps of clinker which can both impede the combustion process and hinder the ash removal process. Molten ash can also adhere to the walls of the combustion chamber (slagging) or to the heat exchanger surfaces (fouling) decreasing the efficiency with which heat is transferred to water. Such deposits can often grow to quite a large size and large pieces of deposit typically break off and fall into the combustion bed further hindering the combustion and ash removal process. Deposit formation typically results in corrosion which erodes metal surfaces resulting in increases maintenance requirements and reduced service life.


Clinker formed on the grate of a boiler

Research at Teagasc, Oak Park has shown that these problems are particularly acute if Miscanthus is burnt in fixed grate boilers. There are various boiler manufacturers and suppliers who claim they would be happy to utilise Miscanthus in their boilers and will stand over the warranty with its use. See Appendix 6.

Their designs tend to use flue gas recirculation or water cooled combustion chambers in order to keep the combustion chamber temperature below the ash melting point of Miscanthus. Invariably if the boiler can utilise Miscanthus it can also deal with less troublesome fuels such as wood but not the other way around. Additives such as lime and kaolin (a clay type material) can also be added to the fuel to increase the ash melting temperature by altering the chemical composition of the fuel. AFBI have conducted research on miscanthus combustion using a ‘BioKompact’ multifuel boiler. This research has shown that the addition of lime can prevent excessive build-up of clinker in the boiler combustion chamber. Teagasc research has shown that such additives can also reduce particulate emissions from Miscanthus combustion.

Emissions from Miscanthus Combustion

Emissions from Miscanthus combustion are dependent largely on the chemical composition of the fuel (concentrations of nitrogen, sulphur, potassium and silicon) and specific emissions will generally increase with increasing concentrations of each of these elements. Emissions will also increase with moisture content but also if the fuel is contaminated with eg soil.

Thus, there are a number of variables which can determine the quantity of emissions from Miscanthus combustion and it is difficult to be specific about the levels of emissions. However, emissions in the following ranges have been reported and may be used as a general guide.

PM_{10}	NO_x	SO_2
27-60	100-174	7-9

Table 12 ***Emissions from Miscanthus combustion (g/GJ)***

PM_{10}: particulate matter less than 10 µm

Fuel Moisture Content

With all fuels, it is important that the moisture content is low as the energy value of the fuel decreases with increasing moisture content. Additionally, emissions increase at higher moisture contents (see above) and the fuel will deteriorate with time if stored at higher moisture contents. Combustion thus becomes less efficient with increasing moisture content, emissions will also increase with moisture content. Boiler manufacturers generally stipulate a moisture content of less than 30%.

Moisture Content	Net Calorific Value (MJ/kg)
10	15.3
15	14.3
20	13.5
25	12.6
30	11.8
35	10.9

Table 13 ***Net (actual) calorific value of Miscanthus at a range of moisture contents (Gross calorific value assumed to be 18.6 MJ/kg).***

Ash Production and Disposal

The combustion of Miscanthus also differs from that of wood combustion with regard to the production of ash (incombustible material). The ash content of Miscanthus may be 4-6 times that of wood and, consequently, greater quantities of ash are produced as a result. A Miscanthus boiler using 100 tonnes per year at 20% moisture content and with an average ash content of 3% will produce 2.4 tonnes of ash. Biomass ash still contains significant quantities of nutrients, particularly Potassium, and can be used as a fertilizer. Little or no nitrogen remains in ash as nitrogen is generally oxidised to oxides of nitrogen during the combustion process and leaves the boiler along with other flue gases. Alternatively, biomass ash is also mixed with construction materials and used as filling.

S (%)	0.85
Mg (%)	1.51
K (%)	10.63
P (%)	0.87

***Table 14** Nutrient content of ash from Miscanthus combustion*

On larger installations, fly ash is collected in addition to bottom ash. However, fly ash is generally not used as a fertilizer as it contains higher concentrations of hazardous materials and is generally disposed of by special means.

Two characteristics of biomass ash generally limit the rate of application to land when used as a fertilizer. Biomass ash is extremely alkaline with pH. values ranging from 11-13 and this restricts its application to soils which have an acidic ph. Heavy metal content is the second characteristic of biomass ash which restricts its application to agricultural land or forestry. Some countries have developed limiting values for the application of biomass ash. In Austria, for example, one tonne per hectare per year can be applied to agricultural land although this application rate can be increased if the heavy metal content of the ash can be shown to be lower than guide values.

Lime is added to increase the ash melting point of Miscanthus (AFBI)

2.3 Transporting Miscanthus

The cost of transporting miscanthus is approximately €1.12 per km (€1.79 per mile).

This includes an empty return journey cost. A 112 km (70 mile) return journey to a power station would therefore cost approximately €250 per delivery. With diesel prices continually increasing these costs will inevitably go up and will increase the cost of delivered miscanthus. There may be a requirement for a surcharge on fuel to deal with price volatility based on transport delivery costs.

The legal limit will allow 31 large Heston square bales in terms of height of the load transported in big Heston bales. If you are operating a stepped

Chipped miscanthus being loaded onto a walking floor trailer ready for delivery to a power station

frame floor you will lose two bales on the floor and you can only achieve nine bales on the floor as opposed to eleven bales on a flat trailer and eleven bales on rows two and three. Most trailers will only take two rows of large square bales height but the step frame will go three bales in height allowing 31 bales in total. The maximum legal height on the road is 4.75 m high.

The 8x4x4 bales tend to be around 500 kg in weight. If they are baled fresh miscanthus bales will be heavier and if they have been stored in the shed they will be lighter. The total tonnage is therefore 15.5 tonnes per load in large bale form. The transport costs for the large baled miscanthus work out at approximately €16 per tonne or €1.18 per Giga Joule (GJ) delivered which then needs to be chopped and shredded prior to utilisation.

Note that cost can vary enormously and can fluctuate with volatile fuel prices.

When transporting miscanthus in bulk chipped form it can be transported in 96m^3 loads. Most operators report minimum loads of 11.5 tonnes per load at 20% moisture indicating a bulk density of about 120 kg/m^3 which equates to €1.60 per GJ of energy delivered. Were the miscanthus to be harvested at 50% moisture there would be 20 tonnes on the load giving a bulk density of 200 - 210 kg/m^3 which again is working out at approximately €1.60 per GJ of energy delivered.

Energy Transported

If we take an example of delivering 20 tonnes of miscanthus at 50% moisture, assuming the Calorific Value (CV) at 8 Giga Joules (GJ) per tonne, you are transporting 160 GJ of energy per load. If you transport 11.5 tonnes at 20% moisture at a CV of 13.7 GJ per tonne, you are transporting 156 GJ of energy per load. If a power station is paying a guaranteed price per GJ delivered the operators will get more or less the same price per load delivered whether it's wet or dry.

Harvesting Costs

The cost of a harvester with a maize Kemper header is approximately €297 per hectare (€120 per acre). If diesel prices increase we could see higher harvest costs on the horizon.

Prices will vary depending on the length of the draw and the number of trailers required.

Based on average yields of 12.5 tonnes per hectare at 20% moisture content, the average cost of harvesting is €9.60 per tonne. Material harvested with a Kemper header at setting number 7mm on the machine has proven to be very suitable for Edenderry Power Station and there was also no difficulty in rolling this finely chopped material and storing it in a pit for a period of one week to ten days while you're waiting to draw the material away.

If the chop length is increased to 17 or 20mm even with rolling there is a tendency for the miscanthus chip to heat. If the moisture is high between 30 – 50% some operators experience has shown that it's better to cut in small chop lengths at 7mm and then to roll the miscanthus material which will keep safely for a week to 10 days. The material would need to be covered and sealed down similar to maize or grass silage in order to achieve anaerobic preservation. Some miscanthus operators experience is that, as the moisture level decreases it's possible to increase the chop length to 17mm or even 20mm and achieve aerobic preservation by aerating the miscanthus and not rolling the miscanthus at all.

The baling costs of an 8 x 4 x 4 bale are approximately €11.50 per bale including VAT.

Bales need to be shredded and require extra handling. A rota-grinder and a tractor to drive it together with a loader to fill it are required. The minimum overall costs are €90 per hour. The tractor and rota-grinder costs approximately €60 per hour and €30 per hour for the hire of an industrial loader. If everything goes well it's possible to achieve 5 tonnes per hour but that does not take setting-up time and costs into account. If we assume an overall cost of €100 per tonne this put a cost of chipping miscanthus out of the bales at €20 per tonne.

3.0 Environmental Impact

MISCANTHUS
Best Practice Guidelines

3.1 Carbon Capture and Storage

CARBON MITIGATION AND CAPTURE

Miscanthus Carbon Capture and Storage:

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

Carbon mitigation:

- The energy content of Miscanthus is approximately 19 MJ kg^{-1}. One hectare 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 8.02 tonnes CO_2.
- Miscanthus is a carbon neutral fuel as carbon that is released during its combustion has been absorbed by the plants when they were growing.
- Greenhouse gas emissions from Miscanthus cultivation will be lower than those from other agricultural activities. This is due largely to lower amounts of fertiliser usage and the absence of animal related emissions.

Carbon sequestration:

- Miscanthus can store (sequester) carbon preventing its release into the atmosphere. Sequestration occurs when the inputs of carbon dioxide are greater than removals from harvesting and decomposition.
- Carbon is stored in the rhizomes and roots of Miscanthus as well as in un-harvested stubble. In addition, an increase in soil carbon will occur if Miscanthus is planted into former tillage land.
- Experiments conducted in Ireland have shown that Miscanthus can store 8.8 tonnes of carbon per hectare in its roots and rhizomes 12 years into its life.
- The amount of carbon captured by Miscanthus can be further enhanced if plantations are used for the bioremediation of effluents and sludge’s.

3.2 General Environmental Benefits of Miscanthus

General Environmental Benefits of Miscanthus

Low Input Requirement

- Herbicides are recommended for the establishment year only. Once mature, the plants are more tolerant of weeds and canopy closure shades many weeds out. Pesticide use is not generally recommended for miscanthus. The application of chemical fertilisers is also not recommended.

Carbon Neutral

- Miscanthus takes up as much carbon as is released when it is burnt so there is no net increase in CO_2 into the atmosphere. Furthermore, some carbon is sequestered into the soil. Carbon budgets which include the use of fossil fuels in the transportation of materials indicate that the entire cycle releases 30 times less carbon than when compared with fossil fuel combustion cycles.

Landscape

- It is not economic to grow crops for energy at great distances from the end user and therefore with correct placement, miscanthus should not cause fragmentation of habitats across a wide area. In addition, machinery access requires large rides on field edges and requires rows to be less than 200m long, therefore fields with hedgerows and grassland rides are encouraged to be maintained.

Wildlife
Compared to Annual Crops

- Two studies, one at IACR-Rothamsted and another in Germany, comparing miscanthus with cereals, indicated that miscanthus seemed to provide a habitat which encourages a greater diversity of species than cereal crops. In these studies three times as many earthworms and spiders were found in the miscanthus crop, miscanthus also supported a greater diversity of spider species. One of the studies also showed that the miscanthus crop had 5 more mammal species and 4 more bird species than a crop of wheat. Spink and Britt (1998) identified miscanthus to be one of the most environmentally benign alternatives to permanent set-aside. The results from the first year of an on-going three year study funded by DTI in the UK to determine how biomass grasses on ex-arable land affect key flora and fauna indicates that miscanthus may support a greater range of plant species than cereal cultivation.

The Benefits of Open Ground Areas to Wildlife

- Within the area for which an establishment grant is applied, up to 10% can be left as open ground where this is used for management or environmental purposes. The open ground areas can be used for crop management purposes such as rides, headlands (which improve the access to the site, particularly at harvest) and stacking areas. The use of open ground areas around the crop will protect edge habitats such as hedgerows which are particularly important for wildlife, by preventing shading to existing habitat. Also, headlands may also act as a sacrifice crop for rabbits or deer to feed on and thus reduce any damage otherwise caused to the newly established crop. Open ground areas next to buildings and footpaths will retain access for maintenance and amenity purposes. Areas next to rivers/drains, hedgerows and woodlands can be left uncropped purely for environmental or aesthetic reasons.

Delayed Harvest Provides Cover for Wildlife

- Miscanthus provides cover for most of the year because, although the crop is harvested annually, it is harvested shortly before the following year’s growth begins. This cover can act as a wildlife corridor linking existing habitats. Miscanthus can also act as a nesting habitat, for both ground nesting birds in the early spring e.g. sky larks, and reed nesting birds such as the reed warbler, later in the summer. Miscanthus might be a useful game cover crop and nursery for young pheasants and partridges.

Other Wildlife Benefits

Habitat for Mammals & Food for Large Carnivores:

- A minimum of nine species have been observed in miscanthus, including the brown hare, stoat, mice, vole, shrew, fox and rabbit. Many of these are a useful source of food for larger carnivores such as the barn owl.

Food for Invertebrates:

- The diverse ground flora which can inhabit the soil beneath a mature miscanthus canopy will provide food for butterflies, other insects and their predators.

Foraging and Cover Areas for Birds:

- Skylarks, meadow pipits and lapwings use miscanthus, as well as 37 other species of birds including wren, linnet and goldfinch that feed on the grass seeds. Once the leaves are shed in winter, a suitable habitat is provided for yellowhammers. Open areas between stools provide ideal habitat for birds such as skylarks and meadow pipits.

Appendices

MISCANTHUS
Best Practice Guidelines

Appendix 1: Bale Storage Guidelines

The storage of Miscanthus bales should follow the same rules as the handling and stacking of any bales produced in agricultural. Bales should be stacked safely. Thus stacks should be sited;

- Away from public roads and footpaths to reduce the risk of fire from discarded cigarette ends,
- Away from overhead power lines,
- Well away from residential properties and where several stacks are sited together they should be built in a line across the prevailing wind and not less than 24 meters apart.

All stacks must not be higher than 1.5 times the shortest baseline measurement. Bales should be stacked on the unstrung sides and overlap bale layers must be included at regularly intervals, as well as binding in the vertical columns.

Whilst stacking and loading lorries is in progress we would always suggest that any spectators and people involved should remain either in their machines or at a safe distance at all times.

Contents

- Storage
- Stack site selection
- Bale density
- Bale size
- Bale handling

Storage

The best way to retain the quality of your Miscanthus product is to treat it like any other biomass material i.e. wheat, barley and oilseed rape straw. To have the driest material possible (which means higher energy value per tonne and less moisture penalties or possible rejection) it is best retained by being kept undercover immediately after harvest. Storage of bales outside can be acceptable practice as long as it’s managed correctly.

Outside stacks need to be built as high as is possible and then pushed together tightly as the machine and bale quality will allow. A correctly built stack should be safe and result in a minimum amount of product being exposed to the weather. It is very important that outside stacks are sheeted to prevent the top and possibly the second layer being spoilt, leading to material degradation. The consequences of bad storage are sodden or starting to rot bales as a result of being exposed to periods of wet weather. Such bales will inevitably not be suitable for their destined market. This must be considered by you when loading your material for collection.

As in example below, 1.2 X 1.3 m bales (such as Big Heston's) are best stacked with the strings facing towards you.

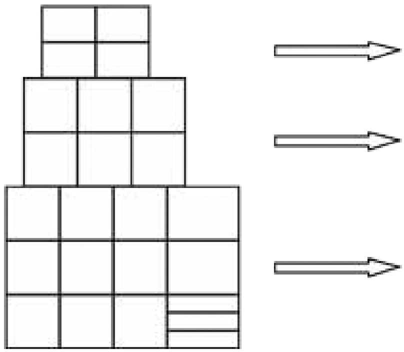


Fig 3. Stack example of 1.2 x 1.3 m bales (e.g. Big Hesston's, MF190 and Krone 12130)

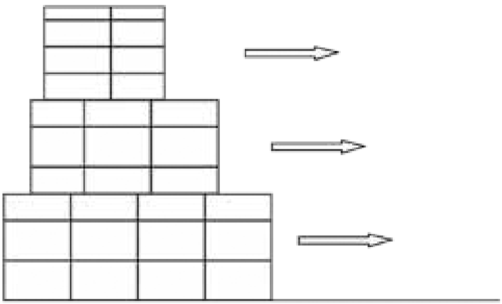


Fig 4. Stack example of 1.2 x 0.7 m bales (e.g. Claas Quadrant 2200 and MF 186)

In the examples above, each layer is stacked in packs of four, three or two; pack size will depend on your machine and operator confidence. The pack size of the top layer will be driven by the reach of your machine and attachment type. The width of the stack should be driven by site, yield and available sheet sizes. Ideally try and build stacks as high and as square as possible to ensure minimum losses. Leaving your baled material in small stacks in field where harvested will lead to a potentially higher number of losses.

It is important that packs are interlinked as demonstrated above and pushed tightly together to ensure maximum stability. It may be necessary to nudge the stack from behind in the early stages of construction to prevent any bales falling from the rear of the stack.

Stack Site Selection

Where is the best place for me to site my stack of bales?

1. Security to satisfy insurance requirements
2. Accessibility for lorries
3. Distance from power lines
4. Free draining ground or ideally a concrete or hardcore pad
5. Good level site
6. Free from holes, ditches and other obstacles.

Bale Density

Growers should ensure that the bales produced by your chosen contractor are baled to the correct density and shape. When baling is in progress it is important to physically check your bales at the start of the operation and monitor them at intervals throughout the day. Good, tight bales should feel hard when kicked and it should prove difficult to get your hands under the strings and lift the string to any distance. It should not be possible to pull the strings off a bale by hand!

Some of the problems of not having your product baled correctly:

1. More broken bales when clearing fields, loading trailers and trucks etc.
2. Excessive bale damage from handling equipment
3. Un-storable in outside stacks, due to being on open bale
4. Hard to achieve a tidy stack and build to a sufficient height
5. Excessive use of indoor storage space
6. Impossible to achieve maximum weight onto the Lorries resulting in increased haulage costs per tonne of material
7. Possible rejection at process site.
8. Increased baling cost to you the producer (as a result of more bales)

Bale Size

Please use the table below for the definition of bale sizes in relation to common baler models. All of the below models produce 6 string bales. 4 string bales are generally not wanted as they do not lend well to haulage and handling systems. (e.g. Mini Hesston, MF182, Claas 2100).
Bales should be produced 2.5 m (8ft) in length so as to ensure maximum weight per bale and value for money from the service supplied to you.

Make	Bale Size (m)	Target Weight (kg)
MF 190 MF190 Hesston 4900 Krone 12130	1.2m x 1.3m	500-550+
MF187	1.2m x 0.9m	360+
MF186 Class Quadrant 2200 Class Quadrant 3200 Welger D6000	1.2 m x 0.7m	330+

Table 15 *Common bale types, based on 15% moisture content.*

Bale Handling

Having the correct handling attachment on you telescopic handler or loader will ensure ease of operation and enable efficient loading for the haulage company. Haulage companies will generally prefer the bales to be loaded lengthways along the vehicle bed.

For this to be achieved when loading the vehicle, at least a two pronged spike should be used, which can handle at least a couple of bales at a time. The more favourable alternative to this is possible, would be a multi bale grab. This type of loading grab is generally safer and considerably quicker to use. Lorries ideally need to be loaded with 45 minutes.

Appendix 2: Advantages and Disadvantages of Miscanthus

Advantages of Miscanthus

1. Planting of the crop is carried out by the rhizome suppliers with specialist equipment and only requires the grower to prepare the ground. This is similar to the situation for SRC willow.
2. The annual yield once established may achieve between 10 and 13 tonnes per hectare or more at 20% moisture content.
3. The biomass is harvested dry, or at least much drier than SRC willow. Under normal/ good conditions, harvesting at under 20% moisture is possible in Ireland and the UK, but under poor conditions the crop may need to be dried after baling or chipping at 25% to 35% moisture.
4. Harvesting can be carried out by existing farm equipment such as mowers, balers and self propelled forage maize harvesters.
5. The annual harvest could readily be carried out by contractors at a time when their equipment is not in use for any other purpose.
6. Once established, the crop provides an annual return to the grower.
7. When returning to grassland or arable farming, Miscanthus can be sprayed off with glyphosate, although it may take two applications to ensure a complete kill.
8. For weed control, a wide range of cereal herbicides can be used on Miscanthus.
9. No significant disease infections or pest attacks have been reported. However, as the area of the crop being grown increases, the likelihood of disease infections or pest infestations increases.
10. In terms of reducing carbon emissions, Miscanthus has been calculated to provide a high level of savings, slightly higher than with SRC willow, particularly where grassbased enterprises are displaced and the biomass is used for electricity generation.
11. Chipped Miscanthus potentially has other markets, for example animal bedding.
12. In the future, Miscanthus may be particularly suited as a feedstock for the production of second generation biofuels from lignocellulosic materials.

Disadvantages of Miscanthus

1. Establishment from field planting of rhizomes is not proving to be reliable. It is known that the viability of rhizomes can decline rapidly between harvesting and replanting if not handled appropriately, but other factors such as method of planting, soil moisture status and soil temperature could also have an effect. Crops can recover from poor establishment but it may take longer to achieve an economic return.
2. The crop takes several years to reach full production capability. Well established crops on fertile sites may reach their full yield potential by the third year, but it may take four or five years.
3. The mild wet winter conditions in the more northern latitudes of Ireland may lead to less complete senescence of the standing crop and higher moisture contents at harvest.
4. Wet ground conditions may lead to excessive soil damage during harvesting operations.
5. If the crop has to be regularly harvested at more than 20% moisture content, then artificial drying may need to be employed which will reduce the economic viability of the crop.
6. The low yields in the first and second year means that it takes many years before a grower will receive an economic return.
7. Potential markets for Miscanthus in Northern Ireland are underdeveloped. In England and Ireland, the main market which has driven the increased planting of Miscanthus has been the co-powering of power stations (e.g. DRAX and Edenderry). It has not been possible so far, to engage with the management of Kilroot Power Station.
8. Not all biomass boilers suitable for SRC willow are capable of utilising Miscanthus. Miscanthus has a higher silica and ash content than willow. The growing of Miscanthus for biomass would have to be introduced hand-in-hand with the development of the capability to utilise the crop.
9. Currently in Northern Ireland, there are no planting grants for Miscanthus, whereas SRC willow attract a planting grant. Planting grants for Miscanthus are available in ROI.

Appendix 3: Calendar of Activity

	Year	Period	Activity
PREPLANTING	-1	Jan - Jun	• Consider site selection and liaise with neighbours, local authorities, • archaeologists, etc. • Prepare evidence of market for miscanthus • Prepare and submit DAFF Establishment Grant application
		Aug – Nov	• Familiarise yourself with the management of miscanthus by reviewing literature on the crop.
ESTABLISHMENT	1	Jan – Apr	• Apply glyphosphate to control perennial weeds from January 15th. • Spring plough from January 15th • Rotovate or power harrow soil immediately prior to planting. • Planting
		Apr – May	• Apply nutrients if required • Herbicide application while crop height below 1m
	2	Feb – Mar	First year growth not usually harvested
CROPPING		Apr – May	• Apply nutrients if required • Herbicide application while crop height below 1m
	3+	Feb – Mar	• Harvest previous years growth with mower conditioner Bale and stack
		Apr – May	• Monitor crop nutrient and apply nutrients if required

Table 16

Appendix 4: Energy Calculations

Material	Typical Bulk Density	Storage Space Requirements
	Metric	Metric
	t/m³	m³/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

***Table 17** Bulk Density and Storage of various fuels*

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

***Table 18** Fuel cost comparison*

	MJ	GJ	kWh	toe	Btu
MJ	1	0.001	0.278	24×10^{-6}	948
GJ	1000	1	278	0.024	948,000
kWh	3.6	0.0036	1	86×10^{-6}	3,400
Ton of oil equivalent (toe)	42,000	42	11,700	1	39.5 x 106
Btu	1.055×10^{-3}	1.055×10^{-6}	295×10^{-6}	25.3×10^{-9}	1

***Table 19** Fuel cost comparison*

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^{13}	Peta (P)	10^{-13}	Femto (f)
10^{18}	Exa (E)	10^{-18}	Atto (a)

***Table 20** Decimal Prefixes*

From/to	1 MJ	1kWh	1 kg oe	Mcal
I 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

***Table 21** General Conversion Factor For Energy*

	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	4.75	18.4	5,111
Miscanthus	17.7	4,917	18.1	5,028
Hay	17.1	4.75	18.4	5,111

***Table 22** Energy Content of Difference Biomass Fuels at 0% M.C.*

	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 havested 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
Cereals as stored after hervest, straw, hay, miscanthus after harvest	13-15%				5.2	18.72	0.34
Silomaize	30%				4	14.4	
Rape seed	9%				7.1	25.6	0.61
Chicken litter as received	68%				2.6	9.6	0.22
To compare with:							
Hard Coal					8.06	29	0.69
Brown Coal					4.17	15	0.36
Peat					2.8	10	0.24

***Table 23** Typical Moisture Content of Biomass Fuels and Corresponding Calorific Values as received*

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

Species	Shape	m.c in %	t/m³	GJ/m³	kWH/m³
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
Beech	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
Beech	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

Table 24 *Examples for Weight and Energy Content (NCV) For 1 M^3 Wood at Different Water Contents, Species and Shape of the Wood*

Liquid Fuels	t CO_2/TJ (NCV)	g CO_2/kWh (NCV)
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	153.6

Table 25 *Emission Factors*

Note: CO_2 emission factors for electricity vary from year to year depending on the fuel mix used in power generation.

Appendix 5:
Miscanthus Carbon ‘Self Off-Setting’

Gary Lanigan, Teagasc, Johnstown Castle

According to EPA, Irish Farming emits a total CO_2 equivalent of 17.5 millions tonnes in GHG’s. Irelands agricultural land use is 4.2 million hectares. This amounts to an average of 3.9 tonnes of CO_2 per hectare total embodied emissions. Methane from enteric fermentation and manure management comprise 70% of these emissions, with nitrous oxide (from fertiliser application and animal deposition) making up the remainder. As a low fertiliser and zero pesticide/herbicide crop, with little management input, the carbon emissions of miscanthus cultivation are lower than those of both livestock production and annual tillage crops. Thus, biomass cultivation can reduce agricultural GHG emissions in two ways either by displacing methane and/or nitrous oxide emissions associated with other farm practices or b) increase soil organic carbon sequestration.

The extent of each of these reductions will be dependent on whether biomass cultivation is displacing arable land or stocked pasture. Greenhouse gas emissions can also be reduced by removal of a proportion of CO_2 via photosynthesis into C sinks. These sinks can be either perennial woody tissue or soil organic carbon (SOC). Sequestration occurs when the input of carbon dioxide is greater than removals from harvesting and decomposition. In the case of arable displacement, there will be a net increase in C-sequestration. This is due to the fact that croplands have been shown to be net emitters of CO_2 of between 1 – 3 $tCO_2\ ha^{-1}\ yr^{-1}$ (Davis et al. 2010). Most of this carbon loss is assumed to be associated with both ploughing and extended fallow periods. Overall C input into the soil associated with the conversion of arable land to biomass has been estimated to increase by between 2.8 and 4.1 $tCO_2\ ha^{-1}\ yr^{-1}$ for miscanthus (Rowe et al. 2007). Indeed this is a conservative estimate. If the biomass accumulation by below-ground biomass (rhizomes and roots) is included, another 0.5 – 1 $tCO_2\ ha^{-1}\ yr^{-1}$ could be added to this total. It should also be noted that, in order to reach these rates of sequestration, may take two to three years post-establishment (Hansen et al. 2004). By contrast, the conversion of pasture to biomass crops (Miscanthus or SRC) is assumed to have no impact on long-term net C sequestration when using IPCC Tier 1 methodologies for estimating C-stocks. Indeed, in the short-term, losses of 2 to 4 tCO_2 ha^{-1} yr^{-1} may be associated with ploughing. However, recent measurements at under a range of soil types have shown that initial C loss after ploughing is much lower (20- 100kg CO_2 ha^{-1}) and that total site preparation losses can be limited to circa. 1 tCO_2 ha^{-1} provided the fallow period is minimised. Therefore, net soil C sequestration may occur on pasture conversion to biomass.

Further savings in emissions are associated with fertiliser usage. Miscanthus are N-use efficient and are considered to require between 50kg and 100kg N ha^{-1} (Styles et al. 2007). This would represent a decrease in N requirement up to 100kg ha^{-1}. The amount of N_2O mitigated would further depend on the soil type being cultivated as emissions are 100 -200% higher on heavy soils compared to sandy soils. There is also an associated saving with the manufacture of N, P and K fertilisers. In terms other emissions associated with cultivation, including liming, pesticide manufacture, fuel and energy usage, these emissions are generally higher than for beef systems but lower than conventional arable systems, due to lower inputs and less annual site maintenance.

References:

Davis, P.A., Lanigan, G.J., Saunders, M., Osborne, B.A & Jones, M.B. (2010) Carbon balance of Irish Croplands. Ag. For. Meterol. 150: 564-574.

Rowe, R.L., Street, N.R. & Taylor, G (2007) Renewable & Sustainable Energy Reviews, doi 10.1016/j.resr.2007.07.008

Styles, D. & Jones, M.B. (2007) Biomass & Bioenergy 31: 759-772.

Hansen, E.M., Christensen, B.T., Jensen, L.S. & Kristensen, K. (2004) Biomass & Bioenergy 26: 97-105.

Appendix 6: Miscanthus as an Energy Crop - Boiler Compatibility and Supply

Miscanthus has a energy density similar to woodchip but has some associated problems that occur during combustion that can have an effect on the equipment used, such as low ash melting point and clinker which gathers in the hearth. Sulphur (S) is converted to SO_2, Chlorine (CL) is present in the formation of hydrogen chloride(HCL), dioxins and furans reacting with other substances, both interactions causing corrosion. It is due to this that boilers need to be specially designed to use Miscanthus.

Boilers capable of burning Miscanthus needed to be installed, if there is to be a continued miscanthus market for energy. We need to develop and deliver educational programmes about boiler and fuel type compatibility.

Market for Miscanthus as an Energy Crop:

Both in Ireland and the UK, a market supply chain has failed to materialise in any significant way. Thousands of hectares of miscanthus where planted with promises of good financial returns, however this has not proven to be the case. In Ireland one quarter of all miscanthus crops have been ploughed in as the market is simply not there. Miscanthus is supplied to the Edenderry power plant but unless living near to the plant it doesn't make economic sense to transport the fuel. Increasing calls are directed towards the government to try and stabilise a Miscanthus market to prevent even more of the crop being ploughed in as approximately €7million has been invested in Miscanthus in Ireland and this would be wasted of the crop was ploughed in.

In the UK, recently launched energy pellet suppliers Terravesta are seeking out contract Miscanthus growers to help grow their business; thus in theory guaranteeing a supply chain for 2014 contracts. Terravesta is offering contracts of £72/tonne and for those whose Miscanthus bales have been barn stored and meet required moisture specification of 16% or less will achieve an extra £2/tonne.

Terravesta seem to have taken the initiative when trying to secure the development of the Miscanthus market and supply chain, by running workshops and having published an 'Essential growers ' Guide' to support existing growers and attract new interest.

Terravesta are currently supplying DRAX power station with over 20,000 tonnes of pellet per annum.

Examples of typical small to large scale boilers designed for Miscanthus Combustion:

Teagasc and AFBI are not recommending these boilers but these are boilers whose manufacturers claim to be suitable for the combustion of miscanthus.

Step Trutnov **STEP-KS 100-1000kW** 	Boiler is able to combust Miscanthus. Automatic feed and ash removal is included in design.
Herlt 	Bale gasifiers capable of burning miscanthus with no negative impacts to the equipment noted. Bales are best used with this boiler as they are a low cost solution with regards to storage and transport.
Hotab	Provide a range of boilers for combustion of complicated fuels like miscanthus, 500kw to 16MW. Warranty covers emissions for bio woodchip or pellets only. Combustion of pellets or briquettes recommended for smoother combustion.

Biokompakt Heiztechnik GmbH BGI: Bio Global Industries 	Recommend AWK/ECO boiler range 30-130kW for miscanthus combustion, but only with an industrial grad room discharger (Screw auger system). They recommend that all boilers to be used for miscanthus combustion have a lime metering system, especially if fuel is contaminated i.e. dust or soil. For Biokompakt boilers miscanthus chip should not exceed 20mm in length, pellets should not exceed 50mm in length and briquettes should not exceed 30mm in length and 50mm in diameter.
Lin-Ka Supplier: Mancoenergy.com 	Multi-fuel boiler with stainless steel automatic ash extraction and flue cleaning installed. Able to combust Miscanthus. Several systems installed in UK burning bale and chipped miscanthus preforming well and meeting emission standards all claiming RHI. If moisture content is lower than 18% Miscanthus is achieving better calorific values that wheat straw.

REKA: HKRST  **and HKRSV** 	Reka guarantee that theses boilers with moving stepped grate/ stepped grate with fully automatic ash removal: can combust Miscanthus without any issue. Bales, chipped and pelleted forms of Miscanthus can be combusted.
Guntamatic: Powercorn 20kW-300kW 	Boilers come with a stainless steel liner, fully automatic and have a step grate system. Combustion with Miscanthus is possible and range is RHI compliant. Pellets (6mm ENPlus A1 and A2) are recommended.
Hargassner: Agrofire 	All models are capable of combusting miscanthus. Hargassner have been at the forefront of developing boilers capable of Miscanthus combustion. Introducing the step grate function to all boilers helping to prevent clinker formation. Miscanthus in Hargassner boilers can be in briquettes, pellets and chipped. A 3 year warranty is offered on all boilers.

Twinheat: **CPI-12**  **M, ME,M-CS, CS** 	These boilers are all suited to miscanthus combustion in pellet and chipped forms
ETA: **HACK20-200kW** 	All these models are designed to cope with Miscanthus combustion in that they are fitted with a tilting grate and a ceramic lined retort.
HDG 	HDG boilers and flues would be greatly reduced when combusting Miscanthus. The boiler can combust Miscanthus however higher maintenance, service costs and wear and tear is observed. Due to this reason HDG do not support the combustion of Miscanthus in their boilers and if associated problems were found any warranty would be invalid.

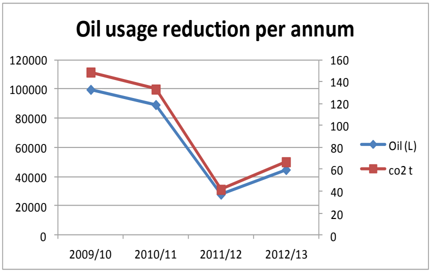
Appendix 7

JB Adams Farms Ltd

Old Manor Farm
Tenbury Wells
Worcestershire

Requirement	Installation of Step Trutnov, STEP- KS 950kW biomass boiler as main heat source. Conversion from LPG
Approximate Carbon Savings per annum	86.74(t)
RHI claimed	£20000
Cost savings of fossil fuel per annum	£15,000
Increased electricity costs	£3,000
Total savings since instalment	£68,000

J B Adams Ltd is situated in Tenbury Wells, Worcestershire, England and is an operational poultry farm. A Step Trutnov, STEP- KS 950kW boiler was installed approximately 4 years ago. They are claiming RHI on middle tariff secured for 20 years. The biomass heating system is providing heat for 5 turkey houses containing 24,500 turkeys (On average three crops of turkeys are produced per annum) and an on floor grain drier. There has been a total of 396,380kWh generated with 348,560kWh consumed on site. A larger capacity heat system than needed was installed.



The Step Trutnov is a multi-fuel boiler and is currently using Miscanthus as a main feedstock, with approximately 125t used per annum. A further 60.78t and 42.06t of woodchip and rape straw respectively have also been typically used. An established supply chain is provided by a local supplier.

The boiler was a primary replacement for an oil heating system which has remained in place as a secondary heat supply. This was previously burning approximately 94,000 l of oil per annum. The introduction of the biomass heat system allowed for the amount of heating oil to be reduced to approximately 29% and 47% of original consumption in first and second year of operation .

Www.afbini.gov.uk

CASE STUDY

Location: J B Adams (Farms) Ltd. The Old Manor House, Bockleton, Tenbury Wells, Worcestershire, WR15 8PP

Boiler: Step Trutnov, STEP- KS 950kW boiler installed for 3 years and claiming RHI on middle tariff tied for 20 years.

Area of business: Poultry production, the biomass heating system is providing heat for 5 turkey houses containing 24,500 turkeys (3 crops per year) and an on floor grain drier.

Amount of fuel per annum: Miscanthus: 125, woodchip: 60.78 and Rape straw: 42.06 tonnes.

Previous heating consumption (LPG):

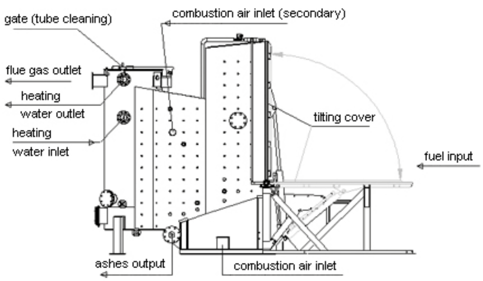
2009/10 99,702 L,
2010/11 89283 L,
2011/12 27,918 L,
2012/13 44,799 L.
Heat Generated: 396,380 kWh

Heat Used: 348560 kWh

RHI claimed: £20,000 (approx)

Costs: Saving £5000 on fuel for one crop, however increase in £1000 of electricity.

Supply chain: Growing portions of his own fuel but also contracts with other suppliers for Miscanthus.



Schematic of Step Trutnov STEP-KS boiler as used by Adams farms.

Appendix 8:
Miscanthus Payback Calulations

Bank Interest (%)	6.00%		**1st Harvest**						
General Inflation (%)	2.00%		Weight in DM / t per ha =			7.00			
Energy Inflation (%)	2.00%		Weight @	20.00	% MC is	8.75	tonnes		
Price Per Tonne	**€65.00**		Total 8x4x3 Bales			23.65	per/ha		
Price (€/GJ)	**€4.74**		Compare to price of oil at			0.60	cent/litre		
VAT Registered	**Yes**		**€16.34**	per GJ					
Cost per Bale	**€7**								
Bank Borrowings €/ha	1,518	over	5	years =	6.17%				
Costs per ha:	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**
Operations	1	2	3	4	5	6	7	8	9
Plough	75								
Cultivate	70								
Spray1	20	20							
Spray2	20								
Plant	400								
Spread fertiliser	0								
Fencing	0								
Rolling	10								
Transport	0		0	0	0	0	0	0	0
Mowing	0	0	50	52	53	54	55	56	57
Baling	0	0	166	202	206	210	215	219	223
VAT (13.5%)	0	0	0	0	0	0	0	0	0
Sub-total	***595***	***20***	***216***	***254***	***259***	***265***	***270***	***275***	***281***
Annual land opertunity cost	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***
Materials									
Round-up	30								
Insecticide	40								
Selective Weedkiller	40	40							
Management Fee	0								
Rhizomes	1900								
Fertiliser	0								
VAT (21.5%)	0	0	0	0	0	0	0	0	0
Rhizomes VAT (13.5%)	0								
Sub-total	***2010***	***40***	***0***	***0***	***0***	***0***	***0***	***0***	***0***
Total	**2,605**	**60**	**216**	**254**	**259**	**265**	**270**	**275**	**281**
Income:									
Est. grant	1,088	363							
Fuel sale	0	0	604	879	897	915	933	952	971
EU Energy Payment	0	0	0	0	0	0	0	0	0
Carbon premium	0	0	0	0	0	0	0	0	0
Total	**1,088**	**363**	**604**	**879**	**897**	**915**	**933**	**952**	**971**
Start up Loan	**1,518**								
Repayment Borrowings		**-362**	**-362**	**-362**	**-362**	**-362**	**0**	**0**	**0**
Net Cash Flow	**0**	**-59**	**26**	**263**	**276**	**289**	**663**	**677**	**690**
Profit/loss	0	303	388	625	638	650	663	677	690
Inflated	0	303	388	626	638	651	664	678	691
Discounted to year 1	0	302	388	624	636	649	662	675	688
Cum. disc. profit/loss	0	302	690	1314	1950	2599	3261	3935	4623
Mean annual profit/loss	**0**	**151**	**230**	**328**	**390**	**433**	**466**	**492**	**514**

Annual dicount rate	5%
Annual land opertunity cost	€0
Net Present Value	€5,898
internal rate of return IRR	34%

Note: The higher the NPV the more viable the investment, negative NPV should not If the annual land opportunity cost is 0 and the discount rate is equal to the borrowin then the NPV is what could be paid for land purchased /ha over this time scale.

Subsequent harvests

Weight in DM / t per ha =		10	
Weight @ 20	% MC is	12.50	tonnes
Total 8x4x3 Bales		27.78	per/ha

2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	
10	11	12	13	14	15	16	17	18	19	20	
0	0	0	0	0	0	0	0	0	0	0	
59	60	61	62	63	65	66	67	69	70	71	
228	232	237	242	247	252	257	262	267	272	278	
0	0	0	0	0	0	0	0	0	0	0	
286	***292***	***298***	***304***	***310***	***316***	***323***	***329***	***336***	***342***	***349***	
0	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	
0	0	0	0	0	0	0	0	0	0	0	
0	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	***0***	
286	**292**	**298**	**304**	**310**	**316**	**323**	**329**	**336**	**342**	**349**	
990	1,010	1,030	1,051	1,072	1,094	1,115	1,138	1,160	1,184	1,207	
0	0	0	0	0	0	0	0	0	0	0	
0	0	0	0	0	0	0	0	0	0	0	
990	**1,010**	**1,030**	**1,051**	**1,072**	**1,094**	**1,115**	**1,138**	**1,160**	**1,184**	**1,207**	
0	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	
704	**718**	**732**	**747**	**762**	**777**	**793**	**809**	**825**	**841**	**858**	11392
704	718	732	747	762	777	793	809	825	841	858	
705	720	734	749	764	780	795	811	828	845	862	
701	715	729	743	758	773	788	803	819	835	851	
5324	6039	6768	7511	8269	9042	1560	2364	3183	4018	4869	
532	**549**	**564**	**578**	**591**	**603**	**614**	**625**	**636**	**647**	**657**	

t be entertained.
g rate of interest available

Average Net Cash Flow per yr over 20 years = **€569.59**

Contacts

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Best Practice Guidelines

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Bord na Móna Energy	Derrygreenagh, Rochfortbridge, Co Westmeath, Ireland	www.bnm.ie	tracy.leogue@bnm.ie	Tracy Leogue t: 044 92 22181 m: 087 6141834
Biomass Energy Northern Ireland (BENI)	Countryside Services, 97 Moy Road, Co.Tyrone BT71 7DX	www.biomassenergyni.com	jcmartin@biomassenergyni.com	0044 (0)78 08060037
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McMahon Eco Fuel Manufacturers LTD	Kantoher Kileedy Co Limerick	www.mcmahonecofuels.com		Tel: (08) 7230 4427
General Renewable Energy	NI Science Park, Queen's Road, Belfast BT3 9DT	www.actionrenewables.org		0044 (0)28 90737821
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