Department for Environment, Food and Rural Affairs **CSG 15**

Research and Development

Final Project Report

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Executive summary (maximum 2 sides A4)

Executive Summary

Introduction and background

1. Grasses such as reed canary grass, spartina and switchgrass have been studied to only a modest extent in the UK in comparison with miscanthus and short rotation coppice. In addition, other less widely known species of energy crops have been examined in various countries across the world, but their comparative potential has not been systematically evaluated. The aim of this desk study is to assess the competitive position of all these giant grasses, particularly the lesser known species, for cultivation in the UK. An objective of this work is to draw together the disparate studies conducted. It is aimed to present an evaluation of the agronomic and economic performances of giant grasses with a view to identifying any species with promise for UK conditions that merit more detailed study.

Summary of agronomic review of crops for consideration

Benchmark crops

2. Wheat, short rotation coppice and miscanthus are selected as benchmark crops and are examined as a basis for providing a comparison for the more novel energy grasses. For wheat the wide spectrum of suitable growing conditions, the thorough knowledge of growing the crop and its low moisture content at maturity are of advantage. The high annual inputs and costs are, however, a drawback. Willow, commonly used in short rotation coppice, is established using cuttings. It's productive life is 25 – 30 years and harvest takes place every 2 – 4 years after an initial year of growth. Current yields in the UK are 10 – 12 t DM/ha/year. Moisture content at harvest is relatively high at around 50% increasing costs of transport and combustion. Miscanthus is a perennial C4 grass, which can be harvested annually after an establishment year. Yields in UK conditions are in the region of 11 – 16 t DM/ha/year. Moisture contents vary from 30 – 60% in Northern Europe. Miscanthus does not set seed in UK conditions, so rhizomes or micropropagated plants must be used, leading to high establishment costs.

Alternative giant grass species

3. Reed canary grass (*Phalaris arundanacea*) is a C3 plant suited to a wide range of temperate conditions. Reported yields vary from 6 – 12 t DM/ha in UK conditions, when the crops are harvested in autumn.

Delaying harvest to the spring following growth reduces moisture content to 15 – 28%, but decreases yield to approximately three–quarters of the autumn level. Higher yields are attained earlier in the life of the crop than with miscanthus. Reed canary grass has the advantage of being established from seed and hence is less expensive to establish than miscanthus.

4. Switchgrass (*Panicum virgatum*) is a C4 grass originating from the tall grass prairies of North America. There are 2 types; an upland type which has relatively thin stems and a lowground type which is taller with thicker stems. Yields in the UK vary from 8 – 12 t DM/ha/year, demonstrating variation in varietal suitability. Moisture content was 47 – 57%. Establishment is from seed and hence is less expensive than miscanthus.

5. Spartina species are C4 grasses with a natural distribution in cool, temperate regions. Trialling has been relatively limited but yields of 3 – 15 t DM/ha/year have been noted in recent work. The yield profile of spartina over its lifespan is similar to miscanthus. Moisture contents of harvested material vary from 36 – 69%. Like miscanthus, the crop is established from rhizomes. Spartina offers few advantages over miscanthus and less is known about methods of production.

Lesser researched species

6. Available bamboo genotypes are generally considered to be rather cold sensitive for UK conditions. There are a large number of varieties which are described as hardy or very hardy, although further work is needed to assess their performance for biomass production and to test the viability of establishing the crop from seed. Giant reed (*Arundo donax*) a Mediterranean grass occurring in marshy areas, is claimed to have very high yields of 20 – 25 t DM/ha. Work is underway to ascertain limitations to its production and hardiness in North and West European environments, and to investigate methods of establishment.

7. Several grasses appear to offer some potential for production, although little work has been carried out to assess their biomass utilisation. Pampas grass (*Cortaderia sellona*) was introduced to Europe as an ornamental and is occasionally cultivated elsewhere for fibre production. New Zealand work shows yields of 5 – 7 t DM/ha when the plant is grown as a forage. The limited work on gallingale (*Cyperus longus*) a C4 member of the *Cyperaceae* family, indicates that yields are slightly lower than other C4 crops and that it does not appear to offer advantages over better developed crop options. Big bluestem (*Andropogen gerardii*) and Indiangrass (*Sorghastrum mutans*) are C4 tall prairie grasses like switchgrass and are useful forage grasses. New Zealand flax (*Phorium tenax*) is a member of the *Agaraceae* family which has been tested as a fibre crop. Its winter hardiness would require evaluation before the crop is further developed. Prairie sandreed (*Calamovilfa longifolia*) is claimed to have good yield potential but little further information is available. Prairie grass (*Bromus willdenowii*) gives good yields under relatively high inputs. In USA work several further herbaceous species are noted as showing promise for use including eastern gamagrass (*Tripsacum datyloides*) birdsfoot trefoil (*Lotus corniculatus*) tall fescue (*Festuca arundinacea*) crimson clover (*Trifolium incarnatum*) and timothy (*Phleum pratense*). However no information is available to suggest that any offer advantages over more thoroughly tested giant grass biomass species in UK conditions.

<u>Combustion characteristics</u>

8. There is no indication of substantial differences in calorific value between giant grass species, and values are consistent with conventional straw and vegetation based biomass materials. One of the major quality factors for biomass is moisture content, and there are a range of disadvantages and consequently high costs associated with high moisture content material. A sliding scale for value relating to moisture content similar to that used for biomass wood by Landen (1993) is proposed. Ash content should be as low as possible to minimise boiler slagging. C4 grasses such as miscanthus are found to have a lower ash content than C3 species such as reed canary grass. Delaying harvest helps to reduce ash content of reed canary grass, miscanthus and switchgrass.

<u>Economic assessment of the biomass grasses</u>

9. A critical economic analysis of the giant grasses reed canary grass, switchgrass and spartina is undertaken in comparison with benchmark crops considering their use in moderate farm scale conditions rather than optimal situations. Assumptions in use reflect this critical evaluation. Average yields from trials literature are reduced by 15% to reflect wastage and unused parts of the field and a further 10% yield reduction after year 7 is assumed to reflect the build up of pests, diseases and loss of vigour. Payment for biomass is based on a sliding scale for moisture content. Costs are calculated to the point of harvest and removal from the field, using full marginal costs. Economic comparison of the production of different crops is best made with no support payments included. For completeness however, comparisons are also made with support included, and also where establishment costs are omitted. A 10 year financial lifespan (12 year for coppice) is assumed, as farmers expect payback within this timescale. An extra sensitivity for short rotation coppice over 25 years is also included. The cashflow

generated by each crop is discounted back to a net present value (NPV) using an interest charge of 8% and then converting to an equivalent annual value (EAV), akin to a crop net margin, to allow comparison with other crop options. Years to breakeven are also calculated.

10. The seeded grasses such as reed canary grass and switchgrass are most attractive from a farmer's point of view (both where grants and set-aside payments are excluded or included) as they give more rapid returns on investments. If grown on set-aside they can generate a higher EAV than putting the land into uncropped conventional set-aside. However, neither compete with average yielding cereal crops as long as these receive area payments. At current yields and establishment costs, short rotation coppice and miscanthus will never produce positive margins without support. Even if set-aside payments and establishment grants (at current levels) are paid, margins within a commercial timescale are poor. Miscanthus is rated between short rotation coppice and the seeded grasses where grants and set-aside payments are excluded. A relatively modest biomass price increase or increase in yield would be required to bring spartina to breakeven. Larger increases for miscanthus, short rotation coppice and wheat would be required. A conventional wheat crop with standard levels of inputs is not attractive as a biomass crop when burned for a biomass value of £23/t compared to £60 – 70/t for the conventional grain market.

11. Where biomass crops are compared with establishment costs omitted (possible perhaps through grant, technology improvements or a combination of both) then the ranking order changes. The elimination of the high establishment costs of short rotation coppice, spartina and miscanthus leads to all three having a better EAV than switchgrass, and all but miscanthus having a better EAV than reed canary grass. In none of these analyses are public good issues (such as wild-life habitat benefits of short rotation coppice) taken into account.

Potential

12. When all crops are considered directly, without support, reed canary grass and switchgrass are closer to commercial success than the other biomass crops. They are allocated an overall score of 6+ and 6 respectively on a scale of 1 (poor) to 9 (good). Miscanthus and spartina receive scores of 3+ and 3 respectively with short rotation coppice at 2. No score is allocated to giant reed, bamboo or others as insufficient information currently exists. Barriers to success include difficulties in competing with conventional crops, high costs of production and the necessity for long term commitment of land.

Key future research and development

13. Reducing establishment costs is a key to the future success of biomass crops unless grants and subsidies for investment are continued. Areas for research and development include true seed production and seed viability, multiplication of stems/rhizomes, mechanisation of planting and reliability of establishment technology. Research and development is required on agronomy, to improve yield and varieties. Research on methods to reduce moisture content at combustion is needed. A fuller evaluation of lesser known grasses in UK conditions would be beneficial.

Conclusions

14. Without support, coppice from willow and the giant grass miscanthus do not achieve positive NPVs at current yields and costings. Where support is included, the finanical performance of these two crops is greatly improved but they still do not out–perform all the other less supported crops. Reduction of establishment costs will improve the economic outcome. Like miscanthus, spartina is established using rhizomes; it does not appear to offer advantages to the farmer compared to miscanthus. Reed canary grass and switchgrass, annually cut grasses established from seed, have the best economic profile. Moisture content of biomass material from both can be reduced through delayed harvesting and this may further improve viability. Winter hardiness and performance of bamboo and giant reed is currently being evaluated. For these and other new crops, yield, moisture content and establishment method are important factors and to be competitive with other conventional crops, improvement of these attributes is necessary. Support for the giant grasses in terms of subsidies/grants, similar to conventional crops may also be required before there can be significant uptake by growers.

Scientific report (maximum 20 sides A4)

Chapter 1 Introduction and background

1.1 Selection of species included in the review

The terms energy or biofuel crops describe crops grown specifically for use as a fuel. These may include liquid biofuels (eg rapeseed for biodiesel, cereals/sugar beet for bioethanol) and solid biofuels (eg short rotation coppice and miscanthus) and may also include solid biofuels processed into liquid biofuels – bio–oils. The remit of this work is to consider perennial crops grown for biomass energy production which provide an alternative to miscanthus and short rotation coppice. Since the majority of these are rapid growing members of the Gramineae family, the term 'giant grass' is used. In order to provide a full assessment of potential candidate species, other species with potential for biomass energy production, outwith the grass family, are also included within the remit of this study.

1.2 Background to energy crop work in the UK

There has been considerable interest in energy crops over recent years because of their ability to provide renewable energy which may help to reduce climate change effects and give an alternative land use compared with over–produced food crops. Coppiced willow is the most advanced energy crop grown for northern European conditions and considerable work on short rotation coppice has been carried out in the UK. Since the early 1990s miscanthus has received much attention and there have been studies on several aspects of the crop. Other grasses such as reed canary grass, spartina and switchgrass have also been studied in the UK. Work on these species and other lesser known species of energy crops have also been carried out in Europe and elsewhere, and this work may be applicable to UK conditions.

1.3 Aims of study

The aim of the study is to assess the competitive position of giant grasses for cultivation in the UK. The emphasis is on comparison between the grasses, using miscanthus as a benchmark, in economic and agronomic terms within the context of arable enterprises. The work brings together the disparate pieces of work conducted on giant grasses which have relevance to the UK. Results from these studies are drawn together with the purpose of providing DEFRA with guidance on prioritising resources available for making strategic decisions on research and development to support giant grass commercialisation. Front runners are identified where further research and development is justified, along with those with poor prospects and those with intermediate prospects. Factors necessary for the development of giant grass cultivation as viable arable enterprises are determined.

1.4 Scope of study

The study deals with comparative energy production potential and does not deal with the niche alternative markets of the crops concerned such as fibre for paper and other uses, eg willow baskets, composting potential etc.

It is assumed that an energy plant is on–hand and consequently issues such as biomass transport, biomass storage, seasonality of production, viability of a biomass plant etc are ignored as these issues are largely common to all crops studied. Where there are major differences in quality of produce, this is identified.

Chapter 2 Summary of agronomic review of crops for consideration

2.1 Introduction – wheat, short rotation coppice and miscanthus as bench markers

The crops wheat, short rotation coppice and miscanthus are discussed with the aim of providing a basis for comparison for the more novel energy grasses. Pros and cons of these benchmark crops as biomass energy crops are considered below.

Wheat (*Triticum aestivum*)

Production

Wheat is the UK's most widely grown arable crop with over 2 million hectares cultivated annually. It is suited to a range of growing conditions and is grown in a wide spectrum of agro–climatic areas across the UK. It is conventionally grown for grain, with the straw as a by–product, but very occasionally it may be harvested early for whole crop production. If harvested at maturity, average yields of 7 – 8 t/ha grain and approximately 4 – 5 t/ha straw are obtained. The low moisture content of 16% which may be expected in many conditions would be of advantage in storage, transport and use as a fuel. Wheat is well adapted for UK conditions and knowledge of growing the crop is thoroughly documented. If grown as an energy crop it could be part of the rotation with a range of arable crops for food production.

Inputs

Wheat is an annual crop, necessitating establishment costs each year, unlike perennial crops where the productive life of the crop is much extended. If wheat were to be grown as a biomass energy crop in addition to its present uses as food and feed, rotational constraints and disease, pest and weed pressures may limit the area grown. It should also be noted that in order to achieve the yields above, relatively high inputs of fertiliser and agro–chemicals are required with consequent potential environmental effects.

Short rotation coppice (*Salix* spp.)

Yields

There has been interest in willow grown for short rotation coppice for a considerable time and it is well suited to northern European conditions. Willow is established using cuttings. After a year of growth, the plants are cut back, or coppiced as the technique is known, leaving a stump which is left to re–grow. Harvest of the new shoots can take place every 2 – 4 years. Short rotation coppice may be harvested 6 – 10 times and has a productive life of 25 – 30 years, although yields may decline over this time. The theoretical yield of short rotation coppice is equivalent to 33 t/ha/year and this has been achieved by small scale trials in Sweden. Yields are variable due to variation in soil and climate, with up to 17 oven dried (od) t/ha/year being achieved in UK trials at the first harvest and even poorer sites achieving 8 od t/ha in a national trials network (Armstrong, 2000). It is expected that yield from subsequent harvests will be higher. Yields of 12 t DM/ha/yr were obtained from a well established plantation in Sweden (Larsson, 1996). There seems to be little information available on a UK basis on the yield decline of short rotation coppice over time, due to most plantations being young and current estimated yields in the UK are in the 10 – 12 t DM/ha/year area. It may be possible, however, to increase yields to 15 od t/ha with further breeding and agronomic development (Anon, 2000a).

Moisture content

Water is present in highly variable quantities in wood – from around 70% in green wood to around 12% in kiln–dried timber (Landon, 1993). Moisture content of short rotation coppice at harvest is relatively high at around 50%, which increases costs of transport and burning. Above 56% moisture content (mc) combustion becomes difficult, and storage for a few weeks may be used to reduce moisture content.

Rust (*Melamspora* spp) can cause damage to willow and is considered to be the most serious threat to cultivation. Inclusion of a range of different willow clones in plantings is being investigated as a means of controlling the development of rust infection. Willow can also be damaged by a number of insects – leaf chewing species and those which feed on shoot tips. Selection for resistance to some of these pests may be possible during plant breeding. Taking land out of coppice back into arable production may lead to difficulties for artificially drained land in some circumstances, but it is claimed that these difficulties are less than with other forestry enterprises.

***Miscanthus* spp.**

Photosynthetic pathway

Miscanthus is a perennial C4 grass originating from eastern Asia. Early work within Europe was carried out on *M x giganteus*, a naturally occurring sterile, triploid, interspecific hybrid which was introduced as an ornamental plant in the 1930s. It is believed that *M x giganteus* is a hybrid between the 2 species, *M sinensis* and *M sacchariflorius*. Miscanthus is characterised by relatively high yields, relatively low moisture content at harvest and a low susceptibility to pests and diseases. As it is a C4 plant, it has a high irradiation conversion efficiency and is more efficient in use of nitrogen and water (Anon, 2000b), using only one half as much water per tonne of biomass produced compared to C3 plants. Production will be adversely influenced by low temperatures, but miscanthus is claimed to be better adapted to temperate climates than most other C4 crops. Species studied for their potential in UK conditions are *Miscanthus* x *giganteus, M sacchariflorus* and *M sinensis*.

Yields

After a year for establishment, miscanthus is harvested and subsequently annual harvests can be taken. The theoretical maximum yield of miscanthus is 55 t/ha/year – approximately 60% higher than theoretical maximum yield for the bulk of other arable species, which are C3 crops (Anon, 2000a). This potential yield advantage is however only likely to be expressed in ideal conditions of high levels of radiant energy and temperature. Several series of work have assessed yield of miscanthus in the UK and in Europe.

The miscanthus productivity network, comparing different areas within the EU, indicate a yield (for *M x giganteus*) of over 24 t DM/ha in Portugal, Greece and Italy, where irrigation was applied. The Irish and British sites in the study gave yields of between 11 and 16 t DM/ha (Anon, 2000b). However, further yield information is needed in order to determine the full yield of mature plants over 3 years old. Results from MAFF funded studies in the UK have indicated variation in yield of *M sacchariflorus* from 12 – 24 t DM/ha across 7 sites of varying fertilities over different seasons, with a mean annual yield of 18 t DM/ha at the best sites (excluding the establishment year). It was concluded that yields of 15 t DM/ha on arable land south of a line drawn from the Severn to the Wash could be expected (Bullard and Nixon, 1999). A study with *M x giganteus* in the same work programme indicated that harvested yield capacity with this species may be lower than with *M sacchariflorus*.

Work by Christian et al. (1999) considered the long term yield of a range of grasses including miscanthus, sown at Rothamsted. Yields of *M giganteus* reached 9 – 11 t DM/ha by the third year of harvest and increased to 15 t DM/ha by the sixth year of harvest, when observations ended. An observation plot of *M sinensis* was planted and revealed a similar yield up to the third year, the last reported yield. Later work reported by Christian and Riche (2000) compared third year yields of *M x giganteus*, *M sacchariflorius* and hybrid and non–hybrid *M sinensis*. Certain varieties of *M x giganteus* and *M sinensis* hybrids tended to have higher yields than others producing 11 – 12.8 t DM/ha.

Yields of miscanthus in the year of establishment are low at 2 – 7 t DM/ha, increasing to a peak of maximum production in subsequent seasons (Bullard and Nixon, 1999). The timing of maximum production will depend on location and climatic conditions and may last 2 – 5 years. The time needed to reach yield optima will be longer in more challenging conditions. Yield will tend to decline from 10 years onwards, although miscanthus plants will survive up to 20 years.

The annual harvest of miscanthus gives the advantage that a return from each area of the crop can be achieved each year. Harvest occurs during winter, once the moisture content of the material has declined, allowing the arable farmer to spread the workload to a time away from conventional work peaks.

Factors affecting production

Initial programmes of work were carried out with one genotype, *M. x giganteus,* which showed significant problems of low first winter survival in the early to mid 1990s (Jorgensen and Schwarz, 2000). Low frost tolerance of *M x giganteus* rhizomes is probably the cause of low winter survival in cool parts of Europe, but within the genus miscanthus better frost tolerance has been found to exist. There are no reports of diseases significantly affecting production of miscanthus according to the productivity network (Anon, 2000b), but it is pointed out that if the area of miscanthus grown increases, a greater risk of disease may arise. Fusarium has been observed in Ireland and barley yellow dwarf virus (BYDV) in the UK. Stem basal diseases may infect stems in the autumn or winter, reducing stem strength. No insect pests in Europe significantly affecting production have been reported, but 2 'ley pests', common rustic moth and ghost moth larvae have been noted feeding on miscanthus (Christian and Riche, 1999). It is unclear whether these will cause a bigger problem once miscanthus is grown on a larger area.

M x giganteus and *M sacchariflorius* do not flower and set seed in UK conditions, therefore rhizomes or micro–propagated plants are used, leading to very high establishment costs. It is claimed that a newly developed planting machine for miscanthus rhizomes can reduce planting cost substantially (Jorgensen, 1995, Schwarz et al., 1998). This allows larger rhizome pieces to be planted, which will improve survival of *M. x giganteus*. Bullard and Nixon (1999) expect production from rhizomes to become more economically viable if techniques for field scale production of rhizomes are developed.

The miscanthus productivity network found that soil nitrogen supply only had a significant effect on yields after the first 2 – 3 years of growth. Herbicides are required to control weeds during the establishment phase as initial growth is slow. Once the crop is established, weed growth is suppressed initially by the litter layer on the soil surface and subsequently by the closure of the crop canopy. It was concluded that the likely nutrient requirement for an established crop was in the region of 130:20:100 kg/ha N:P:K per year (Anon, 2000b).

Moisture content

Trials across Europe indicate that moisture content at harvest ranges from 25 – 40% in Southern Europe to 30 – 60% in Northern Europe. There is also some genotypic variation, with new varieties of miscanthus genotypes having a moisture content of 20 – 30% at harvest compared to 44 – 50% for *M. x giganteus* (Anon 2000b). High rainfall and humidity during winter in the UK indicate that moisture contents below 50% may not be achieved unless some form of stem conditioning is undertaken (Bullard and Nixon, 1999). Miscanthus can be stored in the form of various lengths of chips, bales, bundles or pellets, with bales being convenient for energy cropping. The maximum moisture content for short term storage has been assessed at 25%. For storage of one year or more the maximum moisture content is only 18% mc (Anon, 2000b). Some reduction of moisture content will occur during storage, but if some form of drying is required, this will add to costs.

2.2 Alternative giant grass species

Reed Canary Grass (*Phalaris arundinacea*)

Distribution and characteristics

Reed canary grass is a C3 plant, widely distributed across temperate regions of Europe, Asia and North America and is used, to a minor extent, as a forage crop. It can be grown on less well drained soils where traditional forage grasses are less suitable and is also drought tolerant with good cold hardiness. The large amount of rhizomes produced by the crop give the soil good load bearing capacity and enables easier travel on the ground in wet conditions. It is reported that reed canary grass removes nitrogen more efficiently from the soil than any other cool–season grasses and often produces the highest percentage crude protein analyses amongst grasses at similar stages of maturity (Antony et al., 1993).

Yield

Chisholm (1994) reported from a number of trial programmes, that yields varied between 4 and 12 t/ha DM in the USA, Canada, the UK and Sweden. Trials in Canada have given yields of 7 – 12 t DM/ha from an autumn harvest (Samson et al., 2000). Christian et al. (1999) grew an observation plot of reed canary grass over a 6 year period at Rothamsted. Yields from harvest in winter each year gave an average of 8.1 t DM/ha for the variety Palaton with a minimum of 6.42 t DM/ha in the first year following sowing and a maximum of 12.47 t DM/ha in the second year. Yields in years 5 and 6 showed a slight decline to 6.6 – 6.9 t DM/ha. A further report by Christian and Riche (2000) indicated a slightly higher yield of 7.90 t DM/ha for reed canary grass from the observation plot, and suggested that this may be due to good weather in the further year of harvest.

Moisture content ranged from 76% in the first year due to immature plants, with an average of 33% over the following 5 years (Christian et al., 1999). The presence of green shoots, due to a lack of winter dormancy, at harvest increased moisture content of the samples.

Delayed harvesting technique

An EU funded AIR project has considered the effect of delaying harvesting until spring, instead of autumn, and also evaluated new varieties. Yields from the AIR project indicated yields of between 5.4 and 9.5 t DM/ha for Palaton and 7.2 – 11.6 t DM/ha for an alternative higher yielding variety at sites throughout northern Europe. Delaying the harvest from autumn to spring decreased yield expressed on a dry matter basis to approximately three–quarters of the autumn level, but resulted in an increase in actual dry matter content to around 85% in Northern sites. However, the authors acknowledge that the yield from these sites is rather uncertain due to the small plot size of 1.25 x 2.25m (Olson and Landstrom, 2000). Green shoots found in harvested samples from western regions of the EU trial decreased the quality of the product for energy or paper (Olson and Landstrom, 2000). The delayed harvest technique also decreased mineral content, particularly silica, potassium and chlorine, by permitting leaching of the plant material over winter. This allows nutrients to be recycled to the soil for the next growing season (Samson et al., 2000).

Yields from a trial at Aberdeen by SAC (unpublished) with the variety Palaton, indicated that up to 9.5 t DM/ha could be attained. This was from the first harvest date in September and was associated with a moisture content of 55%. Later harvest dates from December onwards lowered the moisture content to below 28%. Yields from December to March remained at 8.5 – 6.8 t DM/ha.

Yield profile

Reed canary grass reaches high dry matter production levels earlier than miscanthus and the first real yields are achieved after 2 – 3 years (Olson and Landstrom, 1999). Christian et al. (1999) commented that its yield profile was quite different to other perennial grasses tested at Rothamsted in that the yield increased rapidly and reached a maximum the year after planting. Yield subsequently declined, but it was unclear whether this was a normal yield pattern. Cumulative yields from reed canary grass over the 6 years of study were less than that currently obtained from short rotation coppice, unlike the other grasses compared in this work. Trials were undertaken on a farm–scale field in Finland with the variety Venture (Pahkala and Mela, 2000). It was found that the crop took at least 2 years to reach full growth and yield. Yield remained relatively constant for 6 years under the delayed harvest at 6 – 9 t DM/ha when harvested in spring from the second to the eighth years. This compared favourably to other forage grasses whose persistence is normally 4 – 5 years.

Moisture content

Harvest moisture content is potentially lower than the other winter harvested species. In the EU project a target for DM content was set at 85%, with 70% being regarded as the threshold for acceptability for storage, however this target was difficult to reach in Ireland and the UK (Olson and Landstrom, 2000). The AIR project showed that a delayed harvesting method was a possibility, but further analysis would be required to make recommendations to growers.

Factors affecting production

Larvae of the *Opomea* grass moth killed some early shoots and regrowth was leafier with lower biomass in UK trials (Christian et al., 1999). It was concluded that control will add to production costs. Lodging at Rothamsted was also a problem having the effect of restricting drying of the crop and increasing spoilage. These factors were considered to pose significant problems for further development. Lodging or leaning also occurred to some extent for all varieties in the EU project (Olson and Landsrom, 2000).

Reed canary grass has the advantage of being established from seed and hence is less expensive to establish than miscanthus. A ‘minimal input’ of fertilisers, irrigation and pesticides was reported in the AIR project with an average annual supply of around 90 kg N/ha and P and K applications adjusted to site requirements. Pahkala and Mela (2000) considered that application of 200 kg N/ha/year was not economic as it did not provide an adequate yield response; 70 – 100 kg N/ha/year was closer to optimum. Further trials by Pahkala et al. (2000) investigated N applications on different soil types, and revealed that reed canary grass yields responded up to the 150 kg N/ha tested on a clay soil, but on an organic soil with high mineralisation rate the need for N fertiliser was reduced.

There is no indication that there will be difficulties in taking land out of reed canary grass. Christian et al., (1999) commented that reed canary grass readily sheds seed which may spread and become a volunteer problem when crops are destroyed.

Switchgrass (*Panicum virgatum*)

Distribution and characteristics

Switchgrass is a perennial sod–forming warm–season C4 grass originating in the tallgrass prairies of North America and found from the Gulf coast to Canada. It is the predominant pasture species of the southern US corn belt. Experience in Canada suggests that at present switchgrass production is confined to areas suitable for maize silage production. There are 2 main types; the upland type has relatively thin stems and grows to 3 – 5 feet and the lowland type has a thicker stem and grows to 5 – 8 feet (Moser and Vogel, 1995). Christian et al., (1999) concluded that miscanthus and switchgrass are the best choices for low input sustainable production. Switchgrass was lower yielding than miscanthus but cheaper to establish. Work by the Biofuels Development Programme in Tennessee, USA has selected switchgrass as the herbaceous species on which field work is focussed (McLaughlin, 1997). In the US it is noted for growth in late spring and early summer and as with other C4 grasses, this will be the most productive time. In contrast, cool season temperate grasses begin to grow earlier in the spring and may grow for longer in the autumn. Warm season, perennial grasses such as switchgrass can tolerate low fertility better than most cool season grasses (Moser and Vogel, 1995). Switchgrass can also be used to control erosion and is beneficial for wildlife (Wolf and Fiske, 1995).

Yields and moisture content

There are many varieties of switchgrass available which may be suited to different conditions. Yields from a programme of studies in the US, gave average yields for the best adapted varieties of approximately 16 t DM/ha using a 2 cut per annum system (McLaughlin et al., 1999). This technique uses cutting at flowering followed by cutting in October or November, however further work indicated that maintenance of a deep rooting system may mean that the one cut system is superior in variable climates over time. It does not appear to have been tested in UK or European conditions. Yields in Canada indicated 6 – 13 t DM/ha/yr can be achieved depending on harvesting regimes and that, as for reed canary grass, the preferred harvest period may be spring (Samson et al., 2000).

An EU funded project is investigating the introduction of switchgrass as an alternative energy crop with sites at Rothamsted in the UK, The Netherlands, Greece, Italy and Germany (Anon, 1999a). Trials with several varieties have been carried out at Rothamsted in the UK (Christian et al., 1999), where some varieties yielded up to 12.5 t DM/ha in the final year of the experiment. The lowest yielding variety at this time gave 8.7 t DM/ha, demonstrating the large difference in yields and implying that there is varietal variation in suitability to the UK. Moisture content from the Rothamsted work was between 47 – 57% depending on variety. A yield average of 10.5 t DM/ha was recorded with some varieties yielding 11 – 12 t DM/ha. Moisture contents were higher than previously recorded (39 – 53 % depending on variety) due to damp conditions at harvest (Christian and Riche, 2000).

Yield profile

The growth of the crop is slow in the first year, which makes it vulnerable to weed competition. In work carried out in the US, McLaughlin et al. (1999) indicated that stands were not harvested in the first year following establishment, reaching two thirds of their capacity in the second year and full yield potential in the third year. Yields have continued to rise for the 6 years of the experiment by Christian et al., (1999) so optimal yields have not yet been fully elucidated.

Factors affecting production

Some lodging was recorded at the Rothamsted site (Christian et al., 1999). For some of the varieties lodging was quite severe, but it was not possible to quantify yield loss and some recovery to lodging occurred. Barley yellow dwarf virus was also noted.

Although switchgrass has been noted to have high levels of seed dormancy, this can be removed by stratification or allowing adequate time for after–ripening (McLaughlin et al., 1999). Switchgrass can be propagated by seed, and is hence less expensive to establish than miscanthus. Control of weeds in the first year can be achieved by mowing to 10 cm in May. Once established, the crop is more competitive, but less so than miscanthus, due to it being shorter, producing no litter and having later shoot emergence. Nitrogen, phosphate and potash should be applied for maximum yields (Anon, 2001a). However, Christian et al. (1999), found no yield response to nitrogen application. This was confirmed in a later report (Christian et al., 2000) which showed no significant difference in yield between 0 and 60 kg N/ha. Grasshoppers and leafhoppers can be major pests in new seedlings in North America, but there are no reports of pests in the UK. Switchgrass can be affected by damping off and seedling blight and leaf rust is occasionally a problem, but less so for lowland types which are more resistant to rust.

Switchgrass has the potential to become a perennial grass weed, but reports from the US indicate that it does not spread easily.

***Spartina* spp (Cord grass, marsh grass, prairie cordgrass)**

Distribution

Species of spartina, a rhizomatous, perennial grass, occur naturally in W Europe, N America and Africa as pioneer colonists of muddy coastal salt flats. *S cynosuroides* is found on salt or brackish marshes and *S pectinata* on marsh shores or wet prairies. Unusually, for C4 species, they have natural distributions into cool temperate regions and are likely to be well suited to mild wet climate areas in Europe. They are relatively high yielding compared to most grass species with low fertiliser requirements and have greater adaptability to adverse soil conditions.

Yields

Some experimental plantings have given yields of up to 18 t DM/ha in E England (Jones et al., 1989). Annual yields of 1.1 kg/m2 (11 t DM/ha) for *S cynosuroides* and 1.3 kg/m2 (13 t DM/ha) for *S pectinata* were noted from trials undertaken in Essex in the 6 years following establishment (Potter et al., 1995). A low yield of 2.7 t DM/ha in the first year of production, rising to 15.6 t DM/ha in year 6 was obtained from an observation plot at Rothamsted (Christian and Riche, 1999). Spartina yield increased over the 6 year experimental period reported by Christian et al. (1999), after growing slowly in the first year as for the other perennial grasses. The timecourse of yield development was similar to miscanthus and switchgrass but production was higher than for reed canary grass and switchgrass.

Moisture content

Dry matter production in spartina is at its highest in August, but declines towards maturity as photosynthates are translocated to underground rhizomes. Dry matter content rises rapidly in winter to approaching 80% in February (Anon, 2001a). Moisture content of harvested material from the Christian et al. (1999) work was 36% over a 5 year period from 1993 – 1997, and was 68% in 1998.

Factors affecting production

Barley yellow dwarf virus (BYDV) is known to affect spartina, but there is no information on likely yield penalty. In the Rothamsted work fairly severe lodging was observed. Again there is little information on which to base the effect on yield, but lodging susceptibility was considered to present a barrier to selection (Christian et al., 1999).

Rhizomes have been used to establish the trials discussed, but there appears to be potential to establish the crop from seed. Seed is produced by *S cynosuroides* and *S pectinata* in the UK, but it is light and of low germination, giving problems for direct sowing (Christian et al., 1999). Work by Samson et al. (2000), in Canada with *S pectinata*, a native in North America agree that it has significant seed establishment problems. Hence establishment costs for spartina are likely to remain high. The subsequent annual growing costs for spartina appear low, with no response to N fertiliser noted over a 3 year period (Christian et al., 1999). Spartina may be more susceptible to weed competition, as the rhizomes are slow to spread. The authors of this work conclude that spartina offers few advantages over miscanthus and less is known about methods of production. Other evidence would not suggest otherwise.

2.3 Lesser Researched Giant Grasses

Bamboo

Distribution

There are over 1500 varieties of bamboo found in all parts of the world apart from Europe. Most are native of China and the Far East although some originate from South Africa and South America. Around 400 genotypes of bamboo have now been introduced to Europe. Bamboo can be found growing in many old British gardens often having been introduced during Victorian times and selected for their attractive bark and growth habit. Both the Royal Botanical Gardens at Edinburgh and Kew contain reference collections of Bamboo.

Anecdotally they are considered to be rather sensitive for UK conditions but this is not true of all varieties. Approximately 300 varieties are described as hardy or very hardy. The very attractive dwarf bamboos (*Pleioblastus*) are sensitive above ground to frost and this may account for the widespread belief of their non–hardiness.

Most hardy bamboo will remain green during a ‘normal’ winter (–10^{o}C to –16^{o}C) but where there are prolonged periods of heavy frost – particularly when accompanied by strong and dry winds – then leaf burn will result. Those classified as ‘very hardy’ can withstand temperatures of –30^{o}C.

Classification

Bamboos can be classified by appearance as follows:

Decorative ornamental bamboo
Dwarf bamboo
Broad leafed bamboo
Giant bamboo

Alternatively, their botanical classification is as follows:

Genus Phyllostachys	Vigorous and fast growing – some are wind resistant
Genus Semi–arundinaria	A strong evergreen – very hardy
Genus Pleioblastus	Dwarf bamboos, hardy
Genus Sasa and Pseudosasa	Broad leaved, soft evergreens
Genus Arundinaria/Fargesia	Mostly decorative and very hardy

Winter hardiness

In 1994, the Scottish Bamboo nursery was established in West Aberdeenshire. The 2000/2001 winter was the hardest for over 25 years and has allowed a natural assessment of extreme winterhardiness under UK conditions. Informal discussions with nursery staff have identified those species which couple biomass production with good winterhardiness. The following appear worthy of assessment in terms of biomass production potential.

Phyllostachys	*Bissettii*	
Phyllostachys	*Nigra*	Varieties ‘Henonis’ and ‘Borgana’ but not ‘Punctata’
Phyllostachys	*Vivax*	

Most bamboos have been classified in terms of their attractiveness for gardens. There is a dearth of information of their performance in a biomass situation.

Evaluation

An EU programme has been evaluating production of Bamboo in Europe. Emphasis is placed on laminated products and construction materials for low cost housing. Four geographic areas have been selected for planting experiments – 2 in North Portugal, one in the north of Spain and one in Belgium, however no information is available on production of a bamboo biomass crop in northern Europe. According to the EU project bamboo can produce an average of 10 – 15 t DM/ha annually (Anon, 1999b), but this is yet to be verified.

From a managerial point of view, bamboo tends to emulate other giant grasses such as miscanthus in that it is harvested annually and is vegetatively propagated. Cost of individual plants is high however, as nurseries are catering for a market where customers buy one or two plants rather than a number sufficient for several hectares. Economies of scale would reduce current costs of plant material. In addition, some varieties may set true seed under certain conditions. It is not clear how dependable this would be in terms of field crop establishment for biomass purposes.

Giant reed (*Arundo donax*)

Distribution

Arundo donax is a Mediterranean grass from the Poaceae family and grows large enough to be mistaken for sugar cane. Within Europe it is native to Greece and Italy and is quite common in the Mediterranean where it occurs in marshy areas by rivers. It may be used for paper production and for construction of building materials in addition to use as an energy crop.

Evaluation

In suitable conditions it is claimed to be capable of yielding 20 – 25 t DM/ha annually (Anon, 2001a). A European network is investigating improvement of biomass production and quality at several sites including ADAS Arthur Rickwood in the UK. Yields of up to 40 t DM/ha from certain unimproved populations are cited (Anon, 2000c). Maximum yield values of 50 t DM/ha from irrigated experimental plots were reported in Italy, and great variability in performance between clones was noted, implying that there is a possibility of selecting clones for adaptation to different climates (Anon, 2000a). One of the aims for the European project is to establish limitations to production in Northern and Western EU environments. There is conflicting information on the hardiness of the crop with some reports claiming it is hardy only in the milder areas of Britain and others claiming it is hardy to –5 to –10°C. *A donax* is also under investigation in Cornwall for paper production.

A donax does produce seed and the European project will also investigate the most successful and cost effective method of establishment. Propagation by seed may be possible in glasshouse conditions but this has not been tested in the field.

Pampas grass (*Cortaderia selloana*)

<u>Distribution</u>

Pampas grass originated from the temperate areas of South America. It was introduced to Europe as an ornamental and is frequently grown to provide a focal point in a lawn. It is hardy to around
-20°C, but cannot stand prolonged periods of cold weather or an excessively wet winter (Anon, 2001b). It is dioecious and for seed production, both male and female plants must be grown.

<u>Utilisation and Yield</u>

It is occasionally cultivated for fibre which is derived from the leaves and can be used in paper production. For this purpose the leaves are harvested in the autumn and soaked in water before making into a yellow paper. In New Zealand, the Maori have used pampas grass for making mats and other materials. Work has determined that it has, broadly, a similar nutritive characteristic to hay in New Zealand. Yields were variable, seldom exceeding 7.5 t wet weight/ha from established plantations after 4 – 6 years of growth, and an open stand was estimated to yield 5.2 t DM/ha (Bilkey, 1983). Pampas grass can also be used as a ground shelter for livestock in New Zealand. There are however, no records of its use in biomass production. It appears to offer little to UK biomass producers.

Galingale (*Cyperus longus*)

<u>Distribution and utilisation</u>

Galingale is a member of the *Cyperaceae* family and is found in Europe and Egypt. It grows by water in ditches and marshy places and is hardy to around –15°C (Anon, 2001b). Its leaves can be used in basketry, the root and stems in perfumery – it was a favourite spice in Medieval times – and the fibre in paper making.

<u>Yield</u>

Galingale is a C4 rhizomatous species and has created interest due to its natural distribution in cool temperate regions. It was evaluated by Potter et al. (1995) as a biomass crop in comparison with spartina at 2 sites in Essex. It established well and in the 6 years following establishment, yielded an average of 1.0 kg/m^2 (10 t DM/ha), slightly below the 1.1 and 1.3 kg/m^2 average for *Spartina cyanosuroides* and *S pectata* respectively. Galingale was propagated using rhizomes. The work demonstrated that Galingale could be established as a potential biomass crop, but on the limited evidence available its yield appears slightly lower than other C4 crops and it does not seem to offer any advantages over better developed crop options.

Big bluestem (*Andropogon gerardii*)

Distribution

Like switchgrass, big bluestem is a C4 warm season grass native to North America that predominates in the tall grass prairie (Moser and Vogel, 1995). It has a similar range to switchgrass and is most abundant in the Great Plains states. It is a valuable forage crop in the US and is also used for wildlife conservation purposes.

Input requirement

Propagation is from seed, which would lower establishment cost compared to other grass options. Fertiliser recommendations for big bluestem at establishment are 45:45:45 kg/ha N:P:K and 90:56:135 kg/ha N:P:K per year for improved, established plantations where the nutrient status is low (McLaughlan, personal communication 1994). Nutrient application can be reduced for soil with a higher nutrient status. Yields are noted to vary considerably due to soil and precipitation differences, but no record of actual yield could be found. Several diseases and pests of big bluestem are noted including leaf spot or blotch caused by *Phyllostricia andropogonia* and the big bluestem midge (*Contarinia watti*), which has reduced seed yield. No information is available on this grass species being used as a biomass crop.

Indiangrass (*Sorghastrum nutans*)

Distribution

Indiangrass is a third tall warm season C4 grass from the American tall grass prairie and with switchgrass and big bluestem is an important pasture grass in the Great Plains states (Moser and Vogel, 1995).

Propagation

It is propagated by seed, but it is noted that some seed lots have considerable dormancy. It initiates spring growth at the same time as big bluestem but does not develop as quickly. It appears to be closely related to the sorghums and contains cyanogenic glucosides which mean that it should not be grazed as a pure stand. No information is available on yield or suitability as a biomass.

New Zealand flax (*Phorium tenax*)

Distribution

New Zealand flax is a perennial monocot and a member of the *Agavaceae* family. It originates in New Zealand, where it is found in lowland swamps and intermittently flooded land. This species can withstand temperatures down to around –11°C, and may be killed in a cold winter. It is naturalised to the relatively mild south west of England and has also been used as a shelter belt on the West coast of Ireland (Darling, 1955).

Utilisation

Fibre can be obtained from the leaves of New Zealand flax and may be used in the manufacture of ropes and paper (Anon, 2001b). Commercial extraction of fibre has been considered, but this is limited by the presence of a gum in the leaves. New Zealand flax has been tested as a fibre crop in the US, but it was concluded that commercial production could only be encouraged by the introduction of varieties with higher yields (Puri, 1960).

Again, no records are available to demonstrate usefulness as a biomass crop. There do not appear to be any indications that New Zealand flax would give particular advantages over the more extensively studied biomass crops.

Prairie sandreed (*Calamovilfa longifolia*)

Prairie sandreed is another C4 grass originating in North America. With spartina, it was considered by Samson et al. (2000) to be better adapted than switchgrass to the cooler and drier regions of Western Canada. Seedling vigour problems have to be overcome, but it is claimed to have good yield potential.

Prairie grass (*Bromus willdenowii*)

Herbage production and sward quality of prairie grass was compared with perennial ryegrass and hybrid ryegrass at 3 sites in Scotland in a 3 year trial (Frame and Morrison, 1991). A 6–cut and a 4–cut per year experiment was carried out with a correspondingly high nitrogen application of 350 kg/ha/year. Prairie grass gave the highest annual dry matter yield at the west of Scotland (Ayr) site averaging 11.99 and 15.62 t DM/ha for the 6 and 4 cut regimes respectively. This compared
favourably with the ryegrasses, particularly in the 6 cut system where 8 – 10 % higher yields were achieved. This yield advantage for prairie grass confirms work in England and France reported by Frame and Morrison (1991). Winter kill was however a problem at the colder Edinburgh site. The plant has been considered as a specialist forage for milder areas, but there is no evidence of evaluation as a biomass energy crop.

2.4 Minor giant grass species

Although switchgrass was identified as the leading candidate in the US several further herbaceous species were noted as showing promise for bioenergy use in a review undertaken by the USDA, (Kopp, 1999). These include eastern gamagrass, birdsfoot trefoil, tall fescue, crimson clover and timothy.

Eastern gamagrass (*Tripsacum datyloides*)

Eastern gamagrass (also known as sesame grass) is grown as a forage grass in the US. It is a tall grass of wet habitats and is fairly hardy, withstanding severe frosts in the south of England. It has been associated with good daily gains of livestock, but limited information indicates low yields (Anon, 2001b). Difficulties in seed production, seed quality and establishment (Voigt and Sharp, 1995) would also seem to limit its potential.

Birdsfoot trefoil (*Lotus corniculatus*)

Birdsfoot trefoil grows throughout much of Europe and North America and on many different types of soil. It is well adapted to cultivation as a forage usually in combination with grasses and in some areas of the US has replaced much of the red and white clovers for this purpose. As a legume it fixes nitrogen which can contribute to higher forage yield of companion grass species (Beuselinck and Grant, 1995). Lodging, disease and frost heave can be problems when it is grown in pure stands. Available information indicates a yield of 50 – 80 % compared to alfalfa when grown for hay, with alfalfa yielding 8 – 15 t/ha in suitable growing conditions (Barnes and Sheaffer, 1995). This is equivalent to 4 – 12 t/ha. No further information on its use as a biomass crop could be found.

Tall fescue (*Festuca arundinacea*)

Tall fescue (*Festuca arundinacea*) is described as more robust than meadowfescue, more drought and cold tolerant, more competitive with weeds and suitable for a wider range of soils (Slepner and Buckner, 1995). Yields however are given as only 3 – 10 t/ha with autumn growth of tall fescue remaining green. This is claimed to give advantages for winter grazing, but may be less beneficial for biomass utilisation.

Crimson clover (*Trifolium incarnatum*)

Crimson clover (*Trifolium incarnatum*) is native to Southern Europe and has good seedling vigour and ease of establishment with early maturity. It is an annual, therefore will not compete with the other species considered in this study. In addition, yields of hay from crimson clover appear low at 3 – 6 t/ha (Hoveland and Evers, 1995) and it does not appear to offer advantages for biomass production.

Timothy (*Phleum pratense*)

Timothy (*Phleum pratense*) is a cool warm season forage grass widely grown in cool moist areas of North America and Europe as a forage. It can withstand cold temperatures giving advantages over other less hardy species such as alfalfa (McEvoy and Kunelius, 1995). Dry matter yields compare with other forage grasses, and it does not appear to offer many advantages over other more comprehensively tested biomass crop species.

Chapter 3 Combustion characteristics

3.1 Calorific value

There is little to indicate substantial differences in calorific value between giant grass species. A study comparing miscanthus, spartina, reed canary grass, and switchgrass found that the calorific values are consistent with conventional straw and vegetation based material in general (Christian and Riche, 1999). Work by Kristensen (1998) also found the thermal value of miscanthus to be the same as straw.

Calorific value of straw is compared with other fuels in Table 3.1 below. These figures demonstrate the low energy densities of biomass fuels and show that straw and similar biomass materials are low grade compared to fossil fuel such as coal and oil.

Table 3.1 Estimate of calorific value compared to other fuels

Fuel	Energy/unit weight	Density	Energy Density	Unit Price Delivered	Price/GJ	Price/m^3
	MJ/kg	kg/m^3	MJ/m^3	£	£/GJ	£/m^3
Coal (domestic)	33	1300	42900	120–240/t	3.64–7.27	156–312
Coal (industrial)	33	1300	42900	35–70/t	1.07–2.12	46–91
Gas Oil	42	835	35070	0.12/l	3.42	120
Wood	14	300	4200	27/t	1.9	8.1
Straw	14	150	2100	30/t	2.14	4.5

Adapted from Landen (1993)

For miscanthus, 1 kg of crop dry matter equals around 0.4 kg of oil in energy content, when burnt as fuel. The power output of 1t of DM of miscanthus when burnt is approximately 1.67 MWh. (Anon, 2001a). With an energy density of 18.2 MJ/kg miscanthus is comparable to other combustion materials such as straw when co–combusted with coal to produce energy.

3.2 Quality aspects

Studies agree eg Nordin and Kjellstrom (1996); Lewandowski and Kichener (1997) that one of the major quality factors (if not the single major quality factor) for biomass is the moisture content. Crops with higher moisture content use more energy in evaporation of moisture and have less available energy for heat or power generation. Storage problems, plant malfunction, impeded ignition, poor combustion and consequently higher process emissions are also associated with high moisture content biomass. A maximum limit for good combustion of giant grass material is around 22 – 25% and it was suggested that a maximum level in the order of 35% moisture content should be set by operators (Christian and Riche, 1999). Lewandowski and Kicherer (1997) concluded that the maximum moisture contents should be 23% for straw–like material and 30% for woody material. Landen (1993) proposed that volume purchasers of biomass wood should adopt a sliding scale relating to fuel moisture content, penalising wet fuel. A benchmark figure of 25% moisture content for the UK was noted. Contracts that were offered to ARBRE growers of short rotation coppice were based on £18–20 per oven dry tonne with the harvested material being delivered at 30% moisture content or less. Deductions were to be made according to moisture content (Holmes, C., personal communication 2002).

Ash content for biomass should also be as low as possible as boiler slagging of high ash fuels can be a problem (McLaughlin et al., 1999). The presence of minerals can cause corrosion and slagging. The emissions from combustion increase as the content of nitrogen, sulphur, chlorine, potassium and calcium within the feedstock increases. A high ash content decreases the heating value and also leads to heat loss (Lewandowski and Kicherer, 1999). Ashes from biomass have a lower melting point than those from coal and melting of ash can lead to slagging or fouling of the combustion chamber. Lowering potassium and calcium content may help to increase the ash melting point.

Work in Denmark shows that the ash and silica content from miscanthus was generally lower than from cereal straw (Kristensen, 1998) and that a more regular and clean combustion was obtained due to the looser texture of the bales allowing better air access. Nitrogen content of biomass should not exceed 1% in gasification systems (Lewandowski and Kicherer, 1997). The UK miscanthus crop is within this threshold on average, except for first year biomass yields.

This fits with the view that since first year yields are low it may be prudent to delay harvest until the second year after establishment (Bullard and Nixon, 1999).

Quality features are noted in Table 3.2 where this information is available for species.

Table 3.2 <u>Table of quality features</u>

Crop	Cellulose %	Hemicelluloses %	Lignin %	Ash %	Other %	Hot water soluble %
Miscanthus	44	24	17	1.5	13.5	
Reed Canary Grass	28	22	14	8 (a high percentage of this is silica)	28	
Switchgrass	25			1.3		21

Anon, (2001a)

Silica is the largest component of ash in perennial grasses and silica content is a feature which varies considerably between species. Silica rich feedstocks complicate the recycling of chemicals from recovery boilers, increase maintenance costs and shorten the lifespan of machinery (Samson et al., 2000). Silica comes into contact with biomass feedstocks through surface deposition due to soil contamination and through water uptake by passive water flow and metabolic processes. Monosilicic acid is taken up by perennial grasses in water and is responsible for silica content in the resulting biomass. Warm season C4 grasses use only half as much water as C3 grasses per tonne of biomass produced and the decreased water usage reduces the uptake of monosilicic acid resulting in lower ash content of the biomass. C3 species investigated by Samson et al (2000), reed canary grass and Phragmites were found to have more than twice as much ash content as the C4 species, prairie cordgrass, switchgrass, big bluestem, prairie sandreed and miscanthus.

Later harvest of crops has been shown to result in biomass with lower nutrient levels as these are translocated to roots/rhizomes or crowns. This has been shown for reed canary grass (Olson and Landsrom (2000), miscanthus (Lewandowski and Kicherer, 1997) and switchgrass (McLaughlin et al., 1999). It reduces ash content of the feedstock which is an advantage where boiler slagging of high ash fuels can be a problem. Increasing the stem:leaf ratio can also help to reduce ash content.

Chapter 4 Economic assessment of the biomass grasses

4.1 Key baseline financial results

Aim

The aim of this study is to assess the competitive position of giant grasses with the more widely studied biomass crops miscanthus and short rotation coppice. This section aims to present a financial assessment of the production from these crops. In order to do this evenhandedly, crops should be compared without subsidy as differing subsidy levels for each crop will skew the comparison if subsidy were to be included. However, for completeness, a comparison of the same crops is presented with subsidy included, and also where establishment costs are ignored.

Crops selected for this financial assessment are the three "control" crops, short rotation coppice, miscanthus and wheat together with spartina, switchgrass and reed canary grass. These latter three were selected as they demonstrate greatest agronomic potential for biomass production in the UK.

Reed canary grass represents a giant grass established from true seed and switchgrass represents a prairie grass established from true seed well adapted to agro–climatic areas suitable for maize silage production. Spartina is representative of a C4 giant grass adapted to cool temperate conditions.

Assumptions

It is intended that the economic assessment should be a critical evaluation based on moderate field/farm situations rather than optimum conditions.

The approach used in calculating these results is based on the following methodology and assumptions:

Yields

Average yields are assessed from trials literature and corrected into likely field scale harvested yields. This includes a 15% reduction in yield from that achieved in small scale trials to reflect wastage and unused parts of fields, and a further 10% yield reduction from the seventh year of growth to reflect the build up of pests and diseases and the loss of crop vigour. See Appendix 1 for the pattern of yield over time for each crop.

Payment

Payment for the biomass is on a sliding scale dependent on moisture content, based around a core price of £20 per tonne for 25% moisture content. See Appendix 2 for the sliding scale used as the basis for pricing biomass supplied to an energy plant. No variation in price is built in for other characteristics. ARBRE and others have stated that moisture content is an important aspect of pricing.

Costs

The costs are calculated to the point where the crop is harvested and carted off the field. No cost is assumed for transport to the user. Full marginal costs are used i.e. all the extra costs of establishing, growing and harvesting the crop, including machinery and labour on a contract charge basis are derived from Chadwick (2000) and Christian and Riche (1999). Costs for short rotation coppice are also taken from Cook et al (2000). However, no cost for extra management time is included.

The costs of returning land to its original condition, which would normally be built into any investment appraisal, are ignored in this analysis. This in effect reduces the total costs of the short rotation coppice options.

Harvesting is by mower followed by baling (0.5t large square). The only exception is short rotation coppice which is costed as being chopped by a self propelled harvester. Contract charges are shown in Appendix 3 and the full cost breakdown for each crop are shown in Appendix 4.

Support payments

No set aside payments, arable area payments, grants or other subsidies are included in the calculations for Table 4.1a. The comparison of crops with set–aside payments and establishment grants included is presented in 4.1b and a comparison of crops excluding grants and set-aside payments and omitting establishment costs is shown in Table 4.1c. In addition sensitivity analyses for the impact of set aside payments (Table 4.2) and for the scale of annual subsidies or establishment grants needed to allow each one to compete with uncropped set–aside (Table 4.3) are presented. Also the break–even biomass price, the break–even energy price and the yield change required to break–even are all presented at Table 4.4. These are alternative scenarios required to break–even.

Life–spans

The economics aspects of the crops are appraised over a 10 year life and presented in Appendix 5. Commercial farmers will expect payback well within this timescale. A 12 year life is taken for short rotation coppice to match its 4 year production cycle.

As 10 years may be too short for short rotation coppice to achieve its full potential, an extra sensitivity analysis comparing short rotation coppice with reed canary grass over 25 years has been prepared and presented at Table 4.5. The detailed cashflow is in Appendix 6. In the 25 year comparison the reed canary grass is replanted every 7 years.

It should be noted that while 25 years may more accurately represent the productive cycle of a crop like short rotaiton coppice, it does not reflect the economic outlook of investors. Farmers especially, who are considering a range of crop options, will want positive returns in a much shorter timescale. Economic assessments must reflect the investor's outlook.

Economic assessments

In order for the economic performance of the crops to be compared a number of standard economic assessments are presented. The perennial nature of the crops means that economic assessment must take into account the outputs generated and inputs required, known as the cashflow, over the years of the lifespan of the crop. Discounting methodology is used so that the different cashflow patterns of the crops can be compared. The discounting methodology reflects interest charges to give discount factors for each year of the crop's lifespan. An 8% interest rate is used to reflect current borrowing rates and the following resulting discount factors are applied: year 1 – 0.926, year 2 – 0.857, year 3 – 0.794, year 4 – 0.735, year 5 – 0.681, year 6 – 0.630, year 7 – 0.583 year 8 – 0.540, year 9 – 0.500, year 10 – 0.463, year 11 – 0.429, year 12 – 0.397. For the annual crop wheat an annuity factor of 6.71 is used. This is basically a sum of the discount factors for each individual year. These can be summed because the annual cash-flow figure being discounted is constant. The figure generated as a result of the discounting methodology is known as the net present value (NPV). The net present value is the total margin from the crop over the timescale investigated, converted into is equivalent value in today's money.

The NPV is converted to an equivalent annual value (EAV), which is akin to a conventional crop net margin, and allows a more meaningful comparison with other crop options (the returns from which are always expressed on an annual basis). The number of years required to breakeven is also shown (Table 4.1a). The analysis indicates that, with no grants or set–aside payments being allocated to any crop option, the seeded grasses are the only crops to achieve positive EAVs and NPVs. In this economic scenario reed canary grass achieves the shortest time to breakeven, at 3 years followed by switchgrass at 6 years. The other crops studied produced negative EAVs and NPVs. Spartina and miscanthus gave results which were closer to a positive return than wheat for biomass and short rotation coppice. The assessment of approximate years to breakeven indicates that spartina and miscanthus would achieve breakeven in 17 and 50 years respectively. Wheat for biomass and short rotation coppice however, would not achieve breakeven within the conceivable lifetime of a coppice plant, a commercial timescale, where no grant or set–aside payment support is assumed.

Table 4.1a **Biomass crop financial results excluding grants and set–aside payments**

	£ per Hectare Equivalent Annual Margin	 Net Present Value	Approximate Years to Breakeven
Miscanthus	(95)	(638)	50
Wheat for biomass	(154)	(1032)	Never
Reed canary grass	29	192	3
Switchgrass	15	102	6
Spartina	(54)	(366)	17
Short rotation coppice	(137)	(1030)	Never*

Figures in brackets signify a negative result
* "Never" here means not within the conceivable lifetime of the coppice plant.

Cultivation of crops for energy use is permitted on set–aside as this constitutes a non–food use. Therefore such crops are eligible for set–aside under the Arable Area Payments Scheme. The Energy Crops Scheme, run under the England Rural Development Programme, enables qualifying crops to attract an additional grant to assist with establishment. On arable land the rate is £1000/ha for short rotation coppice and £920/ha for miscanthus. The economic assessment of these crops is considered including these grant payments in order to reflect current practice and is presented in Table 4.1b.

All crops will receive set–aside payment but only short rotation coppice and miscanthus currently receive establishment grants. Provision of these grants allows all crops considered to produce positive EAVs and NPVs. Reed canary grass and switchgrass continue to give the best economic performance, using the indicators selected. The inclusion of establishment grant results in a substantial improvement in EAV and NPV for both short rotation coppice and miscanthus, reducing their years to breakeven to 4 and 2 respectively.

Table 4.1b **Biomass crop financial results including grants and set–aside payments**

	£ per Hectare Equivalent Annual Margin	 Net Present Value	Approximate Years to Breakeven	Support included in calculations
Miscanthus	94	633	2	Annual set–aside payments +£920 establishment grant
Wheat for biomass	63	424	1	Set–aside payment alone
Reed canary grass	245	1649	1	Set–aside payment alone
Switchgrass	232	1558	2	Set–aside payment alone
Spartina	163	1091	5	Set–aside payment alone
Short rotation coppice	203	1530	4	Set–aside payment +£1000 establishment grant

When establishment costs are omitted from the analysis, the financial performance of the perennial crops with a high initial establishment cost, such as short rotation coppice, spartina and miscanthus and wheat, which has an annual establishment cost, is much improved (Table 4.1c). In this scenario, spartina, short rotation coppice and miscanthus give a better financial performance than the seeded grass switchgrass. Reed canary grass, also established by seed, gives a similar financial performance as miscanthus. Wheat continues to give the poorest performance, and in this situation it is the only crop giving a negative net present value and equivalent annual value.

Table 4.1c **Biomass crop financial results excluding grants and set–aside payments, and omitting establishment costs**

	£ per Hectare	
	Equivalent Annual Margin	**Net Present Value**
Miscanthus	63	420
Wheat for biomass	(22)	(145)
Reed canary grass	64	429
Switchgrass	50	339
Spartina	103	692
Short rotation coppice	85	638

4.2 Sensitivity analyses

It is assumed that growers will primarily consider energy crops as an option for set–aside, since there are a range of other crop options which can be grown under the Arable Area Payments Scheme (AAPS) on other arable land and which attract the higher AAPS payment. In order to provide an unbiased economic comparison of the different crop options it is necessary to consider the performance of the crops on set–aside, but without crop establishment payments, which can only be claimed for short rotation coppice and miscanthus.

A valid test for economic viability is to consider the performance of a crop compared to likely alternative uses of the land. An energy crop grown on set–aside will have to compete with the margin which could be gained from set–aside alone to be considered as a viable alternative for cultivation. Natural regeneration is selected as the management practice for set–aside, requiring no seed input and cost. Inputs with this management approach are limited to weed control using herbicide. The level of additional funding if any, required to allow each crop to be competitive with set–aside alone is then elucidated.

An important economic sensitivity analysis is to determine the output required to balance the inputs involved in growing the crop, so that viability can be ensured. For an energy crop these outputs are the biomass price, yield and energy price.

The economic analyses indicated in Tables 4.1a and 4.1b already take into account a 10 – 12 year lifespan for the crops, which should be a sufficient period to justify investment. Considering a longer lifespan allows analysis of economic sensitivity to the costs of re–seeding for the seeded grasses compared to vegetatively propagated crops which will incur no further establishment costs.

Further economic analyses were undertaken with the aims of :

- determining the viability of the different crop options without crop establishment grants applied differently to the crops
- evaluating the level of subsidy required to allow each crop to compete in economic terms with uncropped set–aside
- evaluating the breakeven biomass price, yield and energy price for each crop
- considering the longer term comparison between a seed propagated biomass crop, reed canary grass with a vegetatively propagated crop, short rotation coppice.

Key results are shown in Tables 4.2, 4.3, 4.4 and 4.5

When establishment grants are excluded from calculations but set–aside payments are retained, it can be seen that miscanthus does not produce a positive EAV or NPV (Table 4.2). The years to breakeven increase to 16 compared to 2 when the establishment grant is included (as shown in Table 4.1b). The performance of short rotation coppices declines, when establishment grants are excluded, but the equivalent annual margin and net present value remain positive. These indicators however show a higher level of economic performance than wheat for biomass. Approximate years to breakeven are 8, as compared to 4 when establishment grants are included.

Table 4.2 **Impact of set–aside payments on biomass crop financial results (excluding establishment grants)**

	£ Per Hectare		Approximate
	Equivalent Annual Margin	Net Present Value	Years to Breakeven
Miscanthus	(33)	(219)	16
Wheat for biomass	63	424	1
Reed canary grass	245	1649	1
Switchgrass	232	1558	2
Spartina	163	1091	5
Short rotation coppice	80	604	8

Assumptions used in calculating the above are exactly the same as those for table 4.1, but with area aid of £217 per ha per annum added to the income from each crop.

A comparison of performance of the crops with uncropped set–aside (Table 4.3) indicates that reed canary grass and switchgrass are competitive with this option and would require no further funding to provide a return in excess of that achievable from set–aside alone. All other crops require further output to ensure they are competitive. If the extra output is to be supplied as additional subisdy, this could either be provided as an annual payment or as a one–off start–up grant. Spartina would seem to require the smallest payments, followed by short rotation coppice and wheat for biomass. With its high establishment costs miscanthus requires the largest payments.

Table 4.3 **Extra subsidy required (over and above set–aside payment) to allow the crop to compete with uncropped set–aside* (excluding establishment grants)**

	£ Per Hectare	
	As an Annual Payment	As a Start–Up Grant
Miscanthus	250	1675
Wheat for biomass	154	1031
Reed canary grass	–	–
Switchgrass	–	–
Spartina	42	284
Short rotation coppice	152	1145

* i.e. to generate an annual margin of £217 per ha over 10 years (12 years for short rotation coppice)

The set–aside margin assumes utilisation of the natural generation management option for set–aside with a weed control spray using glyphosate typical of farming practice.

NB The annual payment and start up grant are alternatives to allow crops to compete

The biomass prices, yields and energy prices required to enable the crop enterprises to achieve financial breakeven were considered as alternative options (Table 4.4). The analysis indicates that the breakeven biomass price for reed canary grass and switchgrass is lowest of all the crops, with miscanthus, short rotation coppice and spartina requiring a moderate biomass price and wheat requiring the highest price level to break even. Short rotation coppice requires a substantial yield increase to break even at current prices, followed by wheat and miscanthus. The yield increase required for spartina is less and both reed canary grass and switchgrass have sufficiently high yields to break even at current costings.

Table 4.4 Breakeven biomass price, yield and energy price for each biomass crop

	Approx. Breakeven Biomass Price £/t wet weight	Actual Sliding Scale Price	Approx Yield Increase (Decrease) to Breakeven	Breakeven Energy Price £/GJ	Budget Price £/GJ
Miscanthus	18	12.14	40%	2.12	1.43
Wheat	34	23.14	48%	2.10	1.43
Reed canary grass	14	18.43	(20%)	1.09	1.43
Switchgrass	14	15.28	(7%)	1.31	1.43
Spartina	21	16.86	25%	1.78	1.43
Short rotation coppice	21	12.14	80%	2.48	1.43

Assumptions used in calculating the above are exactly the same as those for Table 4.1b. To calculate the breakeven biomass price and the breakeven yield, the individual parameters are adjusted to the point where the net present value is at or near zero. The breakeven energy price is obtained by applying the breakeven biomass price to the crop moisture content in the sliding scale shown in Appendix 2.

Extending the period of economic comparison from 12 to 25 years (Table 4.5) shows that the size of the negative NPV for short rotation coppice is reduced, but that a positive return can still not be achieved in an unsubsidised situation. Reed canary grass retains a positive EAV and NPV despite re–sowing the grass every 7 years.

Table 4.5 Short rotation coppice and reed canary grasses – 25 years comparison (excluding establishment grants and area payments)

	Equivalent Annual Margin	Net Present Value
Short rotation coppice	(66)	(705)
Reed canary grass	25	265

4.3 Discussion and conclusions

Economic analysis indicates that the seeded grasses are most attractive from a farmer's point of view despite their relatively low yields, because they give rapid returns on investment and a positive margin from year 1. At current yields and establishment costs short rotation coppice and miscanthus will never make positive margins without support. Even if these crops are subsidised with set aside payments or establishment grants their basic lack of margin, within a commercial timescale, if they are not further supported, must be a major concern to potential growers. However, if the high establishment costs for spartina, short rotation coppice and miscanthus are eliminated they give better returns than switchgrass, the poorer performing of the seeded grass options, with reed canary grass giving a similar performance to miscanthus. The rapid reduction of planting costs must be the key area for research effort. Trying to get the yield up is futile if the sheer cost of establishing coppice or rhizome established grasses is such a barrier to commercial returns.

To compare subsidised establishment short rotation coppice and miscanthus with unsubsidised seeded grasses would be unfair and economically unjustified. However, if establishment is to be subsidised the levels are shown at Table 4.3. These are similar to the rates paid under the DEFRA Energy Crops Scheme. Miscanthus is caught somewhere between short rotation coppice and the annual grasses. Its high establishment cost negates its relatively good 10 year cashflow, but the yield from SRC is greater making it a better candidate for any establishment grant. Short rotation coppice needs a start–up grant of £1145 to generate a margin similar to uncropped arable set–aside while miscanthus needs a grant of £1675. Note that any land clearance cost (not included in the cashflows in this study) or loss of flexibility of land use in an arable location will work against the attractiveness of short rotation coppice.

Given that these crops could be grown on set aside immediately, reed canary grass and switchgrass look attractive in that they generate an EAV higher than simply putting the land into uncropped conventional set aside. However neither crop compete with average yielding cereal crops (as long as these receive area payments). Reed canary grass and more especially switchgrass should be treated with caution due to the relative scarcity of data.

It would only take a modest biomass price increase (from £16.86 to £20/t) to bring spartina to breakeven. The other less attractive crops (miscanthus, wheat, short rotation coppice) would need very sizeable increases of between 50% to 100%. The situation is the same for yields. A 20% rise for spartina would bring it to breakeven. The others need rises of between 40% to 85%. A conventional wheat crop with a standard level of inputs of seed, fertiliser and pesticides is not attractive as a biomass crop. This is not surprising given that grain normally sold for £60 to £70 per tonne is being burned for a biomass value of only £23. These financial analyses show the size of the gap between current performance and what would be required to breakeven. The future potential of each of these crops must therefore be a component of any decision to support research and development of each crop.

Extending the investment appraisal period to 25 years does not change these conclusions. The size of the negative NPV for short rotation coppice is reduced, but the best seeded grass (reed canary grass) still gives positive returns even if it is replanted every 7 years.

Chapter 5 Potential

5.1 Ranking order of potential of giant grasses

On the basis of the information collected in this report on yields, growing costs, combustion characteristics and returns on investment, all based on performance without subsidy, it is possible to assimilate the data into a ranking order of attractiveness to agriculture.

Table 5.1 Ranking order of potential of giant grasses (without subsidy)

Species	Key R and D required	Establishment and Growing Costs	Combustion	Return on Investment	Overall Score (1–9) 1 = poor 9 = good
Reed canary grass	Validate yield across the UK.	Establishment by seed. Overall low.	Lower moisture content by delayed harvest.	Positive – best potential candidate	6+
Switchgrass	Evaluation of varietal suitability and yield required.	Establishment by seed. Overall low.	Low ash %	Positive	6
Miscanthus	Need to reduce establishment costs and increase yield.	Established using rhizomes – costly.	Low ash %	Negative – very poor.	3+
Spartina	Reduce establishment costs.	Established using rhizomes – costly.		Poor	3
Short rotation coppice	Need to improve yield and reduce establishment costs.	Established using cuttings – fairly costly.	High moisture content.	Negative – poorest.	2
Giant reed	Evaluate yield, cold tolerance and moisture content.	Evaluate seed propagation.	?	?	Unknown
Bamboo	Evaluate yield, cold tolerance and moisture content.	Expensive at present.	?	?	Unknown
Others	More research required for suitability in UK –for more promising species	?	?	?	Unknown

5.2 Proximity to commercial success

- Switchgrass and reed canary grass are closer than miscanthus/spartina.
- If mineral fuel was more expensive, or a higher value is given to the environmental benefits of biofuels compared to mineral fuels, the possibilities for commercial success could be much improved.
- Support on a similar basis as for conventional food crops is necessary for these crops to reach a true competitive position for farmers to consider investing in their production.

5.3 Barriers to commercial success

- Difficult to compete with supported crops
- Cheap mineral fuels
- High costs of production
- Long term commitment of land required – need for long term contract
- High value land
- Seasonality of production
- Breeding work minimal on new crops
- Selection of varieties for agro–environment at early stage, eg switchgrass (and to a lesser extent for Bamboo)

Chapter 6 Key future research and development required to reach commercial success

There are key aspects to the future viability of Giant Grasses which would benefit from further research and development. These are ranked in the order (1) Establishment costs, (2) Yield improvement, (3) Quality of product at harvest (moisture) and (4) Identification of other giant grass biomass crops which have so far simply not been identified by researchers.

Reducing establishment costs is key to the future success of biomass crops unless Government is prepared to continue paying grants/subsidies for the investment. Where biomass crops are established using cuttings or rhizomes rather than with true seed, then establishment costs will always be much higher. However, for those crops established by cuttings, efficiency of cutting multiplication and improved planting mechanisation may reduce costs of establishment. Reliability of current techniques used also require improvement.

1. Establishment costs research and development areas

   (i) True seed production and seed viability
   (ii) Multiplication of stems/rhizomes
   (iii) Mechanisation of planting
   (iv) Reliability of establishment technique

2. Overall yield

   Agronomic research and development to improve yield levels is required. The dearth of data found during this study indicates the paucity of research and development on giant grass agronomy. Improvement of varieties available is also required.

3. Reduction of moisture content at combustion

   (i) Harvest timing
   (ii) Storage
   (iii) Handling method – non–chipping – avoid adding to mineral fuel use

4. Fuller evaluation of lesser known grasses

   Most of the lesser known grasses identified in this study have had little in the way of evaluation under UK growing conditions. Data has been obtained from EU, US, New Zealand and Canada. Some UK evaluation of front runners is required.

Chapter 7 Conclusions

Analysis of the selected benchmark crops shows that the yield of wheat competes with several of the giant grasses, and is of a lower moisture content than all other crops studied. However, the annual establishment costs and high levels of inputs required to attain this yield mean that use of wheat as a biomass feedstock would not be viable under current values. Coppice from willow, and the giant grass miscanthus do not achieve positive net present values at current yields and costings unless an establishment grant is paid. If establishment costs, particularly for short rotation coppice and miscanthus, could be reduced the net margin would be improved. Like miscanthus, spartina is also established using rhizomes and does not appear to offer any advantages over miscanthus.

Annually cut grasses such as reed canary grass and switchgrass have the best economic profile, offering a positive net present value but have tended to attract less research and development funding. They are both established from seed, reducing establishment costs. Work has shown that moisture content of biomass material from both crops can be reduced through delayed harvesting and this may also improve their viability.

Crops such as bamboo and giant reed need to be evaluated for winter hardiness in the UK. EU work is currently considering their suitability for Europe. There are several other C4 grasses originating from the American prairies, which have not been trialled in the UK. Further investigation of the most promising of these, e.g. prairie sandreed may be justified. Yield will be an important factor to evaluate, including assessment of timing of attainment of full yield potential and productive lifespan. Moisture content of biomass produced is an important quality feature and will influence the viability of the crop enterprise. Establishment method will also have a great bearing on viability. Fertiliser input should be low to moderate and the crop should have good resistance to pests and diseases.

Of the other grasses considered, with the limited information available, none appear to offer significant advantages over more researched species. It may be worth keeping a watching brief over work which has relevance for the UK.

The study indicates that to be competitive with conventional food crops such as wheat, an improvement in return to the grower will be required, as the crops would not compete without support. Therefore an improvement in yield, and quality (in terms of moisture content) and a reduction in costs, particularly at establishment is desirable. Also, inclusion of the crops into the Arable Area Payments Scheme so that they are eligible for support similar to conventional crops may be necessary before there can be significant uptake by growers.

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Appendix 1 **Yield patterns and moisture contents**

	Year											
	1	2	3	4	5	6	7	8	9	10	11	12
Short rotation coppice												
Trial DM Yields (t/ha)	0	0	0	44	0	0	0	48	0	0	0	48
Harvested Field Scale yields (t/ha)	0	0	0	37	0	0	0	36	0	0	0	36
Likely Moisture Content (%)				50%				50%				50%
Miscanthus												
Trial DM Yields (t/ha)	2	7	11	14	15	15	15	15	15	15		
Harvested Field Scale yields (t/ha)	0	6	9	12	13	13	11	11	11	11		
Likely Moisture Content (%)	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%		
Wheat												
Harvested Field Scale Yields (t/Ha)												
Grain DM t/ha	7	7	7	7	7	7	7	7	7	7		
Straw DM t/ha	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4	4.4		
Total DM t/ha	11.4											
Likely Moisture Content (%)	16%	16%	16%	16%	16%	16%	16%	16%	16%	16%		
Reed canary grass												
Trial DM Yields (t/ha)	6	9	8	8	7	7	7	7	7	7		
Harvested Field Scale Yields (t/ha)	5	8	7	7	6	6	5	5	5	5		
Likely Moisture Content (%)	40%	30%	30%	30%	30%	30%	30%	30%	30%	30%		
Switchgrass												
Trial DM Yields (t/ha)	0	6	9	10	12	11	11	11	11	11		
Harvested Field Scale Yields (t/ha)	0	5	7.5	8	10	9	8	8	8	8		
Likely Moisture Content (%)		40%	40%	40%	40%	40%	40%	40%	40%	40%		
Spartina												
Trial DM Yields (t/ha)	0	8	9	9	14	14	14	14	14	14		
Harvested Field Scale Yields (t/ha)	0	7	7.5	7.5	12	12	11	11	11	11		
Likely Moisture Content (%)		35%	35%	35%	35%	35%	35%	35%	35%	35%		

Assumptions:

- Approximately 15% reduction in harvested field scale yield compared to trial plot yield.
- Further 10% yield reduction from year 7 onwards for all grasses, reflecting disease build up and loss of vigour.

Appendix 2 **Cost and pricing assumptions: Example of wood fuel price versus moisture content**

MC %	GJ/t	£/t	£/GJ	
0	19.47	27.86	1.43	
10	17.27	24.72	1.43	
15	16.17	23.14	1.43	
20	15.07	21.57	1.43	
25	**13.97**	**20.00**	**1.43**	(Benchmark)
30	12.88	18.43	1.43	
35	11.78	16.86	1.43	
40	10.68	15.28	1.43	
45	9.58	13.71	1.43	
50	8.48	12.14	1.43	
55	7.38	10.57	1.43	
60	6.29	9.0	1.43	
65	5.19	7.42	1.43	
70	4.09	5.85	1.43	

Source of Data: Landen (1993)

Appendix 3 **Cost and pricing assumptions: Contracting machinery charges**

Operation	Cost/Ha (£)
Plough	32.50
Power Harrow	24.60
Leveller	16.40
Roll	8.10
Harrow	7.90
Drill Small seed	15.00
Spread Fertiliser	8.00
Mow	16.30
Bale (large square half tonne)	2.00 per bale
Collect and cart off bales	10.00
Plant rhizomes	69.75
Spot spray	9.00
Spray	9.00

Source of Data: Christian and Riche (1999), Chadwick (2000)

Appendix 4 **<u>Costs for each species: miscanthus</u>**

Year	1	2	3	4	5	6	7 – 10
Machinery Costs £/Ha							
Plough	32.50						
Power Harrow	24.60						
Level	16.40						
Plant	69.75						
Spray	18.00	18.00	9.00	9.00	9.00	9.00	9.00
Apply P & K	8.00	8.00	8.00	8.00	16.00	8.00	8.00
Mow		16.30	16.30	16.30	16.30	16.30	16.30
Bale		48.00	72.00	96.00	104.00	104.00	88.00
Collect & Cart		10.00	10.00	10.00	10.00	10.00	10.00
Input Costs £/Ha							
Rhizomes	1000.00						
Agrochemicals	49.66	46.13	18.33	18.33	18.33	18.33	18.33
Potash	15.60	15.60	15.60	15.60	15.60	15.60	15.60
Phosphate					9.80		
Total Costs per Ha	**1234.51**	**162.03**	**149.23**	**173.23**	**199.03**	**181.23**	**165.23**

Notes:

Average agrochemical costs for weed control. In reality sprays may not be required every year.

Over a 5 year period the miscanthus removes 31 kg P and 353 kg K (ETSU 1999). This requires an application each year of 120 kg/Ha of Muriate of Potash (0:0:60) @ £130/t and every 5 years 70 kg/Ha of Triple Super Phosphate (0:46:0) @ £140 /t,

Appendix 4 **<u>Costs for each species: wheat</u>**

Year	1	2	3	4	5	6	7 – 10
Machinery Costs £/Ha							
Plough	32.50	32.50	32.50	32.50	32.50	32.50	32.50
Power Harrow	24.60	24.60	24.60	24.60	24.60	24.60	24.60
Drill	15.00	15.00	15.00	15.00	15.00	15.00	15.00
Roll	8.10	8.10	8.10	8.10	8.10	8.10	8.10
Spray	36.00	36.00	36.00	36.00	36.00	36.00	36.00
Apply N, P & K	8.00	8.00	8.00	8.00	8.00	8.00	8.00
Mow	16.30	16.30	16.30	16.30	16.30	16.30	16.30
Bale	53.64	53.64	53.64	53.64	53.64	53.64	53.64
Collect & Cart	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Input Costs £/Ha							
Seeds	52.00	52.00	52.00	52.00	52.00	52.00	52.00
Fertilisers	110.00	110.00	110.00	110.00	110.00	110.00	110.00
Agrochemicals	98.00	98.00	98.00	98.00	98.00	98.00	98.00
Total Costs per Ha	**464.14**	**464.14**	**464.14**	**464.14**	**464.14**	**464.14**	**464.14**

Source of Data: Chadwick (2000)

Appendix 4 **Costs for each species: reed canary grass**

Year	1	2	3	4	5	6	7 – 10
Machinery Costs £/Ha							
Plough	32.50						
Power Harrow	24.60						
Level	16.40						
Drill	15.00						
Roll	8.10						
Spray			9.00	9.00	9.00	9.00	9.00
Apply P & K					16.00		
Mow	16.30	16.30	16.30	16.30	16.30	16.30	16.30
Bale	33.33	45.60	40.00	40.00	34.28	34.28	28.57
Collect & Cart	10.00	10.00	10.00	10.00	10.00	10.00	10.00
Input Costs £/Ha							
Seeds	160.00						
Agrochemicals			29.81	29.81	29.81	29.81	29.81
Potash					19.50		
Phosphate					7.00		
Total Costs per Ha	**316.23**	**71.90**	**105.11**	**105.11**	**141.89**	**99.39**	**93.68**

Notes:

Over a 5 year period Reed Canary Grass removes 20 kg P and 93 kg K per Ha (ETSU 1999). This requires an application every 5 years of – 50 kg Triple Super Phosphate (0:46:0) @ £140/t and 150 kg Muriate of Potash (0:0:60) @ £130/t

Appendix 4 **<u>Costs for each species: switchgrass</u>**

Year	**1**	**2**	**3**	**4**	**5**	**6**	**7 – 10**
Machinery Costs £/Ha							
Plough	32.50						
Power Harrow	24.60						
Level	16.40						
Drill	15.00						
Roll	8.10						
Spray	18.00	18.00	18.00	18.00	18.00	18.00	18.0
Apply P & K					16.00		
Mow	0	16.30	16.30	16.30	16.30	16.30	16.30
Bale	0	33.33	50.00	53.30	66.70	60.00	53.30
Collect & Cart	0	10.00	10.00	10.00	10.00	10.00	10.00
Input Costs £/Ha							
Seeds	160.00						
Agrochemicals	32.56	28.17	31.91	31.91	31.91	31.91	31.91
Potash					16.90		
Phosphate					8.40		
Total Costs per Ha	**307.16**	**105.80**	**126.21**	**129.51**	**184.21**	**136.21**	**129.51**

Notes:

Over a 5 year period Switchgrass removes 28 kg P and 76 kg K per Ha. This requires an application every 5 years of – 60 kg Triple Super Phosphate (0:46:0) @ £140/t and 130 kg Muriate of Potash (0:0:60) @ £130/t

Appendix 4 **Costs for each species: spartina**

Year	1	2	3	4	5	6	7 – 10
Machinery Costs £/Ha							
Plough	32.50						
Power Harrow	24.60						
Level	16.40						
Plant	69.75						
Spray		9.00	9.00	9.00	9.00	9.00	9.00
Apply P & K					16.00		
Mow	0	16.30	16.30	16.30	16.30	16.30	16.30
Bale	0	43.00	46.00	46.00	73.80	73.80	67.70
Collect & Cart	0	10.00	10.00	10.00	10.00	10.00	10.00
Input Costs £/Ha							
Rhizomes	1000.00						
Agrochemicals		33.30	32.93	32.93	32.93	32.93	32.93
Potash					16.25		
Phosphate					3.5		
Total Costs per Ha	**1143.25**	**111.60**	**114.23**	**114.23**	**177.78**	**142.03**	**135.93**

Notes:

Over a 5 year period spartina removes 11 kg P and 73 kg K per Ha. This requires an application every 5 years of – 25 kg Triple Super Phosphate (0:46:0) @ £140/t and 125 kg Muriate of Potash (0:0:60) @ £130/t.

Appendix 4 **Costs for each species: short rotation coppice**

Year	1	2	3	4	5	6	7	8	9	10	11	12
Machinery & Labour Costs £/Ha												
Discing	19											
Apply Dung/Fert	40	8	8	8	8	8	8	8	8	8	8	8
Cutting back	70											
Spray	27			9								
Planting Labour	182											
Harvester				251				244				244
Tractor & Trailer				40				40				40
Input Costs £/Ha												
Cuttings	1600											
Herbicides												
Preplanting	18											
Post planting	15											
Pre–emergence	35			35								
Fertiliser		13	13	13	13	13	13	13	13	13	13	13
Total Costs per Ha	**2006**	**21**	**21**	**356**	**21**	**21**	**21**	**305**	**21**	**21**	**21**	**305**

Source of Data: Cook et al. (2000)

Notes:

Harvesting with self propelled forage harvester which blows chips into a trailer. Cost £6.79 per tonne Dry Matter.

100 kg/Ha of 25:5:15 applied annually @ £130/t

Appendix 5 **Margin tables: miscanthus**

Year	**1**	**2**	**3**	**4**	**5**	**6**	**7 – 10**
Output	0	145.68	218.52	291.36	315.64	315.64	267.08
(Average Yield, t/Ha)							
Total Costs (£/Ha)	1234.51	162.03	149.23	173.23	199.03	181.23	165.23
Margin (£/Ha)	(1234.51)	(16.35)	69.29	118.13	116.61	134.41	101.85
Discount Factors	0.926	0.857	0.794	0.735	0.681	0.630	2.09
Present Values (£/Ha)	(1143)	(14)	55	87	79	85	213
Net Present Value (£/Ha)	(638)						
Equivalent Annual Value (£/Ha)	(95)						

Notes:

1. Harvested grass supplied to user at 50% moisture content. Previously tabulated Dry Matter yields are therefore doubled to get wet weight. Payment on "Swedish sliding scale" (standard price of £20/t at 25% MC) of £12.14/t wet weight. This assumes one GJ of energy is worth £1.43 (Landen 1993).

2. 8% Interest rate.

Appendix 5 **<u>Margin table: Wheat</u>**

Year	**1**	**2**	**3**	**4**	**5**	**6**	**7 – 10**
Output (Average Yield, t/ha)	310.30	310.30	310.30	310.30	310.30	310.30	310.30
Total Costs (£/Ha)	464.14	464.14	464.14	464.14	464.14	464.14	464.14
Margin (£/Ha)	(153.84)	(153.84)	(153.84)	(153.84)	(153.84)	(153.84)	(153.84)
Annuity Factors	6.71						
Present Values (£/Ha)							
Net Present Value (£/Ha)	(1032)						
Equivalent Annual Value (£/Ha)	(154)						

Notes:

Harvested crop supplied at 15% moisture content (average yield 11.4t DM/Ha, 13.4t Wet Weight/Ha). Sliding scale price of £23.14/t.

Appendix 5: **Margin table: reed canary grass**

Year	**1**	**2**	**3**	**4**	**5**	**6**	**7 – 10**
Output (Average Yield, t/Ha)	127	211	184	184	158	158	132
Total Costs (£/Ha)	316	72	105	105	142	99	94
Margin (£/Ha)	(189)	139	79	79	16	59	38
Discount Factors	0.926	0.857	0.794	0.735	0.681	0.630	2.09
Present Values (£/Ha)	(175)	119	63	58	11	37	79
Net Present Value (£/Ha)	192						
Equivalent Annual Value (£/Ha)	29						

Notes:

Year 1 40% MC. Sliding scale price £15.28/t
Year 2 onwards 30% MC. Sliding scale price £18.43/t.

Appendix 5 **Margin table: switchgrass**

Year	**1**	**2**	**3**	**4**	**5**	**6**	**7 – 10**
Output	0	127	191	204	255	229	204
(Average Yield, t/ha)							
Total Costs (£/Ha)	307	106	126	130	184	136	130
Margin (£/Ha)	(307)	21	65	74	71	93	74
Discount Factors	0.926	0.857	0.794	0.735	0.681	0.630	2.09
Present Values (£/Ha)	(284)	18	52	54	48	59	155
Net Present Value (£/Ha)	102						
Equivalent Annual Value (£/Ha)	15						

Notes:

At 40% MC, sliding scale price is £15.28/t.

Appendix 5 **Margin table: spartina**

Year	**1**	**2**	**3**	**4**	**5**	**6**	**7 – 10**
Output (Average Yield, t/Ha)	0	182	195	195	311	311	285
Total Costs (£/Ha)	1143	112	114	114	178	142	136
Margin (£/Ha)	(1143)	70	81	81	133	169	149
Discount Factors	0.926	0.857	0.794	0.735	0.681	0.630	2.09
Present Values (£/Ha)	(1058)	60	64	60	91	106	311
Net Present Value (£/Ha)	(366)						
Equivalent Annual Value (£/Ha)	(54)						

Notes:

At 35% MC, sliding scale price is £16.86/t

Appendix 5 **Margin table: short rotation coppice**

Year	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Output (Average Yield, t/Ha)				898				874				874
Total Costs (£/Ha)	2006	21	21	356	21	21	21	305	21	21	21	305
Margin (£/Ha)	(2006)	(21)	(21)	542	(21)	(21)	(21)	569	(21)	(21)	(21)	569
Discount Factors	0.926	0.857	0.794	0.735	0.681	0.630	0.583	0.54	0.5	0.463	0.429	0.397
Present Values (£/Ha)	(1858)	(18)	(17)	398	(14)	(13)	(12)	307	(10)	(10)	(9)	226
Net Present Value (£/Ha)	(1030)											
Equivalent Annual Value (£/Ha)	(137)											

Notes:

Harvested at 50% MC. Payment on sliding scale at £12.14/t

Appendix 6 **25 year comparison of short rotation coppice and reed canary grass**

In the cashflows below only the figures which have been changed or added to those shown in Appendix 5 are shown.

Short rotation coppice: 25 years

YEARS	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Output (£/Ha)				898				874				874				874		
Total costs (£/Ha)	2006	21	21	356	21	21	21	305	21	21	21	305	21	21	21	305	21	21
Net margin (£/Ha)	(2006)	(21)	(21)	542	(21)	(21)	(21)	569	(21)	(21)	(21)	569	(21)	(21)	(21)	569	(21)	(21)
Discount factor	0.926	0.851	0.794	0.735	0.681	0.630	0.583	0.54	0.5	0.463	0.429	0.397	0.388	0.340	0.315	0.292	0.27	0.25
Present value (£/Ha)	(1858)	(18)	(17)	398	(14)	(13)	)12)	307	(10)	(10)	(9)	226	(8)	(7)	(7)	166	(6)	(5)
Net present value (£/Ha) (1030) for 12 years	(1030)												325					
Equivalent annual value	(137)																	

25 years

NPV	=	(1030) + 325	=	(705)
EAV	=	(66)		

Appendix 6 **25 year comparison of short rotation coppice and reed canary grass**

Reed canary grass 25 years

Years	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**1**
Output (£/Ha)	127	211	184	184	158	158	127	211	184	184				127		0			
Total Cost (£/Ha)	316	72	105	105	142	99	316	72	105	105				316					
Net Margin (£/Ha)	(189)	139	79	79	16	59	(189)	139	79	79	16	59	38	(189)	139	79	79	16	[illegible]
Discount Factor	0.926	0.857	0.714	0.735	0.681	0.630	0.583	0.54	0.5	0.463	0.429	0.397	0.388	0.34	0.315	0.292	0.27	0.25	0.
Net present value (£/Ha)	(175)	119	63	58	11	37	(110)	75	40	37	7	23	15	(64)	44	23	21	4	
25 years net present value (£/Ha)	265																		
Equivalent annual value (£/Ha)	25																		