Aspects of Applied Biology 90, 2008
Biomass and Energy Crops III

State and development of bioenergy in the Republic of Ireland

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Summary

To date, *Miscanthus* and, to a smaller extent, willow short rotation coppice (SRC) are the main energy crops for solid biofuel production in Ireland. Hemp is grown on a comparatively small area. For liquid biofuels, oilseed rape, wheat and sugar beet are possible options. However, intensive cultivation of biomass for energy may cause new environmental problems such as increased emissions of trace gases like N_2O.

At present, grassland systems occupy more than 90% of the farmed area. Therefore, large-scale energy crop production would require major land-use change, which may enhance mineralization of soil organic matter and reduce biodiversity. In contrast, grassland biomass used directly in an anaerobic digester may have greater energy yields while increasing C sequestration. A life-cycle approach, which takes into account cultivation inputs, energy production and other possible (environmental) impacts of crop cultivation can identify the optimal way to produce bioenergy in Ireland.

Key words: Bioenergy, willow, short rotation coppice, renewable energy, mitigation, *miscanthus*

Introduction

The aim of the European Union is to increase the share of renewable energy in gross inland consumption to 12% by 2010 and 20% by 2020. In order to increase sustainability and security of fuel supply, it is desirable to generate more energy from renewable and local sources. Energy crops are a potential source of renewable energy and different crops can provide electricity and heat or can be processed into transport fuels. In Ireland, domestic energy consumption has increased considerably in the recent past (e.g. primary energy usage increased by 67% from 1990–2006) making Ireland dependent on imports of oil, petrol and coal (SEI, 2008). Bioenergy could play a major role in the future, as Ireland's mild, temperate climate and strong farming background provide ideal conditions for the cultivation of energy crops At present, more than 60% of the land area is classified as agricultural land and more than 90% of agricultural land is used for forage production (CSO, 2008).

In this paper, we will assess the current state and possible future direction of the development of energy crops in Ireland. To assess the overall suitability of an energy crop, a number of factors have to be considered including cultivation inputs, soil carbon sequestration and nutrient cycling, trace gas fluxes and biodiversity implications. In addition, bioenergy crops may affect groundwater supplies, in particular high water demand by willow and *Miscanthus* may reduce water availability.

Current State of Energy Crops in Ireland

Potential energy crops in Ireland include *Miscanthus* and other giant grasses, willow short rotation coppice (SRC), hemp, oilseed rape and sugar beet (Teagasc, 2008). In what follows we will discuss the current use of each of these crops as well as current research on these crops undertaken in Ireland.

Miscanthus

Miscanthus has so far attracted most interest from both researchers and the farming community. Trials on a private farm and at Teagasc, Oak Park, were funded by the European Union in the 1990s. Data from one of these trials was used by scientists from Trinity College Dublin (TCD) to establish a model of *Miscanthus* productivity covering the whole island of Ireland (Clifton-Brown *et al*., 2000). Yields were projected to be between about 16 and 26 t d.m. ha^{-1} yr^{-1} and increasing from northeast to southwest. Under commercial conditions, yields are expected to be approximately 8 to 15 t d.m. $ha^{-1}yr^{-1}$ (Teagasc, 2008). *Miscanthus* remained a focus of the work at TCD, with researchers investigating aspects such as yield modelling (Clifton-Brown *et al*., 2004; Stampfl *et al*., 2007) and field studies (Clifton-Brown *et al*., 2007). In 2007, Styles & Jones presented a comprehensive life-cycle analysis (LCA) for *Miscanthus* and willow SRC. At present, research at TCD focuses on the influence of *Miscanthus* on soil C dynamics (see contribution by Smyth, 2008 in this volume). Further research into issues concerning the performance and handling of *Miscanthus* is carried out at University College Dublin (see Nolan & Riche (2008), this volume).

In their LCA, Styles & Jones (2007) included emissions of greenhouse gases from land use change as well as from cultivation and fuel-chain emissions and they considered different paths of utilisation (electricity and heating). The economic competitiveness of energy crops for farmers and consumers was assessed and scaled up to result in a national scenario. The authors concluded that *Miscanthus* and willow SRC could generate appreciable gross margins for the producers as well as bring with them considerable consumer savings for domestic heating. Styles & Jones (2007) further predicted that increased cultivation and utilisation of these two energy crops could result in a substantial reduction in national greenhouse gas emissions as well as possible additional positive effects on the environment. They found that the potential of energy crops was especially large in Ireland due to the large agricultural area and comparatively low population density.

Establishment of commercial plantations of *Miscanthus* in the Republic of Ireland started in 2004. Based on the utilisation of planting grants we estimate the total cultivated area today at about 2,000 ha^{-1}. The government supports the crop by paying up to half of the establishment costs and by a top-up for three years of € 80 on the European energy crop payment of €45 $ha^{-1}yr^{-1}$. Storage and handling of the rhizomes poses a challenge for the reliable establishment of the crop. Moreover, large-scale energy generation from *Miscanthus* has not yet been realised. However, the government aims for 30% biomass co-firing at the peat-fuelled power stations in Ireland by the year 2015, so it is foreseeable that the situation will change. In the meantime, most of the harvest is utilised for animal bedding. Other proposed applications for *Miscanthus* include domestic heating (for example in the form of pellets), bio-composites and chipboard as well as second generation ethanol. Prices paid by agents like JHM Crops Ltd. and Quinns of Baltinglass Ltd. are around €65 t^{-1} at a moisture content of 20%. Biorefinery concepts for *Miscanthus* and other lignocellulosic crops are under investigation at the University of Limerick (Carbolea, 2008).

Willow SRC

Findings by Styles & Jones (2007) for willow SRC are generally similar to those for *Miscanthus*, though gross margins calculated for willow SRC are somewhat lower. However, willow plantations can potentially be utilised to remediate wastewater, which may improve the economics of willow cultivation in Northern Ireland (Rosenqvist & Dawson, 2005). This potential would probably apply in the Republic of Ireland as well (Styles & Jones, 2007). Moreover, willow SRC might be suitable for cultivation on wetter and therefore more marginal soils than *Miscanthus* (Styles & Jones, 2007). Therefore, these two crops can be regarded as complementary rather than competitors. Uptake of willow has been slower in Ireland than *Miscanthus*, possibly because it is not considered a proper "crop" by farmers and does not produce an annual harvest. Government support in the form of planting grants and energy crop premium is the same as for *Miscanthus* and we estimate that willow SRC is currently grown on an area of approximately 300 ha^{-1}. Apart from utilisation on the farm, power stations and district heating schemes are possible buyers of willow woodchip.

Hemp

Hemp is envisaged by Teagasc (2008) as a potential bioenergy crop. The fibres may be pressed into solid fuel bricks or processed into second generation ethanol while hemp oil could be utilised for human consumption. Hemp fibres could also be employed for other purposes such as bio-composites or textiles. At present about 35 farmers are growing hemp on a total area of somewhat more than 100 ha^{-1}. Primarily the Green Energy Growers Association (GEGA) is interested in hemp. However, the market is still developing and a definitive end use is lacking at the moment.

Oilseed rape

In 2007, there were 8,200 ha of oilseed rape grown in the Republic of Ireland. Thus, since 2004, the cultivation area has almost quadrupled (CSO, 2008). Like other first generation liquid biofuel crops, oilseed rape suffers from the major drawback of requiring a fairly inefficient process that utilises only a small amount of the plant dry matter. There are six oil-crushing facilities in Ireland that will accept oilseed rape among other feedstocks to produce pure plant oil as a transport fuel for major customers (lorry fleets). However, we understand that it is not yet clear how much oilseed rape will actually be processed there. Oilseed rape may also be used as a co-feedstock at a new biodiesel plant in New Ross, County Wexford, which will mainly utilise recycled waste fats. The main alternative use for oilseed rape is animal feed.

Wheat

The wheat cropping area in Ireland decreased somewhat in recent years, to a value of 84,300 ha in 2007 (CSO, 2008). However, we understand that in 2008 this trend has been reversed due to high grain prices. Wheat can be fermented to ethanol and subsequently used as a liquid (road) biofuel. Research into liquid biofuels is a focus of research at University College Cork (UCC). For example, Power *et al*. (2008) conducted an assessment of three crop rotations involving wheat, rye and sugar beet for the production of ethanol feedstock. They concluded that a rotation with two years wheat followed by one year of sugar beet optimised the energy input/output ratio. In a subsequent publication the authors stated that the efficiency of ethanol production could be improved by utilising residues like straw or stillage (Murphy & Power, 2008). Alternatively, they found that the utilisation of the same crop rotations for anaerobic digestion (AD) was more efficient for transport fuel generation than ethanol (Murphy & Power, 2009). Grain is not utilised for energy generation on any larger scale in Ireland at the moment. Considering the high current grain prices and probable future sustainability criteria for liquid biofuels (requiring a reduction in CO_2 equivalents of at least 35%; European Commission, 2008), conversion of wheat to ethanol does not appear economically viable in the near future.

Sugar Beet

The cultivation of sugar beet in Ireland has declined from 31,000 ha in 2005 to 1,700 ha in 2006 (CSO, 2008). The reason for this dramatic decline is the closure of the last sugar factory in Ireland in 2006. However, sugar beet was a common crop in Ireland, so it can be assumed that farmers are competent and well equipped to cultivate this crop if demand increased. Sugar beet was considered within the crop rotations investigated at UCC (see above) and it was found that sugar beet made economic sense in the rotation if the cost associated with grain was high (Murphy & Power, 2009). However, for reasons outlined above, the utilisation of grain for transport fuel appears unrealistic at present. Moreover, as sugar beet should not be grown more often than one year in three in the same field (Finch *et al*., 2002), it might not be possible to significantly reduce the amount of wheat in the rotation.

Giant grasses

In addition to *Miscanthus*, reed canary grass (RCG) and switchgrass may provide further options. To date there are no results from field trials of these species in Ireland, but experience from Europe indicates they could be grown successfully (Teagasc, 2008) and field trials were started by Teagasc in 2008. RCG may grow on poorer soils than *Miscanthus* (Teagasc, 2008), so if it was proven to be suitable for cultivation in Ireland, the range of sites for energy grasses might be extended. A further advantage is that, contrary to the complicated procedure required for establishment of *Miscanthus*, RCG and switchgrass will grow from seed. However, these two species do not shed all their leaves in autumn, which increases nutrient export with the harvested material as well as emission of N oxides during combustion. This might preclude them from utilisation in a domestic context, where no sophisticated scrubbing of the flue gas is in place.

Forage grass as a bioenergy crop

Since the main agricultural land use currently in Ireland is grassland, it has to be assessed if energy crops can and should replace forage grasses for the production of bioenergy. Forage grasses can be used directly for the generation of biogas via AD, which was shown to be feasible on farm-level by Lemmer (2005). One advantage of this method compared to crops for combustion is the retention of feedstock N in the digestate (Braun, 2007), which can improve the nutrient use efficiency of the cultivation system. Moreover, by keeping grassland in the present state, greenhouse gas emissions associated with land use change are avoided. Soussana *et al*. (2004) estimated that conversion of grassland to an arable crop might, on average, lead to a loss of about 1 ± 0.3 t ha^{-1} yr^{-1} of soil C over a 20 year period. For a specific grassland, rate and extent of loss of change in C is dependent on a number of conditions including the state of soil C pools (Sartori *et al*., 2006).

Land availability and land use change associated with the use of grassland for bioenergy

Current grasslands in Ireland may become available for bioenergy by two mechanisms. The first mechanism is the decoupling of agricultural payments from production. However, a prediction of the amount of land becoming available through this mechanism is complicated (Breen *et al*., 2005). The second mechanism is the abolishment of set-aside requirements. A major advantage of using set-aside areas for growing energy crops is that energy production does not compete with food production. In 2007, an area of about 375,000 ha was under arable usage (CSO, 2008). Assuming that 10 % of arable land had been put under set-aside and is currently managed as extensive grassland, an area of approximately 45,000 ha could potentially be used for the cultivation of energy crops. We understand that part of this area has in the meantime been reverted to arable use, but, considering that farmers would probably not take their best land out of production, it is likely that a certain amount of that land is less suitable for the production of highly priced cereals. Therefore it is necessary to identify the optimal way to cultivate the surplus grassland for the generation of energy.

Assessment of the mitigation potential of different energy crops

In order to contribute to the discussion on the advantages and disadvantages of using different energy crops we conducted a simple hypothetical assessment of greenhouse gas mitigation potentials for the following representative bioenergy crops considered by Teagasc (2008): *Miscanthus*, willow SRC, oilseed rape, wheat and sugar beet. Forage grass as a bioenergy source was not considered here, because the environmentally optimal way of producing energy from grass is not known but currently under investigation (see below).

For this assessment we took into consideration the following elements of the life cycle of these energy crops: agricultural inputs (fertiliser and pesticides), potential energy output from combustion, and land use change. It was assumed that some surplus grassland would be ploughed up to make space for the cultivation of dedicated energy crops. Typical yields per ha and energy contents per t of the respective energy crop were gathered from Finch *et al*. (2002), Department for Environment, Food and Rural Affairs (DEFRA, 2004), Teagasc (2008), and Murphy & Power (2009). Typical application rates of the main fertilisers (N, P, K) were taken from Finch *et al*. (2002), multiplied by energy expenditure for the production of fertilisers (taken from West & Marland, 2002) and deducted from the energy generation per ha of the crop. The same was done for application of pesticides, with the application rate of the respective pesticide taken from the label of a representative agricultural herbicide, fungicide and insecticide, respectively. Application of active ingredients was multiplied by estimates of the energy required for their production (West & Marland, 2002). This agricultural input was again deducted from the energy generated per ha^{-1} of the crop. The result was taken as net energy generation by the respective crop. The energy generated was assumed to replace a fuel with the representative chemical formula $C_{15}H_{32}$ (diesel, heating oil) with a calorific content of 42.5 MJ kg^{-1} and releasing 3.115 kg CO_2 per kg upon complete oxidation. Thus, savings of CO_2 through energy generated by the crop could be calculated.

To complete the greenhouse gas balance, it was assumed that 1% of N applied as fertiliser would be lost in the form of N_2O, with a global warming potential of 296 times that of CO_2 on a 100-year timescale (Intergovernmental Panel on Climate Change (IPCC), 2001, 2006). Mineralization of soil C to CO_2 was estimated according to Soussana *et al*. (2004) as 1 ± 0.3 t C ha^{-1} yr^{-1}. It was assumed that this amount of C was lost every year for crops requiring annual soil cultivation (wheat, oilseed rape, beet) but only once, at initial grassland removal, for perennial crops (*Miscanthus*, willow). Whether this is a realistic assumption remains to be seen and is currently under investigation. The calculations cover a time span of 15 years, which is a conservative estimate for the productive span of an energy plantation of *Miscanthus* or willow. Assumptions are summarized in Table 1 and results in Table 2.

Table 1. *Assumptions concerning the cultivation of potential energy crops in Ireland (from Finch* et al.*, 2002, and Teagasc, 2008)*

Crop	N (kg ha^{-1})	P_2O_5 (kg ha^{-1})	K_2O (kg ha^{-1})	Pesticide applications
Miscanthus	50	13	120	Herbicide annually, insecticide at establishment only
Willow SRC	60	50	50	Herbicide after harvests every three years, insecticide at establishment only
Oilseed rape	180	56	44	Herbicide & insecticide annually
Wheat	185	85	70	Herbicide, insecticide & fungicide annually
Sugar beet	100	50	75	Herbicide, insecticide & fungicide annually
Grass	variable	variable	variable	variable

While the solid fuel crops *Miscanthus* and willow SRC provide large greenhouse gas savings of almost 200 t CO_{2eq}. ha^{-1} yr^{-1} that are largely independent of the estimated scale of soil C mineralization, the liquid biofuel crops perform not as well (Table 2).

Table 2. *Net annual energy production and greenhouse gas savings (t CO_2 equivalents) in 15 years of potential energy crops in Ireland for different assumptions on rate of mineralization of soil C after grassland removal*

Crop	Net energy production (GJ ha^{-1})	Reduction of CO_{2eq}. at mineralization of 0.7 t C	Reduction of CO_{2eq}. at mineralization of 1 t C yr^{-1}	Reduction of CO_{2eq}. at mineralization of 1.3 t C yr^{-1}
Miscanthus	176	187	187	185
Willow SRC	186	198	196	195
Oilseed rape	137	99	83	66
Wheat	108	67	50	34
Sugar beet	138	106	89	73
Grass	variable	variable	variable	variable

Especially the ethanol crop wheat, due to the combined effect of relatively high fertilisation, annual tillage and low energy production, does not appear as a great improvement over the combustion of fossil fuels. Moreover, the results in Table 2 do not yet consider conversion processes and the conversion to ethanol is comparatively inefficient. Murphy & Power (2008) make proposals on how to improve efficiency. AD may be a more efficient way for the production of transport fuel (Murphy & Power, 2009). Table 2 also shows that the reduction in greenhouse gases achievable from annual tillage crops depends on the rate of C mineralization after grassland removal. Mineralization of soil organic matter is also influenced by the duration of the previous grassland (Soussana *et al*., 2004) and would be most severe after removal of long term set-aside. Research currently conducted at Teagasc will provide data on the loss of soil C after removal of grassland for energy crops in Ireland. The emission of N_2O is another aspect that has to be considered. This emission is mainly driven by available nitrogen in the soil, but it is also influenced by abiotic factors such as soil moisture and soil temperature (Machefert *et al*., 2002). Using the IPCC default value of 1% of applied N may be an oversimplification.

Research into grassland for bioenergy

Two 3-year projects are being conducted to evaluate the potential and sustainability of Irish grassland for bioenergy. The research involves universities and other research organizations in both the Republic and Northern Ireland. The first project, Green Grass, is carried out by Teagasc, UCC and Queen's University in Belfast. It is looking at the effect of species and cultivation parameters on the chemical composition, conservation characteristics and, ultimately, usability of the biomass for fibre production and energy generation via AD. Results from the different tasks will be drawn together to derive an optimal grass utilisation strategy.

UCD, Teagasc and the Agri-Food and Biosciences Institute in Belfast cooperate on the second project termed Bio-GrAsS. Investigations are carried out at three field sites located both in the Republic and Northern Ireland and representing different levels of management intensity. The exchange of CO_2, CH_4 and N_2O between soils and atmosphere is characterized and the herbage harvested will be subjected to forage analysis and trial digestion in lab-scale digesters. Thus, it will be possible to derive a detailed life cycle assessment of grassland for bioenergy under different management regimes, which will include a full greenhouse gas balance. A literature review will also look at biodiversity implications of different management regimes and conversion of grassland to energy crops. All data obtained from this project will also be compared to other energy crops. Ultimately, the results from the project will feed into a computer-based decision support system to evaluate the long-term sustainability of the utilisation of grassland for bioenergy in Ireland.

Acknowledgements

The Green Grass and Bio-GrAsS projects are funded by the Department of Agriculture, Fisheries and Food of the Republic of Ireland. We would also like to thank the following people: Ms Aiva O'Brian (Clearpower Ltd.), Dr Kevin McDonnell (UCD), Dr Jerry Murphy (UCC), Dr David Styles (TCD) and Dr Kees-Jan van Groenigen (TCD).

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