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Research paper

Exploring the potential of grass feedstock from marginal land in Ireland: Does marginal mean lower yield?

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ABSTRACT

The production of biomass feedstock from marginal land has attracted much attention as a means of avoiding conflict between the production of food and fuel. Yield potentials from marginal lands have generally not been quantified although it is generally assumed that lower biomass yields can be expected from marginal lands. A three year study was conducted in Ireland in order to determine if grass yields of perennial rhizomatous grasses (cocksfoot, tall fescue, reed canary grass, festulolium) for anaerobic digestion from three marginal land sites (very wet site, very dry site, site prone to flooding) could match yields from better soils. Randomised complete block designs were established on each site in 2012 with two varieties of each grass species as treatments. Three grass harvests were taken from each site in 2013 and in 2014. There was no significant difference between yields from the control site and those from the very dry site and the site prone to flooding. Biomass yields from the very wet site were 85% of those from the control site. Highest yields were obtained from festulolium which were significantly higher than yields from perennial ryegrass. An energy analysis showed that maximising the production of grass from low lying mineral marginal grassland in Ireland could provide enough energy to meet the energy requirements of both the private car fleet and the heavy goods vehicle fleet while avoiding conflict with food production which could be concentrated on conventional land.

1. Introduction

Energy produced from biomass could produce a substantial proportion of global primary energy needs by 2050 [1]. However, estimates for the contribution of biomass resources to global energy production have produced a wide range of results [2,3]. Major differences in estimates have been ascribed to different assumptions on land availability and yield levels [2]. The conversion of large areas of land to bioenergy production has raised concerns over the effect of such a change on the environment [4]. Furthermore, competition between bioenergy and food production for land and resources has led to a fuel vs. fuel debate [5,6] and it is anticipated that such competition will increase as the 21st century unfolds [7].

The use of abandoned agricultural land for bioenergy production has been suggested as a means of potentially avoiding conflicts between the production of food and energy [8,9]. It has been suggested [10] that the use of marginal land for bioenergy production could offer significant environmental and economic benefit but only when perennial energy crops are employed and sustainable land management practises are used. Estimates of the area of marginal land available worldwide for bioenergy production range from 100 Mha [11] to 580 Mha [12]. Wide variation in the estimates of marginal land availability have been attributed to ambiguity in the definition and characterization of marginal land together with uncertainty in assessments of land availability [13]. Various concerns have been expressed over the large scale use of marginal land for the production of biomass. For example, it has been suggested that the use of marginal land for biomass production represents a sub-optimal land use allocation which is costly to society [14]. Additionally, it has been suggested that the cultivation of energy crops on marginal land may lead to losses in soil carbon and changes to biodiversity although such changes may be minimised by using biomass already growing in such areas [13,15].

Biogas obtained from grass silage has the potential to play an important role in reducing Ireland's dependency on imported fossil fuels. Previous studies have shown the impact of biogas obtained from grass silage could have on Ireland's energy supply [16,17]. As much as 1.7 million tonnes DM/ha of grass could be made available under current agricultural practice prior to increased demand from national production target commitments [16]. This could be increased to 12.2 million tonnes DM/ha even after national agricultural production target requirements are taken into consideration by increasing nitrogen (N) inputs and increasing the grazed grass utilization rate of cattle [16]. A

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study conducted in Ireland [18] found that 107 m^3 CH_4/tonne of biomass could be achieved from grass silage and that 1.1% of grassland (45,000 ha) could produce 6.6 PJ of energy while 2.8% of grassland (111,000 ha) could produce enough grass silage to generate 16.07 PJ of energy. These studies examined grass production from conventional agricultural grassland. In contrast, few studies have quantified the productivity of marginal land. This study, however, will examine the production of grass silage from less productive, under-utilised marginal land. Marginal land can be defined as synonymous with those areas beset by natural limitations imposed by soil, topography or climate [19]. According to [20], 56% of the land area in Ireland can be classified as difficult or marginal, this area being divided into 0.81 million hectares (Mha) of lowland, mineral wet land, 1.14 Mha of hill or mountain land and 1.2 Mha of peat. For the purpose of grass production for anaerobic digestion, the only relevant category of marginal land is the 0.81 Mha of lowland, wet mineral soil. This category of marginal land is almost completely used for growing grass, thus the use of this grassland for biomethane production does not represent a change of use. The botanical composition of these grasslands consists of moderate to low quality swards [20] but reseeding can offer enhanced productivity [21]. Perennial ryegrass (*Lolium perenne*) is the dominant grass used for reseeding in Ireland [20,21] due to its high productivity although perennial rhizamatous grasses tend to be more tolerant of conditions found on marginal land [22,23] and it has been suggested that such grasses can be used to maximise biomass production from marginal land [24].

The objective of this study was to (1) quantify the productivity of perennial rhizomatous grasses on different marginal soils in Ireland and (2) quantify the potential contribution of grassland from marginal land to indigenous energy generation and greenhouse gas mitigation in Ireland.

2. Material and methods

Experiment were conducted on four separate sites over a three year period (2012–2014) to determine the effect of marginal site and species on grass yields for anaerobic digestion. The experimental design was a randomised complete block. Four perennial rhizomatous species were included in each trial (*Dactylis glomerata* (cocksfoot); *Festuca arundinacea* (tall fescue); *Lolium x Festuca* (Festulolium); *Phalaris arundinacea* (Reed canary grass)) together with perennial ryegrass (*Lolium perenne*), the predominant grass species used in Ireland which was included as a control. Two varieties of each species were included in all trials (Table 1). The site name, location, altitude and description are presented in Table 2. Three of the sites were located near Carlow (control, dry site, flooding site) while the wet site was located near Johnstown Castle, Co Wexford, approximately 60 km distant from Carlow. Meteorological parameters were recorded at synoptic weather stations located at each site.

The experiments in the control site, dry site and flooding site were all sown on May 24th, 2012 whereas the experiment in the wet site was sown on May 20th, 2012. All locations were sown in good conditions using a Wintersteiger seed drill (Wintersteiger, Dimmelstrasse 9, Ried/L, Austria) using conventional (plough-based) cultivation practices, and rolled immediately afterwards. The plots were sown at a seeding rate of

Table 1
Grass species used in the experiments.

	Cocksfoot *(Dactylis glomerata)*	Tall Fescue *(Festuca arundinacea)*	Perennial ryegrass *(Lolium perenne)*	Festulolium *(Lolium x Festuca)*	Reed Canary Grass *(Phalaris arundinacea)*
Variety	Ambassador Donata	Jordane Emeraude	Carraig Cancan	Felina Hykor	Bamse Cheifton

30 kg/ha. Inclement weather conditions over the summer of 2012 led to flooding at the flooding site which was flooded for a six week period soon after emergence. Consequently, the site was re-sown on September 7th, 2012. All experiments were left to establish during the 2012 growing season, growth was mown and removed at the end of this growing season.

The trial plots were managed to obtain three cuts of silage in each year in order to maximise the quantity of grass produced as a feedstock for anaerobic digestion. To maximise productivity, the highest rates of nitrogen permitted under the nitrates directive were applied prior to each cut [25]. Nitrogen fertilizer was applied approximately six weeks before the intended date of the first cut and then immediately after the first and second cuts of grass were removed. Soil testing was carried out to determine soil nutrient status and phosphorus, potassium and lime were applied to each site as necessary in order to ensure that the supply of all macronutrients was non-limiting. The rate of fertilizer applied is given in Table 3. Lime was applied to the control site as well as the wet site prior to the first cut at a rate of 270 and 370 kg/ha respectively.

2.1. Yield and dry matter determination

The grass crop was harvested on three occasions each year. The first cut was harvested between 4th and 7th of June in 2013, and 27th and 29th of June in 2014; the second cut harvest was carried out between the 29th and 31st of July in 2013 and 2014. The third cut was harvested between the 24th and 23rd of September in 2013 and 17th and 18th of September in 2014. The grass plots were harvested using a Haldrup plot harvester (J. Haldrup, Løgstør, Denmark). A sample of fresh material was collected once the plot weight was recorded and used to determine the dry matter (DM) content of the grasses.

The percentage DM of the crop was determined by weighing the fresh sample collected from the field, oven drying it at 65° C until constant weight was achieved. This DM recorded for each plot was then used to calculate the yield of the each plot on a per hectare basis (t DM/ha).

2.2. Statistical analysis

The data was analysed using a **GLIMMIX** analysis with repeated measures in Ref. [26] to determine statistical differences between the varieties of grass and the trial sites. Year, site, treatment and replicate were the fixed factors in the analysis whereas year was treated as a random factor. Pairwise differences in treatments were evaluated using Tukey's test.

2.3. Energy analysis and Life Cycle Assessment

2.3.1. Scope

The analysis was based on a farm based anaerobic digester as described by Ref. [27] who assumed grass yields similar to those measured in this study.

The scope of this analysis extended from the production of grass, the production of biomethane in an anaerobic digestor through to the final use of the biomethane in vehicles. For the energy analysis, all direct energy inputs used in the production of grass and, subsequently, biomethane were included in the analysis. Indirect energy needed in the production of seed, lime, chemical fertilizer and diesel was also included in the analysis although energy consumed in the manufacture of equipment and infrastructure was not included in line with the methodologies proscribed by the European Union for the calculation of the greenhouse gas impact of biofuels, bioliquids and their fossil fuel comparators [28]. The functional unit was 1 ha/annum.

2.3.2. Harvesting and yields

Three harvests were assumed to be taken each year in order to maximise biomass production from the grass swards (early June, late