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Centralised electricity production from winter cereals biomass grown under central-northern Spain conditions: Global warming and energy yield assessments

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HIGHLIGHTS

- We assess the sustainability of electricity production from winter cereals biomass.
- Productivity ranks are generated from different genotypes cultivated in real farms.
- GHG and energy balances show better performance compared to natural gas electricity.
- Cereals yields below 8 odt/ha do not accomplish objective 60% of GHG savings.
- Marginal yields and sustainability criteria are discussed suggesting optimization.

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ABSTRACT

The goal of this paper is to assess the sustainability of electricity production from winter cereals grown in one of the most important Spanish agricultural areas, Castilla y León Region, situated in central-northern Spain. This study analyses greenhouse gases (GHG) emissions and energy balances of electricity production in a 25 MWe power plant that was powered using straw biomass from three annual winter cereals (rye, triticale and oat) grown as dedicated energy crops. The results of these analyses were compared with those of electricity produced from natural gas in Spanish power plants. Assessments were performed using a wide range of scenarios, mainly based on the biomass yield variability obtained in demonstration plots of twelve different winter cereal genotypes. Demonstration plots were established in two different locations (provinces of Soria and León) of the Castilla y León Region during two crop seasons (2009/2010 and 2010/2011) using common management practices and input rates for rain-fed agriculture in these regions. Our results suggest that production of electricity from winter cereals biomass combustion yielded considerable reductions in terms of GHG emissions when compared to electricity from natural gas. Nevertheless, the results show that low biomass yields that are relatively frequent for Spanish farmers on low productivity lands may produce no significant reductions in GHG in comparison with electricity from natural gas. Consequently, the agronomic management of winter cereals should be re-examined in order to find potential improvements that achieve better energy balances and greater reductions in GHG emissions on land which is relatively uncompetitive in terms of crop yields and on existing low productivity scenarios.

1. Introduction

Climate change coupled with declining oil and gas reserves has led to the development of new energy sources to minimize greenhouse gases (GHG) emissions and expand energy supplies from solar, wind, hydraulic, geothermal and bioenergy sources [1]. The European Union (EU) Member States have committed themselves to increasing the share of renewable energy in the EU's energy mix to 20% and reducing GHG emissions by 20% by 2020 [2]. Furthermore, with the goal of keeping climate change below 2 °C, in February 2011 the European Council reaffirmed the EU objective of achieving by 2050 a reduction in GHG emissions of 80–95% with respect to the 1990 figures [3].

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Table 1
Experimental plots design.

1. Locations	León		Soria	
Coordinates	42° 24′N 5°31′W		41° 29′N 2°23′W	
Altitude	763 m		1079 m	
2. Soil type	Distric cambisol		Calcaric cambisol	
Texture	Sandy clay loam		Sandy loam	
Organic matter	1.82%		0.90%	
3. Plot type and size	Strips of 0.3–0.4 ha per variety		Strips of 0.2–0.3 ha per variety	
4. Experimental periods	2009–2010	2010–2011	2009–2010	2010–2011
5. Climate	Continental mediterranean	Continental mediterranean	Continental mediterranean	Continental mediterranean
Average temperature	8.7 °C	11.0 °C	9.0 °C	9.9 °C
Total rainfall	517 mm	482 mm	482 mm	386 mm
6.Winter Cereals (cultivar)	Oat (Aintre, Prevision) Lopsided Oat (Saia) Rye (Petkus) Hybrid rye (Gutino, Placido) Triticale (Amarillo, Sencozac, Trujillo)	Triticale (Trujillo)	Rye (Petkus) Hybrid rye (Askari) Triticale (Bienvenue, Colegial, Trimour, Trujillo)	Rye (Petkus) Hybrid rye (Askari) Triticale (Bienvenue, Colegial, Trimour, Trujillo)
7. Crop Management				
Seeding dose (kg ha^{-1})	Oat (130) Lopsided oat (90) Rye (165) Hybrid rye (60) Triticale (185)	Triticale (240)	Rye (120) Hybrid rye (60) Triticale (250)	Rye (120) Hybrid rye (60) Triticale (250)
Fertilization (kg ha^{-1})	NPK 8-15-15 (400) Calcium ammonium nitrate 27% N (300)	NPK 8-15-15 (500) Calcium ammonium nitrate 27% N (200)	NPK 8-24-8 (300) Calcium ammonium nitrate 27% N (270)	NPK 8-24-8 (300) Calcium ammonium nitrate 27% N (270)
Herbicides (kg ha^{-1})	Clortoluron (0.720) Diflufenican (0.045)	Clortoluron (0.720) Diflufenican (0.045)	2,4-D (0,25) Tribenuron-methyl (0.016)	2,4-D (0,25) Tribenuron-methyl (0.016)

Solid and liquid biofuels are renewable energy sources that reduce GHG emissions [1,4–9], and may contribute to guarantee fuel security and play an important role in the accomplishment of those EU objectives. According to a study published by the European Environment Agency in the EU 27 [10], about 19 Mha of agricultural land could be available for introduction of energy crops for biofuels production under sustainable conditions, with a primary biomass potential of 295 Mtoe by 2030. Therefore energy crops would become the most important endogenous source for biofuels production. Lignocellulosic energy crops for heat and electricity production may perform better in GHG assessments when compared with crops used as feedstock for first generation liquid biofuels [11–14]. Algae liquid biofuels may also have good GHG assessments [15] due to high production yields [16,17], but they are not yet economically attractive [15].

In Spain, traditional extensive cereal area for food production has decreased by about 1.5 mha after 1991. Low profitability of winter cereals at the farm level in Spain is chiefly due to low crop productivity with a national average grain yield of 2.2 ton/ha [18]. This could be particularly relevant for large extensions of arable lands in continental Mediterranean countries like Spain, with relatively low rain-fed cereal competitiveness compared to other food suppliers like France, Germany or eastern European countries. Both current international market contexts and European Common Agricultural Policy (CAP) reforms have led to total dependency of famers on EU subsidies to guarantee minimum profits [19]. Past studies have suggested that Spanish agri-food system is inefficient and generates high environmental impacts [20,21].

In the described framework, winter cereals lands previously devoted to food production could be used to grow bioenergy crops lands and produce lignocellulosic biomass for electricity generation; that would help reducing current national energy dependence and accomplishing EU objectives of GHG reduction and increased share of renewable energies. Large scale experiences with triticale as feedstock for Spanish biomass power plants have already been reported in several projects [22] with good results. Nevertheless, environmental impacts of this alternative and, in particular, GHG emissions reduction, should be evaluated, as recommended by the European Commission as regards solid biomass production for electricity generation, heating and cooling [23].

Therefore, the aim of this study is to evaluate the energy balances and net reductions in GHG emissions that can be obtained in the production of electricity from the biomass of annual cereal crops in central-northern Spain, one of the most extensive agricultural areas in the country, and compare them with those obtained in Spanish power plants based on natural gas. Barriers and trends to improve the sustainability of this source of energy are also discussed. The environmental management technique selected to evaluate GHG savings and energy balances was Life Cycle Assessment (LCA).

2. Experimental plots design, biomass productivity and characterization

In order to obtain experimental data for LCAs inventories (see Section 3), winter cereals biomass was produced in demonstration plots utilizing traditional farming management techniques in two different locations of the cereal extensive production region in central-northern Spain (Region of Castilla y León). The plots were situated in the provinces of Soria and León.

Several varieties of Oat (*Avena sativa* L.), lopsided oat (*Avena strigosa* Schreb.), triticale (*X Triticosecale* Wittmack), and conventional and hybrid rye (*Secale cereale* L.) were selected for study due to their expected high biomass productivity, rusticity, as well as wide distribution, machinery availability and well known management practices in the region. The trials were carried out on large grass strips (0.2–0.4 ha/strip) in real farmers' plots. In order to establish the crops, commercial machinery was used to carry out typical farmers' management techniques. More detailed information about the experimental design, location and pedo-climatic conditions in the plot sites is shown in Table 1. Plots were established and monitored in agricultural years 2009–2010 and 2010–2011. Oat and lopsided oat plots were only established in