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Mineral concentrations in solid fuels from European semi-natural grasslands after hydrothermal conditioning and subsequent mechanical dehydration

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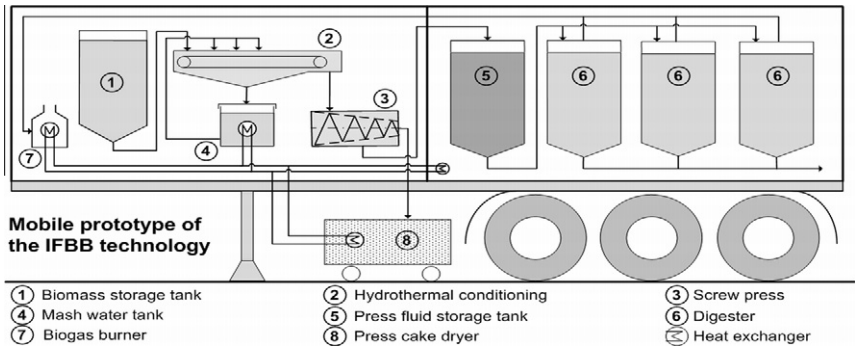
HIGHLIGHTS

- Yield and chemical composition of grassland silage was investigated.
- Chemical composition of silage for combustion could be improved.
- Solid fuel quality was influenced by neutral detergent fibre content of the silage.
- High grass cover of the sward improves the chemical composition for combustion.

GRAPHICAL ABSTRACT



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ABSTRACT

The integrated generation of solid fuel and biogas from biomass (IFBB) is particularly designed for the conversion of semi-natural and high biodiversity grassland biomass into energy. This biomass is problematic in common energy conversion techniques, e.g. biogas conversion or combustion, because of its chemical composition. The IFFB process separates the material into a fibre rich solid fuel and a fluid, which is rich in minerals and highly digestible constituents and is used for anaerobic digestion. Biomasses from 18 European semi-natural grassland sites have been processed in an IFBB prototype. The impact of different chemical and botanical parameters on mass flow of mineral plant compounds and their concentrations in the fuel has been investigated. Fuel quality was significantly influenced by chemical and botanical parameters and the quality could be significantly improved during processing. Biomass with a high grass proportion and fibre content showed the best fuel qualities after IFBB treatment.

1. Introduction

Semi-natural grasslands constitute a major part of the cultural landscape in Central Europe and harbour a vast diversity of plant and animal species. This diversity is threatened by intensification and abandonment (Isselstein et al., 2005). The conservation of these grasslands is therefore one of the main goals of European nature conservation policy. Regular cut of semi-natural grassland is necessary to conserve the current plant inventory, but is often

Abbreviations: ADF, acid detergent fibre; ADL, acid detergent lignin; a.s.l., above sea level; AST, ash softening temperature; CEC, cation exchange capacity; CF, crude fibre; DE, Germany; DM, dry matter; EE, Estonia; IFBB, integrated generation of solid fuel and biogas from biomass; ICP-OES, inductively coupled plasma-optical emission spectroscopy; NDF, neutral detergent fibre; NFE, nitrogen free extract; MF, mass flow; PF, press fluid; PC, Press cake; UK, United Kingdom; WRB, World Reference Base for Soil Resources; XA, crude ash; XP, crude protein.

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not implemented due to decreasing economic returns from animal husbandry (Ostermann, 1998; Rösch et al., 2009). The use of biomass from species-rich grasslands for bioenergy recovery can be considered as one option to maintain the biodiversity status of endangered grassland through profitable use. Chemical characteristics of grassland biomass from nature conservation areas demand specialised techniques for conversion into usable energy carriers. The conventional method, biogas production from digestion of silage, results in a low gas yield due to limited digestibility of the highly senescent biomass produced by delayed harvest (Richter et al., 2009). Combustion of semi-natural grassland hay is also affected by technical constraints, because of high proportions of minerals, nitrogen and sulphur, leading to problems of ash melting (K, Mg), corrosion (K, Cl, S) and increased emissions (N, S) (Obernberger et al., 2006; Prochnow et al., 2009). Furthermore, producing hay from these herbage-rich grassland swards leads to increased dry matter (DM) losses during field drying and harvest and is strongly dependent on weather conditions.

A newly developed approach that aims at the thermal use of the grassland biomass by improving the fuel quality through extraction of minerals is the object of the present paper. The core element of the integrated generation of solid fuel and biogas from biomass system (IFBB, Fig. 1) is mechanical dehydration after hydrothermal conditioning of the ensiled biomass. IFBB produces a solid fibrous fraction for thermal use (press cake, PC) and a liquid fraction with easily digestible constituents for biogas production (press fluid, PF). The fuel quality of the mechanically dehydrated silage is improved in comparison to the untreated biomass, because of the partial elution of organic and mineral compounds, which are detrimental to combustion (Wachendorf et al., 2009). The IFBB process has been investigated comprehensively for a selection of biomass from German semi-natural grasslands on a lab scale (Wachendorf et al., 2009; Richter et al., 2009, 2010). The present study aimed at a broadly based analysis of eighteen European semi-natural grassland sites with a wide range of different vegetation types and the conversion performance of the IFBB process on the scale of a prototype plant. The investigation comprised site characterisation, including soil and vegetation parameters, as well as grassland productivity and quality. Recent research (Richter et al., 2011a,b) has shown that mass flows and fuel quality in the IFBB system can be predicted by regression equations, including the concentrations of DM and neutral detergent fibre (NDF) in the silage as regressor. The implementation of such equations would allow an efficient control of important technical parameters based on chemical characteristics of the biomass.

The present study was conducted to answer the following questions:

(i) How does the quality and quantity of biomass originating from different semi-natural European grasslands affect its usability for combustion?
(ii) Are the elemental mass flows into the PF and the concentrations of minerals in the PC obtained from a scaled-up continuous process comparable to results from small-scale laboratory studies?
(iii) Are the botanical composition of the grassland vegetation and the chemical parameters of the parent silage correlated with elemental mass flows into the PF and with the concentrations of minerals in the PC?

2. Methods

2.1. Site characterisation and experimental set-up of grassland plots

Six experimental sites each in Germany (DE I–VI), the United Kingdom (UK I–VI) and Estonia (EE I–VI) were included in this study. The German sites were situated in the Vogelsberg region, which is a part of the state of Hesse. The long-time average (1961–1990) temperature was, depending on the altitude of the weather station, 8.04 °C (454 m a.s.l.) to 6.67 °C, (606 m a.s.l.).

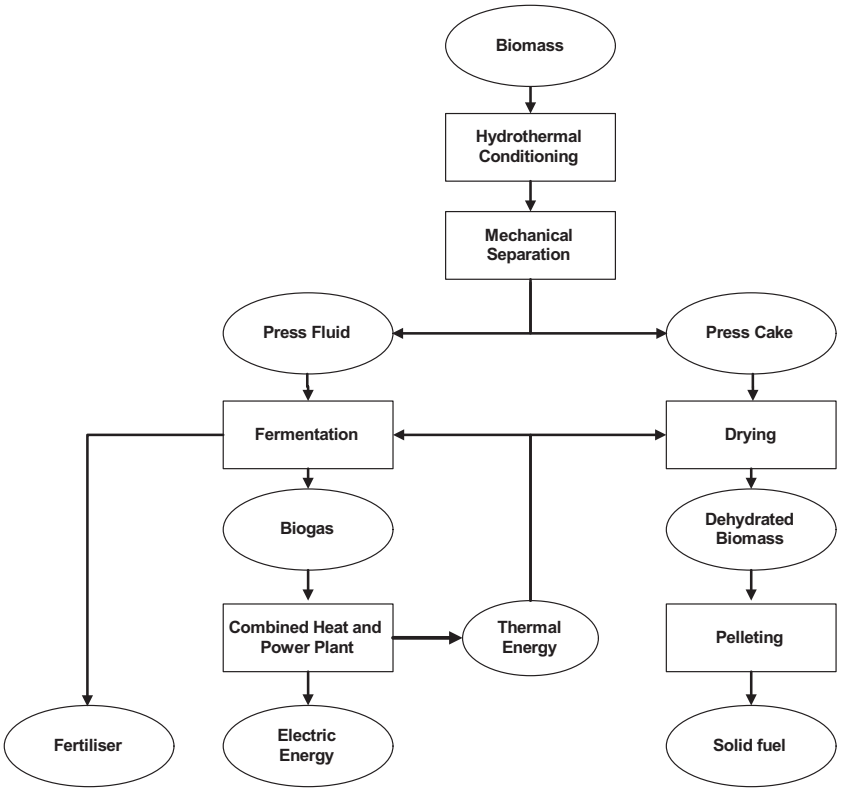

Fig. 1. Process diagram of the integrated generation of solid fuel and biogas from biomass (IFBB).