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Impact of *Miscanthus x giganteus* senescence times on fast pyrolysis bio-oil quality

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HIGHLIGHTS

- Fast pyrolysis of *Miscanthus* harvested at different senescence time was compared.
- Viscosity and water indexes were introduced to define bio-oil quality.
- Senescence impacted bio-oil quality and stability.
- Harvest time of *Miscanthus* can be extended to cover a wider harvest window.

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ABSTRACT

In this study the impact of senescence and harvest time in *Miscanthus* on the quality of fast pyrolysis liquid (bio-oil) was investigated. Bio-oil was produced using a 1 kg h^{-1} fast pyrolysis reactor to obtain a quantity of bio-oil comparable with existing industrial reactors. Bio-oil stability was measured using viscosity, water content, pH and heating value changes under specific conditions. Plant developmental characteristics were significantly different ($P \leqslant 0.05$) between all harvest points. The stage of crop senescence was correlated with nutrient remobilisation (N, P, K; $r^2 = 0.9043$, $r^2 = 0.9920$, $r^2 = 0.9977$ respectively) and affected bio-oil quality. Harvest time and senescence impacted bio-oil quality and stability. For fast pyrolysis processing of *Miscanthus*, the harvest time of *Miscanthus* can be extended to cover a wider harvest window whilst still maintaining bio-oil quality but this may impact mineral depletion in, and long term sustainability of, the crop unless these minerals can be recycled.

1. Introduction

Miscanthus x giganteus (*M. x giganteus*) is one of several dedicated energy crops that have significant potential for direct combustion and co-firing and also for thermochemical conversion. *Miscanthus* has a number of characteristics that make it a particularly good biomass crop: it is a C_4 perennial grass; gives consistently high yields; has low requirements for management and inputs, such as nitrogen fertiliser; and therefore has a relatively low energy requirement after crop establishment (Himken et al., 1997). *Miscanthus* biomass has a high lignin content (~17% of cell wall composition) when compared to woody biomass or other agricultural residues (Allison et al., 2011; Hodgson et al., 2010b; Sanchez, 2009); a high C:N ratio (average of 142.6) throughout the growth season (Heaton et al., 2009) and is capable of significant energy production per hectare (Lewandowski and Heinz, 2003; Long, 2008). Yield and crop quality in *Miscanthus* are determined by the relative progression of senescence relative to harvest time (Lewandowski and Heinz, 2003).

Senescence is a complex, highly controlled stage of plant development with multiple affects that may contribute to, or improve a number of the characteristics that make *Miscanthus* a suitable bioenergy crop. Senescence involves the coordinated degradation of cellular components and molecules (proteins, lipids and carbohydrates) and the subsequent mobilisation of essential nutrients (such as nitrogenous compounds) to below ground storage organs. Consequently senescence affects both the composition of the *Miscanthus* crop that is harvested and the availability of nutrients for the next perennial growth cycle. It is therefore an important determinant of the energy balance and the energy content of the crop. Senescence affects leaf turnover and canopy duration and thus affects the length of the growth season. Senescence is triggered by various abiotic and biotic environmental factors including light, drought, hormones and pests (Lim et al., 2007) that can also have an influence on biomass quality and yield (Robson et al., 2012). Greater understanding of senescence in *Miscanthus* may allow for the optimisation of the crop for both biomass yield and subsequent biofuel quality (Lewandowski and Heinz, 2003).

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