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Research Paper

Methane production potential from *Miscanthus* sp.: Effect of harvesting time, genotypes and plant fractions

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The perennial C_4 grass miscanthus was evaluated for use as an energy crop for methane production when harvested green in the autumn. *Miscanthus* × *giganteus* (*M.* × *giganteus*) and *Miscanthus sinensis* (*M. sinensis*) were harvested on five occasions, from August to November 2012. Methane yields from stems and leaves were analysed using batch assay after 90 d digestion. Estimated dry matter yields were highest on 1st October for *M.* × *giganteus* and 13th September for *M. sinensis*. Cellulose and lignin contents were greater with *M.* × *giganteus* than *M. sinensis* and low lignin content in leaves led to rapid degradation during the early periods of anaerobic batch assay. After 90 d of anaerobic digestion, cumulative specific methane yields for *M.* × *giganteus* varied for stem and leaf from 285 to 333 and 286 to 314 Nl (normalised litre) kg^{-1} [VS] and 291 to 312 and 298 to 320 Nl kg^{-1} [VS] for *M. sinensis*. Estimated methane yields per ha were positively correlated with the dry matter yields of miscanthus ($r = 0.92$) and the optimal harvesting time was between September–October. Methane yield at optimal harvest time was estimated as 3.824×10^6 Nl ha^{-1} (stem) and 1.605×10^6 Nl ha^{-1} (leaf) for *M.* × *giganteus* and 3.507×10^6 Nl ha^{-1} (stem) and 2.957×10^6 Nl ha^{-1} (leaf) for *M. sinensis*. There was a discrepancy between the estimating dry matter yield by sampling single shoots and whole plot harvesting. This needs to be further investigated.

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Nomenclature

ADF	acid detergent fibre
ADL	acid detergent lignin
DM	dry matter
Pa	pressure unit (Pascal)
NDF	neutral detergent fibre
Nl	normalised litre, gas volume corrected to a standard temperature and pressure
TAN	total ammonia nitrogen
VS	volatile solids

1. Introduction

Finding new crops to increase biogas production at biogas plants is vital since manure alone produce low methane yield (Cavinato, Fatone, Bolzonella, & Pavan, 2010). The ultimate goal is to find crops that produce high methane yields per hectare with low environmental impact and that are economical for farmers. Several factors that influence the methane yield are the types of crop used, harvest time and chemical composition (Hübner et al., 2011). Maize is a common co-substrate for agricultural biogas plants operating by fermentating of manure, especially in Germany (Britz & Delzeit, 2013). The low lignin content in maize is the main advantage for efficient biogas conversion, however maize is not suitable over the long term use as competition between energy and food supplies is created. For this reason, there is increasing interest in using agricultural wastes and high yielding perennial crops that may be produced on environmentally sensitive or marginal land. The main obstacle for perennial crops is that their lignocellulosic properties lead to lower biogas production. However, dynamic growth in pretreatment technologies research may overcome this and, in the future, they may produce a wider choice of crops for use as feedstock (Klimiuk, Pokój, Budzyński, & Dubis, 2010).

Miscanthus is a perennial grass native to the East Asian region. It was brought to Europe in 1935 by Aksel Olsen (Anderson et al., 2011) and cultivated and distributed throughout Europe as an ornamental plant. Since the 1980s the potential of miscanthus as a bioenergy crop has been investigated. In Asia, miscanthus is often used as animal feed and for roofing material but it was not considered as an energy crop until the end of 20th century. Miscanthus is highly persistent and the estimated life time of a plantation is 20–25 years. About 25 species of the genus *Miscanthus* have been listed by various researchers but three species, namely *Miscanthus sinensis*, *Miscanthus sacchariflorus* and *Miscanthus* × *giganteus* are mainly used for biomass production (Chung & Kim, 2012). Miscanthus is harvested once a year and shoots start to emerge during spring (April) and accumulate rapidly through summer with the highest yield around September. The yield then starts to decline around October until February as results of the shedding of dead leaves and translocation of nutrient to the rhizomes (Beale & Long, 1997).

In the agricultural sector, the economic feasibility of energy crops used for biogas production partly depends on the biomass yield per hectare harvested and of the necessary amount of nitrogen to apply. Miscanthus has high biomass yield with low or no nitrogen requirement and high adaptability to different soil and climatic environments (Christian, Riche, & Yates, 2008). Lewandowski, Scurlock, Lindvall, and Christou (2003) reported that nitrogen fertilisation is required when miscanthus were planted on soils with low levels of nitrogen available and nitrogen fertilisation can be avoided or limited to 50–70 kg ha^{-1} per year if miscanthus is planted at locations with sufficient nitrogen mineralisation. This is due to the characteristic of miscanthus, where it translocates nitrogen and other minerals from aboveground biomass to the rhizome during the autumn and winter and reuses the nutrients during shoot growth in spring (Lewandowski, Clifton-Brown, Scurlock, & Huisman, 2000).

Genotypes, soil types, nutrients used, crop age, bioclimatic location, and weather during the growing season were found to be factors that affect the biomass yield of miscanthus (Brosse, Dufour, Meng, Sun, & Ragauskas, 2012). Chemical compositions of the crops varied with its development stages (Brosse et al., 2012). Jørgensen, Mortensen, Kjeldsen, and Schwarz (2003), evaluated the development and yield quality of four different groups of miscanthus over three years in Denmark. The crops were established in 1997 and harvested during autumn and spring for three years. The yield was low during the establishment year but started to increase in the two subsequent years. Eleven genotypes of miscanthus gave different biomass yields and a hybrid of *M. sacchariflorus* and *M. sinensis* was found to have the highest dry matter (DM) yield compared to the others. Clifton-Brown, Breuer, and Jones (2007) reported that DM yields of *M.* × *giganteus* were influenced by crop age and harvesting time. In this study, development of *M.* × *giganteus* was monitored over 16 years at a site in Southern Ireland. Results showed an increase in DM yields for five years following establishment and started to decline after ten years of development. Yields varied when *M.* × *giganteus* was harvested in different seasons (autumn and spring). Average autumn and spring yields over the fifteen harvest years were 13.4 ± 1.1 and 9.0 ± 0.7 t ha^{-1} respectively.

Most research papers available have focused on the establishment, development and yield quality of miscanthus as an energy crop for combustion (Beale & Long, 1997; Christian et al., 2008; Jørgensen et al., 2003). Few studies have emphasised the potential of miscanthus as feedstock for biorefinery and biogas purposes. Hayes (2013) investigated the effect of different harvesting time on mass and compositional changes in *M.* × *giganteus* relevant for biorefinery purposes in Ireland. In this study, it was found that early harvest (October to December) produced greater DM yield than at late harvest (March and April), when leaves had been lost during winter. In contrast with the combustion process, low moisture content of feedstock is not the main concern in a biorefining process, thus early harvesting may be a better option.

The potential of miscanthus as an energy crop for ethanol production was also investigated by Zhuang, Qin, and Chen (2013). A data model assimilation analysis was used to estimate land and water requirement for three crops, namely maize, miscanthus and switchgrass, to achieve the US national biofuel target of 79 billion l of ethanol. It was assumed that the crops will be planted on the current maize producing areas to produce biomass feedstock. Comparisons were made