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Yield and quality development comparison between miscanthus and switchgrass over a period of 10 years

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ABSTRACT

The establishment of perennial crops has emerged as a very viable option for biomass-based energy production mainly due to their comparative ecological advantages over annual energy crops. This study is based on data collected from a field trial between 2002 and 2012 and was carried out with the main objective of evaluating the yield and quality performance of miscanthus and switchgrass using different harvest dates and N fertilization regimes (0 kg, 40 kg, 80 kg). Over the whole plantation period (including three years of establishment period), the mean yield of miscanthus was 16.2 t DM ha^{-1} a^{-1}, while switchgrass yielded 10.2 t DM ha^{-1} a^{-1}. In miscanthus, each increase in fertilizer level increased the N content in the harvested biomass, whereas in switchgrass, no significant difference was recorded for 0 kg and 40 kg N levels. The effect of N fertilization on ash was significant but independent of the crop. Both miscanthus and switchgrass biomass samples from the late harvests had a significantly lower N content than those from the early harvests. A Life Cycle Assessment covering the conducted field work and inputs of this trial showed relatively low energy input and emissions connected to the cropping of miscanthus.

1. Introduction

In the last decade, policy support and biofuel-driven mandates have led to a significant increase in the production of dedicated energy crops in Europe and America. However, criticism of the production of food and feed crops grown especially for energy purposes, such as maize or rapeseed, has motivated the search for high-yielding non-food energy crops. In recent years, the establishment of perennial crops has emerged as a very viable option mainly due to their comparative ecological advantages over annual energy crops [27,28,32]. Among these, the C4 grasses miscanthus and switchgrass combine the potential to deliver high biomass yield and ability to grow under a wide range of climatic conditions [21].

Miscanthus is characterized by a high dry matter yield potential [6], and can be grown without any pest or weed control measures once the crop is established [24]. However, because there is presently only one commercially available clone, *Miscanthus x giganteus*, it has some limitations such as a lack of winter hardiness during the establishment period [21]. Additionally *M. x giganteus* needs to be propagated vegetatively resulting in high plantation costs [3]. Contrary to this, switchgrass can be established via seeds and the lower production costs make it a more practical option among the energy crops [26]. However, the biomass yield potential of switchgrass is considered to be lower than that of miscanthus [21].

Miscanthus and switchgrass can be cultivated on marginal soils (mainly low fertile) due to their low nutrient requirements and high net primary production potential [31]. The low nutrient requirements of miscanthus in particular [8] are accommodated by its well-developed rooting system [27] and the relocation of nutrients back to rhizomes at the end of the growth season. The annual dry matter yield production potential of the aforementioned C4 perennial crops is 10–20 t ha^{-1} in temperate climates [36]. Under optimal growth conditions however, the yield can be higher than 30 t ha^{-1} [27]. The productivity can be further improved by the optimized combination of management practices, such as the appropriate N fertilization rate [1] and choice of appropriate harvest time [24]. However, improvement in yield through various management practices can, over time, affect the composition of the produced biomass and subsequently the thermo-chemical conversion processes for energy production.

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Currently, the biomass produced from these crops is mainly used for direct combustion. However it can also be used for the production of so-called 2nd generation liquid fuel [3] and biogas [26].

The energy production through thermo-chemical conversion of biomass can be categorized into three main processes; a) direct combustion; b) gasification; c) pyrolysis. To carry out problem free thermo-chemical conversion, all aforementioned processes require feedstock with defined quality. For example, in direct combustion, high contents of Cl and K lead to deposition, slagging, fouling and corrosion problems [4]. In energy crops, the content of Cl is comparatively high, which makes it challenging to combust such biomass for bioenergy production [44]. In addition, the high ash, moisture and other inorganic constituents such as N also influence the combustion process along with environmental issues. High contents of N lead to NOx emissions and high ash contents increase the operational cost. Therefore, it is important to improve the biomass quality through different on field quality management practices such as selection of cop, fertilization and harvesting time. The composition of biomass is mainly dependent on climatic conditions, genetic background [17], location, and agronomic practices especially fertilization rate and harvest time [25]. Research has shown that on-field quality management can be performed by the adjustment of harvest date but with compromised yield. The timing of the harvest is mainly dependent on the end use of the biomass e.g. early harvest for liquid fuels [15] and late harvest for combustion [4]. The comparatively high N content in energy crops [41] has raised concerns over the use of biomass for direct combustion mainly due to chances of NO_x formation. The N content is higher in leaves than in stems. Therefore delayed harvest can contribute to lower NO_x formation by affecting the leaf-to-stem ratio and providing sufficient time for relocation mechanism. Moreover, along with biomass composition analysis and optimization of biomass compositions through on field quality management practices, it's also crucial to give an overview about the whole value chain from crop production till thermo-chemical conversion by performing LCA (life cycle assessments). These analyses can help to better estimate the environmental impacts of the production of different feedstock.

The aim of this study was to evaluate the effect of different 'on field management practices' such as N levels, crop age, harvest time including weather conditions (mainly rainfall and temperature) on dry matter yield and quality parameters of miscanthus and switchgrass at the same time on the same place. Hence, a comparison of both crops in terms of productivity and quality characteristics was a second focus. In addition a comparison of the N removal from the soil by both crops was calculated at different N fertilization levels to identify the optimal cropping system. To get a rough estimation of possible emissions linked to the cropping of these perennial grasses in this trial, an LCA was conducted for the miscanthus cropping system including all the management practices and inputs used. Biomass samples of both crops were collected from 2002 to 2012 from the field trial established in 2002 at the research station of the University of Hohenheim, Ihinger Hof, in south-west Germany. The harvested biomass was processed before calculation of dry matter yield, moisture, ash and N content.

Three hypotheses were developed: a) morphological characteristics especially number of shoots and plant height are good indicators of crop yield: b) high N fertilization levels can increase the N content in the harvested biomass, whereas delayed harvest decreases the N content: c) miscanthus is a better feedstock than switchgrass in terms of quantity and quality of biomass and ecological benefits under the climatic conditions of the experimental area.

2. Materials and methods

2.1. Site characteristics

The field trial was planted in May 2002 with the main objective of evaluating annual and perennial cropping systems under different fertilization regimes. For the current study, two of these crops – miscanthus and switchgrass – were selected. The experimental field plots are located at the University of Hohenheim research station, Ihinger Hof, south-west Germany (48.75°N and 8.92°E). According to the FAO classification, the soil of this site belongs to Haplic Luvisol with a predominantly silt clay texture and overlying loess loam. Some of the physical and chemical properties of the soil profile are given in Table 1.

The weather data for each year (2002–2012) were collected by a nearby meteorological station. During the period 2002–2012 the mean annual rainfall was 707.5 mm and the mean annual temperature was 9.2 °C. Weather data and harvest dates are presented in Table 2.

2.2. Experimental design and management practices

The field trial was established as a randomized split plot design with different crops as main plots, divided into three subplots (180 m^2 each) with different N levels (0, 40, and 80 kg $ha^{-1}a^{-1}$). Each variant had 4 replicates.

The clone *M. x giganteus* was planted as micro-propagated plantlets. The planting density was two plants m^{-2} with a row spacing of 66 × 75 cm. Switchgrass (*Panicum virgatum* L.) 'Kanlow' was established through seeds at the rate of 10 kg ha^{-1}.

Fertilizer application was carried out through ammonium-stabilized N-fertilizer Entec 26 (K+S Nitrogen GmbH, Mannheim, Germany) to tackle the problem of N losses. The fertilizer contains 7.5% nitrogen-N, 18.5% ammonia-N and 13% sulfur. Fertilizer was applied each year from April to May before the emergence of new shoots.

Weed control was carried out by herbicide application. In the first two years, the herbicide Basagran DP (BASF, Ludwigshafen, Germany) was applied at a rate of 999 g Bentazon and 699 g ha^{-1}Dichlorprop-P. In 2005 Clinic (Nufarm, Cologne, Germany) and in 2006 Durano (Monsanto, Antwerpen, Belgium) were applied at the same rate of 1080 g ha^{-1} Glyphosate.

2.3. Field data collection

Measurements of growth components for both crops were taken at random intervals over the years. These included number of shoots, height, stem diameter and leaf to stem ratio. Soil parameters, especially carbon and nitrogen contents, were determined regularly from 2005 to 2009 except for 2008.

2.4. Harvesting and sample preparation

Starting from 2002, harvesting was carried out every year between October (early harvest) and April (late harvest). For switchgrass, in some years, samples were collected twice in the same year, for instance, early harvest in June or August followed by final harvest in April. Final harvest for both crops was performed at the same time of the year. For each crop, the sampling area was 1 m^2 to 12 m^2. For each harvest the total fresh weight of the collected biomass samples was recorded. Then sub-samples were chopped, weighed and put in the oven to dry at 60 °C for 48 h to estimate the dry matter content. For the laboratory analysis, all the samples were milled using a mill with 1 mm sieve to ensure a uniform particle size.