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Research paper

Combustion quality of poplar and willow clones grown as SRC at four sites in Brandenburg, Germany

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The fuel quality was assessed for nine poplar clones (AF2, Androscoggin, Max1, Max3, Max4, Monviso, Muhle-Larsen, NE42, Weser6) and one willow clone (Inger) grown as short rotation coppice (SRC) on four sites in the Brandenburg area in Germany. Fuel quality was analysed in 3-year old shoots in terms of dry matter (DM) mass fraction, total ash mass fraction and concentration of 14 ash-related elements (Al, Ca, Cd, Cl, Cu, Fe, K, Mg, Mn, Na, P, S, Si, Zn). Clone significantly affected DM and ash mass fraction and concentration of 11 of the 14 elements, site affected concentration of 7 elements, and clone and site interacted on DM, ash mass fraction and concentration of 7 elements. Among the poplar clones, Androscoggin and NE42 generally exhibited highest quality with higher DM mass fraction and lower concentrations of ash, Ca, K, P, Cd and Cu than other poplar clones. The willow clone had high DM mass fraction, low ash mass fraction and generally low concentrations of the major ash-forming elements compared to poplar clones. However, willow had significantly higher mean concentration of Cd, Mn and Zn than all poplar clones but with significant clone-site interactions and, on some sites, the concentrations were no higher in willow than in the poplar clones.

Shoot diameter significantly affected fuel quality with thin shoots generally having higher ash mass fraction and element concentrations than thicker shoots. In conclusion, fuel quality of SRC biomass may be improved by selecting appropriate clones and by increasing shoot diameter at harvest.

1. Introduction

SRC poplar and willow may contribute significantly to the wood-based bioenergy system as an alternative feedstock resource, e.g. for combustion to produce heat and power [1,2]. However, woody biomass is not as homogenous as fossil fuels. The diverse physical and chemical properties of biomass feedstock cause challenges during the combustion process. Mineral elements in plant tissues are one of the contributors to undesirable combustion performance of biomass. Many mineral elements that are essential for plant growth are, at the same time, determinants of ash behaviour during combustion. High feedstock concentration of certain elements such as K, Si, S and Cl increase the risk of fouling, slagging and corrosion and, consequently, reduce the efficiency of thermal conversion of biomass [3,4]. Also, Al, Fe, Ca, Mg, Mn, Na and P also related to ash deposition, corrosion and ash melting [4–9]. Heavy metals in biomass feedstock, including Cd, Zn and Cu, can accumulate in ashes and in waste water from flue gas cleaning after combustion, which may cause adverse effects on environmental sustainability and increase the costs of handling and processing in power plants [9–11]. On the other hand, phytoremediation which involves the extraction of heavy metals from agricultural soils by non-food biomass can contribute to the reduction of food contamination if subsequent smart ash handling or reuse is secured [12].

Therefore, it is important to enhance scientific knowledge to improve the quality of biomass feedstock, either for reducing the concentration of ash-related elements in harvestable SRC biomass or for increasing heavy metal extraction from agro-ecosystems. Genetic variation and environmental conditions are the two key

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factors to not only control the biomass yield but also the fuel quality. Tharakan et al. [13] documented two to three-fold variations in the concentrations of P, K, Ca, Mg and Na between 30 willow clones and seven poplar clones. As for site effects, Adler et al. [14] showed significant differences in the concentrations of P, Zn and Cd in willow biomass between two Swedish sites with the same fertilization, with lower yield and poorer fuel quality in terms of high element concentration on one of the sites. It was also found that willow grown on the poorer site had more shoots with smaller diameter, resulting in higher element concentration due to a higher bark proportion [14]. Bark proportion can partly explain the variation in fuel quality for combustion since it is widely agreed that the bark fraction of woody biomass is richer in inorganic elements [15–19]. Therefore, a smaller shoot diameter, which is in most cases associated with a larger bark proportion, can be used as an easily measured indicator for higher concentrations of elements compared to SRC biomass with larger shoot diameter. This has been proven within willow shoots [16,20,21] and among willow shoots of different age [14,15,22,23]. Rytter [24] reported a similar relationship between diameter and element concentrations for shoots of hybrid aspen. Also, Tullus et al. [25] found a significant negative relationship between shoot diameter and concentrations of P and K in the above-ground biomass for one aspen clone. It is relevant to investigate if such a relationship also exists across different poplar clones and different sites and to investigate if fuel quality for combustion of SRC poplar biomass can be evaluated by determining the mean shoot diameter before harvest.

Danish experiences with SRC poplar production have been limited compared to the rest of Europe. Therefore, we established a collaboration with German partners to investigate a series of four trials in the Brandenburg area in Germany with the same poplar and willow clones grown on all sites. However, poplar experiments have recently been established also in Denmark and results from them have been presented by Lærke et al. [26].

The objectives of this study were: 1) to characterize DM mass fraction, total ash mass fraction and concentrations of 14 elements associated with fuel quality for combustion for nine poplar clones and one willow clone grown as SRC at four German sites, 2) to assess the effects of clone, site and their interaction on fuel quality for combustion, and 3) to assess the effect of shoot diameter on fuel quality for combustion. The yield results of the poplar trial have been reported elsewhere [27].

2. Materials and methods

2.1. Sites and clones

The four trials were established in 2007 at four sites (Cahnsdorf, Gerswalde, Kummerow, and Rutenberg, Fig. 1) as part of a greater SRC trial network in the Brandenburg area in Germany. Detailed information of the four sites, such as location, climate, soil type etc. are shown in Table 1. The trials included 25–33 clones but for our study we chose nine poplar clones (AF2, Androscoggin, Max1, Max3, Max4, Monviso, Muhle-Larsen, NE42 and Weser6) and one willow clone as a reference (Inger) (Table 2). However, samples of the poplar clone Max4 were not available from the Rutenberg site.

To analyse the basic soil parameters, soil samples were taken at two depths: 0.0–0.3 m and 0.3–0.6 m. The mass fraction of sand, silt and clay were determined by sieving, dispersion and gravimetry procedures. The mass fraction of C was determined by loss of ignition according to DIN EN 12,879 [28]. Results are presented as the mean value for 0.0–0.6 m depth except for Kummerow where sufficient data were only available for 0.0–0.3 m (Table 1). The groundwater level was measured using an extendable Pürckhauer gouge auger. The soils were classified according to the USDA Soil Survey Manual [29].

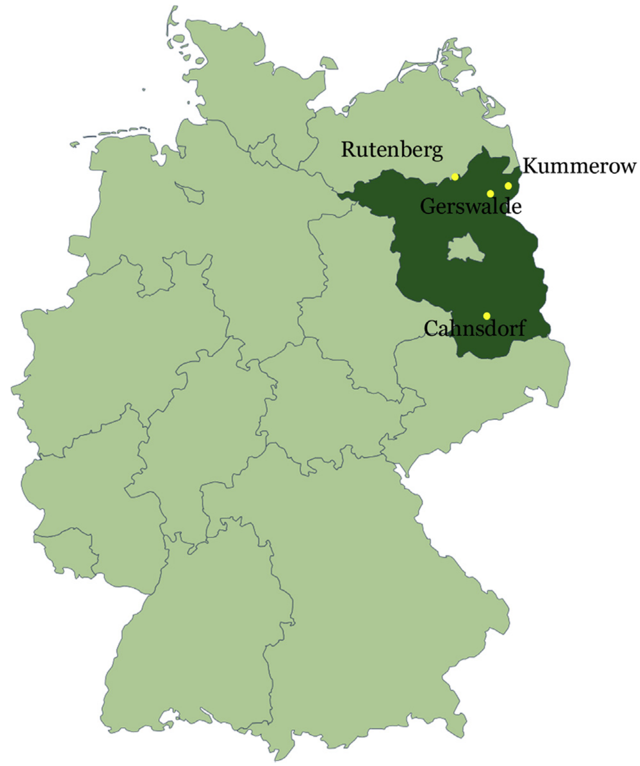

Fig. 1. Locations of the four trial sites in the Brandenburg area in Germany.

Temperature and rainfall was monitored at meteorological stations close to each experimental site. For each of the four sites, temperature data were obtained from one climate station located within 10–26 km distance and precipitation data were obtained as the average from two climate stations within 0.6–26 km distance. Climate data were obtained on a daily base and are summarized as the mean annual temperature and the mean annual sum of precipitation for the years 2007–2012.

The trial sites were either prepared by ploughing (Cahnsdorf and Rutenberg) or by the use of a field cultivator (Gerswalde and Kummerow). For planting, furrows were drilled with a potato plough, and 0.2 m cuttings were planted by hand into the drills. The trials were irrigated during April 2007 either by a sprinkler system or a hose system. Weeds were controlled mechanically during the first growing season using a brush-cutter and mulcher, supplemented by glyphosate spraying at one location (Gerswalde). No fertilization was carried out during the period from 2007 to 2012.

At each site, a completely randomized design was applied, consisting of five replications for each clone. Cuttings were planted in a double-row system. The internal spacing between rows within double-rows was 0.75 m and the spacing between double-rows was 1.5 m. Plant distance within rows was 0.6 m, resulting in an initial planting density of 14,800 plants ha^{-1}. Gross plot size was 27 m^2 with 10.8 m^2 of net plot. There were 40 trees in each gross plot and 16 trees in each net plot. The first harvest was carried out in January 2010 after the third growth year, and the second harvest was done in January–February 2013 after the sixth growth year.

2.2. Sampling of biomass

Biomass samples were harvested from January to February 2013 at the end of the second three-year harvest rotation cycle, i.e. the sampled shoots were three years old and the rootstock was six