Industrial Crops and Products 81 (2016) 72–82

Contents lists available at ScienceDirect

Industrial Crops and Products

journal homepage: www.elsevier.com/locate/indcrop

Miscanthus × *giganteus* as a biomass feedstock grown on municipal sewage sludge

Barbara Kołodziej[a,*], Jacek Antonkiewicz[b], Danuta Sugier[a]

[a] Department of Industrial and Medicinal Plants, University of Life Sciences in Lublin, 13 Akademicka Str., 20-950 Lublin, Poland

[b] Department of Agricultural and Environmental Chemistry, Agricultural University in Kraków, 21 Al. Mickiewicza Str., 31-120 Kraków, Poland

ARTICLE INFO

Article history:
Received 8 September 2015
Received in revised form
17 November 2015
Accepted 20 November 2015
Available online 2 December 2015

Keywords:
Miscanthus × *giganteus*
Biomass yield
Harvest date
Propagation
Sewage sludge application

ABSTRACT

Utilization of sewage sludge seems to be an attractive option for fertilization of bioenergy crops; therefore the objective of this study was to determine the effect of different doses of municipal sewage sludge on yields and bioenergy feedstock characteristics of *Miscanthus* × *giganteus* (Greef et Deu.). In a six-year field experiment, located on loamy clay, five doses of sludge (0, 10, 20, 40, 60 Mg DM ha^{-1}), two methods of plantation establishment (by rhizome divisions and micropropagation), and three dates of biomass harvesting (autumn, winter, spring) were tested in order to determine which one should be recommended in cultivation of this species.

Dry matter yields of giant miscanthus increased each year and exceeded 25 Mg ha^{-1} in an optimized system within this study. It was found out that application of lower doses of sludge (10–20 Mg DM ha^{-1}), resulted in obtaining the highest yield of biomass. On the other hand, the content, uptake and bioaccumulation factor of macronutrients contained in the sludge increased along with increasing dose of applied biosolids. *M. giganteus* biomass was characterized by favorable parameters: net and gross calorific values were in the range of 16.2–16.8 MJ kg^{-1} and 17.7–18.2 MJ kg^{-1}, respectively. The highest energy value of biomass yield was obtained in the case of rhizomes used for plantation establishment, especially in the treatments with 20 Mg DM ha^{-1} of sludge application. Spring harvest improved quality of biomass for thermochemical conversion, but at the same time significantly (by 22%) reduced yields, whereas winter harvest resulted in biomass loss without its quality amelioration compared to the autumn one.

1. Introduction

Bioenergy resources are considered to be primary energy sources. In agricultural areas biomass derived from field crops should be the main source of renewable energy (Lewandowski and Heinz, 2003; Kuś and Matyka, 2009). The potential of biomass production is enormous, since it is of importance for bioenergy, and non-fuel biorefinery by-products in the future. Calculations of available energy contained in biomass show that it ranged from 130 to 270 EJ/year around the world (Beringer et al., 2011), and assessment of its contribution in the European Union shows, on average, 5.4 EJ (130 Mtoe) (Stampfl et al., 2007). Biomass for energy production could be categorized as: residues from agriculture and forestry, organic waste, surplus forestry and energy crops. The last category (dedicated energy crops) is considered to be the most important group; however, the large-scale cultivation of these crops could compete directly with food production, especially on the most fertile lands. Recently, a great attention has been paid to the so-called second-generation energy crops, whose biomass, rich in lingo-cellulose, is a raw material in conversion to electricity, heat, biofuels or biomaterials. It is expected that production of these second-generation energy crops will develop to a large scale in the next 20 years (Atkinson, 2009). Among these energy crops, giant miscanthus is less dependent on favorable soil and climatic conditions, requiring fewer inputs of agrochemicals and not competing with food production (Beringer et al., 2011; Anderson et al., 2011; Godin et al., 2013). *Miscanthus* × *giganteus* Greef et Deu. (hereinafter referred to as *M. giganteus* or giant miscanthus) is a spontaneous sterile triploid discovered in Japan in 1935, combining the features of two species from Asia (*Miscanthus sinensis* and . *sacchariflorus sacchariflorus*) with better yields occurring during warm, humid summers (Atkinson, 2009; Heaton et al., 2004; Borkowska and Molas, 2013; Meehan et al., 2013). For many years it was treated as an exotic ornamental plant when, at the beginning of the 1980s,first plantations in Denmark and Germany, and later on in other European countries (inter aliain Poland) were established

* Corresponding author. Fax: +48 81 4456591.
E-mail address: barbara.kolodziej@up.lublin.pl (B. Kołodziej).

http://dx.doi.org/10.1016/j.indcrop.2015.11.052
0926-6690/

(Kuś and Matyka, 2009; Himken et al., 1997; Clifton-Brown et al., 2001; Jeżowski et al., 2008). *M. giganteus* from Poaceae family is one of the promising perennial C_4 crops, having relatively low input requirements, great potential for C mitigation, drought tolerance and ability to maintain high yields under a wide range of environmental conditions (Jørgensen, 1997; Borzęcka-Walker et al., 2008; Roncucci et al., 2014). Its tall stalks can be used for fiber or subjected to direct combustion, conversion to bioethanol, or used as a substrate for biogas production (Meehan et al., 2013). Projected production of giant miscanthus in Poland could reach 52 TWh/year if it were cultivated on 10% of agricultural land available (Stampfl et al., 2007).

This species has low requirements for soil fertility, tolerates growing on light soils, has no high demands for nitrogen, and efficiently uses water (Pude and Jeżowski, 2003). One can say that it grows quite well in the European climate. However, the disadvantage of giant miscanthus is its high sensitivity to frost, especially in the first year after planting (Jeżowski et al., 2008; Clifton-Brown and Lewandowski, 2000). Another barrier to the introduction of *M. giganteus* on a large scale is also the fact that this plant is characterized by self-sterility and can be reproduced vegetatively by using tissue cultures (micropropagation) or rhizome division (macropropagation), costly and not so effective methods of plantation establishment in comparison to seed sowing (Anderson et al., 2011; Clifton-Brown and Lewandowski, 2000).

Annual yields of *M. giganteus* across Europe range from 10 to approximately 40 Mg DM ha^{-1} and over 400 GJ ha^{-1}/year, and are higher than short rotation coppice (Atkinson, 2009; Godin et al., 2013). Full establishment of a giant miscanthus stand takes from 2 to 5 or even 7 to 8 years, depending on climatic conditions, but productive life span is estimated between 20 and 30 years (Heaton et al., 2004; Larsen et al., 2014).

Although giant miscanthus has many traits that make it ideal for biofuel production, environmental and management conditions can affect its productivity (Lewandowski and Heinz, 2003; Kuś and Matyka, 2009; Anderson et al., 2011; Meehan et al., 2013; Larsen et al., 2014). As shown by many authors (Kalembasa and Malinowska, 2008; Krzywy et al., 2003; Lisowski and Porwiślak, 2010), *Miscanthus* can produce much higher biomass yield after applying a fertilizer, e.g. municipal sewage sludge, which is the source of many valuable nutrients and has a value close to manure, but contains a number of potentially harmful constituents such as heavy metals or metalloids (Singh and Agrawal, 2008; Seleiman et al., 2013). The use of sewage sludge could not only increase yields but also positively affect biological and physicochemical properties of the soil profile (Singh and Agrawal, 2008; Seleiman et al., 2013; Casado-Vela et al., 2006; Usman et al., 2012). That is why the interest in the use of biosolids in the cultivation of energy crops such as giant miscanthus has been studied by many authors (Lisowski and Porwiślak, 2010; Smith and Slater, 2010; Ociepa-Kubicka and Pachura, 2013).

The objective of this work was to determine the effect of increasing doses of municipal sewage sludge on giant miscanthus yielding and biomass quality. We assumed that due to the fact that this species is not used for food production, municipal sewage sludge could be used to fertilize giant miscanthus as a valuable source of minerals, preferably affecting plant growth and development. Additionally, efforts were made to assess the impact of biosolids on chemical composition and structure of the experimental plant yield and selected physicochemical properties of the soil. Apart from the effect of sewage sludge dose, the study also attempted to determine the best method of giant miscanthus plantation establishment (by rhizomes or micropropagation) under conditions of south-eastern Poland and to indicate the optimum harvest date (autumn, winter or spring) of its biomass intended for combustion.

2. Materials and methods

2.1. Site description

The six-year (2008–2013) field study was established at the landfill belonging to the Janów Lubelski Department of Public Utilities in south-eastern Poland (50°43′17.7″N 22°22′08.0″E). The soil was a clay loam, characterized by slightly acidic pH, average humus content, low phosphorus, potassium and magnesium content, and where the heavy metal content remained at the natural level (Kabata-Pendias, 2011) (Table 1). According to the IUSS Working Group WRB (2007) classification, the soil belongs to Cambisols.

2.2. Experiment design and sample preparation

The experiment was organized as a randomized complete block design with three treatment factors: sewage sludge application, harvest date, and method of plantation establishment on plots with harvesting area of 14.4 m^2 with three replicates. For five years prior to the study the field had been fallow, without conventional disk tillage. In September 2007, municipal sewage sludge was applied in doses according to experiment design and mixed with topsoil. In the spring 2008, several weeks before planting, the seedbed was prepared by tilling with a moldboard plow and disk harrow (20 cm). The experiment was established as follows: 22 April 2008 by planting rhizome sections and 28 May 2008 by planting micropropagated seedlings of giant miscanthus at spacing of 0.75 × 0.8 m.

The experiment comprised five levels of municipal sewage sludge, three dates of biomass harvesting, and two methods of plantation establishment (from seeding of rootstock (rhizomes) and seedlings produced *in vitro*). Sewage biosolids were applied only once, before experiment establishment, at four rates: I—60 Mg DM ha^{-1}; II—40 Mg DM ha^{-1}; III—20 Mg DM ha^{-1}; IV—10 Mg DM ha^{-1}; control treatments were not fertilized with sewage sludge (V—0 Mg DM ha^{-1}). Municipal sewage sludge, which contained 13.3% of dry matter, 7.45% of N total and 2.35% of N ammonium, was used in the experiment (Table 1). The sewage sludge had relatively low content of heavy metals compared to the content found in the literature (Singh and Agrawal, 2008; Usman et al., 2012; Werle and Wilk, 2010). Due to the high water content, it was mixed with topsoil to a depth of 40 cm in the autumn of 2007. In addition, due to the low potassium levels in the soil and in the sludge, supplemental fertilization with 100 kg K ha^{-1} was applied to all plots. No irrigation or twice mechanical weeding were applied during the first growing season, while in the subsequent years weeds were removed incidentally. Plant survival was qualified by counting the number of plants producing new stems in the middle of May (until 2013, when stems filled empty spaces between plants), and percentages of the total plants planted in 2008 were calculated. To avoid border effects, the outermost rows were not taken into account.

In order to check the dynamics of dry matter content in the biomass and indicate the best date for biomass harvesting in terms of energy use (for combustion), three harvest dates of the aboveground parts of plants were used: autumn (end of October), winter (mid-January), and spring (end of March) following the growing season. Plants were harvested using hand implements at a stubble height of ca. 10 cm and stems were counted in the plots. Biometric measurements (height and diameter at the base of 25 stems per plant as well as weight of a single plant of five randomly selected plants in each plot) were performed during autumn biomass harvesting. After that, all aerial biomass from a plot was chopped in Bear Cat 70080 s-8HP chipper shredder (Colorado, USA), and three subsamples (600-g, 1000-g and 2000-g) were taken. 600-g subsamples were collected in paper bags and dried in an air force oven at 70 °C for 48 h in order to adjust fresh mass to air-dry mat-