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Research paper

The effect of harvest frequency on yielding and quality of energy raw material of reed canary grass grown on municipal sewage sludge

Barbara Kołodziej [a,*], Magdalena Stachyra [a], Jacek Antonkiewicz [b], Elżbieta Bielińska [c], Janusz Wiśniewski [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
[c] Institute of Soil Science, Environment Engineering and Management, University of Life Sciences in Lublin, Leszczyńskiego 7 Str., 20-069 Lublin, Poland

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ABSTRACT

The four-year-lasting field experiment located on loamy clay aimed at determination of yielding and biofuel characteristics of reed canary grass 'Bamse' variety cultivated at different doses of municipal sewage sludge (0, 10, 20, 40, 60 Mg ha^{-1} DM). In the experiment, three frequencies of energy feedstock harvesting were used: a one-harvest management system (in autumn), a two-cut regime (in spring and autumn), and a three-cut regime (in spring, summer, and autumn) in order to determine which of them has the best advantage of yielding potential obtained at application of sewage sludge.

It was found out that application of 40 Mg ha^{-1} DM of sludge resulted in the highest yield of biomass. The content and bioaccumulation index of macronutrients in plants increased along with the increasing dose of applied sewage sludge, reaching the maximum at 60 Mg ha^{-1} DM. Biomass was characterized by favourable parameters: net calorific value in the range of 15.2–16.1 MJ kg^{-1} as well as low ash (5.5%–7%) and sulphur (0.11%–0.24%) mass fractions. The most favourable was the single harvesting run in late autumn as well as the two-cut regime. In the cultivation of reed canary grass for energy purposes, excessive amounts of swaths of biomass should be avoided in order to prolong plant growth on the field, increase accumulation of dry matter, lower the moisture content, and at the same time reduce the mineral content. Application of increasing doses of sewage sludge positively affected soil physico-chemical properties as well.

1. Introduction

In recent years, there has been an increasing interest in the cultivation of energy crops, which is associated with the Polish Energy Policy [1] and Directive 2009/28/EC [2] on the promotion and use of energy from renewable energy sources. Currently, the main source of renewable energy in Polish conditions is forest residues. Due to the prognosis of exhaustion of this resource, there is a wide interest towards production of bioenergy raw material on agricultural land [1]. One of the native plants that can produce high yields of biomass is reed canary grass (*Phalaris arundinacea* L.) [3,4]. Reed canary grass (subsequently called RCG) is a perennial rhizomatous plant of the type C_3 photosynthesis, which gives high yields of good quality energy raw material. It is widely distributed across the temperate regions of Europe, Asia, and North America, preferring moist and nutrient-rich (especially nitrogen and phosphorus) habitats with a pH close to neutral [4,5]. Currently, cultivation of the species occupies a substantial area mainly in the Nordic countries, where this crop has been investigated for bioenergy options for a long time [3,6–9]. RCG can be used both in the agricultural (as animal feed and bedding) and industry sector (energy, paper) [8]. In addition, due to the favourable characteristics associated with the accumulation and collection of heavy metals from the soil, it can also be used as a phytoremediation plant, in areas degraded by industry or mining [10,11]. Intensive research is conducted on the use of reed canary grass for removal of nitrogen, phosphorus, and heavy metals from waste water or sewage sludge [10,12–14]. RCG biomass can also be subjected to direct combustion or used as a substrate for biogas production [10,15], making the plant one of the most promising energy plants, containing a significant amount of lignin and cellulose [3,8,16].

* Corresponding author.
E-mail address: barbara.kolodziej@up.lublin.pl (B. Kołodziej).

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In the cool Nordic climate, RCG harvesting is done in winter or even early spring [6,8,9]. Although they significantly lower the yields, the dry and cold conditions during the winter raise biomass quality by improving the dry matter content and reducing the mineral content of the biomass [16]. Due to the wetter and milder winter conditions than in Scandinavia, RCG biomass harvests in Poland are carried out two or even three times a year until late autumn [17,18]; however, an optimum harvesting time clearly needs to be defined.

Besides quantitative parameters, quality indicators for combustion such as gross calorific value as well as the content of moisture, ash, and alkali metals in biomass are important for energy purposes. Typically, the content of ash and alkali metals in herbaceous biomass is in good correlation and is significantly higher than those in wooded biomass [3]. According to Grzelak [5] and Burvall [6], the gross calorific value of reed canary is (17–18) MJ kg^{-1} DW. In addition, the usefulness of reed canary grass as an energy source is ensured by its low ash content and low humidity (similar results in terms of ash content have been reported for biomass plantations of fast-growing trees). According to Jasinskas and co-authors [19], the energy yields from reed canary grass plantations are approx. 115 GJ ha^{-1} to 130 GJ ha^{-1}, with its relatively small contribution during cultivation (approx. 13.6 GJ ha^{-1}).

The aim of the study was to determine the effect of different doses of sewage sludge on the yield of RCG grown for energy purposes. The research hypothesis assumes that non-contaminated municipal sewage sludge can be a valuable source of minerals for plants that are not grown for consumption, positively influencing their growth and development. In addition, the use of municipal sewage sludge as a fertilizer could become an alternative to the current management thereof, which poses a storage-related threat to the environment. In contrast to Western Europe, over 40% of sewage sludge produced in Poland is stored on lagoons and only 17% are used in agriculture [20]. The possibility of the use of sludge in the cultivation of biomass for energy purposes would therefore bring many positive natural and economic effects and could become an alternative to the use of conventional fertilizers [21,22]. For this purpose, four levels of municipal sewage sludge (10, 20, 40 and 60 Mg ha^{-1} DM) were used in a field experiment, under current legislation, and compared with the control plot not treated with the sludge. The direct and successive effects on the chemical composition and structure of RCG yield as well as selected physicochemical properties of the soil were assessed. In addition, efforts were made to determine the effect of the cutting frequency on biomass yield. To this end, the results of the different numbers of swaths, i.e. - single cutting (performed at the end of the growing season in autumn), a two-cut regime (carried out in two swaths: when fully headed and in autumn, and a three-cut regime (carried out in three swaths: when fully headed, after plant regrowth, and in autumn) were compared.

2. Materials and methods

2.1. Site description

The experiment was conducted between 2008 and 2011 at the landfill belonging to the Janów Lubelski Department of Public Utilities in southeast 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 contents, and heavy metal content remaining at the natural level [23] (Table 1). According to the WRB [24] classification, the soil represents Cambisols.

2.2. Experiment design and sample preparation

The experiment comprised five levels of municipal sewage sludge and three frequencies of RCG biomass harvesting. Sewage sludge was applied only once, before establishment of the experiment, in the following amounts: I – 60 Mg ha^{-1} DM; II – 40 Mg ha^{-1} DM; III – 20 Mg ha^{-1} DM; and IV – 10 Mg ha^{-1} DM; the control objects were not fertilized with sewage sludge: V – 0 Mg ha^{-1} DM. Sewage sludge used in the experiment contained 13.3% of dry matter, 7.45% of total N, and 2.35% of N ammonium, and had no pathogenic bacteria from the genus *Salmonella* and viable eggs of intestinal parasites *Ascaris* sp. *Trichuris* sp. and *Toxocara* sp. (Table 1). The sewage sludge was characterized by relatively low content of heavy metals compared to that found in the literature [20, 25, 26]. Due to the high water content, it was mixed with topsoil to a depth of 25 cm in the late autumn of 2007. Because of the low levels of potassium in the sludge, supplemental fertilization with K at 100 kg ha^{-1} was applied to all plots.

Seeds of the Swedish variety RCG 'Bamse' were sown on the 26th of June 2008 at 15 kg ha^{-1} in rows of 12 cm at depth of 2 cm. The experiment was established as a randomized complete block design with two treatment factors: the sewage sludge application and the harvest management system on plots with a harvesting area of 14.4 m^2 with three replicates. In the experiment, three frequencies of biomass cutting were compared: a one-harvest management system (at the end of the growing season in autumn – October); a two-harvest management system (two swaths: in spring, when fully headed (late May) and in autumn (October); and a three-harvest management system - simulating hay harvesting (three swaths: in spring, when fully headed (late May), in summer after plant regrowth in the vegetative phase and after formation of an approximately 30 cm of tiller (late August), and in autumn – October). In Year 1, all plots were harvested only once (March 2009) and the yields obtained were added to the total second year yields, while in the subsequent years the treatments consisted in one, two, and three cuts. Plants were harvested using hand implements at a stubble height of ca. 5 cm. Before the harvest, biometric measurements were performed. Herbage yields (given as the whole aboveground biomass (culms, leaves, and panicles) were measured and the number of culms per 1 m^2 was calculated as a sum of yields harvested during following cutting. The total yearly biomass yield for each sewage treatments was computed by summing the biomass yield from each individual harvest; the total yearly biomass yield was the trait analysed. After that, all aerial biomass from a plot was chopped in a 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 forced air oven at 70 °C for 48 h in order to adjust fresh mass to air-dry matter basis, 2000-g subsamples of RCG feedstock were used for assessment of its bioenergy characteristics (collected from the three-harvest management system and placed in plastic bags). Three 1000-g subsamples were taken from each plot for chemical analysis and dried at 70 °C for 48 h in paper bags. The subsamples were ground and analysed for macronutrients by ICP-AES as well as total nitrogen content (with the Kjeldahl method) and phosphorus content (with a spectrophotometer) [27,28]. In order to assess the suitability of the test plants for disposal of sewage sludge, the index of bioaccumulation (IBA) was calculated as a ratio of the element concentration in the RCG plants to the element concentration in the soil. A four-scale bioaccumulation rate was adopted for evaluation, where 0.001–0.01 was the lack of bioaccumulation; 0.01–0.10 – a slight degree of bioaccumulation; 0.1–1.0 – a medium degree of bioaccumulation; 1.0–10.0 – an intensive degree of bioaccumulation [23]. In the 2000 g subsamples of the three-harvesting