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Research article

Modification of properties of energy crops under Polish condition as an effect of sewage sludge application onto degraded soil

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A B S T R A C T

Energy crops are one of the possible solutions for reclamation of degraded or contaminated terrain. Their cultivation requires adequate fertilization typically containing high content of organic matter, nitrogen and phosphorous. While sewage sludge may be one source of these necessary nutrients, it may also modify some plant biomass properties, such as total carbon content. In our study, we determined whether sewage sludge (containing different value of heavy metals) could be an effective fertilizer to obtain good quality energy crops (such as *Miscanthus x giganteus* and reed canary grass, *Phalaris arundinacea*) and simultaneously play positive role for improvement of phytoremediation. The 3-year experiment was performed on degraded soil from terrain of steel mill of Czestochowa (Silesian region, Poland). During the study, it was confirmed that sewage sludge (also in combination with urea, CH_4N_2O) influences the mobility of Pb, Zn, Cd in soil solution, however the intensity of the process can be limited by plant species and time. Both *miscanthus,* and reed canary grass were characterized by the low value of bioconcentration factor (BCF), but because biomass was high, the total concentration of heavy metals in crops was comparable with hyperaccumulators. Additionally, modification of the fertilization affected energetic parameters, such as the content of carbon, S/Cl ratio, unitary CO_2 emission. However, this effect was not statistically significant.

1. Introduction

Increasing energy requirements have become a key issue to be solved around the world (Long et al., 2013). Therefore, in the previous decade, mandatory national targets were set to start replacing petroleum fuels by 2020 (Mehmood et al., 2017). Currently, global energy demand in the scenario by 2030 (Skevas et al., 2014) is considered to come from energy crops cultivated sustainably on non-usable land and/or degraded land (Tripathi et al., 2016) and by 2050 (Pant et al., 2011) will constitute more than a quarter of global demand. The use of bioenergy can not only fill the shortage of fossil fuels, but also stabilize the concentration of greenhouse gases (Long et al., 2013).

In accordance with the objectives of the European Union defined by the Directive of the European Parliament and Council Directive 2009/28/EC of April 23rd, 2009 on the promotion of the use of energy from renewable sources as well as amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC, by 2020 Poland should reach a 15% share of electricity generated from renewable energy source (RES) in the gross electricity consumption.

Unfortunately, the current energy production is not enough to meet the global energy demand (Pandey et al., 2016), so is needed to looking for more environmentally friendly and economical solutions (Long et al., 2013). To avoid negative competition between the use of land for the production of fuels and food, the marginal land or degraded terrain areas deserve attention recently (Fargione et al., 2010). The concept is based on the newly created so-called "sustainable phytoremediation" of such soils by energetic crops and it means that this crops can be grown in areas contaminated and bring many benefits like: reclamation of pollutants, production of bioenergy, improvement of the quality of the soil substrate, aesthetically pleasing landscape and carbon sequestration (Pandey et al., 2016).

The problem of degraded land management occupies an

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important place in policy agenda of developed countries. This primarily due to the mining processing, and energy or chemical industrial activity in the area. For example, in Poland, according to data from the Polish Central Statistical Office, the surface of degraded and devastated lands amounted to 61,958 ha (Central Statistical Office in Poland, 2016).

Typically, research regarding phytoremediation of contaminated soil are concerned on the slowly growing plant species (Pandey et al., 2016) while much less attention was given to fast growing perennial plants. Data published in 2015 indicate the positive impact of cultivation of perennial grasses on reducing leaching of heavy metals to groundwater (Fernando et al., 2015) and helped ease the climate in the region (Monti and Cosentino, 2015).

There are several species of plants that have potential to be used as energy plants and at the same time have the potential for growth in degraded areas which are low in nutrients and water. These plants called “second generation energy crops” are represented by *miscanthus* perennial grass, which besides high biomass production potential, has low soil requirements and a deep root system, which has a large impact on the prevention of soil erosion and the spread of pollutants (Pandey et al., 2016). *Miscanthus* tolerates high temperatures climate, and reed canary grass cool climatic conditions. Currently, *Phalaris arundinacea* it is considered a promising energy plant also due to the fact that it has an effective internal mechanism of N-recycling from shoots to roots, so it is itself efficient in using nutrients (Partala et al., 2001). Research conducted in England by Lord (2015) indicated that reed canary grass is best adapted energy crop to difficult soil conditions in this climate zone.

It is well known that the energy crop cultivation on polluted terrains is technically difficult to conduct, because plant production will be significantly hampered by toxicity of pollutants and depletion of nutrients (Kacprzak et al., 2017). Due to the fact that in the phytoremediation processes, over 20% of the management costs are absorbed by the artificial fertilizers application (Wan et al., 2016) so there is a need to use cheap and equally effective and even better solutions (Ociepa et al., 2017). Replacement of mineral fertilization by the organic fertilizers such as sewage sludge, in addition to enriching the substrate with nutrients (Grobelak, 2016), contributes to the reduction of crop emissions from 0.4 to 1.5 Mg CO_2 eq.$^{-1}$ ha year^{-1} (Finnan and Styles, 2013). The use of sewage sludge in the soil seems to be one of the most ecological and cost-effective options (Boudjabi et al., 2017).

The energy contained in biomass is a key factor influencing the energy production and is generally indicated by the amount of heat generated during the total combustion in the standard state. It is limited by composition of elements, especially carbon content in biomass. Higher and lower heating values (HHV, LHV) are used both for calculating energy potentials in biomass (Long et al., 2013).

Pandey et al. (2016) indicated in the proposed strategy of “sustainable phytoremediation” an assessment of the quality of biomass in terms of energy, which was produced from contaminated areas. Researchers from India Kumar et al. (2015) pointed out that in order to consider the energy usefulness of plants should be examined its calorific value and carbon content. Unfortunately, currently there is no data from this scientific area, mainly the assessment of the impact of organic waste (sewage sludge and other biosolids) on the calorific value and carbon content in biomass of energy crops cultivated in degraded areas, which is the subject of this study.

Hence the aim of the work was to determine whether the use of modifications of fertilization (combination of sewage sludge with additional foliar mineral fertilization by urea) can be useful tools for “hybrid” monitoring of “sustainable phytoremediation” properties with the energy potential of crop plants such as *miscanthus* or reed canary grass.

2. Materials and methods

2.1. Materials

The soil originated from the terrain of Czestochowa Steelworks (Poland, Silesia region). The sewage sludge was taken from municipal (OW) and industrial (OJ, food processing) wastewater treatment plants WWTP's (Table 1).

2.2. Experiment conditions

The experiments were carried out under semi-controlled conditions (containers) over the course of 2.5 years. A total of 12 containers were used throughout the experiment, each with a carrying-capacity of 240 dm^3. All containers were equipped with a drainage and hose system that allow them to collect soil leachates. The top layer of soil in 8 of these containers was fertilized with sewage sludge with a composition of 10% of dry matter by weight (equivalent to 45 Mg ha^{-1} 3years^{-1}, according to the Polish law's permissible value) to the depth of 30 cm. In the first 4 containers, the topsoil layer of soil was mixed with municipal sewage sludge (OW) and in the next 4, with industrial sewage sludge (OJ). The remaining 4 containers were controls. Two plant species: *miscanthus* (*Miscanthus x gigantheus* L.) and reed canary grass (*Phalaris arundinacea* L.), were used as test plants due to their use as high-value energy potential. After 2 weeks of geochemical equilibration, the *miscanthus* seedlings were planted (5 plants per container) in 6 of the containers, while seeds of reed canary grass (in the amount of 20 kg ha^{-1}) were planted in the remaining 6 containers.

At the beginning of the second vegetation period, foliar mineral fertilization with nitrogen (urea) was carried out with a dose of 60 kg N ha^{-1} and 80 kg N ha^{-1} in *miscanthus* and reed canary grass, respectively.

2.3. Sampling

To determine pertinent physio-chemical properties, the soil and sewage sludge samples were air-dried, sieved through a mesh with

Table 1
Characteristic of soil and sewage sludge used in experiments.

Parameter		Value	Average
Soil			
pH in H_2O		–	**7.88 ± 0.01**
pH in 1 M KCl		–	**7.40 ± 0.01**
CEC (cation exchange capacity)		cmol kg^{-1} d.m.	**19.00 ± 0.14**
C		mg kg^{-1} d.m.	**17.45 ± 0.95**
N		mg kg^{-1} d.m.	**481.00 ± 4.9**
P		mg kg^{-1} d.m. P_2O_5	**15.00 ± 1.40**
Cd		mg kg^{-1} d.m.	**2.30 ± 0.33**
Cr		mg kg^{-1} d.m.	**26.32 ± 2.83**
Cu		mg kg^{-1} d.m.	**29.44 ± 0.01**
Ni		mg kg^{-1} d.m.	**28.99 ± 1.70**
Pb		mg kg^{-1} d.m.	**46.57 ± 5.25**
Zn		mg kg^{-1} d.m.	**112.00 ± 9.83**
Sewage sludge			
Metal	value	OW	OJ
Cd	mg kg^{-1} d.m.	**6.1 ± 0.46**	**0.36 ± 0.1**
Cr	mg kg^{-1} d.m.	**341.0 ± 3.4**	**90.6 ± 0.3**
Cu	mg kg^{-1} d.m.	**293.4 ± 1.4**	**61.6 ± 3.6**
Ni	mg kg^{-1} d.m.	**116.9 ± 1.0**	**18.3 ± 0.5**
Pb	mg kg^{-1} d.m.	**153.8 ± 3.5**	**25.4 ± 0.1**
Zn	mg kg^{-1} d.m.	**2,6 ± 2.8**	**299.2 ± 5.3**