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Willow (*Salix viminalis* L.) in purifying sewage sludge treated soils

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Abstract. Willow is a plant that can be cultivated in contaminated soils because of its ability to take up harmful substances and accumulate it in aboveground biomass. Fast development of big agglomerations in developing world, increased consumption and need of mankind lead to production of huge amounts of wastes that are stored at landfill sites. The surface of landfill sites is decreasing year by year. There is no enough place to store it. The part of wastes could be reused without wasting its beneficial properties. Sewage sludge is an inevitable product of waste treatment containing major contaminants such as: PAH (Polycyclic Aromatic Hydrocarbons), polychlorinated biphenyls, polyphenols, polychlorinated dibenzodioxins and heavy metals which restricts its use in agriculture. On the other hand, it contains appreciable substances needed in normal plant growth. Willow could be used in Poland as source of biomass to produce renewable energy. Poland is obliged to increase the contribution of renewable source of energy in energetic balance in accordance to the 3x rule. This plant gives many possibilities especially in natural habitat. Its properties allow willow to be fertilized with sewage sludge. The problem of application of sewage sludge seems an efficient method of its management.

key words: heavy metals, phytoremediation, sewage sludge, willow

INTRODUCTION

A growing demand for energy biomass production has resulted in an increased interest in willow cultivation. However, its growth and yield depend on soil and local climate. According to legal regulations, sewage sludge before its application to soil has to be tested for its hygienic properties and heavy metal content. Recent research showed that sludge is environmentally utilizable since it is rich in macronutrients that are essential for growth and development (Czekała, 1999; Mazur, 1996; Lazdina et al., 2007; Nasr, 1997; Michałowski and Gołas, 2001; Tack et al., 2005; Wieshammer et al., 2007). According to Polish rules on fertilizers and fertilization sewage sludge is a special substance that may ameliorate soil properties [Rule accepted on the 10th of July 2010 on fertilizers and fertilization], but it cannot be used in rough condition [Rule on sewage sludge, 2002]. Is it possible to use sewage sludge in a willow plantation? We should look for a more ecological method to utilize sewage sludge and we should not waste its natural values.

Willow plants may be used to extract heavy metals from contaminated soils due to their tolerance to specific heavy metals, adaptation to soil and climate characteristics, heavy metal uptake capability and spatial fitting of roots to pollution distribution. There are basic two phytoextraction strategies available: one is the use of hyperaccumulators like *Thlaspi caerulescens* or *Nicotiana tabacum* L., *Alyssum bertolonii* L. (Keller et al., 2003). They take up specifically one or two metals and produce often low biomass compensated by high metal concentrations in shoots. The second strategy comprises plants that produce high biomass and are usually not metal-specific which are compensated by their high biomass (Greger and Landberg, 1999). They take up heavy metals more effectively from contaminated soils, especially willow is characterized by a well-developed root system. Willow has many desirable traits that make it amenable to ecotechnologies. For instance high content of cellulose in the wood of willow may be used to produce high quality paper and generally to protect environment: soil, water and air (Kuzovkina and Volk, 2009).

WILLOW AS A SOURCE OF RENEWABLE ENERGY

Perspective of depleting of fossil fuels resources and environmental concerns caused a growth of interest in

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utilization of renewable energy sources in EU countries including Poland. One promising source of renewable energy is willow's biomass [Stategy of Renewable Energy Development].

Willow belongs to the family *Salicaceae* that comprises more than three hundred species, in Poland 30 species, indefinite number of natural and synthetic halfbreeds (Kościk, 2003; Frankowski, 1961; Szczukowski et. al., 2002). Production of willow is projected to be an important source of renewable energy in the coming decades. The average annual willow biomass is estimated from 10 to 15 Mg ha^{-1} (Adegbidi et al., 2001; Lazdina et al., 2007; Stolarski et al., 2006, 2008; Sulima et al., 2006; Meers et al., 2007; Szczukowski et al., 2000). According to Adegbidi et al. (2001) willow takes up with the annual production 15–26 Mg ha^{-1} 75–100 kg ha^{-1} of nitrogen (N), 10–12 kg ha^{-1} of phosporus (P) and 25–40 kg ha^{-1} of potassium (K). As opposed to coal, willow wood, shares with other wood materials neutrality to the greenhouse effect but has an additional benefit of accumulating low amounts of heavy metals so it can be used for energetic purposes. Small amount of nitrogen, sulphur and chlorine during the burning qualifies this plant as an eco-friendly. During the combustion the emission of toxic substances is much lower compared to combustion of coal (Jóźwiakowscy, 2001). Poland aims to gain sustainability to enhance the quality of natural habitat and to reduce the emission of toxic substances. It is a priority of our Ecological Policy. We should support this type of policy. The strategic aim of this document is to increase the contribution of energy from renewable source to 7.5% in 2010 and 14% in 2020 (Ecological Policy of Poland). The strategy of the Development of the Renewable Energy Sector in Poland describes possibilities of increasing the amount of renewable source of energy by cultivating willow because we are obliged to increase it. Under our conditions willow seems to have the highest biomass potential.

We distinguish many energetic plants in Poland that can be used for those purposes: willow (*Salix viminalis*), hollyhock (*Sida hermaphrodita*), *Miscanthus* and *Helianthus tuberosus*. We ought to increase the area to cultivate energetic plants, in 2020 to 2.2%. The threat and perspective of depletion of non-renewable sources of energy pressures us to seek for renewable source of energy. Willow material features the high biomass that can be obtained on soils that are not productive from agricultural point of view or contaminated.

CHEMICAL PROPERTIES OF SEWAGE SLUDGE

Sewage sludge is a waste but bearing in mind its organic matter and other nutrients content, the best system to manage it is to use it in agriculture. Thus it becomes necessary to always analyse sewage sludge before directing it towards agricultural use and also we should know the content of heavy metals of the soil where it is applied. Apart from providing organic matter and nutrients it might enrich soils with other elements like heavy metals. Nitrogen in sewage sludge is in organic form and the average content of nitrogen is about 3.2% dry mass. Phosphorus is in organic and mineral form and the average content amounts to about 3% of dry mass. The use of phosphorus by plants in the first year totals about 20% and is higher in succeeding years. The use of nitrogen is problematic. Some scientists claim that it amounts to 20% in the first year and is higher by 25% in succeeding years. According to others it amounts to 70% in the first year. The content of calcium totals 3.1%, magnesium 0.54% and sulphur 0.87%. The content of dry mass of sludge depends on the technology of purifying the wastes and amounts from 16.2% to 48.7% (Czekała 1999, 2000). Sewage sludge containing more than 54.2% of organic matter can be treated like "organic fertilizers". The high nutrient content makes it an excellent fertilizer. Heavy metals are distinguished into two groups: micronutrients that are needed for normal growth and development of plants but the excessive amount of which can contaminate dairy products. The second group comprises toxic metals like Cd, Pb and Hg, but their role is not clearly understood. Excessive amounts of both groups may become toxic to plants. Long terms effects can occur in the food chain.

On the other hand sewage sludge contains toxic substances that cause mutagenic and cancerogenic changes (Karczewska, 2002; Soler-Rovira et al., 1996). These substances are found in sewage sludge in relatively small amounts compared with its other components but they may be excessive in many cases and represent a risk of toxicity even in small concentrations because of their persistence and accumulative effect. Sewage sludge is a heterogeneous material since it depends on kind of wastewater, on the technology used and on the time of the year. Industrial effluent provides more polluted sewage sludge than that from treating wastewater of another type, mainly urban. Among negative aspects of applying sewage sludge as a fertilizer are also those related to pathogenic microorganisms. Therefore we should check sewage sludge before its distributing and take into account its content of heavy metals and pathogenic microorganisms. According to Polish regulations the amount of biological contaminants used in agriculture must be zero.

WILLOW AS A PHYTOFILTER

Salix clones with high-metal accumulating capacity in shoot and above ground biomass may be suitable for phytoextraction of moderately contaminated sites, such as agricultural soil with elevated metal levels and to purify sewage sludge from excess of heavy metals. Willows can thus be used to remove many heavy metals, especially Cd (Vervaeke et al., 2003; Labrecque and Teodorescu, 2003). Problems connected to uptaking heavy metals by willow from sewage sludge is a new subject matter and their reac-

tion to polluted environment. Among crossbreds of willow scientists are aiming to obtain species able to accumulate heavy metals. There are many clones that are capable to take up macronutrients especially N and P from sludge. Willow is called "filter" for contaminants because it shows high tolerance to some heavy metals. This was proved by Polish and foreign scientists (Cosio et al., 2006; Kalembasa et al., 2009; Keller et al., 2003; Ohllson et al., 2008). Willow takes up nitrogen, phosphorus, magnesium and potassium from sewage sludge and accumulates heavy metals in aboveground biomass. The mechanism of its accumulation depends on taking up heavy metals via root and migration to aboveground biomass. It is connected with intensive change between roots and particles of contaminated soil. The biggest concentration of heavy metals is observed in leaves, then in the bark and the least in wood (Labrecque et al., 1997). The uptake of heavy metals by the biomass of willow usually is the highest for the treatments fertilized with the highest doses of wastes. This trait allows willow to be used to clean up wastes and sewage sludge especially of Cd (Klang-Westin and Eriksson, 2003; Landberg and Greger, 1996). Cadmium is one of the most toxic microelements. This element belongs to the group of heavy metals that induces functional and morphological changes in plant organisms. Willow may accumulate ten times more cadmium than its concentration in sewage sludge or soil. Accumulation of heavy metals is strongly influenced by genotype. It allows also to use willow for remediation of degraded areas. Information on the biological transformation of organic pollutants by willow and associated microorganisms is limited (Amos et al., 2011).

In the growing season willow takes up the biggest amount of macronutrients especially nitrogen and phosphorus from sewage sludge (May–July) – in the period of the biggest development of biomass. This trait is now used in wastewater treatment plants to purify wastes from heavy metals. The shoots of willow contain the least amount of nitrogen and phosphorus and therefore they can be used for combustion without concern that it can cause environmental pollution.

This trait is also used in purifying sewages within sewage plants. Willow can create third grade of purifying sludges after its mechanical effluent treatment. Therefore there are many domestic sewage treatment with willow. It constitutes also garden's decoration (Jóźwiakowscy, 2001).

CONCLUSIONS

Sewage sludge can be considered as an organic fertilizer for agriculture and forestry because it contains high concentrations of nitrogen and phosphorus which are needed by plants and also willow. Willow seems to be promising for the phytoextraction of heavy metals what is proved by foreigner and Polish scientists. The newest research are connected to improve the capacity of uptaking heavy metals via willow. Scientists attempt to increase the ability to absorb heavy metals by using NIC and NiA (nicotinic acid). The main aim of these substances is to increase the tolerance the clones that are sensitive to heavy metals. In a future it allows to use clones of willow to work on broad canvas on contaminated sites. Willow is an excellent producer of biomass because of high yield of wood and it has several characteristics that make it promising for use in phytoremediation especially its ability to take up heavy metals from contaminated soils and accumulate in its tissues in the following order: leaves>bark>wood. Sewage sludge should not be deposed on the dumping grounds because valuable elements like nitrogen and phosphorus are lost. Purified sewage sludge may be excellent example of organic fertilizer especially for willow that constitutes filter for contaminants.

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