Organic Soil Amendments in the Phytoremediation Process

Anna Grobelak

Abstract Land application of biosolids, such as sewage sludge or compost, has a great incentive in view of its fertilizer and soil amendment values, unless they contain toxic elements. The heterogeneous nature of biosolids produced in different processes necessitates knowledge of the chemical and biological properties of biosolids prior to the land application. Plant wastes are being increasingly used to produce compost, which is an important amendment to improve the properties of degraded soils. Some soil amendments can be used directly for the remediation of degraded areas and to fertilize the soil. One of the challenges of environment management is connection in usage as many resources towards achieving maximum benefit with minimum damage to the environment and even with achieving the improvement of the soil conditions. The biomass, land, and wastes are extremely important resources in the green economy. The biomass becomes an increasingly important raw material that can be produced using a wide group of wastes and by-products during the soil reclamation process. The main objective of this study was to estimate the effectiveness of the conjugation of three processes: waste, land, and biomass management. The pot and field studies were conducted on degraded area, using by-products and organic waste, in order to achieve soil phytoremediation effect. The study was conducted using biosolids, e.g., compost from municipal sewage sludge, sewage sludge, and lacustrine chalk and two plants species, for wood biomass—pine (*Pinus sylvestris* L.) and for green biomass as energy crops giant miscanthus (*Miscanthus giganteus*).

Keywords Biosolids • Phytoremediation • Soil amendments • Trace elements • Soil reclamation • Compost • Sewage sludge

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1 Introduction

The organic soil amendments due to their high variability in chemical, physical, and sanitary parameters must be subjected to appropriate examination before their use. Introducing the organic additives into the soil can result in decreased mobility of heavy metals [1, 2]. Organic additives, obtained mainly from plants, are characterized by great variation in the content of biogenic elements such as nitrogen, phosphorus, and potassium. They contain large amounts of carbon and other elements, which are part of the main organic substances. The quality of plant substrate for the production of compost is influenced by: the content of organic material and fertilizers and the ratio of carbon to nitrogen. Sawdust, wood chips, bark, straw, plant wastes, and food waste from households are commonly used to produce compost [3]. Sewage sludge must also be seen as a valuable organic fertilizer. Sewage sludge contains trace elements and easily degradable organic substances. Sewage sludge contains also important nutrients such as nitrogen and significant amounts of phosphorus but low amount of potassium [4].

The use of sewage sludge in reclamation processes contributes to the possibility of valuable elements recovery, for example, nitrogen, phosphorus, and other nutrients which are important for plant growth [5]. The contents of individual components in sewage sludge result from the processes of wastewater treatment and the composition of influent [6]. The use of sewage sludge for fertilization and remediation is associated with certain limitations, which are caused by, e.g., the presence of hazardous substances, microorganisms in sewage sludge, and pathogenic micropollutants and undesirable odor. Despite such limitations, sewage sludge improves soil structure by the generation of large amounts of humus. For this reason, sewage sludge plays an important role in the phytoremediation. In the heavy metal binding process, both inorganic substances (sulfides, phosphates, hydroxides and oxides of noncrystalline iron and aluminum, and manganese) and organic substances (living microorganisms, organic and mineral remains of dead organic compounds) are involved [7].

Mechanisms playing a significant role in the binding of heavy metals in sewage sludge and composts are: ion exchange, precipitation and co-precipitation reactions, and adsorption of contaminants on the outer and inner surface of minerals [8]. The sewage sludge and composts that contain even a small content of heavy metals has a positive effect on the growth of the microbial biomass and microorganisms present in the soil [9]. Composts and sewage sludge used for the restoration of degraded land are involved in the processes such as: chemophytostabilization (the formation of stable metal salts), immobilization (immobilization of metals with functional groups of fulvic and humic acids which have available negatively charged loads), phytoremediation (phytoextraction and phytostabilization), bioaugmentation (application into the environment of some microorganisms), and biostimulation (addition of nutrients to stimulate the activity of soil microflora) [10, 11]. Composts, containing sewage sludge from municipal wastewater sources, may contain excessive amounts of heavy metals, such as Sn, Zn, Cd, Pb, Mn, Fe, Co, and Si, which in high concentrations can be toxic. In this case, the use of sewage sludge is not suitable for reclamation of degraded areas. Too much toxic elements in sewage may be leached into groundwater and surface water, creating threats for the whole ecosystem [12].

2 Sewage Sludge and Compost Soil Application: The Laws and Regulations of the European Union

The ever-growing need to protect the environment from degradation requires rationalization of sewage sludge management. The legislation of the European Union concerning the disposal of sewage waste is included in the Council Directive 86/278/EEC on environmental protection of 12 June 1986 (the so-called Sludge Directive). The 2000/60/EC of the European Parliament and Council of Europe of 23 October 2000 sets the norms of joint Community action in the field of Water Policy (Official Journal EC L 327 of 22 December 2000). The Water Framework Directive (WFP) defines sludge not as waste material, but as a “product” of sewage treatment.

The operational directive of the Water Framework Directive is the Directive 91/271/EEC of 21 May 1991 concerning the treatment of municipal sewage. The Directive obliges to monitor and report municipal sewage treatment and final disposal of municipal sewage sludge for agglomerations. Article 14 of Council Directive 91/271/EEC refers to sludge produced in course of sewage treatment and states that sewage has to be reused in every appropriate case, provided that adverse effects to the environment are prevented at all times. Implementation of this Operational Directive by the end of 2015 will increase the stream of sewage sludge, but on the other hand it will enable other methods of sludge reuse. Limits regarding storage of sludge are introduced by Directive 99/31/EC of 26 April 1999 on sludge storage, called the Landfill Directive.

Sewage sludge is subject to European Parliament and Council Directive 2008/98/EC of 19 November 2008 on sewage that is the Waste Framework Directive which regulates waste recycling including sewage sludge. According to the above-mentioned Directive, sludge defined as waste is subject to the procedure assigned for waste treatment. The Directive states that prevention of waste production is the first priority, the next being preparation of waste for reuse, recycling, or other forms of recovery and finally waste disposal. It is not possible to prevent the production of sewage waste. That is why other steps of dealing with waste are very important, that is preparation for reuse, understood as sludge reprocessing (including possible energy recovery or organic recycling).

Directive 2010/75/EC of 24 November 2010 on industrial emission officially updates and combines other directives, including Directive 2008/1/EC on integrated prevention of pollution and its control (IPPC), Directive 2001/80/EC on reduction of air pollutants emission from LCP’s another document, the Technical Report for End-of-Waste Criteria on Biodegradable Waste Subject to Biological treatment—Third Working Document (September 2012) places sewage sludge on the positive waste list and allows clean sludge to be used as fertilizer and gives way to qualify it as a waste product. The use of organic wastes as amendments to improve soil organic matter level and long-term soil fertility and productivity is gaining importance. The disposal of the large quantity of organic wastes produced by the municipal, agricultural, and agro-industrial activities is causing energetic, economic, and environmental impacts. Sewage sludge composting process for use in agriculture should be given a priority for its disposal. These organic amendments should not be treated as a waste but a valuable non-farm source of organic matter to soil. The composting process is a useful method of producing organic matter that can be used as a source of nutrients and soil amendments. Land application of sewage sludge has a great incentive in view of its fertilizer and soil amendment values, unless it contains toxic elements. The heterogeneous composition of biosolids produced in different wastewater treatment plants requires the chemical and biological investigation prior to land application [13, 14].

For the legal issues, in Europe the sludge (in agriculture) directive (86/278/CEE), the landfill directive (99/31/UE), and the waste incineration directive (CEC, 2000) are relevant to the fate of biosolids. Other relevant instruments are the urban wastewater treatment directive, nitrates directive, water framework directive, and the hazardous substances regulations that have controlled the production and use of substances such as PCBs and brominated flame retardants. These have affected the quantity and quality of biosolids. For example, by harmonizing requirements for phosphate removal during wastewater treatment, the urban wastewater treatment directive has increased the quantity of sludge produced and also increased phosphate content of sewage sludge. Regulations have reduced the concentrations in biosolids of the substances they regulate. The portal to EU legislation is available at http://eur-lex.europa.eu/en/index.htm.

3 Impact of Compost Initial Conditions on the Phytoremediation Process of Contaminated Soils

Compost is considered a multifunctional soil improver. It is, therefore, used in agriculture and horticulture as well as in producing topsoil for landscaping or land restoration. The application of compost usually improves the physical, biological, and chemical properties of soil. Repeated application of compost leads to an increase in soil organic matter, it often helps to reduce erosion, it increases the water retention capacity and pH buffer capacity, and it improves the physical structure of soil (aggregate stability, density, pore size). Composts may also improve the biological activity of the soil. Compost is often considered an organic fertilizer although the fertilizer function of compost (supply of nutrients) is, in many cases, less pronounced than the general soil improvement function [15–18]. The presence of heavy metals in the environment, and in areas used for agriculture, is an important issue for environmental concerns. Trace elements can be included in the food chain and biological circulation. A characteristic feature of heavy metals is also their capability to remain in the environment for long period of time, as well as resistance to chemical and biological degradation [19]. For this reason, it should be assured that potential soil biosolids contain as little heavy metal as possible [20]. The second issue is the problem of large areas, mainly post industrial, that are contaminated with heavy metals [11].

One of the methods for remediation of such areas is phytoremediation technique, which involves the plants for the treatment of soil from organic and inorganic contaminants (e.g., heavy metals). Phytoremediation method is economically justified, least environmentally invasive and generally acceptable by society. An additional advantage of phytoremediation of soils is the possibility of using waste and by-products (e.g., sewage sludge, composts, organic wastes, organic fertilizers, coal mules, lacustrine chalk) as soil additives to support this process and at the same time to affect the recycling and disposal of a significant amount of waste substances. Also the large areas of post-mining land like lignite mine dumping sites are characterized with poor organic and biogenic compounds. Soil organic additives are a source of organic matter, carbon, and biogenic elements which provide a significant improvement in the quality of the soil environment. Moreover, they have the sorption ability related to immobilization of contaminants in soil, e.g., heavy metals.

4 Case Study: Comparison of Composts for Remediation Purposes

Selected composts based on the organic wastes were prepared (Table 1) and tested for their suitability as a biosolid for improved phytoremediation. Compost samples were analyzed (Tables 2 and 3) for their chemical composition, dry matter content, organic carbon, total Kjeldahl nitrogen, total P, heavy metals, *Salmonella* spp. according to standard methods [14].

During the composting process, organic matter is decomposed and transformed to stable humic compounds. Humic substances have a capacity to interact with metal ions and the ability to buffer pH and to act as a potential source of nutrients for plants. The heavy metal concentration in the final product deserves consideration

Table 1 Composition of composts I–VI

Compost	Municipal sewage sludge (%)	Bulking agent (%)	Green plants (%)	Organic fraction of municipal solid wastes (%)	Organic home wastes (%)
I	65	5			30
II vermicompost	65	5			30
III	81	5		14	
IV vermicompost	81	5		14	
V	40	5	55 rape		
VI	40	5	55 grass		

Table 2 Composts physical and chemical parameters of different composts I–VI

Parameter	I	II	III	IV	V	VI
Organic matter [%]	65.7 ± 2.3	72.6 ± 2.3	74.9 ± 2.9	71.1 ± 2.7	65 ± 6.0	75 ± 4.2
C [% d.m.]	31.1 ± 0.8	33.3 ± 0.6	30.1 ± 0.9	26.7 ± 0.8	29.5 ± 1.3	44 ± 2.1
Kjeldahl N [% d.m.]	1.4 ± 0.06	1.7 ± 0.0	2.1 ± 0.1	1.9 ± 0.05	1.3 ± 0.1	1.4 ± 0.02
P [% d.m.]	2.21 ± 0.0	2.43 ± 0.0	1.8 ± 0.0	1.65 ± 0.0	1.7 ± 0.52	0.18 ± 0.01
K [% d.m.]	5.24 ± 0.4	5.71 ± 0.5	7.39 ± 0.7	4.99 ± 0.4	4.32 ± 0.3	1.05 ± 0.1
C/N ratio	22.2 ± 0.8	19.6 ± 0.9	14.3 ± 0.8	14.05 ± 0.5	22.68 ± 2	31.42 ± 1

Table 3 The heavy metals concentration in the composts I–VI

Metal [mg/kg d.m.]	Limit[a]	I	II	III	IV	V	VI
Cd	5	2.0 ± 0.2	1.4 ± 0.15	1.6 ± 0.2	1.3 ± 0.1	1.4 ± 0.1	0.49 ± 0.1
Cr	100	17.9 ± 1.8	15.5 ± 1.6	13.5 ± 1.4	22.3 ± 2.2	55 ± 3.1	4. 9 ± 0.8
Ni	60	5.3 ± 0.6	5.5 ± 0.6	4.5 ± 0.5	7.2 ± 0.7	19.51 ± 1.3	2 ± 0.20
Pb	140	20.8 ± 2.1	22.5 ± 2.3	26.9 ± 3.1	25.1 ± 2.5	20.29 ± 2.10	5.14 ± 0.3
Hg	2	0.30 ± 0.001	0.20 ± 0.001	0.10 ± 0.001	0.10 ± 0.001	0.20 ± 0.01	0.10 ± 0.001

[a]Limits imposed by Polish regulations for soil organic amendment

since they may enter the food chain when the biosolids are applied on land. The obtained results show (Table 3) that the concentrations of heavy metals in all composts were within the limits of regulation for soil organic amendments. One of the issues encountered by the direct use of composted sewage sludge and organic fraction of municipal solid waste in agriculture is the risk of plant and human contamination by pathogens in addition to heavy metals. During the composting process, *Salmonella* and a number of live helminth eggs were removed from the final product, what confirms that composting is a proper method for biosolids production and the method of disposal of organic waste. It was found that composting process of different wastes resulted in obtaining a valuable source of organic amendment, which can be safely used for remediation purposes.

5 Trees in the Process of Phytoremediation of Degraded Areas

Phytoremediation is a green technology to remove environmental pollutants. Of the growing interest in the processes of phytoremediation of contaminated sites are perennial plants with high biomass, i.e., trees. Their extensive and deep root system enables purification of ground–water environment and the possibility of reaching the roots in a place inaccessible to smaller green plants. In addition, these plants are characterized by high resistance to adverse environmental conditions such as lack of nutrients and water scarcity. Trees used in phytoremediation process should have a resistance to high levels of toxic substances, high capacity for the collection and storage of pollutants and should produce a large amount of biomass [21]. Trees such as poplar, pine, or spruce are species that have the ability to actively respond to the presence of high concentrations of heavy metals in contaminated soil. Due to exudates release to the soil in rhizosphere layer (organic acids), roots are able to extract the trace elements to the roots and to aboveground parts of plants.

A more effective method of metal detoxification is their binding in the roots until reaching a maximum concentration. The most popular trees exhibiting a high capacity to accumulate heavy metals are: silver birch (*Betula pendula*), alder (*Alnus tenuifolia*), black locust (*Robinia pseudoacacia*), willow (*Salix* sp.), and conifer trees [22]. Pine (*Pinus sylvestris* L.) is an important element in the whole forest ecosystem with a very wide range of prevalence in the world. It is one of the most important tree species in Central Europe and Scandinavia. These species, take up nutrients including heavy metals, from soil. They are used for afforestation of areas and in the process of phytoremediation of soils contaminated with heavy metals. The heavy metals are stored mainly in the root system. The trees development over the years has secured them against the loss of genotypes responsible for tolerance to high concentrations of pollutants, and slower adaptation of selected species on degraded areas. A characteristic feature of heavily degraded areas is the lack of any shrubs and trees.

However, the immune mechanism created by the selected species of trees allow for their development on such areas without toxic symptoms [23]. The key mechanism used in phytoremediation is the limited ability of trees to capture and take up the pollutants from the root zone, and then the slow transport to upper plant parts. An important feature of these trees is their ability to propagate roots into soil layers which contain a lower amount of pollutants, thus increasing the chances of their survival under unfavorable conditions [24]. The tree species differ in the ability to immobilize the heavy metal in the cells, tissues, and organs. A method for binding metals depends not only on the age of the trees, environmental conditions, but also on the properties of the trace elements. The bioconcentration index of heavy metals by trees is diverse, often they do not demonstrate the ability to take up metals by the roots of trees (the index is low, the tree is not capable of accumulating contaminants). On strongly contaminated soils, the roots of trees cannot cope with high levels of heavy metals and toxic substances. As a result, excess contaminant is accumulated in the organs and tissues of trees, showing toxic effects [23, 25].

6 The Use of Selected Organic Amendments for Improved Phytoremediation

6.1 Experiment Description

For improved phytoremediation process, a growth chamber study was conducted using organic soil amendments under controlled conditions of phytotron chamber. Soil material used in the study was collected from two sites (Poland) (Table 4): from

Table 4 The physical and chemical properties of soil materials (modified after Dusza [33])

Parameter	Soil material from zinc smelter area (MS)	Soil material from lignite mine dumping site (B)
pH in H_2O	5.49 ± 0.02	8.11 ± 0.04
CEC [cmol(+) kg^{-1} d.m.]	3.18 ± 0.12	23.93 ± 0.21
C total [g kg^{-1} d.m.]	12.91 ± 0.02	4.05 ± 0. 05
N Kjeldhal [mg kg^{-1} d.m.]	577.50 ± 18.12	108.50 ± 11
P total [mg kg^{-1} d.m.]	176.55 ± 1.34	132.16 ± 1.11
Zn [mg kg^{-1} d.m.]	751.60 ± 57.49	15.22 ± 0.12
Cd [mg kg^{-1} d.m.]	28.78 ± 1.23	0.38 ± 0.01
Pb [mg kg^{-1} d.m.]	1696.20 ± 87.13	4.84 ± 0.08

the area of zinc smelter influence located in Silesia region and also from lignite mine dumping site near Belchatow. In this experiment, (1-year-old seedlings of *Pinus sylvestris* were used. The amendments used in the study were different types of organic amendments: compost (K), sewage sludge (OS). The following parameters were investigated for the soil subsamples collected : pH in H_2O and in KCl suspension, total Kjeldahl N, total carbon, total and available P, CEC (Cation Exchange Capacity), available heavy metals, total heavy metals using inductively coupled plasma/optical emission spectrometry (ICP-OES; Thermo apparatus). Both at the beginning of the experiment and after a year (12 months, $t = 1$), the analysis of physical, chemical parameters and changes in the content of elements and compounds in the soil material in all the pots was done.

The resulting biomass during the experiment was collected, dried, ground, and treated with digestion, and then the elemental analysis was performed. Plants aboveground biomass was harvested after 12 months of growth and also analyzed for the content of elements. Tested soil (Table 4) obtained from the area near zinc smelter (MS) was characterized by a high concentration of heavy metals (mainly Cd, Pb, and Zn), low pH, low sorption capacity, and low levels of organic matter and trace nutrients, i.e., N and P. It is a sandy soil, anthropogenically altered by the operation of the zinc smelter. The area of the lignite mine (B) is mainly podsol. Soil material from the lignite mine dumping site was characterized by a lack of soil profile (soil material is selected during operation of the mine from different deposits), alkaline pH, low humidity, low concentration of nutrients, and low concentrations of heavy metals.

Sewage sludge (OS) used in the study originated from an anaerobic co-digestion process. The compost (K) used in the experiment was obtained from the processing of municipal waste, which include: sewage sludge from anaerobic co-digestion process, plant biomass (grasses and rape grown on degraded soil), sawdust, and the organic fraction of municipal waste (OFMW). The composting process was conducted in a bioreactor according to standard procedure. Sewage sludge and municipal compost used in the pot experiment were characterized by a relatively neutral pH, relatively large hydration and the high content of nutrients (N and P) and carbon (Table 5) and additionally low concentrations of heavy metals. Due to the lower content of selected metallic elements, they fulfill the low criteria and can therefore be used in the restoration of degraded land and agriculture.

Table 5 The physical and chemical properties of organic amendments (modified after Dusza [33])

Parameter	Sewage sludge (OS)	Compost (K)
pH in H_2O	6.07 ± 0.01	6.86 ± 0.14
C total [g kg^{-1} d.m.]	401.1 ± 0.4	295.05 ± 6.15
N Kjeldhal [mg kg^{-1} d.m.]	4025 ± 247.49	13,545 ± 148.49
P total [mg kg^{-1} d.m.]	5197.39 ± 15.56	5207.29 ± 15.24
Cd [mg kg^{-1} d.m.]	0.6613 ± 0.03	1.443 ± 0.85
Pb [mg kg^{-1} d.m.]	6.249 ± 0.28	40.29 ± 2.93
Zn [mg kg^{-1} d.m.]	259.8 ± 11.24	453.2 ± 14.17

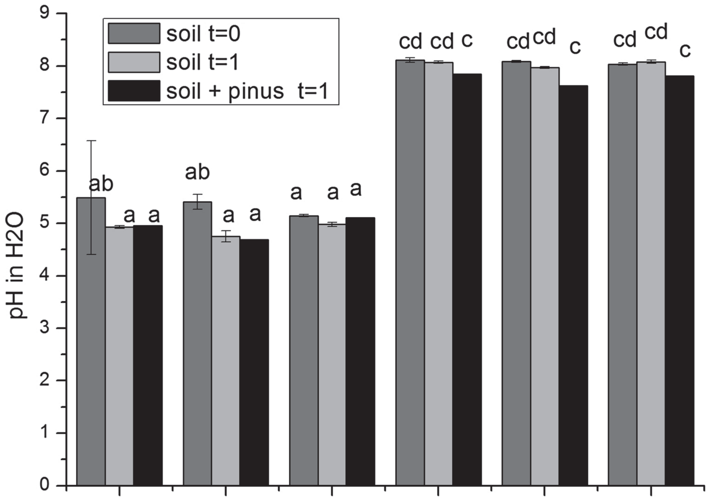

Fig. 1 Changes of soil pH value during the experiment (modified after Dusza [33])

6.2 *Results*

6.2.1 Changes of the Parameters of Soil Material and Plants Biomass

In the experiment, the pH value was determined in soil both at the beginning ($t=0$) of the experiment and after 12 months ($t=1$) (Fig. 1).

The soil material obtained in the affected zone located in zinc smelter (MS) was characterized by acidity and soil originating from the lignite mine dumping site (B) characterized by an alkaline pH. In both types of soils, similar trend of a slight decrease in pH after the application of sewage sludge was observed. The compost applied to metal contaminated soil (MS) resulted in halting the decline of pH. For every treatment, the vegetation of a Scots pine to soil contributed to lower pH of only lignite mine soil, due to root exudates of trees, i.e., organic acids. Decrease of soil pH after sewage sludge application is very slight and only marginally reduces this value, what was also confirmed by Ahmed et al. [26]. More pronounced effect was noted after Scots pine growth for alkaline soil. Another important parameter is sorption capacity, which is an important indicator for assessing the soil degradation. Some organic amendments like biochar can increase the sorption capacity of soil significantly [27].

Moreover, another advantage of biochar application is that unlike compost and manure, biochar does not need to be applied repeatedly. Usually, the soil organic matter, pH, phosphorus, and CEC generally increase after treatment with biochar, what confirms that fairly large amounts of carbon and exchangeable cations are introduced by biochar application. The main disadvantage of biochar is the energy input that is necessary to convert the biomass into biochar [28]. The less energy-consuming process is using organic amendments like compost, vermicompost, or sewage sludge directly into soil. It was found that the used organic additives significantly contributed to the increased sorption capacity of the soil from the area of lignite mine dumping site at the beginning of the experiment. However, after half a year, this effect was not observed.

Moreover, there was no effect on sorption capacity increase for soil which was strongly contaminated and with low pH. In the conducted field study, this parameter remained very low even after biosolids addition. The carbon content in the soil proves the soil condition and the ability to proper growth and development of plants. In the conducted study (Fig. 2), there was an increase in the total carbon content after the addition of compost and sewage sludge into the soil from the area of zinc smelter, as well as in the soil from lignite mine dumping site. The growth of pine caused a decrease in the content of total carbon only in soil with low pH.

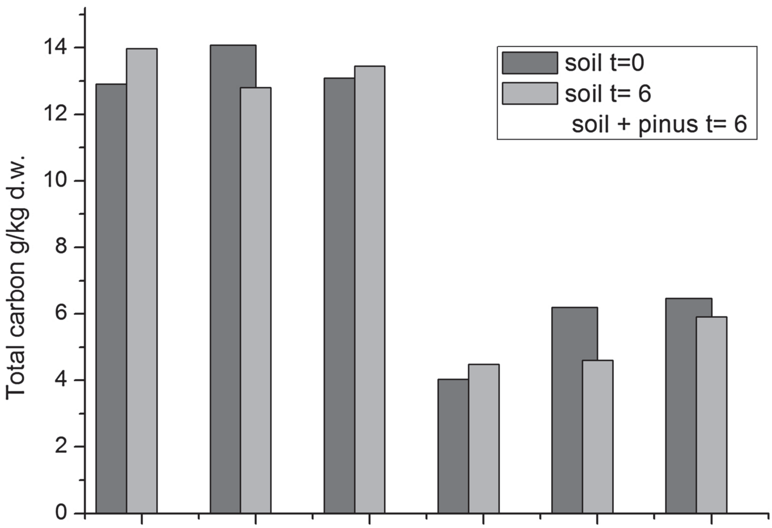

Fig. 2 The impact of organic additives and pine trees on the total carbon content in two types of degraded soils; B—lignite mine dumping site, MS—zinc smelter area, K—compost, OS—sewage sludge

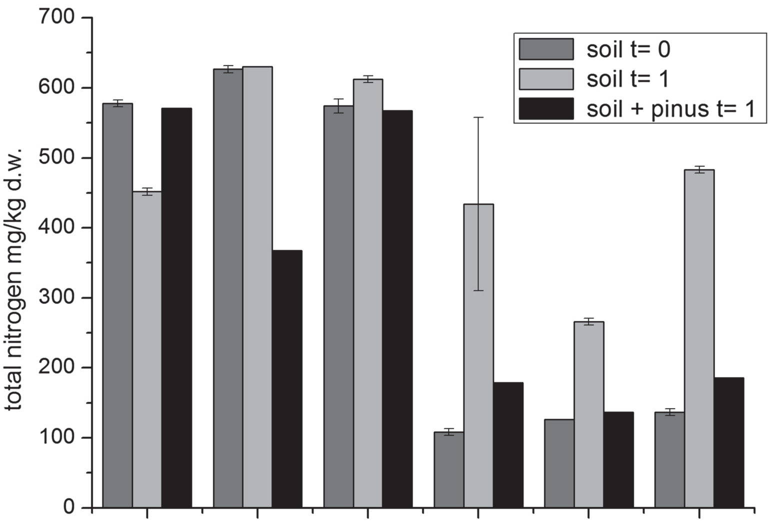

Fig. 3 The effect of organic additives and pine trees on the change of the total nitrogen content in two types of degraded soils; B—lignite mine dumping site, MS—zinc smelter area, K—compost, OS—sewage sludge

The nitrogen concentration is a very important indicator of soil fertility and crop yield. Based on the amount of the element in the soil material, plant growth, and development in the certain area, the effectiveness of the biological remediation can be estimated. The changes in the level of nitrogen in the soil are included in Fig. 3.

The use of organic additives caused an increase in nitrogen content in both investigated soils (Fig. 3). After 12 months of the experiment, nitrogen content in the soil increased in both degraded soils and amended with biosolids. However, in soils with pine, nitrogen decreased in both treatments with soil alone and with additions of biosolids. Probably, this is the result of extensive leaching processes of strongly acidic soils as also indicated by Suárez-Abelenda et al. [29]. Phosphorus performs a key role in plant growth, and therefore its contents in the soil have a significant impact on the efficiency of phytoremediation processes of degraded soils. Changes of total phosphorus content in the soil occurring during experiment are shown in Fig. 4.

At the beginning of the experiment, low levels of phosphorus were reported in soils from both sites of degraded areas. However, the amount of this element in the soil slightly increased after the application of organic additives (Fig. 4). After half a year of pot experiment, the increase in the concentration of this element in the soils with the addition of organic matter was observed. Also, the amount of phosphorus in the soil with additives and with plants increased compared with the control. Another significant parameter is the soil organic matter content presented in Fig. 5.

It was found that organic matter content was highest for the samples with the addition of compost. After a year of experiment, the highest recorded organic matter content in the soil from MS with sewage sludge was recorded. Organic substances were used in the pot experiment in order to supply organic matter and biogenic

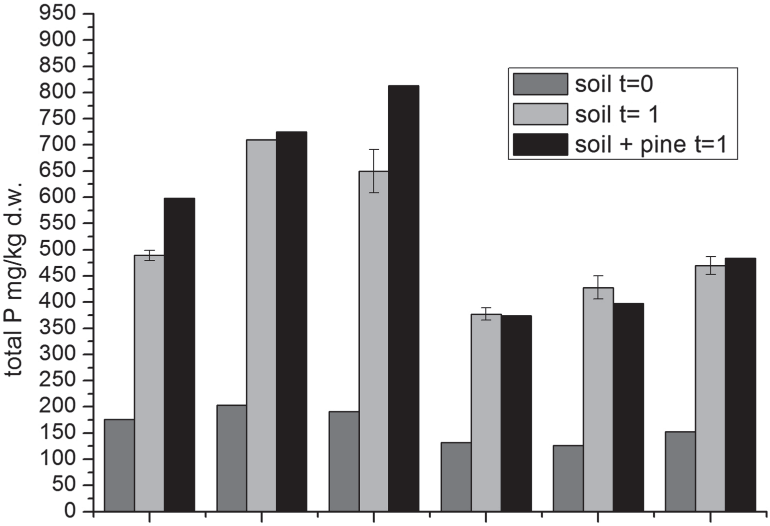

Fig. 4 The effect of organic additives and plants on the changes of the total phosphorus content in two types of degraded soils; B—lignite mine dumping site, MS—zinc smelter area, K—compost, OS—sewage sludge

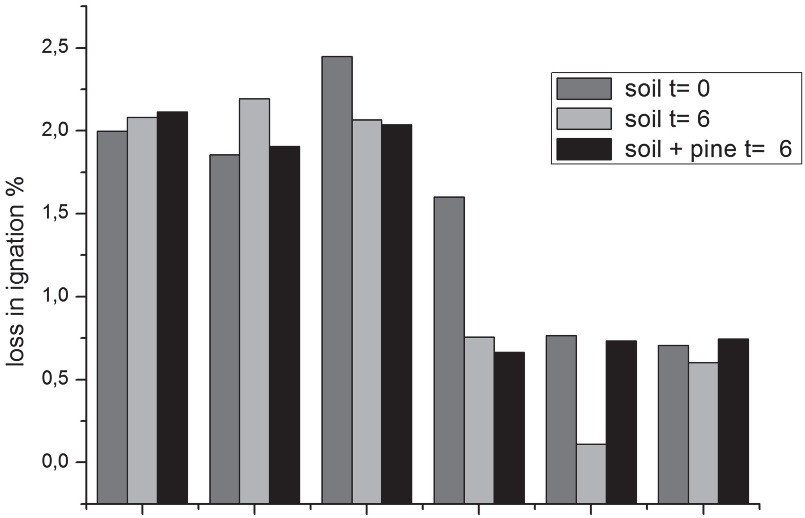

Fig. 5 The effect of organic additives and plants on the changes of the content of organic matter (expressed as losses on ignition) in two types of degraded soils; B—lignite mine dumping site, MS—zinc smelter area, K—compost, OS—sewage sludge

elements to the soil, limit the mobility of heavy metals and improve its water conditions. To support the phyto-sequestration process of soils, another five organic additives were used: the sewage sludge from the food industry, compost from the biodegradable fraction of municipal waste, compost from sewage sludge from household wastewater treatment plant, coal sludge, and lacustrine chalk. The experiment was carried out in the growth chamber for 12 months. This chapter focuses on the analysis of carbon and organic matter, including TOC (total organic carbon) OC (organic carbon) humic acids, in pore water and soil after different treatments. Studies have indicated that composts and coal mules were characterized by a similar content of organic carbon and total carbon.

By contrast, lacustrine chalk and sewage sludge contained much lower content of organic carbon than the total. In the experiment, an increase in OC content in combination with composts, coal mules, and plants were noted. However, there was a decrease of TOC in the soil after application of sewage sludge on the acidic soil. Whereas for compost used in acid soil, a high content of TOC after a year of research was still remained. For the neutral soil, this effect was not observed, on the contrary, the used additives resulted in higher total carbon content of soil. TOC analysis in pore water showed decreasing releasing of carbon into the soil solution. Furthermore, the lowest amount of carbon in the mobile form was observed after application of coal mules. Humic acids content after the application of additives was significantly higher compared to the control samples. However, after one year humic acids content decreased slightly in all combinations (also in controls) in the acidified soil.

Moreover, in the neutral soil humic acids content increased after one year of the experiment. Entering the organic additives, i.e., compost and sewage sludge are not justified on acidic soils because they do not cause permanent increase in the content of OC in these soils. However, such action is justified on neutral soil. The highest concentration of OC in the soil provides composts and coal mules. Lacustrine chalk and coal mules can be successfully used on acidic soils. For neutral soil, the content of exogenous carbon increases with time. In acidic soil, the organic matter content just after the application of additives increases, however 1 year after its content decreases. Additionally, acidic soils are not retaining introduced exogenous humic acids. The addition of compost compared to the sewage sludge results in higher retention of total carbon in the soil.

The content of available forms of heavy metals was examined, and the results are presented in Figs. 6 and 7. It was found that shortly after the application of organic additives ($t=0$), an increase in the content of bioavailable Zn and Pb occurred. However, the bioavailable Pb decreased after the application of sewage sludge. In contrast, organic amendments did not affect the content of bioavailable Cd.

During the pot experiment, the content of available heavy metals in soils with Scots pine was determined. Content of available Zn, Pb, and Cd in the soil decreased significantly for all treatments (Fig. 7). This effect confirms the strong leaching process for acidic soils. The effect of immobilization process by organic amendments is dominated by leaching process in this study conditions. Fertilization of heavy metals contaminated soil with organic wastes and the pine vegetation contributed to the immobilization of metal elements in the soil and the rhizosphere and caused the transfer of some metal parts to the aboveground parts of plants (Fig. 8). The applied organic additives resulted in a reduction of Pb and Zn in plant biomass (Fig. 8). The applied sewage sludge caused a slight reduction of Ag, Co, Cr, Cu, Ni, and Tl in plant biomass. Compost influenced the reduction of Cd and Ni content slightly. The lowest Cd and Ni content were in plants fertilized with sewage sludge (Fig. 9).

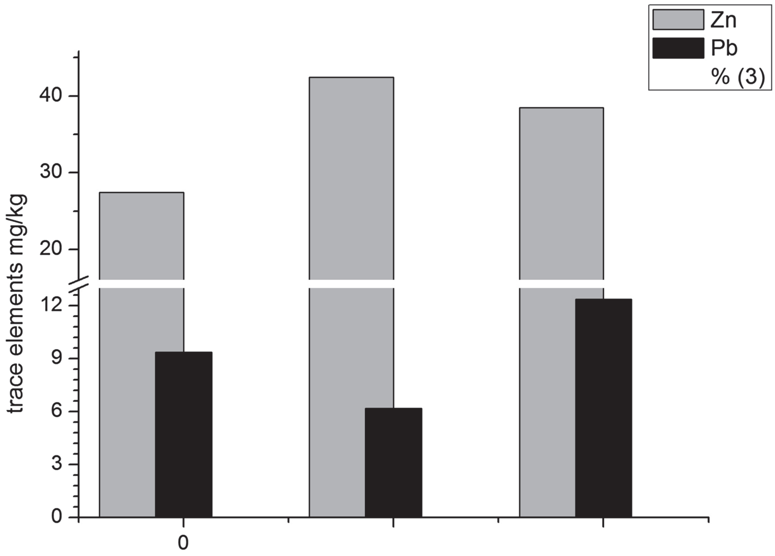

Fig. 6 The influence of organic additives on the content of trace elements (bioavailable) in the soil from the zinc smelter area for $t = 0$; MS—zinc smelter area, K—compost, OS—sewage sludge

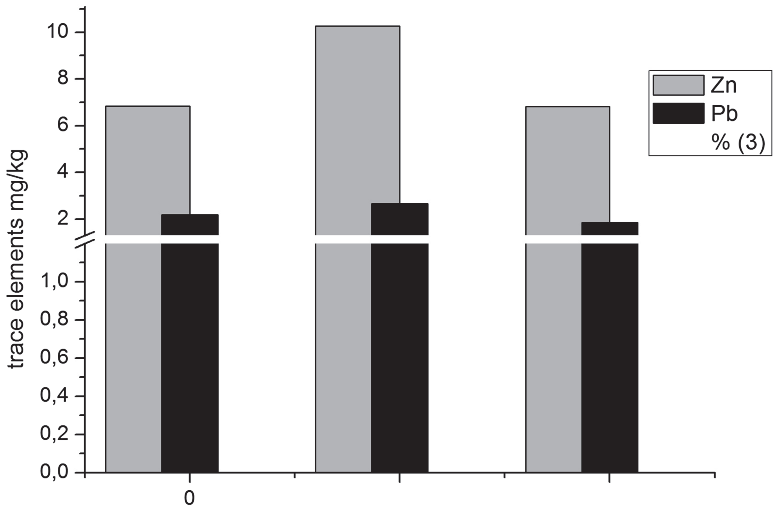

Fig. 7 The influence of organic additives on the change of the content of trace elements (bioavailable) in the soil with pine trees from the zinc smelter area for $t = 1$; MS—zinc smelter area, K—compost, OS—sewage sludge

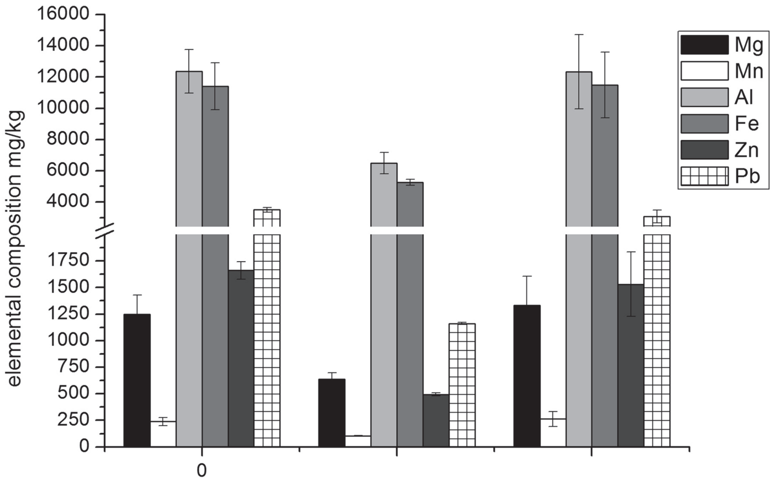

Fig. 8 The impact of organic additives on the metal content in the biomass of Scots pine on degraded soil from the zinc smelter area; $t = 1$; MS—zinc smelter area, K—compost, OS—sewage sludge

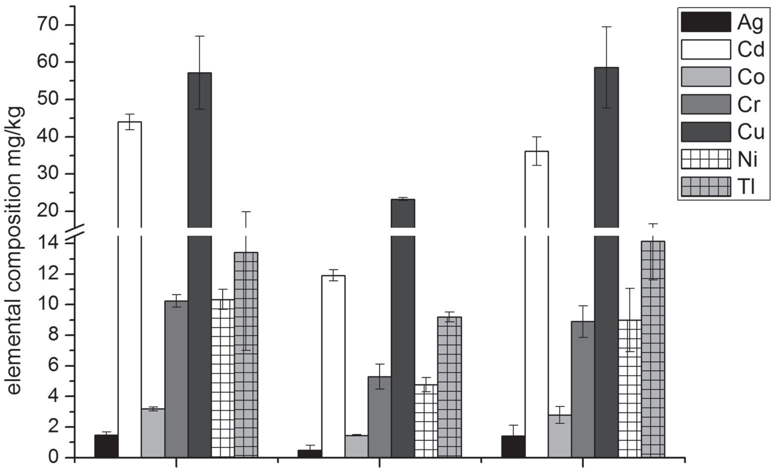

Fig. 9 The elemental composition of pine biomass growing on soil from zinc smelter area $t = 1$; MS—zinc smelter area, K—compost, OS—sewage sludge

7 A Field Study

A field study was conducted using selected soil amendments and biosolids: sewage sludge-based compost, sewage sludge, and lacustrine chalk. The two plants species planted were pine (*Pinus sylvestris* L.) and energy crops (*Miscanthus giganteus*) on the area surrounding zinc smelter and post-mining land lignite mine dumping site. This experiment was conducted using two doses of biosolids. The dose 16 Mg/ha of organic amendments was applied for the 1 year experiment and the dose of 45 Mg/ha of organic amendments were applied for the 3 years experiment. After two vegetation periods, soil samples were collected and analyzed; moreover, the bioavailable (dissolved) compounds were also determined. The following parameters were investigated for the soil subsamples: pH, available (dissolved) P, dissolved N, dissolved organic carbon (DOC), IC (inorganic carbon).

For zinc smelter soil it was found that after two vegetation periods with sewage sludge application the dissolved compounds and biogenic elements were quite similar in soil solution compared to control without any biosolid treatment. Especially, it was noticed for dissolved organic carbon. Compost application gave similar results. Only when biosolids were used together with lacustrine chalk, the values of dissolved organic carbon are still high. This indicates that biosolids should be used only together with substances increasing pH value of soil. Three times higher dose of amendments did not increase the soil biogenic compounds concentration. These compounds were infiltrated into deeper soil layers. For soil from lignite mine dumping site, it was found that DOC was at similar level in control and biosolid-treated soils. Only soils treated together with biosolids and lacustrine chalk contained still high values of DOC. Moreover, the serious issue is the migration of nitrogen compounds into soil profile. In this research, it was found that for the zinc smelter soil (heavy metal contaminated), despite similar initial nitrogen content, much higher dissolved nitrogen was found for sewage sludge-treated soil than to compost treated. This indicates the more safety and beneficial usage of sewage-based compost than only sewage sludge. For dissolved nitrogen, the lacustrine chalk in addition with biosolids had no impact on total nitrogen in the soil solution. For soil from lignite mine dumping site, the high levels of dissolved nitrogen were found only for sewage sludge treated soil also with lacustrine chalk. And moreover, extremely high levels were found the second dose of sewage sludge.

8 Summary

The use of organic wastes as amendments to improve soil organic matter level and long-term soil fertility and productivity is gaining importance. The disposal of the large quantity of organic wastes produced by the municipal, agricultural, and agro-industrial activities is causing energetic, economic, and environmental problems. Sludge composting for use in agriculture should be given a priority for its disposal. Sludge should not be treated as a waste but a valuable non-farm source of organic matter to soil [30]. Land application of biosolids, such as sewage sludge or compost, has a great incentive in view of its fertilizer and soil amendment values, unless they contain toxic elements. The heterogeneous nature of biosolids produced in different processes necessitates knowledge of the chemical and biological properties of biosolids prior to the land application [31].

One of the methods for remediation of such areas is phytoremediation technique, which involves the plants for the treatment of soil from organic and inorganic contaminants (e.g., heavy metals). Phytoremediation is economically justified and generally acceptable by society method. An additional advantage of phytoremediation of soils is the possibility of using waste and by-products (e.g., sewage sludge, composts) as soil additives to support this process and at the same time to affect the recycling and disposal of a significant amount of waste substances [11]. Also the large areas of post-mining land lignite mine dump are characterized with poor organic and biogenic compounds. Soil organic additives are a source of organic matter, carbon, and biogenic elements which provide a significant improvement in the quality of the soil environment [2]. Moreover, they have the sorption ability related to immobilization of contaminants in soil, e.g., heavy metals [32]. Revitalization of industrial and mining areas, if only because of the large surface area, is often a matter of great importance for planning sustainable development at local and regional levels.

To achieve a successful revitalization of even smaller projects with lower complexity of remediation, it is essential to strategically integrate analysis of planning, legal, cultural, and economic aspects. Only the analysis of the kind of degradation or contamination and contaminants migration in the environment or impact on the ecosystem is not sufficient. The standard approach to revitalization will not produce appropriate results for the remediation of large areas, as is the case for opencast mining of lignite, or degradation as a result of metalliferous dust emissions from steel mills. Therefore, the type and extent of the required procedures for the remediation and redevelopment costs must be included in the expected benefits of the intended use of the land. The results of the study indicate, that taking into account the protection of soil and water environment, it is not justified the use of such high permitted doses of biosolids. Especially, large threat carries application of sewage sludge, while the application of compost-based sewage sludge is much more safety. It was also found that application of biosolids to different soils can give also not fully predicted results.

For some cases, the concomitant use of biosolids and calcium amendments is highly justified, when considering the soil protection. It was found that the effect of bio-waste on the promotion of plant growth and biomass increment in shoot and roots was significant. Moreover, most of the applied organic substances improved the condition of degraded soils. The results obtained lead to the following conclusions: “Application of sewage sludge, municipal compost and lacustrine chalk improved the condition of degraded soil and lead to increased production of plant biomass. The growth improvement and visible quality enhancement of aboveground biomass was recorded in rape and miscanthus after the application of organic substances to degraded soils. The release of nutrients from sewage sludge into the soil may pose a potential threat by contamination of surface and ground waters with main biogenic compounds”.

Moreover, the chosen organic soil additives, derived from organic by-products, enable the development of plants on degraded lands and the establishment of vegetation cover, thus reducing water and wind erosion. The mobility of heavy metals in the soil and from soil to soil solution can be decreased by the application of organic additives such as: compost from organic fraction of municipal solid waste and lacustrine chalk. Selected energy crops, like *Miscanthus giganteus*, have excellent adaptability to change habitat conditions and the possibility to gradual reclamation of degraded land and the ability to prevent the migration of heavy metals into the soil and groundwater. Thus, this plant can be used in the remediation of soil and of devastated areas as pioneering plants. Moreover, as a biosolid, the treated sewage sludge should be used in the form of compost to achieve significant efficiency of carbon phyto-sequestration. Conducted research on degraded areas, deprived of humus layer and vegetation, allowed exploring the relationship between the application of organic substances and selected plant species on improving the quality of soil. It was also found that selected soil amendments and plants species improve the soil organic carbon sequestration (SOC). This indicates that biosolids should be used only together with substances increasing pH value of soil. Three times higher dose of amendments did not increase the soil biogenic compounds concentration. These compounds were infiltrated into deeper soil layers.

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