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Influence of organic components on changes of the properties of reclaimed soils damaged by fire from coniferous dry forest

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Abstract. The main objective of the study was to analyse the influence of compost produced from urban green waste, sewage sludge from municipal treatment plants and horticultural peat on changes of selected chemical and microbiological parameters of forest soil reclaimed after a fire. Soil samples were collected one and two years after the components had been applied to the soil. The results from experimental sites were compared with those from control samples. In the soil samples the following parameters were determined: content of carbon and nitrogen, reaction, hydrolytic acidity and the total amount of alkaline cations. Also the total number of bacteria and fungi, including moulds and yeast, was analysed. A year after components application, pH and the number of yeasts and moulds in the soil increased. After two years the content of nitrogen and the total number of bacteria in the soil increased as well. The most beneficial effect on changes in soil properties had the application of sewage sludge, which manifested itself in a decrease of the C/N ratio. This indicated the suitability of sewage sludge in reclamation of poor forest habitats. Peat underwent the slowest mineralization among all the organic components applied to the soil.

Keywords: compost, sewage sludge, peat, soil chemical properties, microbiological analysis of soil

1. Introduction

One of the causes of soil degradation in forest environments is fire. It significantly changes the physical and chemical properties of forest soils, causing the mineralization of organic matter, a reduction of nitrogen content in the soil, and an increase in the soil's pH (Olejarski 2003). The process of regenerating forest habitats degraded by fire can even last a dozen or so years (Fritze et al. 1993, Zwoliński et al. 2004) and depends on the reclamation methods used, including the treatments used to prepare the soil in the fire affected area (Olejarski 2003). In order to reclaim areas degraded by fire, tree stands are most often replanted after the soil is properly prepared (Kaczmarek et al. 2004, 2011). The literature lacks information on the use of wastes, such as sewage sludge, compost or peat, in the work carried out in fire affected areas. The organic matter introduced with these components is used for the reclamation of degraded land in post-industrial areas. Both sewage sludge (Fijałkowski, Kacprzak 2009, Klimont 2011) and compost (Gilewska 2006; Sądej, Namiotko 2010; Ciesielczuk, Rosik-Dulewska 2012) initiate soil-forming processes. The application of peat to mineral soil primarily results in an increase in the soil's humus content and accelerates its regeneration (Zwoliński, Hawryś 2002).

In 1999, a fire occurred in the Sokołów Forest District (Mazowieckie Province), and in the following year, measures were taken to properly prepare the soil to plant pine. In the opinion of the foresters, despite the passage of over a dozen or so years after undertaking reclamation measures, the pine trees are growing poorly in the dry coniferous forest habitat.

We were interested in investigating the effect of adding organic matter in the form of bio-waste and peat on changes in the chemical and microbial characteristics of soils exposed to fire, over a dozen or so years after the revitalization efforts were initiated.

The scope of the study included:

1. Designation of study sites and introduction of organic matter into the soil in the form of compost, sewage sludge and horticultural peat.

2. Collection of soil samples from control and experimental plots treated with organic components.

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3. Chemical analysis of soil samples and the organic material applied, measuring the content of organic carbon and nitrogen, level of soil pH, hydrolytic acidity, total alkaline cations, soil sorption capacity, and saturation of the soil's sorption complex with alkaline and hydrogen cations.

4. Microbiological assessment of the studied soil measuring the total number of bacteria, as well as moulds and yeasts.

5. Comparison of analysis results of soil samples from the experimental sites with samples from the control sites.

6. Analysis of the results obtained in the context of effectiveness of components applied to the soil depending on the time after the activities took place (one or two years after starting the experiment).

2. Material and methods

Sokołów Forest District is located in eastern Poland, in the Mazovian-Podlasie Lowland, in the middle Bug River drainage basin, on the left side of the river. The study was conducted in Treblinka Forest (52°37'02''N, 22°01'07''E, 125 m a.s.l.). The forest covers an area of about 750 hectares. This is the area that is most at risk of fires in the Sokołów Forest District. In 1999, a fire destroyed a 60-year-old pine forest in an area of 156 hectares, and in 2000, young pine trees were planted on the degraded land. Despite the passage of over a dozen or so years, both the soil and the destroyed forest are regenerating very slowly.

In October 2012, in consultation with foresters from the Sokołów Forest District, six experimental sites of 1 m x 1 m in size were selected for testing in the dry coniferous forest habitat of the Treblinka Forest, where the fire occurred. Each site was marked with a 20 cm wide garden palisade. Three sites were selected as control plots. The next three sites were treated with 4 kg/m^2 of compost, sewage sludge or horticultural peat. The organic components were dug into soil to a depth of 20 cm. The organic components came from the municipal sewage treatment plant in Siedlce (sewage sludge), the waste disposal plant in Wola Suchożebrska near Siedlce (compost) and the peat was from a randomly chosen gardening shop in Siedlce.

In October 2013 and 2014, after clearing away the leaf litter with the use of an Egner cane, four soil samples of approximately 0.5 kg each were taken from each experimental and control site and placed in bags. In addition, representative samples of soil were taken and placed in jars for microbiological analysis. Soil samples for chemical analyses were air dried and then sieved through a 2 mm mesh screen. The Tiurin method (Ostrowska et al., 1991) was used to determine the amount of organic carbon and the indophenol method (Marczenko 1979) was used to determine the amount of total nitrogen in the representative sub-samples of soil homogenized in an agate mortar. In order to determine the nitrogen content of the soil samples, they were previously mineralized in Kjeldahl flasks in 95% H_2SO_4 and 30% H_2O_2 (3:1, v/v). The amounts of organic carbon and nitrogen were also determined for the organic components applied to the soil. In addition, soil pH in 1 M KCl, hydrolytic acidity (Hh), the sum of alkaline cations (S), soil sorption capacity (T), percentage of soil saturation with alkaline cations (V), and the percentage of hydrogen in the soil sorption complex (VHh) were also determined for the soil samples. The research was carried out according to the method described by Ostrowska et al. (1991).

After being transported to the laboratory, soil samples taken for microbiological testing were directly analysed or stored at 4°C for 24 hours prior to analysis. Analyses determining the total number of bacteria, moulds and yeasts were conducted in accordance with the methodology provided by Frąc et al. (2011).

The significance of differences between the values of the tested chemical indicators of soil from the control and experimental sites was checked using the analysis of variance after checking normality of distributions (Shapiro-Wilk test) and the homogeneity of variance of independent variables (Brown-Forsythe test).

Introduced into the soil organic components or lack thereof were the differentiating factors of the tests. In case of statistically significant differences, Tukey's honest significance test was used. The given significance level was $\alpha = 0.05$. Statistical calculations were done with Statistica (ver. 12).

3. Results

The results of analysis of the chemical composition of organic components applied to the soil are summarized in Table 1.

Among the components applied to the soil, the largest amount of carbon and nitrogen was found in sewage sludge. Peat contained the least amount of organic carbon and nitrogen.

The statistical analysis showed no significant difference in the organic carbon content of the soil after one and two years of having applied the organic components to the soil (Table 2). One year after the application of compost to the soil, a significant increase in nitrogen content was observed as compared to the amount of nitrogen in the soil of control sites. But after two years, there was an increase in the nitrogen content of the soil under the influence of all components introduced to the soil (Table 2).

Table 1. Chemical composition of organic components applied to the reclaimed forest soil

Component	**Corg. [%]**	**N [%]**	**C/N**
Compost	21.7 ±1.95	1.7 ±0.08	12.8
Sewage sludge	33.0 ±1.23	3.8 ±0.11	8.7
Peat	14.3 ±0.86	0.7 ±0.09	20.4

In the first year, a statistically significant increase of C/N values was noted as a result of the addition of peat. In the second year of the study, decreased C/N values resulting from the addition of sewage sludge was recorded (Figure 1).

The organic components applied to the soil resulted in a statistically significant increase in the soil pH in the first year of the study. In the second year, changes in soil pH due to the added organic components were not significant (Table 2). After one year, there was a slight decrease in hydrolytic acidity (Hh) compared to the control sites that was only significant in the plot with added compost. After the second year, the hydrolytic acidity was similar for all plots and did not differ from the hydrolytic acidity of the control sites soil. A clear increase in the sum of alkaline cations (S) in the soil compared to the control sites was reported one year after applying compost and peat. After two years, the sum of alkaline cations was significantly higher in the soil to which compost and sewage sludge were introduced. On the site with introduced peat, however, the sum of exchangeable alkaline cations was reduced relative to the control sites and to the first year of the study. The organic components applied to the soil contributed to an increase in soil sorption capacity (T). After one year, there was an increase in sorption capacity compared to control sites for soils treated with peat and compost, whereas after two years – for soils treated with compost and sewage sludge. Also, the significant increase after two years of the saturation of soil's sorption complex with alkaline cations (V) at sites treated with compost and sewage sludge is noteworthy.

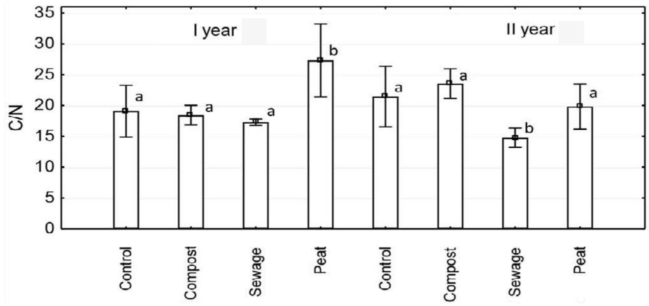

Figure 1. Changes of the C/N value in the forest soil after application of organic components (statistically significant differences were marked with different letters)

Table 2. Results of chemical analysis of forest soil samples at the study sites one and two years after the application of organic components (n = 16; statistically significant differences were marked with different letters)

Parameter	Unit	Control	Compost	Sewage sludge	Peat
		I year			
C	%	$0.304^{a}\pm0.15$	$0.45^{a}\pm0.03$	$0.33^{a}\pm0.04$	$0.44^{a}\pm0.10$
N	$g \cdot kg^{-1}$	$0.154^{a}\pm0.046$	$0.24^{b}\pm0.01$	$0.19^{a}\pm0.01$	$0.16^{a}\pm0.02$
Reaction	pH	$4.24^{a}\pm0.28$	$4.94^{b}\pm0.17$	$4.66^{b}\pm0.12$	$4.94^{b}\pm0.16$
Hh		$1.83^{a}\pm0.21$	$1.42^{b}\pm0.08$	$1.54^{a}\pm0.16$	$1.61^{a}\pm0.14$
S	$cmol(+) \cdot kg^{-1}$	$1.40^{a}\pm0.20$	$2.50^{b}\pm0.14$	$1.62^{a}\pm0.23$	$2.46^{b}\pm0.21$
T		$3.23^{a}\pm0.38$	$3.92^{b}\pm0.07$	$3.16^{a}\pm0.09$	$4.07^{b}\pm0.09$
V	%	$43.3^{a}\pm2.33$	$63.7^{b}\pm2.47$	$51.2^{a}\pm6.11$	$60.4^{b}\pm4.09$
VHh		$56.7^{a}\pm2.33$	$36.3^{b}\pm2.47$	$48.8^{a}\pm6.11$	$39.6^{b}\pm4.09$
		II year			
C	%	$0.34^{a}\pm0.05$	$0.54^{b}\pm0.04$	$0.34^{a}\pm0.04$	$0.62^{b}\pm0.12$
N	$g \cdot kg^{-1}$	$0.16^{a}\pm0.05$	$0.23^{b}\pm0.05$	$0.23^{b}\pm0.03$	$0.32^{b}\pm0.02$
Reaction	pH	$4.29^{a}\pm0.44$	$4.61^{a}\pm0.24$	$4.43^{a}\pm0.49$	$4.87^{a}\pm0.44$
Hh		$1.91^{a}\pm0.09$	$1.93^{a}\pm0.13$	$1.88^{a}\pm0.19$	$1.99^{a}\pm0.09$
S	$cmol(+) \cdot kg^{-1}$	$1.43^{a}\pm0.14$	$1.86^{b}\pm0.15$	$2.58^{c}\pm0.14$	$1.17^{a}\pm0.12$
T		$3.34^{a}\pm0.09$	$3.79^{b}\pm0.18$	$4.46^{c}\pm0.06$	$3.16^{a}\pm0.06$
V	%	$42.8^{a.c}\pm3.30$	$49.1^{a}\pm2.75$	$57.9^{b}\pm3.84$	$37.1^{c}\pm3.33$
VHh		$57.2^{a.c}\pm3.30$	$50.9^{a}\pm2.75$	$42.1^{b}\pm3.84$	$62.9^{c}\pm3.33$

The results of microbiological analysis showed that after one year of applying compost, sewage sludge and peat into the degraded soil, the number of moulds and yeasts increased compared to the control sites. The plot with applied peat had an overall growth of bacteria compared to the control sites. Two years after introducing the organic components into the soil, the number of bacteria in each case increased compared to the control sites, while the number of yeasts decreased. Also, it is noteworthy that the number of mould cells in the peat treated site is distinctly higher than in the remaining sites (Fig. 2).

4. Discussion

It is extremely difficult and time-consuming to restore the natural properties of soils in a forest that has been burned. In order to analyse the changes occurring in such areas, frequent monitoring of the reclaimed area, as well as of the activities undertaken to regenerate degraded ecosystems is needed. As demonstrated by the study, the application of organic fertilizer, such as sewage sludge, compost, or peat, to remediate the soil leads to its enrichment with nutrients, improved retention and increased microbial activity. The effect of the applied organic matter in changing the selected forest soil properties in a remediated habitat depends on the type of matter applied and the time of its mineralization.

The mineralization of organic matter is a process involving bacteria and fungi, which provide essential ingredients for the development of plants. The biological processes resulting from the activity of microorganisms in the soil generate easily soluble organic compounds, such as simple sugars, simple organic acids and amino acids (Bednarek et al. 2004). After the introduction of organic matter, the activity of soil microorganisms increases (Bastida et al. 2007; Fijałkowski, Kacprzak 2009), and their presence is conducive to the release of nitrogen (Fijałkowski, Kacprzak 2009). The results presented in this paper show that the mineralization of compost and sewage sludge mainly occurred in the first stage due to the activity of moulds and yeasts. The effect of metabolic activity of microorganisms in the form of a statistically significant increase in the amount of nitrogen in soil was noted only after the second year of experiment, when the overall number of bacteria also increased. Nowak et al. (2010) emphasize that the beneficial effect of sewage sludge on degraded soils (pH increase, increase in C, N content) persists for 4–6 months

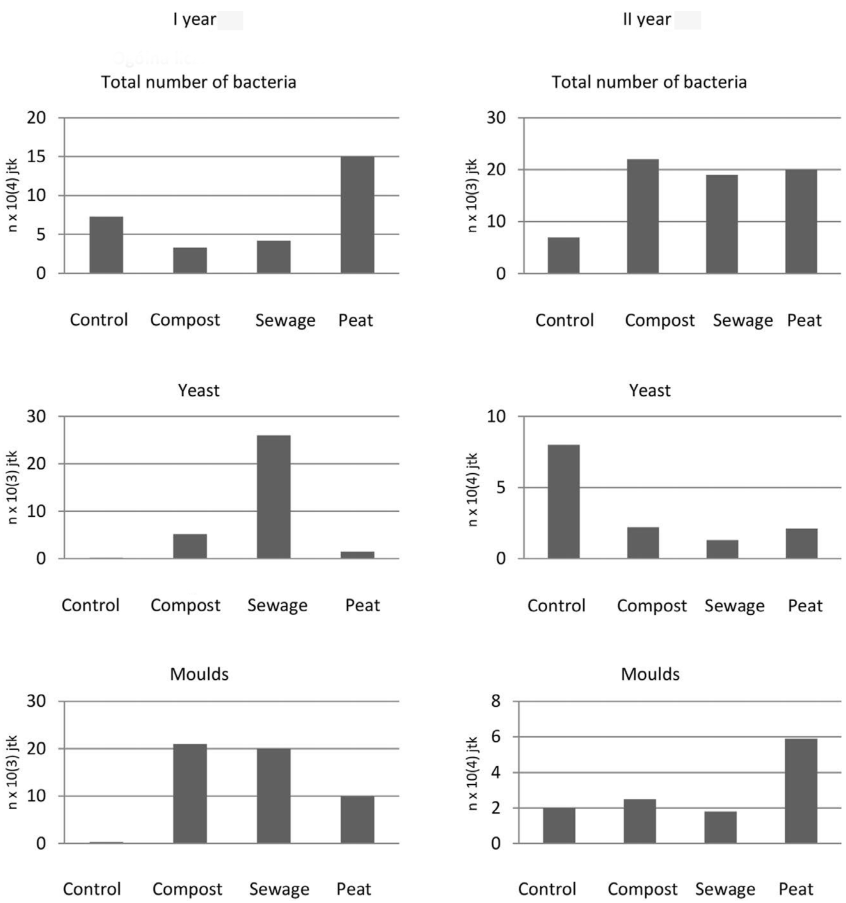

Figure 2. Occurrence of microorganisms in reclaimed forest soil degraded by a fire after application of organic components

after application. In turn, Joniec and Furczak (2007) show that the addition of sewage sludge initiates soil-forming processes, reflected in an increase in the number of microorganisms in the soil, which persists within two years of applying the sludge to the soil. Similar results concerning the increase of nitrogen after two years of treating the soil with sewage sludge were noted by Żukowska et al. (2002), as well as Napora and Grobelak (2014). The literature (Januszek et al., 2001; Mocek et al. 2004; Kaczmarek et al. 2011) draws attention to changes in the C/N ratios of re-cultivated soils.

A result of regenerating forest soil after a fire through habitat restoration is the reduction of the C/N ratio. This ratio is considered as one of the most important indicators of the quality of forest habitats (Jóźwiak et al. 2009). The present study reports a significant reduction in the C/N ratio in the treated soil as compared to the control samples after two years in the site, where sewage sludge was applied. The organic matter in sewage sludge is in the form of easily hydrolysed compounds, unlike, for example, the peat, in which non-hydrolysing and scarcely hydrolysing forms of carbon compounds predominate (Becher 2013). Barzdajn (1993) and Kwiatkowska and Maciejewska (2008) call attention to the slow decomposition of organic matter contained in peat.

It should be noted that all the organic components introduced into the soil contributed to an increase in the soil's pH and the degree of soil saturation with alkaline cations in the first year. Kwiatkowska and Maciejewska (2008) emphasize that the use of different types of organic substances increases the pH of the soil, reduces the hydrolytic acidity, increases the soil's sorption capacity and the degree of saturation of the soil's sorption complex with alkaline cations. Similarly, Lekan et al. (1997) showed that the use of composts increases the sum of exchangeable cations and reduces soil acidification. Other authors (Gilewska 2006; Sądej, Namiotko 2010; Ciesielczuk, Rosik-Dulewska 2012) also showed the beneficial influence of composts on changes in soil properties. On the other hand, Mazur (1996) emphasizes the important role of sewage sludge in remediating degraded soils and states that it is necessary to use sludge in reclamation efforts for four successive years. Due to the mineralization process of its organic matter, sewage sludge is referred to as a fertilizer with a free and progressive release of nitrogen, and its use also improves soil sorption properties (Nowak et al. 2010). The results of our own research confirm the data in the literature. It should be noted that among the applied organic components, only the addition of peat resulted in an increase in the second year in the proportion of hydrogen in the soil sorption complex compared to the control samples, which may be an evidence of the slower decomposition of peat in the studied habitat than is the case with compost and sewage sludge. The hydrogen ions released in the mineralization of peat are absorbed in the soil sorption complex. However, the processes of increased hydrogen ion sorption resulting from the mineralization of compost and sewage sludge were not recorded in the study period.

The C/N ratio in the mineralized material reflects the rate of its decomposition. Bednarek et al. (2004) emphasize that the lower the C/N ratio in the mineralized material, the faster the decomposition of the organic matter. Of the organic components applied to the forest soil, sewage sludge and compost contained more C and N than peat, with C/N ratios at 8.7 and 12.8, respectively, which were lower than peat (20.4). The C/N values indicate that sewage sludge should have the fastest rate of mineralization and peat the slowest, which is consistent with the results of this study.

The presented results indicate various rates of conversion of the organic matter applied to the remediated forest soil after the fire. Of all the introduced organic components, the addition of sewage sludge provides the most beneficial changes in the tested soil properties. Currently in Poland, a significant problem exists with the management of sludge at medium and small municipal sewage treatment plants. Current regulations allow the use of sewage sludge for remediation purposes (Rozporządzenie ... 2015). The results of this study show that using municipal sewage sludge for the remediation of forest habitats degraded by fire may be a good direction of its application for the benefit of nature.

5. Conclusions

1. A favourable C/N ratio, which indicates the rate of decomposition of organic matter applied to the reclaimed forest soil after a fire, was observed in the soil treated with sewage sludge and was least favourable in the soil treated with peat.

2. After one year, the introduced organic components caused a significant increase in soil pH and an increase in the number of yeasts and moulds; after two years, they contribute to an increase of nitrogen content and the total number of bacteria in the soil.

3. Two years after introduction into the soil statistically significant increase of total amount of alkaline cations, soil sorption capacity and the least C/N value ratio in soil, indicates that sewage sludge can be useful in reclamation of poor dry coniferous forest habitat.

Conflict of interest

The authors declare no conflicts of interest.

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Authors’ contribution

E.K. – concept of the paper, field research, participation in writing the text, statistical analysis; B.K. – participation in writing the text; K.S. – field and laboratory research; A.T. – field and laboratory research; E.Z. – field and laboratory research; E.P. – laboratory research.

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