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EFFECT OF SEWAGE SLUDGE ON SELECTED MICROBIOLOGICAL AND BIOCHEMICAL INDICES OF SOIL FERTILITY IN VIEW OF DOMESTIC AND WORLD WIDE STUDIES: A REVIEW

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Abstract. This paper reviews the characteristics of sewage sludge and its influence on the microbiological and biochemical properties of soils. Among others, changes of the enzymatic activity (protease, urease, dehydrogenases and phosphatases) as the effect of sewage sludge application to soil are discussed. The next part of this paper is concerned with the impact of sewage sludge on ammonification and nitrification as well as population numbers of microorganisms responsible for those processes, and on the respiration activity and total number of soil microorganisms.
Keywords: sewage sludge, enzymatic activity, soil, microorganisms

INTRODUCTIONS

Until recently sludge management has not been analysed statistically. The first data referring to that issue appeared in 1997 (Jaroszyński and Socha 2003). In Poland, in the year 2006 the amount of municipal sludge produced exceeded $501 \cdot 10^3$ Mg d.m. and that of industrial sludge accounted for ca. $563 \cdot 10^3$ Mg d.m. (Roczniki GUS 2007). A dairy sewage treatment plant with the throughput of 1800 $m^3\ d^{-1}$ produces ca. 270 tones d.m. of sewage sludge annually (Filipek and Fidecki 1999). Disposal of such a high production of sludges offers a daunting challenge both to science and to farming practice (Rosik-Dulewska 2000).

Analysis of the latest data from yearly statistics books indicates that proper management of sewage sludge still poses a great problem. In Poland, 30% of municipal and 41% of industrial sewage sludge are deposited. This constitutes nearly half of all the sludges produced in Poland (Roczniki GUS 2007). Also in the Member States of the European Union a considerable part of sewage sludge is still subject to deposition (40%) (Davis and Hall 1997).

Disposal of such a large mass of sludge, characterized by high concentrations of N and P, poses a threat to the environment as biogenes are likely to transfer to ground waters, consequently evoking the eutrophication of waters (Rosik-Dulewska 2000, Filipek 1999). Also gaseous products of nitrogen metabolism (NO_x, N_2) may contribute to atmosphere pollution (Mazur 1996, Mazur 1991).

CHARACTERISTICS OF SEWAGE SLUDGE

Due to their fertilizing properties, sewage sludges generated in treatment plants of municipal and industrial waste waters may be applied for the enrichment or reclamation of biologically weak or degraded soils (Wierzbicki 2003, Ślizowski 2002, Wystalska *et al.* 1999). They are characterized by a high content of nutrients, mainly of N and P (Skorbiłowicz 2002b, Czekała 1999, Kalembasa *et al.* 1999), thus contributing to high yielding (Czekała 2000). Sewage sludges contain also high quantities of organic carbon (Czekała 2002, Czekała 1999), owing to which they increase the content of humus (Czekała 2000, Grzywnowicz and Strutyński 1999), and improve the quality of soils, especially of those characterized by low contents of organic matter (Moreno *et al.* 2003).

Nevertheless, apart from compounds valuable to plant production, sewage sludge may contain a number of detrimental substances (Baran and Oleszczuk 2002, Skorbiłowicz 2002a, Grzywnowicz and Strutyński 2000, Gorlach and Gambuś 1999). Those undesired compounds include heavy metals (Skorbiłowicz 2002a, Gorlach and Gambuś 1998, Hemida *et al.* 1995), polycyclic aromatic hydrocarbons (Baran and Oleszczuk 2002, Czekała *et al.* 2002), as well as pathogenic bacteria and parasite eggs (Loc 2002, Nowak *et al.* 1998). Heavy metals inhibit the growth of soil micro-organisms and interrupt processes they take part in (Moreno *et al.* 2003, Khan and Scullion, 1999, Giller *et al.* 1998). The contents of heavy metals and pathogenic bacteria in sludges allowed for agricultural application are specified by the Regulation of the Minister of Environment of the 1st of August 2002 on municipal sewage sludge (2002). Sludges characterized by contents of heavy metals and other toxic substances as well as sanitary contaminants exceeding standard levels should not be applied in agriculture (Mazur 1996). Sewage sludges may be subjected to composting in order to reduce the number of pathogens occurring in them (Czyżyk *et al.* 2002, Siuta 2002, Hryńczuk and Weber 1999, Siuta 1999). Sewage sludge from dairy plants belongs to sludges characterized by a low load of undesirable compounds, the concentrations of which are substantially lower than the permissible levels. In addition, the dairy sewage sludge displays high concentrations of N and P, as well as a lower content of K (Magrel 2003, Ciećko *et al.* 2001, Filipek and Fidecki

1999), and C:N ratio (7-8:1) approximating that observed in municipal sludge (Fidecki 2002, Filipek and Fidecki 1999).

Of the multiple ways of sewage sludge management, the most reasonable seems to be their agricultural application due to the fact that nutrients they contain return to soil, thus fertilizing it (Wierzbicki 2003, Ślizowski 2002, Siuta 2002). In Poland, 11% of sewage sludges are utilized agriculturally (Roczniki GUS 2007), whereas in the different countries of Europe more of the sludges produced are applied in farming practice, that is: Luxemburg 81%, Spain 62%, Switzerland, Great Britain and Denmark 50%, Germany, Italy and France 30% (Jackowska and Olesiejuk 2004).

EFFECT OF SEWAGE SLUDGE ON SELECTED MICROBIOLOGICAL AND BIOCHEMICAL INDICES OF SOIL

Impact of sewage sludge on the enzymatic activity of soils

The administration of organic matter to soil has a direct impact on higher yields and improvement of the physical, chemical and microbiological status of the soil (Bhattacharyya *et al.* 2001, Janvier *et al.* 2007). Sewage sludges are slowly decomposing organic material. The rate of that decomposition is determined by the C:N ratio, which is of significance especially to microorganisms that utilize both of these compounds readily (Czekała 2002). The organic matter administered to soil is metabolised with enzymes whose activity increases in soils fertilized with that matter (Martyniuk *et al.* 1998). The enzymatic activity of soil may be considered as an indicator of the total microbiological activity (Koper and Piotrowska 2001, Nannipieri *et al.* 2003). It is one of the indicators used in the evaluation of soil fertility and productivity. In addition, it enables complex cognition of changes proceeding in the soil environment (Myśków *et al.* 1996, Gostkowska *et al.* 1993). The intensity of enzymatic reactions proceeding in the soil is determined by a number of factors, including pH, temperature and the presence of inhibitors (Kizilkaya and Bayrakli 2005). Climatic conditions, cultivation, the type of plant, edaphic factors, and substances administered to the soil, including sewage sludge, also affect the changes in the enzymatic activities (Pascual *et al.* 1997).

Kucharski *et al.* (2000) demonstrated that the effect of sewage sludge on the enzymatic activity of soil is linked with the levels of mineral and organic compounds occurring in the soil. The enzymatic activity has also been reported to depend on organic carbon content of soil (Kizilkaya and Bayrakli 2005). In their investigations, Baran and Bielińska (1998) and Baran *et al.* (1999) proved a higher correlation between the dose of sewage sludge and enzymatic activity of soil. Also Bielińska *et al.* (2000) reported that the activity of soil enzymes was observed to intensify with an increasing dose of sewage sludge administered to the soil. The occurrence of positive correlation between intensified nitrogen fertilization, proteolytic activity and bacterial biomass was also demonstrated by Burton and McGill (1992).

In sewage sludge, nitrogen occurs mainly in the form of organic compounds, the metabolism of which depends on the rate of their degradation (Krzywy *et al.* 2000). Activities of protease and urease are indicators of decomposition intensity of organic nitrogen compounds. Investigations by a number of authors (Marschner *et al.* 2004; Garcia-Gil *et al.* 2004; Jezierska-Tys *et al.* 2004b; Jezierska-Tys and Szwed 2002) demonstrated the stimulating effect of sewage sludge on the proteolytic activity of soil. Bielińska and Żukowska (2002) showed that the activity of those enzymes increased under the influence of high doses of sewage sludge (300 and 600 $Mg \cdot ha^{-1}$). That activity was also observed to be correlated with contents of organic C and total N in the soil. Those authors found also a significant correlation between urolytic activity and $N\text{-}NH_4^+$ content of soil. According to Moreno *et al.* (1999), sewage sludge administered to soil stimulated the activity of both protease and urease; what is more, those activities increased with higher doses of the sludge. Saviozzi *et al.* (2002) demonstrated that the addition of sewage sludge to soil caused an increase in the proteolytic activity which was further observed to decline in the course of the study. Those authors reported that the sludge administered to the soil stimulated the proteolytic activity to a greater extent than the sludge applied together with manure. Investigations by Zaman *et al.* (1999, 2004) indicated that after the initial increase of proteolytic activity, its slow decrease was observed throughout the study, which resulted from the depletion of organic nitrogen substances applied to soil with liquid dairy sludge. A research by Jezierska-Tys *et al.* (2004b) demonstrated a stimulating impact of sewage sludge from a dairy plant on the activity of protease, and an inhibitory one on the activity of urease. Baran and Bielińska (1998) reported on the positive effect of municipal sewage sludge on the urolytic and proteolytic activities and a linear correlation between the dose of the sludge and activities of those enzymes. In addition, Zaman *et al.* (2002) showed that the proteolytic activity stimulated by liquid dairy sludge administered to soil was also affected by the depth of soil. The activity of urease was observed to diminish with increasing depth of soil. A number of authors (Tasatar and Haktanir 2000; Ataman and Arkac 2000; Karaca *et al.* 2002) reported on the significant effect of sewage on the activity of urease and its decrease over the experimental period. Ample studies (Lima *et al.* 1996; Fernandes *et al.* 2005; Kizilkaya and Bayrakli 2005; Tasatar and Haktanir 2000; Ataman and Arkac 2000) demonstrated, in turn, a significant increase in the activity of urease with higher doses of sewage sludge added to soil. In contrast, Lai *et al.* (1999) proved a positive influence of sewage sludge on the activity of urease and a decrease in its activity with higher doses of lignite ash added to the sludge. Other authors (Li *et al.* 2005; Garcia-Gil *et al.* 2004; Fernandes *et al.* 2005; Kizilkaya and Bayrakli 2005) also confirmed that the administration of sewage sludge to soil resulted in enhanced urolytic activity.

The activity of dehydrogenases is referred to as a general, indirect, indicator of the number and activity of bacteria in soil (Brzezińska 2006, Koper *et al.* 2003). It was demonstrated to increase with growing doses of organic matter administered to soil, thus indicating more intensive processes of its mineralization (Baran *et al.* 1996, Wielgosz 1996). Those authors (Baran *et al.* 1996, Wielgosz 1996) observed also that the activity of that enzyme was stimulated by the sewage sludge incorporated to soil. A number of authors (Saviozzi *et al.* 2002, Moreno *et al.* 1999, Lai *et al.* 1999, Pascual *et al.* 2007) demonstrated the positive impact of sewage sludge on the activity of dehydrogenases. Investigations carried out by Saviozzi *et al.* (2002) and Lai *et al.* (1999) proved a decrease in the activity of that enzymes during soil incubation, which is linked with depletion of respiratory substrates. According to Lai *et al.* (1999), lignite ash added to the sludge reduced the activity of that enzyme. On the contrary, Moreno *et al.* (1999) observed that the high stimulation of dehydrogenase activity was maintained over the entire experimental period. Jezierska-Tys *et al.* (2004b) demonstrated that the dehydrogenase activity was stimulated by dairy sewage sludge only in October, whereas in the spring time no significant differences were observed in that activity as compared to the control soil. Investigations carried out by Saviozzi *et al.* (1999) proved that sewage sludge combined with manure stimulated the activity of dehydrogenases to a greater extent than the sludge alone. On the other hand, a research by Jezierska-Tys *et al.* (2004b) demonstrated that dairy sewage sludge had a more profound effect on the activity of that enzyme than the sludge supplemented with manure.

In their experiments, Garcia-Gil *et al.* (2000) and Lai *et al.* (1999) and Brzezińska (2006) observed a significant correlation between the dehydrogenase activity of soil and biomass of soil bacteria, whereas Myśków (1981) demonstrated significant correlations between crop yield, dehydrogenase activity and organic carbon content of light and medium-heavy soils. The activity of dehydrogenases is also linked with the respiratory activity of soil as well as the total number of soil bacteria and fungi.

Phosphatases are enzymes that serve an important function in soil, namely they participate in the transformation of organic compounds of phosphorus to inorganic phosphates being directly available to plants and edaphic organisms (Tabatabai 1994). Numerous authors (Lai *et al.* 1999, Ataman and Arcak 2000, Lima *et al.* 1996) demonstrated the stimulating influence of sewage sludge administered to soil on the phosphatic activity. Lai *et al.* (1999) and Fang *et al.* (1997) reported on the lower activity of phosphatases along with increasing doses of lignite ash added to sewage sludge applied to soil. Garcia-Gil *et al.* (2000), in turn, showed the inhibiting effect of organic matter on the activity of enzyme discussed as well as its increase with diminishing content of phosphorus available in the soil. Investigations of Karaca *et al.* (2002) proved the stimulating impact of sewage sludge on the activity of acid and alkaline phosphatase as well as its decline as affected by contamination with cadmium. Opposite results were obtained in a research by Moreno *et al.* (1999), who claimed that the activity of phosphates increased in the soil enriched with sewage sludge contaminated with high doses of cadmium.

Investigations into enzymatic activities provide information on biochemical processes that proceed in soils and may be sensitive indicators of their ecological status (Kizilakya and Bayrakli 2005, Giller *et al.* 1998). It is difficult, however, to obtain a complex picture of soil condition based on the assay of the activity of one selected enzyme. Such research should, therefore, be carried out simultaneously on several selected enzymes (Barabasz 1992, Kobus 1996).

Impact of sewage sludge on amonification and nitrification as well as population numbers of microorganisms responsible for those processes

Sewage sludges are characterized by high contents of nitrogen (Gambuś and Gorlach 1998, Filipek and Fidecki 1999), due to which their fertilizing utilization affects the microbiological changes of soil nitrogen (Strauss and Lamberti 2002, Wong *et al.* 1998, Dar 1997) and population numbers of ammonifying, nitrifying and denitrifying bacteria (Loc and Piontek 2000, Piontek and Loc 2000).

Ammonification and nitrification are processes providing information on the metabolism of soil nitrogen (Kobus 1996, Barabasz 1991, Barabasz 1992, Corstanje and Reddy 2006), whereas the content of nitrate and ammonia ions constitutes an important link in the balance of that element in the soil (Baran *et al.* 2002). Investigations carried out by Tasatar and Haktanir (2000) indicated that sewage sludge exerted a positive effect on the intensification of both the ammonification and nitrification processes. The above-mentioned authors reported, however, that the intensity of the ammonification process decreased with the time of soil incubation, whereas that of the nitrification process increased throughout the experimental period. A study by Zaman *et al.* (1999) demonstrated an increase in the nitrification intensity along with increased mineralization of organic matter and release of ammonia nitrogen to soil. In their experiments, Jezierska-Tys *et al.* (2004a) proved that fertilization with sewage sludge from a dairy plant contributed, to a negligible extent, to the increase in the intensity of the ammonification process and had an inhibiting effect on the nitrification process. The stimulating impact of sewage sludge on the intensity of the ammonification and nitrification processes was also observed by Dar (1997). On the contrary, in their study into the influence of sewage sludge on nitrogen metabolism, Wong *et al.* (1998) demonstrated that only very high doses of those wastes were capable of stimulating the ammonification process, whereas they did not observe any differences in the intensity of that process upon the application of lower doses of the sewage sludge, as compared to the control soil. Blechschmidt and Schaaf (1999), in turn, reported on the stimulating effect of sewage sludge on the intensity of the ammonification process only at the initial stage of their experiment, which was followed by a decrease in the intensity of that process below values observed for the control soil. The above-mentioned authors (Wong *et al.* 1998; Blechschmidt and Schaaf 1999) demonstrated also the stimulating influence of sewage sludge on the intensity of the nitrification process as well as a reduction in the intensity of that process in the course of the study. Zaman *et al.* (2004) postulated that also composted sewage sludge evoked an increase in the intensity of the nitrification process.

The number of ammonifying and nitrifying bacteria may also provide information on the processes they carry out, although the intensity of those processes is not always correlated with population numbers of those bacteria, as indicated by Jezierska-Tys *et al.* (2004a). Such a correlation was not confirmed in the experiment of Gostkowska and Wielgosz (1994), either. The ammonifying bacteria occur in high numbers in sewage sludges and serve an important function in the degradation of organic nitrogen links contained in them (Loc and Piontek 2000).

The nitrifiers are bacteria susceptible to changes of the physical and chemical properties of medium they colonize. Owing to this, their activity is considered as a reliable indicator of both the biological degradation of soil and the improvements of its properties as affected by different reclamation factors (Kobus 1996, Barabasz 1991). The biological activity of soils may be improved by their enrichment with e.g. sewage sludge, compost and other waste materials of organic origin (Baran and Turski 1999). Investigations by Wielgosz *et al.* (1997) demonstrated that the municipal sewage sludge remarkably increased the number of nitrifying bacteria in soil. Stimulation of the population numbers of those bacteria was also reported in the research of Jezierska-Tys *et al.* (2004a) as affected by soil administration with sewage sludge from a dairy plant.

Impact of sewage sludge on the respiration activity and total number of soil microorganisms

The respiration activity is acknowledged as an indirect indicator of the total number and activity of bacteria in soil (Koper *et al.* 2003, Kucharski and Niklewska 1991). It may also be used as an indicator of changes in soil quality (Fernandes *et al.* 2005).

An increase in the level of organic matter and basic macroelements in soil is likely to stimulate the bacterial activity, thus contributing to increase in the respiratory activity (Emmerling *et al.* 2000). Sewage sludges, especially from a dairy plant, may also affect changes in the intensity of soil respiration as they are characterized by high contents of organic matter and nutrients.

Our earlier experiments (Jezierska-Tys and Frąc 2005) demonstrated a significant stimulating effect of sewage sludge from a dairy plant on the respiratory activity of soil. Similar results were obtained by Gibbs *et al.* (2006) and Pascual *et al.* (1997), however the sludge used in that study originated from municipal wastewaters. As in the research of Jezierska-Tys and Frąc (2005), the above-mentioned authors observed that the sewage sludge exerted a stimulating effect on the respiratory activity of soil at the initial stage of the experiment. During further incubation of soil, they noted a decrease of that activity below values recorded for the control soil. Investigations of Moreno *et al.* (1999), Tasatar and Haktanir (2000) as well as Atman and Arcak (2000) showed that a sewage sludge dose of 20 t · ha^{-1} had a positive impact on the respiratory activity of soil. In addition, Tasatar and Haktanir (2000) reported on the highest stimulating effect of the sludge at the beginning of their experiment and a decline in that activity in the course of the study. Emmerling *et al.* (2000) demonstrated, in turn, that the respiratory activity of soil was stimulated to the greatest extent by sludge enriched with lignite ash. Quemada and Menacho (2001) showed that a year after sewage sludge application, the respiratory activity was higher in the soil fertilized with sewage sludge than in the control soil. Experiments carried out by Johansson *et al.* (1999) proved that the addition of sewage sludge had no effect on soil respiration, yet in this study the sludge was applied at a dose of 12 t ha^{-1}.

According to Myśkow (1981), a reliable indicator of soil fertility is the ratio of bacteria to fungi occurring in the soil. Our previous research, Jezierskaj-Tys and Frąc (2005), demonstrated that dairy sewage sludge evoked a significant increase in the number of bacteria and an insignificant increase in that of fungi colonizing the soil. In addition, it was noted that straw administered to soil with the sludge stimulated significantly the growth of bacteria, which was probably affected by changes in the C:N ratio. Kobus *et al.* (1990) observed that the addition of sewage sludge to soil increased considerably the population numbers of bacteria, actinomycetes and fungi. Investigations of Marschner *et al.* (2004) proved that the numbers of soil bacteria and fungi were significantly correlated with the content of organic carbon on the C:N ratio in soil fertilized with sewage sludge. Experiments by Nowak *et al.* (2001) and Karaca *et al.* (2002) confirmed the positive effect of sewage sludge on the growth of endaphic bacteria. The research by Kacprzak and Stańczyk-Mazanek (2003) demonstrated that sewage sludge increased the number of fungi at the initial stage of experiment up to 6 months, and that in the course of the study the activity remained at a level comparable to that in the control soil. A number of authors (Emmerling *et al.* 2000, Johansson *et al.* 1999, Lai *et al.* 1999, Pascual *et al.* 1997) showed that sewage sludge exerted a stimulating impact on the growth of soil microflora.

SUMMARY

The major part of the presented overview of studies refers to municipal sewage, as the available literature provides sparse data on the effect of sewage sludge from dairy plants on the microbiological and biochemical activities of soil.

Population numbers and activities of those microorganisms in soil environment are determined by a number of factors. Still, the main factor stimulating their activity is the content of organic matter available to them. Biological processes modifying soil fertility consist mainly in the transformation of organic matter introduced to soil with, among others, sewage sludge.

The literature data discussed indicate that microbiological changes of organic compounds and population numbers of different physiological groups of microorganisms may be utilized as microbiological and biochemical assays in the evaluation of the fertility and quality of soils fertilized with municipal sewage sludge as well as that originating from dairy plants.

Agricultural utilization of sewage sludges from dairy plants deserves special attention as they are characterized by a high content of organic matter and low contamination with heavy metals and pathogenic bacteria. Therefore, the application of sewage sludges in farming practice is one of the best and an environment-friendly natural mode of their disposal.

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WPŁYW OSADÓW ŚCIEKOWYCH NA WYBRANE MIKROBIOLOGICZNE I BIOCHEMICZNE WSKAŹNIKI ŻYZNOŚCI GLEB W ŚWIETLE BADAŃ KRAJOWYCH I ZAGRANICZNYCH: ARTYKUŁ PRZEGLĄDOWY

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Streszczenie. W prezentowanej pracy przedstawiono obszerny przegląd literatury dotyczący wpływu osadów ściekowych na mikrobiologiczne i biochemiczne wskaźniki żyzności gleb. Praca została podzielona na kilka części, w których kolejno omawiane są następujące zagadnienia: charakterystyka osadów ściekowych, oddziaływanie osadów na aktywność enzymatyczną gleb, amonifikację i nitryfikację oraz liczebność drobnoustrojów przeprowadzających te procesy, wpływ osadów ściekowych na aktywność respiracyjną oraz ogólną liczebność bakterii i grzybów glebowych. Poszczególne rozdziały zostały przygotowane w oparciu o literaturę krajową i zagraniczną. W podsumowaniu stwierdzono, że mikrobiologiczne przemiany związków organicznych, aktywność enzymatyczna oraz liczebność różnych grup fizjologicznych drobnoustrojów mogą być wykorzystywane jako testy mikrobiologiczne i biochemiczne w ocenie żyzności i jakości gleb nawożonych osadami ściekowymi.

Słowa kluczowe: osad ściekowy, aktywność enzymatyczna, gleba, mikroorganizmy