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CHANGES IN THE BIOCHEMICAL PROPERTIES OF SOIL IN THE OUTER DUMPING GROUND OF A SULPHUR MINEFIELD RESULTING FROM LAND RECLAMATION

ZMIANY WŁAŚCIWOŚCI BIOCHEMICZNYCH GLEBY NA ZWAŁOWISKU ZEWNĘTRZNYM KOPALNI SIARKI W WYNIKU REKULTYWACJI

Key words: sulphur mine, anthropogenic soil, land reclamation, enzymatic activity.

Summary: The present work summarises the results of many years' work (1988-2001) on the enzymatic activity of the anthropogenic soil originating from sandy formations on the outer dumping ground of a sulphur mine covered by forest in Piaseczno at Tarnobrzeg (50° 35' N; 21° 47' E). The significant and favourable changes of the biochemical and chemical soil properties observed over several years pointed to the stability of the silvo-ecosystem studied and achieved as a result of the land reclamation process. After more than 30 years of land reclamation, the enzymatic activity of this anthropogenic soil was at the sandy soil level in the natural forest ecosystems. This proves that the soil formed achieved the status of 'dynamic biological balance' and the soil formation process was complete. In the practical sense, this soil had properties which allowed the normal growth and development of a forest plantation with the application of the technologies of forest production in general use.

Słowa kluczowe: gleba leśna, antropogeniczne zakwaszenie, aktywność enzymatyczna.

Streszczenie: W niniejszej pracy prezentujemy wyniki wieloletnich (1988-2001) badań aktywności enzymatycznej gleby wytworzonej z utworów piaszczystych na zalesionym zwałowisku zewnętrznym kopalni siarki w Piasecznie koło Tarnobrzega (50° 35' N; 21° 47' E). Obserwowane na przestrzeni kilkunastu lat istotne i korzystne zmiany właściwości biochemicznych i chemicznych gleby wskazują na stabilność badanego silvoekosystemu, uzyskiwaną w procesie rekultywacji. Po ponad 30 latach rekultywacji aktywność enzymatyczna gleby antropogenicznej kształtowała się na poziomie aktywności enzymatycznej gleb piaszczystych w naturalnych ekosystemach leśnych. Świadczy to o tym, że wytworzona gleba uzyskała stan dynamicznej równowagi biologicznej, a proces glebotwórczy został zakończony. W znaczeniu praktycznym jest to gleba charakteryzująca się takimi właściwościami, które przy technologiach

powszechnie stosowanych w produkcji leśnej umożliwiły nasadzeniom leśnym prawidłowy wzrost i rozwój.

INTRODUCTION

One of the methods of decreasing the burden of dumping grounds on the natural environment is their forestation. The biochemical processes related mainly to the micro-organisms and enzymes released by them not only influence soil fertility in the ecosystems but also decide the functioning of each biocenosis. The object of the present research was the analysis of the changes in the enzymatic activity of the soil originating from sandy formations on the outer dumping ground of a sulphur mine covered with forest in order to evaluate the degree of progress in the soil formation process. Enzymes take part in the soil metabolism catalysing processes that are decisive for the course of the soil formation process. Enzymatic tests allow the synthetic evolution indices of technogenic soils to be obtained [Kiss et al., 1993].

Materials and methods

The present studies were located in an area of an outer dumping ground of a sulphur mine covered with forest in Piaseczno at Tarnobrzeg (50° 35' N; 21° 47' E). The dumping ground was formed in the period 1959-1965 from sand and clay. The overlay was located above a deposit of sulphur-bearing deposits from which the dumping ground was formed from the materials of the old Miocene sea. Due to the geological structure of the sulphur deposit overlay, Tertiary and Quaternary sandy formations with the following granulometric composition are predominant on the outer dumping ground: >1 mm – 2.3-5.9%; 1-0.1 mm – 78-96%; 0.1-0.02 mm – 2-7%; 0.02-0.002–1-6%; <0.002–1-9%. Trees were introduced in the period 1968-1969 after technical land reclamation treatment had been carried out. The land reclamation included some of the top part (about 3 ha) and part of the slope (about 4 ha) with the north exposition. In the composition of the forestation, several bush and tree species were mixed. In 1966, before land reclamation, the humus content in the dumping material ranged from 0.03 to 1.68%. Nitrogen was also found amounting to 0.003 to 0.086%. The mean sulphur content in the sandy material was 0.01%, and the reaction was at a level representing neutral soil. In 1978, the sandy formations were characterised by a grey layer - about 5 cm thick - with a humus content of 3%. The pH reaction of the soil cover reforested decreased slightly.

Three objects on the top-table were selected for the studies on the enzymatic activity of the anthropogenic soil originating from sandy formation, i.e.: 1 – in the Red Oak community (*Quercus rubra* L.) and the small-leafed Linden community (*Tilia cordata* Mill.); 2 – in the Red Oak monoculture (*Quercus rubra* L.); 3 – in the Scots Pine monoculture (*Pinus sylvestris* L.); and the fourth object on the slope, i.e.: 4 – in the False Acacia monoculture (*Robinia pseudacacia* L.).

Soil samples for enzymatic studies were collected from the mineral soil layer, from three depths viz: 0-5, 5-10 i 10-20 cm, in the second decade of May 1988 and 2001. The following parameters were determined in the soil samples collected: dehydrogenases activity [Thalmann, 1968], phosphatases activity [Tabatabai, Bremner, 1969], urease activity [Zantua, Bremner, 1975] and proteases activity [Ladd, Butler, 1972]. Additionally, the following chemical soil properties were also determined: reaction – pH in 1 mol dcm^{-3} KCl (pH_{KCl}) [ISO 10390], total organic carbon (TOC) (ISO 14235), total nitrogen (TN) (ISO 13878) and total sulphur (TS) (ISO 15178).

RESULTS

In 2001, the content of TOC and TN in the soil layers analysed in all study objects was about 2-times higher, and the ratio of C:N was lower than in 1988 (tab. 1). TOC and TN accumulation in the soil was clearly differentiated in relation to the species composition of the tree communities. The content of the above components up as far as the table of the Scots Pine monoculture and in the soil of the slope in the monoculture of the False Acacia was several times lower compared to the content of the same components in the top of the soil table in the tree communities of the Red Oak and the small-leafed Linden. The lowest content of TOC and TN was found in the soil of the Scots Pine monoculture. The content of TOC and TN in the soil layers analysed decreased with depth.

In 2001, as compared to 1988, soil pH decreased from 0.2 to 0.8 pH units in 1 mol dcm^{-3} KCl (tab. 1).

Tab. 1. Chemical properties of soil

Site#	Layer (cm)	pH (in 1 mol dcm^{-3} KCl)		TOC (%)		TN total (%)		C:N		TS (mg kg^{-1})	
		1988	2001	1988	2001	1988	2001	1988	2001	1988	2001
1	0-5	6.9	6.7	0.95	2.05	0.08	0.18	11.9	11.3	14.0	13.2
	5-10	7.0	6.6	0.79	1.74	0.07	0.16	11.3	10.8	14.1	13.3
	10-20	7.0	6.6	0.36	0.95	0.03	0.08	12.0	11.8	14.4	13.3
2	0-5	6.8	6.4	0.62	1.70	0.05	0.14	12.4	12.1	12.8	12.7
	5-10	6.2	6.0	0.48	1.16	0.04	0.10	12.0	11.6	13.0	12.8
	10-20	6.0	5.7	0.24	0.45	0.02	0.04	12.0	11.2	13.3	12.9
3	0-5	5.2	4.4	0.22	0.54	0.02	0.05	11.0	10.8	11.7	11.5
	5-10	5.1	4.3	0.12	0.23	0.01	0.02	12.0	11.5	11.8	11.6
	10-20	4.6	4.2	0.10	0.18	0.01	0.02	10.0	9.0	11.8	11.7
4	0-5	5.3	4.6	0.48	0.86	0.04	0.08	12.0	10.7	12.0	11.8
	5-10	5.2	4.5	0.36	0.73	0.03	0.07	12.0	10.4	12.1	11.9
	10-20	4.9	4.4	0.25	0.47	0.02	0.05	12.5	9.4	12.1	12.0

#1 – top, Red Oak (*Quercus rubra* L.) and Small-leafed Linden (*Tilia cordata* Mill.)
2 – top, monoculture Red Oak (*Quercus rubra* L.)
3 – top, monoculture Scots Pine (*Pinus sylvestris* L.)
4 – slope, monoculture False Acacia (*Robinia pseudacacia* L.)

Tab. 2. Enzymatic activity of soil (DhA – dehydrogenases in cm^3 H_2 $kg^{-1} \cdot d^{-1}$, PhA – phosphatases in mmol PNP kg^{-1} h^{-1}, UA – urease in mg $N\text{-}NH_4^+$ kg^{-1} h^{-1}, PA – protease in mg tyrosine kg^{-1} h^{-1})

Site	Layer (cm)	DhA		PhA		UA		PA	
		1988	2001	1988	2001	1988	2001	1988	2001
1	0-5	0.89	3.64	2.27	9.24	11.95	48.34	4.66	12.28
	5-10	0.35	1.53	1.20	5.18	6.72	22.78	2.02	7.35
	10-20	0.21	0.89	0.68	2.62	2.96	16.40	1.18	4.82
2	0-5	0.75	3.12	1.52	4.11	10.84	41.52	3.89	10.43
	5-10	0.32	1.39	1.03	2.03	6.37	10.94	1.72	5.20
	10-20	0.18	0.69	0.44	1.25	3.18	8.26	0.99	4.16
3	0-5	0.62	1.18	1.10	3.05	2.47	29.82	1.58	5.39
	5-10	0.29	0.78	0.73	1.96	1.63	8.21	1.11	3.12
	10-20	0.14	0.61	0.28	0.84	1.21	3.95	0.74	1.94
4	0-5	0.79	2.04	1.28	3.86	8.16	31.82	3.23	9.11
	5-10	0.32	1.27	0.86	1.63	4.62	9.53	1.38	6.02
	10-20	0.19	0.72	0.55	0.90	2.22	6.29	0.90	3.65
$LSD_{0.05}$ for:									
Site		0.12		0.34		0.84		0.53	
Years		0.10		0.22		0.55		0.42	
Layer		0.12		0.34		0.84		0.53	

The highest soil acidification was observed on the table-top in the monoculture of Scots Pine (*Pinus sylvestris* L.), and the lowest in the table-top in the tree communities of the Red Oak (*Quercus rubra* L.) and the small-leafed Linden (*Tilia cordata* Mill.). Also the soil from the slope with False Acacia (*Robinia pseudacacia* L.) monoculture was characterised by acidic or very acidic reaction.

The total S content (TS) in the soil of the objects studied ranged in the section of low values, i.e. from 11.5 to 14.4 mg $\cdot kg^{-1}$ (tab. 1).

In all study objects, soil enzymatic activity in 2001 was several times higher than in 1987 (tab. 2). Forest tree species significantly differentiated soil enzymatic activity. The highest activity of the enzyme studied was found in the top of the soil table with the Red Oak species and the small-leafed Linden, and the lowest in the table-top soil in the monoculture of Scots Pine. A weakening of soil enzymatic activity was recorded also on the slope in the monoculture of False Acacia. Soil enzymatic activity decreased with soil depth.

DISCUSSION

The enzymatic activity of the soil studied in 2001 was several times higher as compared to its enzymatic activity in 1987 and was accompanied by a considerable increase in the content of organic carbon and total nitrogen and a decrease in the value of the C:N ratio. This proved that nutrients were included into biological circulation and certified that land reclamation had a favourable influence on the fertility of the habitat studied. Enzyme activity totally depends on the amount and the size of the pool of the reacting compounds rather than on enzyme catalytic efficiency [Murray et al., 1995]. Additional factors (both abiotic and biotic) influence catalytic efficiency in the soil environment such as: content of organic matter, temperature, water-air properties, soil pH, content of biogenic elements, amount and species composition of micro-organisms [Abrayman, 1993]. The most dynamic properties of forest soils are closely related with the functioning of the forest biocenosis. Over a longer period of time, the properties of forest soils change along with changes in species' composition, age and the health of the tree community [Pokojska et al., 1998]. The present authors observed favourable biochemical and chemical changes of the soils spanning many years which points to the stability of the silvo-ecosystem studied obtained in the land reclamation process. After more than 30 years of land reclamation, the enzymatic activity of sandy soils was at the level of the enzymatic activity of the sandy soils in natural forest ecosystems [Januszek, 1999]. This showed that the soil formed had reached a dynamic, biological balance and the soil formation process had been completed. The condition of the biological and chemical soil properties enables the ecosystem studied to qualify as a natural forest ecosystem resembling a national park and a nature reserve. In the practical sense, this is a soil characterised by those properties which facilitated the correct growth and development of forest plantation when technologies, common in forest production, were applied. Pokojska et al. [1998] stressed that the degree of binding between the soil and biocenosis is different in natural ecosystems as opposed to commercial forests. In ecosystems resembling the natural, a certain balance between biocenosis and soil is established whereas in commercial forests, the whole forest ecosystem never reaches a balance [Pokojska et al., 1998].

The enzymatic activity of the soil studied decreased with increasing depth. Such regularity, observed by most researchers, is mainly related to the humus distribution in the soil profile as the humus content decreases rapidly in the deeper soil layers. Studies by Januszek [1999] on the enzymatic activity of some selected forest soils in the southern part of Poland showed that the above phenomenon does not occur in every soil. According to this latter author, the lower enzyme activity in the surface soil layer in comparison with the deeper layers can be related to the longer and more frequent periods of drying-out to which the surface soil layer is subjected. It can also prove enzyme transfer to the deeper soil layers or higher microbiological activity in the deeper layers of the pedeon due to the higher content of organic substance in these layers.

CONCLUSIONS

1. After 30 years of land reclamation, the enzymatic activity of sandy ground was at the level of enzymatic activity of the sandy soil in natural forest ecosystems. This proves that the soil formed has achieved a dynamic biological balance and the soil formation process has been completed. In the practical sense, it is a soil characterised by such technological properties as would ensure the correct growth and development of seedlings when generally applied technologies were used in forest production.

2. Favourable changes in the biochemical and chemical soil properties of the soil observed over several years, point to the stability of the silvo-ecosystem examined which was obtained in the land reclamation process; favourable changes in the biochemical and chemical soil properties observed over a period of several years show the stability achieved as a result of the land reclamation process in the ecosystem studied which allows this ecosystem to qualify as a forest ecosystem resembling natural ecosystems (national parks, nature reserves).

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