

The relationship between soil properties, enzyme activity and land use

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Abstract. The aim of this study was to assess the effects of different types of land use (forest, tillage and pasture) on soil properties, especially enzyme activity. Our investigation was carried out on 53 research plots with 11 plots in broadleaved forest stands, 12 plots in mixed broadleaved stands, 10 plots in mixed coniferous stands, 9 plots on tillage and 11 plots on pasture. The soil samples were collected from a depth of 0–15 cm after removing the organic horizon. Contents of organic carbon and nitrogen, pH and soil texture were investigated. Furthermore, dehydrogenase and urease activity were determined. Significant differences in the enzyme activity between forest and agricultural soils were observed, thus demonstrating that enzyme activity is influenced by the organic matter content of the soil. The highest enzyme activity was recorded in the forest soil within broadleaved stands, whilst the lowest activity was found in tillage soil, because tillage soil contained significantly less organic matter. High enzymatic activity of pasture soils is the combined result of vegetation type and the lack of plowing.

Keywords: forest soil, dehydrogenase activity, urease activity, land use

1. Introduction

Soil enzymes are natural mediators and catalysts of many important soil processes, such as decomposition of organic matter released into the soil during vegetation, reactions of humus formation and decomposition, production of mineral nutrient forms available for plants, nitrogen fixation, as well as the flow of carbon, nitrogen and other basic elements of the biochemical cycle. Determination of enzyme activity along with the comprehension of its regulating factors are indispensable to characterize the metabolic potential, soil fertility and quality, as well as are useful in soil assessments with regard to bacteria and fungi amounts. At the same time, they can be used to study soil biochemical processes and to evaluate soil quality (Dick 1992, 1994, 1997; Trasar-Cepeda et al. 1998; Acosta-Martinez et al. 1999; Olszowska 2009, 2016). Information on the activity of enzymes in combination with data on other soil properties facilitate the selection of soil use methods (Shaw, Burns 2003).

Enzyme activity is a sensitive indicator of changes in the soil environment. According to Koper and Piotrowska (1999), the activity of enzymes varies depending on the system of soil use. The activities of dehydrogenases and proteases, along with the

content of organic carbon and total nitrogen, are higher in the soil with crop rotation, when compared to those in the soil under crops cultivated as monoculture. Analogous observations were reported by Gianfreda et al. (2005). Saviozzi et al. (2001) obtained higher values of the soil metabolic potential and the biological index of fertility (BIF) – as proposed by Stefanic et al. (1984), in meadow and forest soils, when compared to cereal field. According to Dahm (1984) and Burns (1985), the effects of higher plants on soil enzymes depend on the plant chemical composition, which even in the case of root exudates may considerably differ between the genera, species and also – varieties. Krämer et al. (2000) believe that tree stands stimulate enzyme activity in soils as a result of increasing biomass of microorganisms producing enzymes.

The activity of dehydrogenases – as the group of intracellular enzymes, and that of soil microflora provide information about biologically active microbial population in the soil. According to Gil-Sotres et al. (2005), dehydrogenases represent enzymes, which indicate the status of environment and microbial activity in the soil. Dehydrogenase activity assessments can be used in the evaluations of soil quality, the effect of soil utilisation on soil quality, as well as a degree of recovery of degraded soils.

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In the soil, urease is closely related to organic matter and silts (Alef, Nannipieri 1995). According to many authors, urease activity should be used as an indicator of soil quality and changes under the effect of soil use (Sotres-Gil et al. 2005). The present study attempted to determine relationships between dehydrogenase and urease activities and the mode of soil use. There are presented differences in soil physical and chemical properties depending on the soil use method. In addition, efforts were made to verify the relationship between enzyme activity and physico-chemical characteristics of soils used in various ways. The understanding and ability to assess the quality of soils utilised in different ways can enable the more efficient use of soil potential and production capability.

2. Materials and Methods

2.1. Study area and sample collection

The study areas were located in south-western and central Poland, in the Forest Districts: Przedborz, Radomsko, Spała, Smardzewice, Włoszczowa, Kolumna, Piotrków, Chmielnik, Kielce, Prószków, Kup, Wieluń, Prudnik and Brzeg. The studied soils developed primarily on fluvioglacial sand and clay deposits. The soils tested were classified as Cambisols and Arenosols (WRB 2006).

Soil samples (53) were taken from the mineral horizon at a depth of 0–15 cm, after retrieving the organic horizon. The study areas represented different management manners: forest land with diverse proportions of deciduous and coniferous species (deciduous stands – 11 plots, mixed deciduous – 12 plots, coniferous – 10 plots) and agricultural lands (crop cultivation – 9 plots and pastures – 11 plots). There dominated oak and beech trees in deciduous stands and fir and pine – in coniferous stands, whereas agricultural lands were covered with maize and cereals. Species composition of pastures was dominated by grasses and legume plants.

2.2. Soil properties

Particle size of soil samples was determined using laser diffraction (Analysette 22, Fritsch, Idar-Oberstein, Germany), soil reaction – by potentiometry in water and 1M KCl, total nitrogen and organic carbon contents – with the use of LECO CNS True Mac Analyzer (Leco, St. Joseph, MI, USA) including the calculation of the C/N ratio.

Enzyme activity was assessed in newly collected soil samples with natural moisture. Dehydrogenase activity ($\mu\text{mol TPF} \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$) were determined using the Lenhard method according to the Casida procedure (Alef, Nannipieri 1995). Urease activity ($\text{mmol NH}_4^+ \cdot \text{kg}^{-1} \cdot \text{h}^{-1}$) was determined with the use of the method described by Tabatabai and Bremner (1972) (Alef, Nannipieri 1995).

2.3. Statistical analysis

Statistical analyses were performed using Statistica 10 software. Basic descriptive statistics were calculated, that is, the arithmetic mean and standard deviation. The Kruskal-Wallis test was used to appraise statistically significant differences between the mean values of the soil properties tested. Principal component analysis (PCA) was used to interpret relationships between the studied variables and to investigate relationships between soil use patterns and the studied properties.

3. Results

The investigated soils of different use were characterised by the contents of sand ranging from 48% to 62%, silt – from 10% to 32% and clay – from 3% to 6% (Table 1). No statistically significant differences were found between sand, silt and clay contents in the soils tested. There was a clear difference between agricultural (crop cultivation, pasture) and forest soils with regard to the pH value (Table 1). Statistically significantly higher $\text{pH}_{\text{H}_2\text{O}}$ was observed in agricultural soils: crop cultivation – on average 5.96 and pastures – on average 6.01. In forest soils, the average pH ranged from 4.18 to 4.51. The highest average carbon content was recorded in forest soils from mixed deciduous and coniferous stands, 9.05% and 8.05%, respectively. Agriculturally, cultivated soils showed the lowest carbon content – 0.99%. When compared with forest soils, pasture soils did not differ significantly in carbon content (Table 1). A better distribution of organic matter – expressed by the C/N ratio – was observed in agriculturally used soils. Significantly higher C/N ratio was observed in forest soils.

In the observed soils of different use, the activity of the tested enzymes showed considerable variability. The highest activity of dehydrogenases was found in forest soils covered with deciduous and mixed deciduous tree stands. In the soils from mixed coniferous stand and from pastures, the activities of dehydrogenases were analogously low. The lowest activity of dehydrogenases was recorded in the soils where crops were cultivated (Fig. 1). The activity of urease was similar to that of dehydrogenases. The highest activity was found in deciduous stand soils and the lowest – in the soil used for crop cultivation (Fig. 1). Statistically significant differences between forest and crop cultivation soils were observed with regard to the activities of the enzymes tested.

Figure 2 shows the results of principal component analysis (PCA). Factors 1 and 2 found in the analysis course explain 48.04% of variance of the analysed soil properties; factor 1 explains 32.06% and factor 2 – 15.98% of soil properties variability. Soils from deciduous and mixed deciduous forest showed a strong relationship with dehydrogenase and urease activities, as well as with the C/N ratio. The activities of the

Table 1. Selected properties of investigated soils of different types of land use

Properties	Land use				
	L	LM	IM	U	P
Sand	61 ^a ±25.18	59 ^a ±8.91	54 ^a ±12.08	62 ^a ±24.46	50 ^a ±25.24
Silt	13 ^a ±9.66	10 ^a ±9.81	20 ^a ±6.94	32 ^a ±20.97	25 ^a ±12.26
Clay	4 ^a ±0.47	3 ^a ±1.02	6 ^a ±2.01	5 ^a ±2.24	6 ^a ±1.77
pH _{H2O}	4.34 ^b ±0.47	4.18 ^b ±0.37	4.51 ^b ±0.86	5.96 ^a ±0.66	6.01 ^a ±0.76
pH _{KCl}	3.48 ^b ±0.44	3.32 ^b ±0.31	3.64 ^b ±0.95	4.85 ^a ±0.87	5.18 ^a ±0.95
C	8.01 ^b ±3.01	9.05 ^b ±2.24	8.05 ^b ±2.57	0.99 ^a ±0.25	5.44 ^a ±4.77
N	0.38 ^a ±0.11	0.37 ^a ±0.11	0.37 ^a ±0.20	0.08 ^a ±0.01	0.37 ^a ±0.14
C/N	21 ^b ±3.6	24 ^b ±2.59	19 ^b ±5.42	12 ^a ±1.71	13 ^a ±2.22

Explanation: different lower case letters in the upper index of mean values indicate significant differences; L – soils of broadleaf stands, LM – soils of mixed broadleaf stands, IM – soils of mixed coniferous stands, U – soils of tillage, P – soils of pasture

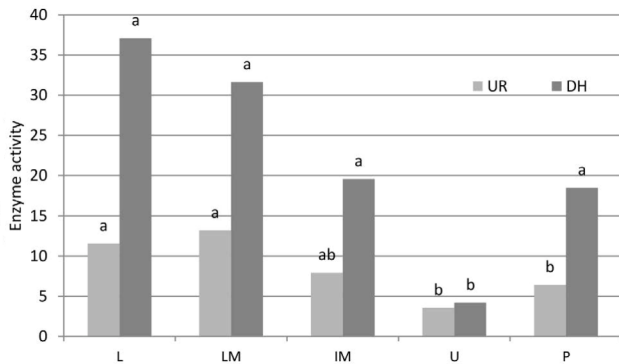


Figure 1. Enzyme activity of soils of different types of land use (different letters indicate significant differences of enzymes activity between different types of land use; L – soil of broadleaf stands, LM – soil of mixed broadleaf stands, IM – soil of mixed coniferous stands, U – soil of tillage, P – soil of pasture, DH – dehydrogenases activity ($\mu\text{mol TPF}\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$), UR – urease activity ($\text{mmol NH}_4^+\cdot\text{kg}^{-1}\cdot\text{h}^{-1}$))

tested enzymes showed a positive relationship with the C/N ratio. Agricultural soils had higher pH.

4. Discussion

Soil management affects microorganisms and microbiological processes by changing the quantity and quality of plant remains, which are the primary source of soil organic matter. In the present study, the soil properties' variability, and especially the enzymatic activity, were observed; among others, this is a result of different methods of soil management. The highest activities of dehydrogenases and urease were recorded in forest soils, which were characterised by the highest accu-

mulation of soil organic matter. Soil fertility and productivity depend on the content of organic matter, which is a nutrient reservoir—very important in the nutrient cycle (Steiner et al. 2007), and which improves the physical, chemical and biological properties of soils (Bhattacharya et al. 2010).

The process of transformation of organic matter in to the soil takes place with the participation of soil microorganisms and enzymes (Schimel, Bennett 2004). In general, cultivated soils contain significantly less organic matter, and this results in weaker soil structure and smaller amounts of microorganisms. In the present study, low activities of dehydrogenases and urease were observed in the agriculturally cultivated soils, whereas higher activities of these enzymes showed pasture soils. The activities of enzymes in pasture soils were comparable to those in forest soils from mixed coniferous stands. High enzyme activity of pasture soils is associated with fairly high contents of organic matter of a good decomposition rate, which was confirmed by the low C/N ratio observed. High enzyme activity in pasture soils also resulted from the effects of vegetation coverage and tillage abandonment. Similar observations were reported by Avellandea-Torres et al. (2013). Diverse species composition of pasture vegetation, and especially the presence of legume plants, contribute to the increased activity of soil microorganisms. The relationship between enzyme activities and the C/N ratio confirms the importance of the quality of organic matter supplied, inter alia, by plants. The C/N ratio has been a long known parameter, used to assess a degree of organic matter decomposition and in the construction of indicators to assess the quality of forest soil fertility and habitats (Brożek et al. 2001; Ostrowska, Porębska 2015).

The observed higher enzyme activity of forest soils can be attributed to the fact that these soils contain more fungal biomass in comparison to arable and meadow soils. Fungal

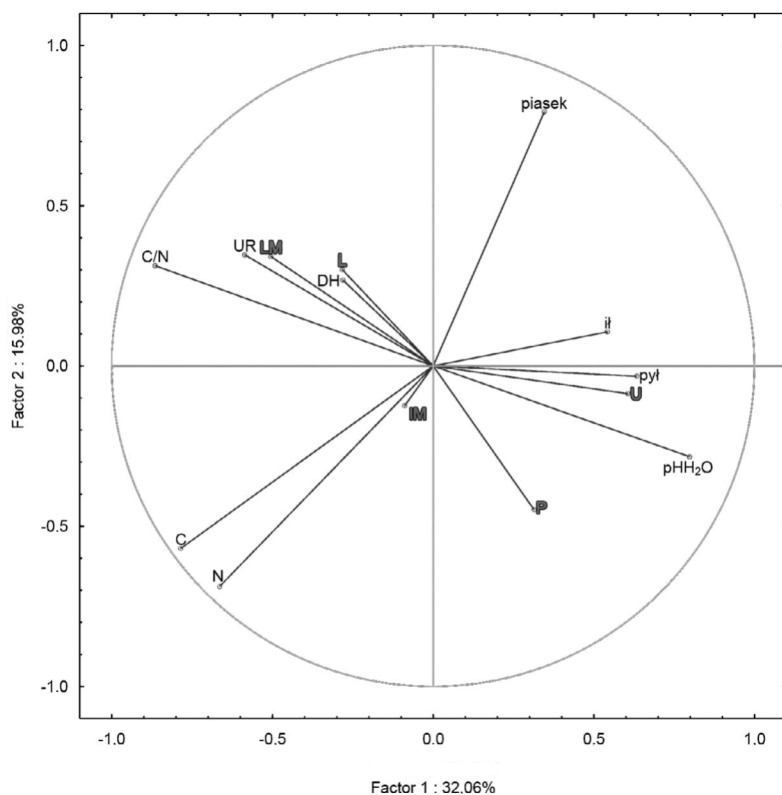


Figure 2. The projection of variables on a plane of the first and second factor (L – soil of broadleaf stands, LM – soil of mixed broadleaf stands, IM – soil of mixed coniferous stands, U – soil of tillage, P – soil of pasture, DH – dehydrogenases activity, UR – urease activity)

organisms play an important role in the first stages of breakdown of large molecule compounds, such as lignin and cellulose. Mycorrhizas associated with the roots of small trees in coniferous and deciduous tree stands excrete extracellular enzymes and cause enzyme activity increase (Colpaert, Van Laere 2006). Species composition within forest tree stands determines the diversity of microorganisms along with their enzymatic activity (Baldrian 2014). The results of the present study indicate that enzyme activity varies considerably within the studied forest soils. The highest activities of dehydrogenases and urease were determined in the soils covered with deciduous stands, whereas the lowest were recorded in the soils of mixed coniferous stands. Tree species shape soil properties by varying the amount and quality of organic matter that gets into the soil (Vesterdal et al., 2008; Goke et al. 2009). In addition, tree species affect soil pH. The pH value has a significant effect on the activity of microorganisms in the soil; enzymes are highly susceptible to soil reaction (Błońska et al. 2016).

Plant cover affects soil properties directly, and indirectly – by modifying the microclimate conditions inside the forest. Different species of trees have different effects on microclimate (Augusto et al. 2002). There develop different humus horizons in deciduous and coniferous stands. In the soil of coniferous stands, there occur the organic horizons (Ofh), and in

deciduous – the humus-mineral horizons (A). The thickness and a degree of decomposition of these levels have an effect on the temperature and humidity of the upper soil levels. According to Brzezinska et al. (2001), Brzostek and Finzi (2012) and Wallenstein et al. (2012), temperature and humidity shape the enzyme activity in the soil. An increase of soil water content has a significant effect on the activity of dehydrogenases (Brzezińska et al. 2001). Forest soils exhibit greater stability in terms of thermal and moisture conditions, when compared to agricultural soils – subject to drastic changes of temperature and humidity. Plant protection products are an additional factor limiting biological activity in cultivated soils.

5. Conclusion

The obtained results confirm the usefulness of assessment of enzyme activity to evaluate the differently managed soils. The results of the present study demonstrated the strong relationship of enzyme activity with the amount and quality of soil organic matter. Forest soils showed the highest activity of dehydrogenases and urease, and the lowest activity of enzymes was recorded in the soils used for crop cultivation, which contained significantly less organic matter. Deciduous and mixed deciduous tree stands provide more favourable conditions for the

decomposition of microbial organic matter, when compared to coniferous mixed stands. High enzyme activity of pasture land is due to the effects of vegetation and lack of tillage.

Conflict of interest

Authors declare no potential conflicts.

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Authors' contribution

E.B. – 80% participation in fieldwork and data collection, statistical analysis, development and interpretation of the results, manuscript writing; J.L. – 15% participation in fieldwork and data collection; MZ – 5% participation in fieldwork and data collection.