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Enzymatic activity as a popular parameter used to determine the quality of the soil environment

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Abstract. In the soil environment, there are many enzymes whose origin is related to microorganisms. Enzymes participate in the synthesis of proteins and nucleic acids, they are also elements of the carbon, nitrogen and phosphorus cycles. They also play a role in less known cycles, such as the sulphur cycle or cellulose decomposition. Determination of soil enzymes activity is very popular in microbiology, biochemistry and agricultural sciences. Their activity may be a measure of soil fertility. The present report describes the importance of selected soil enzymes and the methods of their determination. However, it is important to remember that a single enzyme cannot be an indicator of the environment. The enzymatic activity is sensitive to many natural and anthropogenic factors affecting soil microorganisms. Only comprehensive researchers on the activity of many, different enzymes can provide reliable information on the state of the soil environment.

Keywords: enzymatic activity, microorganisms, soil environment, soil parameters, soil quality, quality indicators

INTRODUCTION

Soil quality can be defined as the ability to maintain plant productivity (Paluszek, 2011). Soil quality is assessed on the basis of soil properties, such as, inter alia, enzymatic activity, micro- and macronutrient content, carbon and nitrogen content, moisture content, pH, microbial abundance. The analysis of these parameters allows the observation of changes occurring in the soil environment under the influence of human activity and changing natural conditions. Physicochemical properties of soils are of great importance for plant yields, however, microbiological and enzymatic activity is also important. Microorganisms have an impact on soil durability and functioning, and changes in the composition and activity of the microbial community may affect the species diversity of plants and their productivity.

Soil microorganisms are responsible for the various biogeochemical cycles that are responsible for maintaining soil fertility. Microorganisms produce a number of compounds responsible for stimulating plant growth or circulation of biogenic elements in the environment, and enzymes are specialized compounds for catalyzing biological reactions. In the soil environment, there are many enzymes of microbial origin that catalyze such processes as synthesis of proteins and nucleic acids, hydrolysis of complex nitrogen compounds, distribution of amino acids or transformations of organic forms of phosphorus (Table 1). As a result of these processes, nutrients are released and made available to plants, which is important from the point of view of plant production. Therefore, the issue of soil enzymatic activity is an important subject of research.

The first report on soil enzymes was published in 1899 by Woods, who recorded peroxidase activity in soil (Woods, 1899). A few years later, it was concluded that without the metabolism of microorganisms and the presence of enzymes secreted by them and higher plants, the soil would quickly become unsuitable for life, as enzymes are essential for the decomposition of organic compounds and, consequently, for agricultural processes. Years of research have shown that microorganisms are the main source of most soil enzymes.

Enzymatic activity is a sensitive parameter of soil environment quality. It is influenced by many factors, both natural and anthropogenic (Fig. 1), and it is considered that the knowledge of enzymatic activity in combination with other soil properties provides the basis for the assessment of soil quality (Furtak, Gajda, 2018). It was also shown that the activity of some enzymes (phosphatase, invertase, urease and β-glucosidase) correlates with crop yields and with the content of organic matter in the soil and its pH. Human

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Process	Enzyme	References
Transformations of nitrogen and its compounds	Urease	Kandeler et al., 2011
	L-asparaginase	
	L-glutaminase	
	Arylamidase	
	Amidase	
Nitrification	Ammonia monooxygenase	
	Nitrite oxydoreductase	
	Hydroxylamine oxydoreductase	
Denitrification	Nitrate reductases	
	Nitrite reductases	
Ammonification	Deaminase	
Formation of peptides/amino acids	Proteases	Landi et al., 2011
	Peptidase	
Sulphur transformations	Arylsulphatase	Klose et al., 2011
	Cystathionine lyase	
	Rhodanase	
	Sulfite reductase	
Phosphorus transformations	Acidic and alkaline phosphatases	Acosta-Martinez, Tabatabai, 2011
	Phosphodiesterase	
	Pyrophosphatase	
	Trimetaphosphatase	
Hydrolysis of carbohydrates	Cellulase	Deng, Popova, 2011
	Amylases	
	Chitinase	
	Invertase	
	α- & β-glucosidases	
	α- & β-galactosidase	
	N-acetylglucosaminidase	

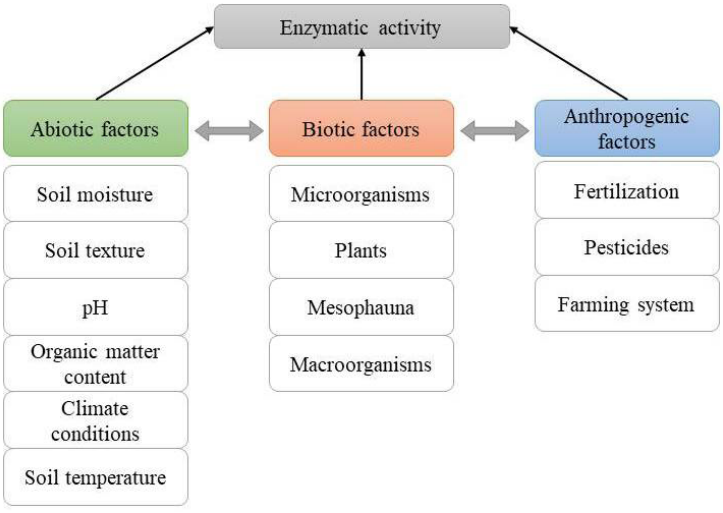

Figure 1. Factors influencing enzymatic activity in soil (authors' compilation).

agricultural activity, especially the intensification of agriculture and the use of plant protection products, influence soil microorganisms and thus the enzymatic activity and soil quality (Nannipieri et al., 2003). It is therefore important to monitor the state of the soil environment for cultivation. Currently, the biological status of soils is generally assessed by analysing the activity of four enzymes: dehydrogenases, phosphatases, urease and proteases.

The aim of this report is to present the most important enzymes synthesized by soil microorganisms, which are used in soil activity and fertility measurements. Enzymatic activity is sensitive to various physical and chemical factors, both natural and anthropogenic, and knowledge of them may enable a better understanding of them as indicators of the soil environment.

OXYDOREDUCTASES

Oxydoreductases (EC 1; EC - Enzyme Commission number) are the largest class of enzymes. They catalyze redox reactions (oxidation and reduction) where one substrate is oxidized (donor) and the other is reduced (acceptor). The acceptor can be e.g. molecular oxygen and hydrogen peroxide.

Dehydrogenases

Dehydrogenases (EC 1.1.1.) are an important group of oxydoreductases, which catalyze the sep-

aration of the hydrogen atom from the substrate (various organic compounds). These enzymes are an element of the cellular respiratory chain regardless of the state of soil oxygenation. Under aerobic conditions, protons and electrons are transferred to the downstream respiratory chain, while in anaerobic acceptors become inorganic forms such as NO^{3-}, SO_4^{2-} or organic compounds available in soil (fermentation processes). Dehydrogenases are active only within living cells, so their measurement indicates the presence of physiologically active microorganisms. In cells, they are located in cytoplasm or cytoplasmic structures formed from membranes but do not accumulate outside the cells (Wolińska, Stępniewska, 2012).

Dehydrogenases are one of the most sensitive indicators in soil analysis. Since they occur only in living cells, they are strictly dependent on the number and type of population of microorganisms. The determination of their activity is also an indicator of the respiratory metabolism of soil microorganisms. The activity of dehydrogenases is related to the presence of living microorganisms, and thus correlated with the content of microbiological biomass in the soil. With a decrease in the total number of bacteria in the soil, lower and lower values of dehydrogenases activity were recorded (Järvan et al., 2014).

The activity of dehydrogenases is closely related to many processes taking place in the soil environment. Their correlation with nitrification potential, denitrification, proteolytic activity, organic matter cycle and respiration was shown. Additionally, the dependence on the activity of other soil enzymes, such as catalase, alkaline and acid phosphatase and β-glucosidase, was observed (Brzezińska, Włodarczyk, 2005). It was noted that the activity of dehydrogenases is influenced by physical and chemical parameters of soil, salinity and contamination with heavy metals and polycyclic aromatic hydrocarbons (PAHs).

In the studies of agriculturally utilized soils, it was found that the activity of dehydrogenases depends on the depth of soil profile (Furtak, Gajda, 2017), and the use of nitrogen fertilizers (ammonium nitrate) has an inhibiting effect on the soil profile. Numerous studies aimed at comparing soil from different tillage systems indicate that simplified organic systems and direct sowing have a higher dehydrogenases activity than conventional tillage (Furtak, Gajda, 2017). Studies on the diversity of agricultural soils in the Lublin region showed that soils used for agricultural purposes had lower dehydrogenases activity than control soils not cultivated (Wolińska et al., 2015).

The most commonly used method to determine the dehydrogenases activity is the colourimetric method, in which a colourless 2,3,5-triphenyltetrazolium chloride (TTC), which is reduced to coloured triphenyl formate (TPF), is used as a substrate.

Catalase

Catalase (EC 1.11.1.6.) is an enzyme from the group of oxidoreductases. Like dehydrogenases, it occurs in the cells of living aerobic microorganisms as well as in plants and animals. It catalyzes the breakdown of hydrogen peroxide from respiration into the water and molecular oxygen. This function is extremely important for cells because hydrogen peroxide irreversibly damages cell structures.

The catalase secreted outside the cells has low activity but is associated with a soil organic colloid. It was shown that catalase activity in soil correlates with organic matter content and dehydrogenase activity (Brzezińska, Włodarczyk, 2005). Higher catalase activity was observed in soils under simplified tillage systems compared to conventional ones (Kabiri et al., 2016).

The catalase activity is determined by manganometric or colourimetric methods using peroxidase (Holz, 1986).

ENZYMES OF THE NITROGEN CYCLE

Nitrogen is a very important element in plant production. The type and concentration of various nitrogen compounds in the soil and nitrogen fertilizers added to the soil have a direct impact on the nitrogen cycle in the environment. Soil microorganisms (Fig. 2), which produce a number of enzymes, participate in nitrogen metabolism. Selected ones are discussed in this chapter.

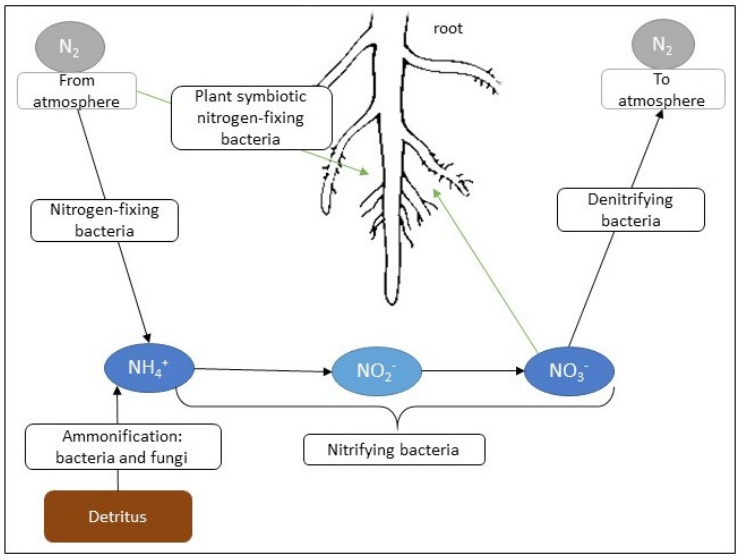

Figure 2. The nitrogen cycle in soil (authors' compilation based on Adamczyk, Godlewski, 2010).

Urease

Urease (EC 3.5.1.5.) is closely related to the biological cycle transformation and the bioavailability of nitrogen. Produced by cells of higher plants and microorganisms, in particular, bacteria, it represents up to 63% of the total enzymatic activity in soil. It is an extracellular, stable enzyme which has the ability to form complexes with soil colloids (Zantua, Bremner, 1977).

The activity of urease is influenced mainly by the soil reaction. Increased salinity and soil sodium content decrease urease activity. Additionally, this enzyme is associated with hummus and clay minerals in the soil (Mocek-Płóciniak, 2010). Its activity is influenced by the physical and chemical properties of the soil, organic matter content, depth of soil profile, tillage, and temperature. Correlations between the activity of urease and the content of organic carbon, organic nitrogen and ammonium nitrogen in soil were shown (Bielińska, Żukowska, 2002). Experiments have shown that the presence of heavy metals, including zinc and copper, has an inhibiting effect on the activity of urease (Wieczorek et al., 2015).

Urease is a sensitive indicator of eutrophication of agricultural and swampy areas. Determination of urease activity can be used to control the effectiveness of nitrogen fertilization of soil and the quality status of the soil environment. Bielińska et al. (2008) show that urease activity is lower in ploughed soils by up to 30–40% compared to those under simplified cultivation. In addition, a decrease in urease activity after soil contamination with a herbicide containing fluroxypyr was demonstrated (Kucharski et al., 2004). Manure application causes an increase in urease activity compared to other fertilisers (Ramdas et al., 2017). The use of chemical fertilisers in conventional cultivation significantly reduces the level of urease activity (Heidari et al., 2016).

Ureolytic microorganisms (producing urease) include both fungi (e.g. *Aspergillus* sp., *Neurospora* sp., *Penicillium* sp., *Coprinus* sp.), yeasts (e.g. *Aureobasidium* sp.), soil bacteria (e.g. *Sarcina ureae*, *Bacillus* sp., *Streptococcus* sp., *Nitrosomonas* sp.) and cyanobacteria (e.g. *Spirulina maxima*). The activity of urease in the soil is related to the presence of these microorganisms and their activity, mainly in the presence of plant residues. The effect of inoculation of rice and barley with ureolytic bacterial isolates using urea as a fertilizer was analyzed. A significant increase in yields and higher nitrogen uptake by plants were observed (Hasan, 2000). Ureolytic microorganisms occur in soils contaminated with urea, urine and sewage sludge (Zhu, Dittrich, 2016). Fungi, which more effectively use urea as a source of energy in comparison to bacteria, dominate among them (Hasan, 2000).

The activity of urease is determined by the colourimetric method using, as a substrate, e.g. urea or ammonia.

Proteases

Proteases (EC 3.4.) belong to the digestive enzymes and catalyze the hydrolysis of proteins to less complex compounds – polypeptides and amino acids by breaking the peptide bonds.

Depending on the substrate (protein/peptide), proteases are divided into two groups: protease and peptidase. They are produced by bacteria, actinobacteria and fungi belonging to the group of proteolytic microorganisms. Proteolysis is an important process in the nitrogen cycle, considered as a stage limiting the rate of nitrogen mineralization in soils. Proteases activity is an indicator of the potential for mineralization of organic nitrogen compounds in the soil environment, and thus of the availability of nitrogen for plants. The majority of soil microorganisms show proteolytic activity. Bacterial and fungal proteases are important for the global carbon and nitrogen cycle. Proteins are decomposed by microorganisms in response to an increase in the carbon and nitrogen content in soil or a decrease in the concentration of sulphur (Gougoulias et al., 2014).

The activity of proteases in the soil is regulated by its pH and temperature. It is also correlated with carbon and nitrogen biomass content, humidity, CO_2 concentration, humus content, flavonoids and tannins (Vranova et al., 2013). It was found that different tillage and soil management practices also had an effect on proteases activity (Vranova et al., 2013). It was shown that in ploughed soils the activity of proteases is about 25–35% lower than in unploughed soils from the simplified system (Bielińska et al., 2008).

The determination of proteases activity in soil is based on the determination of the number of free amino acids formed as a result of protein hydrolysis. Colourimetric measurement of free tyrosine obtained using the Folin reagent is determined by the Ladd and Butler (Ladd, Butler, 1972) method of determination of proteases where the substrate is sodium caseinate.

L-asparaginase & L-glutaminase

L-asparaginase and L-glutaminase are amidohydrogenases acting on C-N bonds other than peptide bonds. They play a very important role in the mineralization of nitrogen in the soil (Kandeler et al., 2011).

L-asparaginase catalyses the hydrolysis of L-asparagine to L-aspartic acid and ammonia. It was shown that asparaginases synthesized by microorganisms differ from one another for solubility, and optimal pH. In *Escherichia coli* cells two asparaginase isoenzymes were discovered, including one produced by cells cultured under anaerobic conditions. The L-asparaginase activity can be determined by incubating the soil in L-asparagine and toluene buffer on the basis of the determination of NH_4-N release.

L-glutaminase catalyses the deamination of L-glutamine to L-glutamic acid and ammonia. It is an enzyme commonly found in nature in animals, plants and microorganisms. The main sources of L-glutaminase in the environment are bacteria, yeasts and fungi. Among the microorganisms with a high level of L-glutaminase, one can distinguish *Achromobacteraceae*, *Tilachlidum humicola* and *Verticillium malthousei*. Method for determining the activity of L-glutaminase in soil looks similar to L-asparaginase and relies on incubation of the soil sample in buffer solution (L-glutamine and toluene) (Kandeler et al., 2011).

ENZYMES OF THE PHOSPHORUS CYCLE

The content of phosphorus in the soil in the forms available to plants is important because it affects the early growth of plants and is essential for all living organisms to carry energy. Its excessive concentration in the soil is again toxic to plants and harmful to water. Phosphorus, besides nitrogen, is one of the main components supplied in the form of fertilisers to the soil. The presence and activity of enzymes from the phosphatase class catalyse the transformation of phosphorus compounds from insoluble organic to plant available inorganic molecules.

Phosphomonoesterases

Phosphomonoesterases (EC 3.1.3.) are enzymes catalysing the hydrolysis of esters and anhydrides of orthophosphoric acid. In soil, they are responsible for transforming organic forms of phosphorus into inorganic phosphates, which are forms directly available to plants (Eivazi, Tabatabai, 1977). This is an important process from the agricultural point of view, as it is estimated that about 40% of Polish soils are poorly supplied with phosphorus (Kozieł, Gałązka, 2017). According to the division proposed by Hoffmann (1968), phosphatases are divided into two groups according to a different optimum pH: alkaline (EC 3.1.3.1) and acidic (EC 3.1.3.2). In soil, the synthesis of phosphomonoesterases takes place via both microorganisms and plant roots. However, studies show that acid phosphatases of microbiological origin decompose organic forms of phosphorus more actively than do phosphatases of plant origin (Gałązka et al., 2017). From soil microorganisms, fungi are considered to be the main source of phosphatases, especially those of the genera *Aspergillus* and *Penicillium*. Among the phosphatases producing bacteria one can distinguish *Pseudomonas* sp., *Bacillus* sp., and *Micrococcus* sp.

The phosphatases activity in the soil can be used as an indicator of the mineralisation potential of organic phosphorus, and thus of the biological activity of the soil. It was shown that soil's biological activity is related to the diversity and abundance of soil microorganisms, soil moisture, pH, fertilization level and land use (Gałązka et al., 2017). The activity of soil phosphatases is monitored in Sweden and the United States of America. These enzymes have been shown to be sensitive to heavy metal and petroleum contaminants. High activity of acid phosphatases was recorded in a soil from organic farming (Tautages et al., 2016). Phosphatase activity increases with the lack of available phosphorus forms in the soil (Lemanowicz et al., 2018).

Methods for the determination of phosphatase activity in the soil are based on the incubation of a soil mixture and a substrate. The most commonly used substrate is synthetic p-nitrophenyl phosphate (PNP) according to the Tabatabai and Bremner procedure (Tabatabai, Bremner, 1969). Due to differences in the optimum pH of soil phosphatases, the required pH during incubation (6.5 for acid phosphatases and 11.0 for alkaline phosphatases) should be maintained when determining phosphatase activity. This method is modified with respect to the substrate used and the composition of the buffer. Acetyl or borate buffer may be used to maintain an adequate pH. Among the substrates, two-sodium phenylphosphate salt and phytin (natural substrate) can be distinguished.

Phosphodiesterase

Phosphodiesterase (EC 3.1.4.1) participates in the degradation of nucleic acids and phospholipids, thus supplying organic phosphorus to the soil. It is produced by plants, animals and microorganisms. Reactions catalyzed by phosphodiesterase cause the formation of substrates for phosphomonoesterases in the soil, which then catalyze reactions leading to the release of phosphates assailable by plants (Fig. 3).

The activity of phosphodiesterase in the soil is related to its pH. The activity of this enzyme even doubled as a result of liming of the soil and increasing its pH (Acosta-

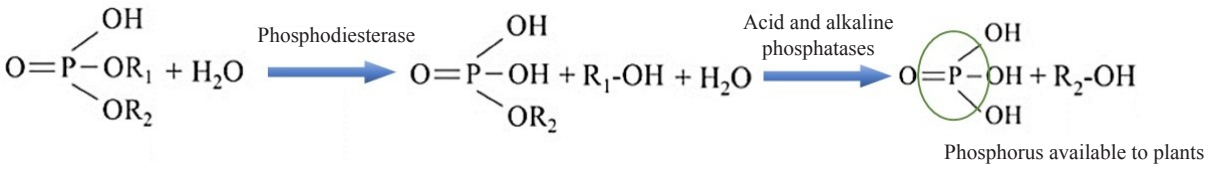

Figure 3. Scheme of transformations of phosphorus compounds with phosphodiesterase and phosphomonoesterases in the soil; R1 and R2 – alcohol groups/phenolic groups/nucleosides (authors' compilation based on Acosta-Martínez, Tabatabai, 2011).

-Martínez, Tabatabai, 2000). High phosphodiesterase activity is also observed in soils fertilised with manure (Parham et al., 2002).

The method of determination of phosphodiesterase activity looks similar to that of acid and alkaline phosphatase, i.e. it is based on the colourimetric determination of p-nitrophenol released. Bis-p-nitrophenyl phosphate (BPNP) is used as a substrate (Browman, Tabatabai, 1978).

ENZYMES OF THE SULPHUR CYCLE

The circulation of sulphur in the environment is caused by its transformations between different degrees of oxidation that occur under the influence of certain microorganisms. The main form of sulphur occurring in nature is sulphate (SO_4^{2-}) available to plants. Anaerobic microorganisms decompose organic sulphur-containing matter, leading to the formation of sulphides. Subsequently, sulphides can be oxidized by the so-called green and purple (anaerobic) bacteria, or thiobacteria and archetypes (aerobic) to native sulphur.

Arylsulphatase

In the natural environment, there are several enzymes from the sulphatase group (EC 3.1.6.), such as arylsulphatase, alkyl sulphatase, steroid sulphatases, glucosulphatases, which catalyses the hydrolysis of ester sulphates. However, the largest number of studies focus on arylsulphatase (EC 3.1.6.1.), which was the first sulphatase detected in nature. It is an enzyme produced by bacteria and fungi that catalyzes the hydrolysis of sulphate esters in soil by breaking the O-S bond.

The activity of arylsulphatase in agricultural soils was shown to be dependent on the method of soil fertilisation (Siwik-Ziomek, Koper, 2008). The use of mineral fertilizers has an inhibiting effect on its activity (Siwik-Ziomek, Koper, 2008). Additionally, it was found that different plant species may influence microorganisms and changes of sulphur in soil (Cregut et al., 2009). Arylsulphatase activity is also influenced by organic matter content, soil moisture, clay fraction, temperature and average annual rainfall (Zwikel et al., 2007). The introduction of organic carbon into the soil by leaving plant residues after harvesting increases the activity of arylsulphatase. Cregut et al. (2009) researches showed that the composition of the arylsulphatase producing bacteria in the soil varies according to the type of plant growing in that environment. The researchers found a higher activity of this enzyme in the rape rhizosphere in comparison to that of barley's.

It has been demonstrated that arylsulphatase can be used for soil biological activity analysis and quality assessment due to its sensitivity to environmental conditions (Zwikel et al., 2007).

The arylsulphatase activity is determined by the classical colourimetric method using potassium p-nitrophenyl sulphate (PNS) as substrate (Tabatabai, Bremner, 1970).

Rhodanase

Rhodanase – thiosulphate sulphurtransferase (EC2.8.1.1) is an enzyme catalyzing the formation of thiocyanate and sulphites from thiosulphate and cyanide. Thiocyanate is an intermediate product formed during the oxidation of elementary sulphur. Rhodanase occurs in the plant, animal and human tissues. Some bacteria (*Escherichia coli, Thiobacillus* sp., *Chromatium* sp.) and fungi (*Fusarium* sp., *Trichoderma* sp.) also produce rhodanase. Rhodanase activity was detected in soils.

The correlation between the activity of rhodanase and the concentration of sulphuric amino acids in soil was also determined (Klose et al., 2011). Rhodanase activity also correlates with soil carbon biomass, phosphorus ion content, soil texture and soil water content (Tabatabai, Singh, 1976). The application of sulphur fertilizer as K_2SO_4 or Na_2SO_4 resulted in a decrease in the activity of rhodanase resulting from the presence of SO_4^{2-} ions, which are the final product of sulphur oxidation. High activity of rhodanase was observed in rhizospheric soil and in soil under continuous cultivation (compared to crop rotations) (Klose et al., 2011).

The method of determining the activity of rhodanase consists of quantitative determination of cyanide produced during soil incubation with solutions of $S_2O_3^{2-}$ and CN^- (Tabatabai, Singh, 1976).

CARBOHYDRATE-DECOMPOSING ENZYMES

Soil organic matter usually contains 5–25% carbohydrates. Plant residues introduce into the soil carbohydrates in the form of simple sugars, hemicellulose, cellulose, etc. They are degraded by bacteria, actinobacteria and fungi that use them to synthesize polysaccharides and other carbohydrates (Stevenson, 1994).

β-glucosidase

β-glucosidase (EC 3.2.1.21) is a hydrolytic enzyme involved in the decomposition of plant residues – the degradation of cellulose and other carbohydrates present in the cell wall. It catalyzes the reaction of cellulose decomposition and separates glucose molecules from the ends of oligosaccharides. The activity of this enzyme is important for maintaining a labile carbon as an energy source in the soil. Microorganisms are the main source of glucosidase in the soil, therefore glucosidase activity is closely correlated with their abundance. Microorganisms produce small amounts of this enzyme and its synthesis is inhibited by the final product of β-glucosidase activity, *i.e.* glucose. Plant cells also produce β-glucosidase, which takes part in defence processes, cell wall metabolism and phytohormone activation (Ahmed et al., 2017).

Fungi of the genera *Trichoderma, Acremonium, Aspergillus, Chaetomium* and *Penicillium* produce β-glucosidase

in significant quantities. In addition, *Aspergillus niger* is used in the industrial production of this enzyme. Bacteria produce smaller amounts of β-glucosidase. Among the bacteria excreting glucosidase, there are those of the genera: *Clostridium*, *Bacillus*, *Thermobifida*, *Pyrococcus*.

The activity of β-glucosidase is related to the content and metabolism of soil organic matter. There is a seasonality of glucosidase activity resulting from the gradual decomposition of plant residues in the soil (Piotrowska, Koper, 2011). An increase in the activity of this enzyme was also observed during the fertilisation of the soil with manure (Böhme, Böhme, 2006).

The activity of β-glucosidase is determined on the basis of the colourimetric determination of *p*-nitrophenol, which is formed during soil incubation with p-nitrophenyl-β-d-glucosidase (Eivazi, Tabatabai, 1988).

Amylases

Amylases (EC 3.2.1.) are a group of enzymes classified as hydrolases that catalyses hydrolytic depolymerization of polysaccharides including starch to readily available glucose. In nature, there are three natural types of amylases: α, β and γ. The largest amounts of amylases are produced by microorganisms, Thallophyta and animals. The following fungi are known for their synthesis of amylases: *Aspergillus niger, Aspergillus oryzae, Penicillium expansum* and bacteria: *Bacillus* sp., *Lactobacillus plantarum, Pseudomonas* sp. (El-Fallal et al., 2012).

The amylase activity is influenced by temperature, pH and soil moisture, it also correlates with the number of fungi and bacteria in the soil. An increase in amylase activity was observed during the use of insecticides and pesticides (Gopinath et al., 2017).

CONCLUSIONS

1. Soil is a reservoir of many different microorganisms, which are specialized to perform a variety of functions, including enzyme synthesis. Some of them are still not known, although it is known that the activity of soil enzymes can affect soil fertility.

2. The evaluation of soil enzymatic activity allows to track changes in soil ecosystem and to observe soil condition. Enzymatic activity is a useful indicator of microbial status and environmental quality, which can help in soil management. However, the activity of a single enzyme cannot be a stand-alone, universal indicator of soil quality. Only the combination of analyses of physicochemical and microbiological parameters of soil, plants and climate allows for a complete depiction of the soil environment, its fertility and, consequently, productivity.

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