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Study on the effect of organic fertilizers on soil organic matter and enzyme activities of soil in forest nursery

Abstract: The aim of the study was to assess the effects of organic fertilization on selected chemical properties of the soil and the activity of dehydrogenase and β -glucosidase in the soil of forest nursery. The main goal was to evaluate the role of organic fertilizers in carbon storage in the forest nursery soil. Sample plots were located in northern Poland in the Polanów Forest District on a forest nursery. Soil samples were collected from horizon 0–20 cm for laboratory analyzes. In soil samples pH, soil texture, and organic carbon, nitrogen, base cation contents, dehydrogenase activity and β -glucosidase activity were determined. The obtained results were used to evaluate the carbon storage. The results confirm the beneficial effect of the applied organic fertilizer on chemical properties of the soils under study and their biological activity. The applied organic fertilizers had an impact on increased accumulation of soil organic matter. In the soils investigated, there was an increase in the activity of such enzymes as dehydrogenases and β -glucosidase.

Keywords: enzyme activities, fertilization, soil organic matter

INTRODUCTION

The primary objective of forest nurseries is the production of high quality planting material. One of the requirements to achieve this goal is to take care of the maintenance of appropriate soil quality and microbial balance of the soil. The condition of the soil is dependent on the degree of nutrition, soil condition, and the quality of planting material. Soil fertility and productivity depend on soil organic matter (SOM) which is the reservoir of nutrients and plays an important role in cycling the nutrients (Steiner et al. 2007). Soil organic matter improves the physical, chemical, and biological properties of soils (Bhattacharyya et al. 2010). Chemical and organic fertilization can affect the carbon rates in soils (Gong et al. 2009, Lou et al. 2011). Fertilization is often recommended to increase SOM in soil (Laggett and Kelting 2006, Mann et al. 2007, Wang et al. 2013). Many studies have shown that application of organic fertilizers was positively related to soil carbon accumulations (Wu et al. 2004, Rudrappa et al. 2006). Fertilization could prove to increase the saturation of the organic matter by metal ions and improved soil structure. In forest nurseries soil similar to the agricultural soil, we can observe a decrease of organic matter content. The application of organic fertilizers is one of the management practices that can help to maintain or increase the content of organic matter and improve soil fertility

(Dębska et al. 2016). The physical and chemical properties of soil change slowly over time with the environmental changes, whereas biochemical properties such as enzyme activity react quickly to changes in the environment, as they are directly related to the number and activity of soil microorganisms (Trasar-Cepeda et al. 2000, Zhang et al. 2015). Enzyme activity is sensitive to soil changes due to tillage, use of cropping systems, and land use (Acosta-Martínez et al. 2007). Many researchers have studied the effects of fertili-

FIGURE 1. Location of research plots (northern Poland, Polanów Forest District)

zation on overall soil fertility by investigating the level of soil enzyme activity (Nannipieri et al. 2012, Błńska et al. 2016b). The processes for transformation of organic matter in the soil occur in the presence of soil microorganisms and their enzymes. Generally, enzyme activities are correlated with soil organic carbon content, because they play the key role as a precursor for enzyme synthesis. Enzyme activities are generally the most sensitive indicators of changes in the belowground microbial community, because soil enzymes are directly responsible for the initial processing of detrital carbon and organically bound nutrients (Hinojosa et al. 2004). The soil enzyme activities are controlled by the soil carbon availability (Veres et al. 2015). The dehydrogenase enzyme production is a good indicator of microbial activity, and changes in the studied soils occur as a result of management. Dehydrogenases are enzymes that provide information about the state of the environment and the activity of microorganisms in the soil. β -glucosidase is an enzyme that participates in the decomposition of cellulose to glucose. The enzyme catalyzes the hydrolysis of glucosides. Cellulose is quantitatively the most important organic compound in the biosphere; hence, a product of its enzymatic hydrolysis is not only important as an energy source for soil microorganisms, but also of great importance in the carbon cycle (Sinsabaugh et al. 1991).

The aim of the study was to assess the effects of organic fertilization on selected chemical properties of the soil and the activity of dehydrogenase and β -glucosidase in the soil of forest nursery. The main goal was to evaluate the role of organic fertilizers in carbon storage in the forest nursery soil.

MATERIALS AND METHODS

Study sites

Sample plots were located in northern Poland in the Polanów Forest District on a forest nursery. The study area is characterized by the following conditions of climate: the average length of the growing season is 230 days, the average temperature in that period is 13°C and the average precipitation amounts to 300 mm. The test area was dominated by *Brunic Arenosols* (IUSS Working Group WRB, 2015). The study area was divided into three blocks (I, II and C). On I and II blocks organic fertilizers was applied. Block C served as control (C). The blocks were divided into smaller acres, from which surface soil samples were collected (0–20 cm) for specific laboratory analyzes. The samples were collected according to the scheme presented in Figure 2. Block I was divided into 5 fragments on which 6 smaller areas were formed (A–F), from where the pooled sample composed of 9 sub-samples was collected. Block II was divided into 3 fragments, on which 6 smaller areas were formed (A–F) from where the pooled sample composed of 9 sub-samples was collected. The samples for laboratory analysis were collected in September in 2015.

In total, 30 samples of soil were collected from the block I and 18 samples were collected from the block II. Block C was divided into 4 fragments from which a pooled sample consisting of 10 sub-samples was collected (Figure 2). The organic fertilizer applied was prepared from the post-harvest residues. The properties of organic fertilizer used were shown in Table 1. The 4 m³ of organic fertilizer per 1 are was applied. The samples for the analyzes were collected 1 year after fertilization.

FIGURE 2. Scheme of soil samples point; I, II, C – number of blocks on study area; 1–5 – number of lanes in one block; A–F – soil sampling plots

TABLE 1. Properties of used organic fertilizer

pH _{H₂O}	pH _{KCl}	C	N	C/N	Ca ²⁺	K ⁺	Mg ²⁺	Na ⁺
		g kg ⁻¹			mg 100g			
4.57	3.55	15.06	0.66	22.7	116.51	106.93	14.58	2.16

Basic laboratory analysis

The particle-size distribution was determined using the laser diffraction (Analysette 22, Fritsch, Idar-Oberstein, Germany), pH was analyzed in distilled water and 1 M KCl using the potentiometric method, as well as the content of total nitrogen (N) and organic carbon (C_l) content were measured using LECO CNS True Mac Analyzer (Leco, St. Joseph, MI, USA). Exchangeable aluminum (H_{Al}) was determined via the Sokołow method, hydrolytic acidity (Y) was determined using the Kappen method (Ostrowska et al. 1991). The concentration of cations was determined by an ICP (ICP-OES Thermo iCAP 6500 DUO, Thermo Fisher Scientific, Cambridge, U.K.). In each sample chemical properties were determined, in two repetitions. Sum of the base cations (BC) was calculated.

The obtained results were used to evaluate the carbon storage in soil after organic fertilizer.

$$CS = Ct \cdot BD \cdot T \cdot S / 100$$

where:

- CS – carbon storage in soil (kg m⁻²)
- Ct – carbon content in soil (g kg⁻¹)
- BD – bulk density of soil (g cm⁻³)
- T – thicknesses of soil horizon
- S – surface (1 m²).

Activities of enzymes

The dehydrogenase activity (DH) was determined by the reduction of 2,3,5 triphenyltetrazolium chloride (TTC) to triphenyl formazan (TPF) using Lenhard's method according to the Casida procedure (Alef and Nannipieri 1995). Briefly, 6 g of soil was incubated with 1 ml of 3% TTC for 24 h at 37°C. The TPF was extracted with ethyl alcohol (95%) that was contaminated with methanol. The TPF was measured spectrophotometrically (485 nm). The DH activity was given in μmol TPF kg⁻¹ h⁻¹. The activity of β-glucosidase (BG) was determined with the method of Eivazi and Tabatabai (1988) using as a substrate of p-Nitrophenyl-β-D-glucopyranoside (PNG). The enzyme activity was given in mmol pNP kg⁻¹ h⁻¹. In the soil samples the enzymes activity were determined in three repetitions.

Statistical analysis

The Principal Component Analysis (PCA) method was used to evaluate the relationships between soil properties. In the PCA analysis, the variables used included chemical properties and enzyme activity of soil. The differences between the mean values of soil properties were evaluated with the nonparametric Kruskal-Wallis test. Pearson's correlation coefficients between enzyme activities and soil characteristics were also calculated. The statistical significance of the results was verified at the significance level of $\alpha = 0.05$. All of the statistical analyzes were performed with Statistica 12 software.

RESULTS

Physico-chemical properties of the studied soils

The pH in H₂O of the soils studied ranged 4.10–6.09. The highest average pH value in H₂O was reported in the surface soil of the control (5.39), whereas the lowest (5.10) in the surface soils of block I (Table 1). The discussed soils showed a diverse degree of organic matter decomposition, which is expressed by C/N ratio. The mean values of C/N ratio were similar in the surface soil of block I (15.98) and II (16.34), slightly higher value was reported in the surface soil of the control block (21.28).

The highest average organic carbon (24.2 g kg⁻¹) and nitrogen (1.5 g kg⁻¹) content was observed in the surface soils of block I, although slightly lower, similar values were reported in the surface soils of block II (23.0 g kg⁻¹ and 1.4 g kg⁻¹). Soils of the control block were characterized by the lowest content of carbon (15.1 g kg⁻¹) and nitrogen (0.7 g kg⁻¹) (Table 2). Using nonparametric Kruskal-Wallis test, statistically significant differences in the content of nitrogen, carbon, silt, sand fraction, potassium, sodium, C/N ratio, and the total acidity between the soils tested were observed (Table 2).

The highest average value of carbon accumulation was observed in the soils of surface II (7.56 kg m²). In the soils of surface I, the average value was slightly lower and accounted for 7.07 kg m², while the lowest average carbon accumulation was observed in the soils of control area (C), which was 5.32 kg m²

TABLE 2. Soil characteristics (mean value and range)

Properties	I			II			C		
	mean	max	min	mean	max	min	mean	max	min
pH _{H2O}	5.10 ^a	5.58	4.10	5.29 ^a	6.09	4.92	5.39 ^a	5.88	5.11
pH _{KCl}	4.12 ^a	4.39	3.90	4.23 ^a	5.09	3.93	4.36 ^a	4.77	4.10
Ct	24.2 ^a	34.7	17.9	23.0 ^a	42.2	12.3	15.1 ^b	19.2	13.5
N	1.5 ^a	2.0	1.0	1.4 ^a	2.3	0.8	0.7 ^b	0.9	0.6
C/N	15.9 ^b	19.1	14.5	16.3 ^b	18.9	13.7	21.3 ^a	22.6	20.6
Hw	2.30 ^a	3.33	1.17	2.08 ^a	2.92	0.79	1.62 ^a	2.12	0.87
Y	6.05 ^a	8.25	5.00	5.91 ^{ab}	8.28	3.50	4.50 ^b	5.70	3.62
Al	84.03 ^a	150.4	21.43	71.75 ^a	119.25	5.54	46.00 ^a	67.15	10.92
Sand	58.10 ^b	71.00	43.00	60.28 ^b	68.00	45.00	77.75 ^a	84.00	74.00
Silt	36.47 ^a	51.00	24.00	34.50 ^a	49.00	27.00	18.00 ^b	21.00	14.00
clay	5.57 ^a	7.00	4.00	5.39 ^a	7.00	4.00	4.00 ^a	5.00	2.00
Ca ²⁺	36.95 ^a	80.87	17.03	44.53 ^a	112.85	19.86	31.66 ^a	45.94	23.48
K ⁺	16.16 ^a	24.81	9.61	14.71 ^a	32.58	3.92	4.43 ^b	5.16	3.94
Mg ²⁺	2.21 ^a	3.45	1.17	2.68 ^a	4.97	1.35	1.81 ^a	2.18	1.53
Na ⁺	0.38 ^{ab}	0.64	0.25	0.46 ^a	0.95	0.18	0.26 ^b	0.33	0.21
BC	2.45 ^a	4.96	1.25	2.84 ^a	6.19	1.21	1.85 ^a	2.56	1.41
DH	8.33 ^a	12.38	4.46	7.20 ^a	11.77	2.21	3.02 ^b	3.66	2.47
BG	1.66 ^a	2.45	1.10	1.67 ^a	4.18	0.92	0.78 ^b	0.98	0.61
CS	7.07 ^{ab}	9.68	5.41	7.56 ^a	13.17	4.47	5.32 ^b	7.67	4.39

Ct – carbon content (g kg⁻¹); N – nitrogen content (g kg⁻¹); Hw – exchangeable acidity (cmol(+) kg⁻¹); Y – hydrolytic acidity (cmol(+) kg⁻¹); Ca, K, Mg and Na content (mg 100 g); DH dehydrogenases activity (μmol TPF kg⁻¹ h⁻¹); BG β-glucosidase activity (mmol pNP kg⁻¹ h⁻¹).

(Table 2). Location of carbon was the most homogeneous on the block I. On the block II, we could clearly observe very large accumulation at one place of the first fragment, while the accumulation in the third fragment was very small. On the whole, control block accumulation is very low and a greater content of carbon was concentrated in the third fragment (Figure 2).

Enzyme activities of the studied soils

Activity of dehydrogenases and β-glucosidase was different within the soils under study. Using the nonparametric Kruskal-Wallis test, statistically significant differences in the activity of dehydrogenases and β-glucosidase were observed (Table 2). The highest average dehydrogenase activity was observed in the soil of block I (8.33 μmol TPF kg⁻¹ h⁻¹), lower in the soil of block II (7.20 μmol TPF kg⁻¹ h⁻¹) and the lowest in the soil of control (3.02 μmol TPF kg⁻¹ h⁻¹). The results on the activity of β-glucosidase in soils of block I and II were almost identical and were equal to 1.66 and 1.67 mmol pNP kg⁻¹ h⁻¹, respectively; lower activity of this enzyme was observed in soil samples from the control (0.78 mmol pNP kg⁻¹ h⁻¹) (Table 2). Dehydrogenase activity was inversely correlated to the sand content (r = -0.61) and C/N ratio (r = -0.39), while positive correlation was

reported with carbon (r = 0.51), nitrogen (r = 0.62), silt (r = 0.61), and clay (r = 0.34) content and with the sum of base cations (r = 0.44) (Table 3). β-glucosidase activity was inversely correlated to the sand content (r = -0.38) and C/N ratio (r = -0.36), whereas positive correlation was observed with carbon (r = 0.30), nitrogen (r = 0.40), silt (r = 0.37), and clay (r = 0.31) content (Table 3).

TABLE 3. The correlation coefficient between soil characteristics and enzyme activities

Soil properties	DH	BG
pH _{H2O}	-0.10	0.00
pH _{KCl}	0.01	0.00
Ct	0.51	0.30
N	0.62	0.40
C/N	-0.39	-0.36
Hw	0.03	0.01
Y	0.30	0.20
Al	0.03	-0.01
sand	-0.61	-0.38
silt	0.61	0.37
clay	0.34	0.31
Ca ²⁺	0.40	0.24
K ⁺	0.42	0.22
Mg ²⁺	0.30	0.25
Na ⁺	0.34	0.11
BC	0.44	0.26

DH dehydrogenases activity; BG β-glucosidase activity; bold p<0.05

FIGURE 3. Spatial variability of carbon storage (kg m^{-2}) in investigated soil; I, II, C – number of blocks on study area; 1–5 – number of lanes in one block; A–F – soil sampling plots

A projection of the variables on the factor plane clearly demonstrated correlations between the soil properties and enzyme activity. Two main factors had a significant total impact (57.9%) on the variance of the variables. Factor 1 explained 34.32% of the variance of the examined properties, and factor 2 explained 23.6% of the variance (Figure 3). Factor 1 can be defined as “biological activity of soil”. The DH and BG activities were strongly correlated with carbon content. On the control plots, lower enzyme activity and carbon content were determined. Those plots were characterized with higher C/N ratio.

FIGURE 4. The projection of variables on a plane of the first and second factor in soil; I, II, C – number of blocks on study area

DISCUSSION

The results obtained confirm the beneficial effect of the applied organic fertilizer on chemical properties of the soils under study and their biological activity. The applied organic fertilizers had an impact on increased accumulation of soil organic matter. In the case of surface soils of block I, accumulation increased by 33% in relation to the control surface soil while in the surface soils of block II, an increase of above 40% was reported. Similar observations were reported by other authors. In the studies by Dębska et al. (2016), as a result of the use of organic fertilizer, increased carbon content in the control block was observed. The studies conducted by Adamus et al. (1989) showed that organic fertilization ensures reproduction of organic matter and increase in carbon content. In their studies, an increase in nitrogen content and improvement in C/N ratio on the fertilized surfaces was also noted. Górski and Kuszelewski (1963) recorded that under the influence of organic fertilization, increase and stabilization of carbon content in the soil was observed with simultaneous accumulation of nitrogen resulting in a decrease in C/N ratio. In nursery soils, it is important to maintain an adequate level of organic matter because it constitutes a source of nutrients for the planting material produced. The quality of young seedlings is a direct result of the properties of surface soil levels and changes that occur in the soil.

Undoubtedly, in parallel with the introduction of organic fertilizer produced as a result of post-harvest residues, microorganisms specific for the forest environment are introduced into the soil. In the soils

investigated, there was an increase in the activity of such enzymes as dehydrogenases and β -glucosidase. Activity of dehydrogenases in the soil occur as an integral part of intact cells, and determination of the activity of these enzymes in the soil is an indicator of the metabolism of soil microorganisms. Natural fertilization has a big impact on soil microorganisms (Natywa et al. 2014). According to Acosta-Martinez and Tabatabai (2000), organic fertilization has a more beneficial impact on the overall biological activity in comparison to the mineral fertilization, which, by improving the physico-chemical properties of the soil, can adversely affect its enzymatic activity. Increase of dehydrogenase activity under the influence of organic fertilizers was observed in the studies by Kopper and Siwik-Ziomek (2003) and Marinari et al. (2000). In studies by Kucharski and Niklewska-Larska (1992), addition of cellulose to the soil resulted in 7.5-fold increase in dehydrogenase activity in the lighter soil, whereas 4.2-fold increase was reported for a more concise soil. Moreover, Kobus et al. (1987) observed a positive effect of the addition of organic fertilizer (including compost from the bark) on the activity of dehydrogenases. Microbial activity of the soil is usually dependent on the presence of carbon and nitrogen in the soil (Błońska et al. 2016a). During the studies conducted, a correlation was observed between the activity of dehydrogenase, β -glucosidase, and the content of carbon and nitrogen, which confirms the participation of these enzymes in the element cycle and their role in the decomposition of organic matter. In studies by Ciarkowska and Gambuś (2004), it was found that dehydrogenase activity is strongly related to the content of organic carbon and nitrogen in the soil. In the studies conducted by Jezierska-Tys (2004) and Jezierska-Tys et al. (2004), addition of the organic matter to the soil resulted in increased dehydrogenase activity. Rybacki et al. (2014) also noted an increase in the activity of β -glucosidase in soil fertilized with organic fertilizer. In the experiment conducted, the applied dose of organic fertilizer has resulted in approximately two-fold increase in β -glucosidase activity in relation to the control soil. Acidic organic matter predominantly stimulates the activity of fungal organisms, which exhibit especially strong relationship with the activity of this enzyme. According to Esen (1993), β -glucosidase is produced by different organisms (plants, animals, fungi, and bacteria); however, it originates mostly from fungi such as *Actinomucor* and *Mortierella*.

The presence of humus determines the preferred arrangement of the entire complex of soil properties, which affects soil fertility. Organic fertilization using post-harvest residues could be a way to improve the

content of organic matter in the soils of nurseries. The use of this type of organic fertilizers can constitute a practice that will contribute to the maintenance or increase in the organic matter content, improvement of the biological activity of soils, and simultaneous improvement in soil fertility.

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REFERENCES

- Acosta-Martinez V., Tabatabai M.A., 2000. Enzyme activities in a limed agricultural soil. *Biology and Fertility of Soils* 31: 85–91.
- Acosta-Martínez V., Cruz L., Sotomayor-Ramírez D., Pérez-Alegria L., 2007. Enzyme activities as affected by soil properties and land use in tropical watershed. *Applied Soil Ecology* 35(1): 35–45.
- Adamus M., Drozd J., Stanisławska E., 1989: Wpływ zróżnicowanego nawożenia organicznego i mineralnego na niektóre elementy żyzności gleby. *Roczniki Gleboznawcze – Soil Science Annual* 40(1): 101–110.
- Alef K., Nannipieri P., 1995. Enzyme activities. [In:] Alef K. and Nannipieri P. (eds.) *Methods in applied Soil Microbiology and Biochemistry*. Academic Press, London, New York, San Francisco.
- Bhattacharyya R., Prakash V., Kundu S., Srivastva A.K., Gupta S.M., 2010. Long term effects of fertilization on carbon and nitrogen sequestration and aggregate associated carbon and nitrogen in the Indian sub-Himalayas. *Nutrient Cycling Agroecosystems* 86: 1–16.
- Błońska E., Lasota J., Gruba P., 2016a. Effect of temperate forest tree species on soil dehydrogenase and urease activities in relation to other properties of soil derived from loess and glaciofluvial sand. *Ecological Research* 31(5): 655–664.
- Błońska E., Januszek K., Małek S., Wanic T., 2016b. Effects of serpentinite fertilizer on the chemical properties and enzyme activity of young spruce soils. *International Agrophysics* 30(4): 401–414.
- Ciarkowska K., Gambuś F., 2004. Aktywność dehydrogenaz w glebach zanieczyszczonych metalami ciężkimi w rejonie Olkusza. *Zeszyty Problemowe Postępów Nauk Rolniczych* 501: 79–85.
- Dębska B., Długosz J., Piotrowska-Długosz A., Banach-Szott M., 2016. The impact of a bio-fertilizer on the soil organic matter status and carbon sequestration-results from a field-scale study. *Journal of Soils and Sediments* 16: 2335–2343.
- Eivazi F., Tabatabai M.A., 1988. Glucosidases and galactosidases in soils. *Soil Biology and Biochemistry* 20: 601–606.
- Esen A., 1993. β -Glucosidases: overview, [W:] Esen A. (ed.), *beta-Glucosidases: biochemistry and molecular biology*. American Chemical Society, Washington, DC: 1–14.
- Gong W., Yan X., Wang J., Hu T., Gong Y., 2009. Long-term manure and fertilizer effect on soil organic matter fractions and microbes under a wheat-maize cropping system in northern China. *Geoderma* 149: 318–324.
- Górski M., Kuszelewski L., 1963. Wpływ nawożenia organicznego i mineralnego na zawartość substancji organicznej i skład próchnicy glebowej w świetle 38-letnich doświadczeń w Skier-

- niewiczach. Roczniki Gleboznawcze – Soil Science Annual 13: 323–341.
- Hinojosa M.B., Carreira J.A., Garcia-Ruiz R., Dick R.P., 2004. Soil moisture pre-treatment effects on enzyme activities as indicators of heavy metal contaminated and reclaimed soils. *Soil Biology and Biochemistry* 36: 1559–1568.
- IUSS Working Group WRB, 2015. World Reference Base for Soil Resources 2014, update 2015. International soil classification system for naming soils and creating legends for soil maps. World Soil Resources Reports No. 106. FAO, Rome.
- Jezierska-Tys S., 2004. Aktywność respiracyjna i dehydrogenazowa oraz liczebność mikroorganizmów proteolitycznych w glebie zanieczyszczonej siarką i wzbogaconej osadem ścieków komunalnych. *Acta Agrophysica* 3(3): 1–8.
- Jezierska-Tys S., Frąc M., Fidecki M., 2004. Wpływ nawożenia osadem ściekowym na aktywność enzymatyczną gleby brunatnej. *Annales UMCS, sec. E. Agricultura* 59(3): 1175–1181.
- Kobus J., Kurek E., Czechowska E., Słomka D., Kulpa D., 1987. Wpływ nawożenia organicznego na aktywność biologiczną zdegradowanej gleby lessowej. *Roczniki Gleboznawcze – Soil Science Annual* 38: 133–143.
- Koper J., Siwik-Ziomek A., 2003. Następce oddziaływanie monokultury i zmianowania tradycyjnego na aktywność amylaz i dehydrogenaz glebowych na tle właściwości fizykochemicznych gleby. *Zeszyty Problemowe Postępów Nauk Rolniczych* 493: 637–643.
- Kucharski J., Niklewska-Larska T., 1992. Wpływ substancji organicznej i niektórych grup drobnoustrojów na liczebność i aktywność mikroorganizmów glebowych: III. Aktywność enzymów. *Acta Academiae Agriculturae ac Technicae Olstenensis* 426, *Agricultura* 54: 33–42.
- Laggett Z.H., Kelting D.L., 2006. Fertilization effects on carbon pools in loblolly pine plantations on two upland sites. *Soil Science Society of America Journal* 70: 279–286.
- Lou Y.L., Xu M.G., Wang W., Sun X.L., Zhao K., 2011. Return rate of straw residue affects soil organic C sequestration by chemical fertilization. *Soil Tillage Research* 113: 70–73.
- Mann M.C., Swarup A., Wanjar R.H., Mishra B., Shahi D.K., 2007. Long-term fertilization, manure and liming effects on soil organic matter and crop yields. *Soil Tillage Research* 94: 397–409.
- Marinari S., Masciandaro G., Ceccanti B., Grego S., 2000. Influence of organic and mineral fertilisers on soil biological and physical properties. *Bioresource Technology* 72: 9–17.
- Nannipieri P., Giagnoni L., Renella G., Puglisi E., Ceccanti B., Masciandaro G., Fornasier F., Moscatelli M.C., Marinari S., 2012. Soil enzymology: classical and molecular approaches. *Biology and Fertility of Soils* 48: 743–762.
- Natywa M., Selwet M., Maciejewski T., 2014. Wpływ wybranych czynników agrotechnicznych na liczebność i aktywność drobnoustrojów glebowych. *Fragmenta Agronomica* 31: 56–63.
- Ostrowska A., Gawliński S., Szczubiałka Z., 1991. Metody analizy i oceny właściwości gleb i roślin. Instytut Ochrony Środowiska, Warszawa. ISBN 83-85805-69-9.
- Rudrappa L., Purakayastha T.J., Singh D., Bhadraray S., 2006. Long-term manuring and fertilization effects on soil organic carbon pools in a Typic Haplustep of semi-arid sub-tropical India. *Soil and Tillage Research* 88: 180–192.
- Rybacki M., Polkowska M., Piotrowska-Długosz A., 2014. Przydatność testów enzymatycznych do oceny wpływu nawożenia naturalno-mineralnego na aktywność biologiczną gleby. *Ekologia i Technika* 22: 248–255.
- Sinsabaugh R.L., Antabus R.K., Linkins A., 1991. An enzymic approach to the analysis of microbial activity during plant litter decomposition. *Agriculture Ecosystems and Environment* 34(1): 43–54.
- Steiner C., Teixeira W.G., Lehman J., Nehls T., de Macêdo J.L.U., Blum W.E.M., Zech W., 2007. Long term effects of manure, charcoal and mineral fertilization on crop production and fertility on a highly weathered Central Amazonian upland soil. *Plant Soil* 291: 275–290.
- Trasar-Cepeda C., Leiro's M.C., Seoane S., Gil-Sotres F., 2000. Limitations of soil enzymes as indicators of soil pollution. *Soil Biology and Biochemistry* 32: 1867–1875.
- Veres Z., Kotrocó Z., Fekete I., Tóth J.A., Lajtha K., Townsend K., Tóthmérész B., 2015. Soil extracellular enzyme activities are sensitive indicators of detrital inputs and carbon availability. *Applied Soil Ecology* 92: 18–23.
- Wang J., Lu C., Xu M., Zhu P., Huang S., Zhang W., Peng C., Chen X., Wu L., 2013. Soil organic carbon sequestration under different fertilizer regimes in north and northeast China: Roth C simulation. *Soil Use and Management* 29(2): 182–190.
- Wu T.Y., Schoenau J.J., Li F.M., Qian P.Y., Malhi S.S., Shi Y.C., Xue F.L., 2004. Influence of cultivation and fertilization on total organic carbon and carbon fractions in soils from the Loess Plateau of China. *Soil Tillage Research* 77: 59–68.
- Zhang L., Chen W., Burger M., Yang L., Gong P., Wu Z., 2015. Changes in soil carbon and enzyme activity as a result of different long-term fertilization regimes in a greenhouse field. *PLoS ONE* 10(2): e0118371.

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Badania nad wpływem nawożenia organicznego na glebową materię organiczną oraz aktywność enzymatyczną gleb szkółki leśnej

Streszczenie: Celem badań była ocena wpływu nawożenia organicznego na wybrane chemiczne właściwości gleb oraz na aktywność dehydrogenaz i β -glukozydazy w glebach szkółki leśnej. Podstawowym celem było ukazanie wpływu nawożenia organicznego na zapas węgla w glebach szkółki leśnej. Powierzchnie badawcze zostały zlokalizowane w północnej Polsce w szkółce leśnej w Nadleśnictwie Polanów. Próbkę gleb do analiz laboratoryjnych zebrano z głębokości 0–20 cm. W próbkach gleby oznaczono: pH, uziarnienie, zawartość węgla i azotu, zawartość kationów zasadowych, aktywność dehydrogenaz i β -glukozydazy. Uzyskane wyniki wykorzystano do wyliczenia zapasu węgla. Wyniki potwierdzają korzystny wpływ zastosowanego nawożenia organicznego na chemiczne właściwości gleb oraz ich biologiczną aktywność. Zastosowane organiczne nawożenie miało wpływ na wzrost akumulacji glebowej materii organicznej. W badanych glebach zanotowano wyraźny wzrost aktywności dehydrogenaz i β -glukozydazy.

Słowa kluczowe: aktywność enzymatyczna, nawożenie, glebowa materia organiczna