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Impact of poultry manure fertilization on chemical and biochemical properties of soils

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ABSTRACT

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The aim of the research was to evaluate the chemical properties and enzymatic activity of arable soils which, for the period of 10 years, were fertilized with poultry manure (PM). Fertilization with PM resulted in a significant increase in the content of organic carbon and total exchangeable bases in soil. The application of that fertilizer increased the pH value. Fertilization with PM also slightly increased the total content of copper, manganese and iron. There was found, however, a significant increase in the total content of Zn. The annual application of 10 tonnes of PM significantly increased the content of phosphorus and potassium available to plants. That fertilizer inhibited the activity of both alkaline and acid phosphatase, which must be related to a very high content of phosphorus available to plants. Poultry manure resulted in higher values of the biological index of fertility of soil, whereas the activity of phosphomonoesterases was significantly lower.

Keywords: heavy metals; enzymes; soil properties; organic fertilizer; nutrient; contamination

Poultry manure as one of the organic fertilizers contains all the essential nutrients required for crop production (Hanč et al. 2008). Factors affecting its composition include: type of birds, feed nutrient density, bedding material type and other management factors. Long-term agricultural use of manure can however result in important environmental problems, such as phosphate and nitrate contamination of surface waters and accumulation of heavy metals (Adeli et al. 2007). Problems of metal residues in manure have received scientific attention (He et al. 2009) because some of them are added to poultry feed to prevent diseases and to enhance feed efficiency (Jackson et al. 2003). Increased concentrations of Zn and Cu in the surface horizons of soil receiving annual applications of poultry litter were identified (Kingery et al. 1994). For an optimal use of poultry manure for fertilization, it is necessary to know its chemical composition due to the amount of macro- and microelements introduced to soil (Bolan et al. 2010). Organic fertilizers, more considerably than mineral fertilizers, induce proliferation of soil microorganisms, at the same time intensifying biochemical processes (Marinari et al. 2000). Enzymes are biological catalysts of innumerable

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reactions and are of great agronomic and ecological value. However, there is little recognition of the poultry manure (PM) effect on the enzymatic activity of soils. Soil enzymes play the key role in catalysing the decomposition of organic matter and nutrients cycling (Nannipieri et al. 2011). Determining the biochemical properties gives a possibility of a more comprehensive evaluation of the changes that occur in soil as a result of many years of fertilization with natural fertilizer.

The primary objective of the present research was to evaluate the chemical properties as well as the enzymatic activity of soil fertilized with 10 t PM over the period of 10 years. This publication provides information about the appropriate application and the most effective use of poultry fertilizer.

MATERIAL AND METHODS

Soil was sampled from the surface horizon of arable Luvisols (tillage farming systems) in the vicinity of the Żuromin city, central Poland (52°97'88''N, 19°78'25''E). The analysis involved 10 soil samples taken from the field (4.7 ha) fertilized only with PM and 5 samples from the field (2.1 ha) non-fertilized with that fertilizer (control field). A core-sampling tool was used to obtain soil samples (10–20 sampling sites per average soil samples).

Fresh poultry manure from farm of egg laying hens (free-range, cage-free production systems) was applied for 10 years at the dose of 10 t/ha/year. Representative samples of poultry manure were digested in nitric acid and hydrochloric acid with peroxide. Concentrations of K, Zn, Cu, Mn, Fe in digest solution were determined using the atomic absorption spectroscopy (AAS, Philips 9100, Cambridge, UK). Phosphorus concentration was determined on the basis for the vanado-molybdophosphoric acid colorimetric procedure using spectrophotometer Genesis 6 (Madison, USA). The total content of nitrogen was determined using the Vario MAX CN-Elementar (Hanau, Germany). Average total content of study nutrients in wet weight basis of poultry manure was: N 1.31 ± 0.18%, P 0.69 ± 0.11%, K 0.98 ± 0.09%, Zn 171 ± 10.4 mg/kg, 29.5 ± 2.1 mg/kg, Mn 90.3 ± 3.7 mg/kg and Fe 49.5 ± 3.8 mg/kg. Therefore it can be assumed that every year the following amounts of nutrients were applied with the dose of 10 t of poultry manure: 131 ± 18 kg N, 69 ± 11 kg P, 98 ± 9 kg K, 171 ± 10.4 g Zn, 29.5 ± 2.1 g Cu, 90.3 ± 3.7 g Mn and 49.5 ± 3.8 g Fe.

Mineral fertilization of soil non-fertilized with PM did not exceed 100 kg NPK/ha/year (no liming). Soil pH value in 1.0 mol/L KCl was measured using the pH-meter Schott Gerate CG 840 (Hofheim, Germany). Soil total organic carbon (TOC) was determined with the TOC analyzer VarioMax CN Elementar Analysensysteme GmbH (Hanau, Germany). Soil texture was measured with Mastersizer 2000 (Malvern Instrument, Malvern, UK). Cation exchange capacity (CEC) was calculated from the hydrolytic acidity (Hh) according to the Kappen method, in a solution of sodium acetate and the content of exchangeable cations (TEB: Ca^{2+}, Mg^{2+}, K^{+}, Na^{+}) by using 0.1 mol/L $BaCl_2$ solution. The contents of plant-available phosphorus (AP) and potassium (AK) were extracted according to the Egner-Riehm method. Once the soil samples were mineralised in a mixture of HF and $HClO_4$, the total content of Zn, Cu, Mn and Fe were assayed. Applying the atomic absorption spectrometry method using the AAS spectometer (Philips PU 9100, Cambridge, UK), the content of metals was assayed. The activity of selected redox enzymes was recorded: dehydrogenases activity (DHA) according to the Thalmann method (1968) and the activity of catalase (CAT) in soil – with the Johnson and Temple method (1964). The activity of selected enzymes representing the class of hydrolases was also defined: alkaline phosphatase (AlP) and acid phosphatase (AcP), with the method of Tabatabai and Bremner (1969). With the values of the activity of alkaline and acid phosphatase reported, enzymatic index of soil pH (AlP/AcP) (1) was calculated (Dick et al. 2000). Based on the enzymatic activities of the catalase and dehydrogenases, the biological index of fertility (BIF) was calculated according to the Stefanic et al. (1984):

$$BIF = \frac{1.5DHA + 100kCAT}{2} \qquad (2)$$

Where: k – factor proportionality equal to 0.01.

The resistance index (RS) determined according to the activity of enzymes to soil was calculated using the formula proposed by Orwin and Wardle (2004):

$$RS = 1 - \left[\frac{2|D0|}{C0 + |D0|}\right] \qquad (3)$$

Where: D0 – difference between control sample (C0) and fertilized soil samples.

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Mean values of the enzyme activities were also used to calculate the relative changes (RCh) according to the formula defined by Chaer et al. (2009):

$$RCh = \left(\frac{T}{C} - 1\right) \times 100 \quad (4)$$

Where: T – mean enzyme activity in soil fertilized with poultry manure; C – mean value obtained for the control.

The indices of biochemical soil activity (B12 and B13) (Wyszkowska et al. 2013) were proposed based on the activities of soil enzymes, the content of clay and the content of organic carbon:

$$B12 = log_{10}C_{org}\sqrt{DHA + CAT + AlP + AcP} \quad (5)$$

$$B13 = log_{10}Clay\sqrt{DHA + CAT + AlP + AcP} \quad (6)$$

For processing of the research results, a single-factor analysis of variance ANOVA (Tukey's test) and the analysis of correlation (Pearson's correlation) were used. Before statistical calculations the normal distribution test was performed.

RESULTS AND DISCUSSION

Soil material from the analysed soils revealed the grain size composition of fine sandy loam with a considerable content of silt fraction (Table 1). As a result of the PM application a significant increase in the pH value was noted; in the non-fertilized soil it ranged from pH 4.34 to 4.54, while in the fertilized soil it was from pH 5.30 to 5.95. The results of the research performed by Rós et al. (2013) show that the application of PM increased the pH value and decreased the acidity of soils. Horswill et al. (2008) observed that the soil reaction after the application of PM can change by 0.2 units to pH 4.4 if manure is applied for a longer time (8–10 years). In the soil sampled from the control field, the mean value of the cation exchange capacity was 6.20 $cmol_+$/kg and it was significantly lower than that noted in soil following the application of PM (8.03 $cmol_+$/kg) (Table 2). The mean value of organic carbon in non-fertilized soil was 9.42 g/kg, whereas in the soil sampled from fertilized field it was significantly higher – 14.9 g/kg. The application of PM for 10 years resulted in a 58.6% increase in the content of organic carbon. There was recorded a significantly positive effect of the PM application on the content of plant-available forms of phosphorus and potassium (Table 2).

In the control field soil, the mean content of AP was 69.0 mg P/kg, as class II of soils with a high

Table 1. Soil fertilized with poultry manure (*n* = 10) – after 10 years

Parameter	Soil fertilized with poultry manure (*n* = 10) – after 10 years				Soil non-fertilized with poultry manure (*n* = 5)			
	min.	max.	SD	*CV* (%)	min.	max.	SD	*CV* (%)
Sand (wt.%)	59.1	67.4	2.79	4.5	60.6	62.2	0.61	1.0
Silt (wt.%)	29.5	36.7	2.43	7.3	33.0	34.5	0.58	1.7
Clay (wt.%)	3.1	4.2	0.44	11.7	4.3	4.9	0.23	5.0
Total organic carbon (g/kg)	13.2	16.7	1.29	8.7	8.2	10.8	1.14	12.1
pH	5.30	5.95	0.25	4.4	4.34	4.54	0.08	1.8
Hydrolytic acidity (cmol/kg)	1.10	2.90	0.50	23.4	3.00	5.20	0.78	18.8
Total exchangeable bases (cmol/kg)	3.50	7.30	1.41	23.5	1.40	2.70	0.46	22.3
Cation exchange capacity ($cmol_+$/kg)	6.40	9.50	1.27	15.8	5.70	7.20	0.61	9.8
Available phosphorus (mg P/kg)	140.6	222.2	26.7	14.6	52.8	86.9	15.2	22.0
Available potassium (mg K/kg)	160.3	389.5	83.8	33.7	84.7	98.8	6.4	6.8
Alkaline phosphatase (mmol pNP/kg/h)	0.83	1.16	0.10	10.6	1.12	1.27	0.06	5.0
Acid phosphatase (mmol pNP/kg/h)	1.55	2.14	0.23	12.8	2.43	2.69	0.10	3.9
Dehydrogenases (mg TPF/kg/24h)	0.46	0.88	0.12	20.0	0.28	0.38	0.04	12.1
Catalase (µmol H_2O_2/g/min)	0.06	0.07	0.01	16.7	0.03	0.06	0.01	25.0

SD – standard deviation; *CV* – coefficient of variation

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Table 2. Mean values of the statistical analysis (Anova, Tukey's test)

Parameter	Fertilized soil (*n* = 10)	Non-fertilized soil (*n* = 5)	Significance level
Total organic carbon (g/kg)	14.9	9.42	0.0002
pH	5.65	4.41	0.0002
Hydrolytic acidity (cmol/kg)	2.14	4.14	0.0002
Total exchangeable bases (cmol/kg)	6.00	2.06	0.0002
Cation exchange capacity ($cmol_+$/kg)	8.03	6.20	ns
Available phosphorus (mg P/kg)	182.9	69.0	0.0002
Available potassium (mg K/kg)	249.2	93.9	0.0014
Alkaline phosphatase (mmol pNP/kg/h)	0.94	1.20	0.0003
Acid phosphatase (mmol pNP/kg/h)	1.80	2.50	0.0002
Dehydrogenases (mg TPF/kg/24 h)	0.60	0.32	0.0001
Catalase (µmol H_2O_2/g/min)	0.06	0.04	0.0003

ns – not significant

content of phosphorus available to plants (according to PN-R-04023, 1996) and 93.9 mg K/kg, as class IV of soils with a low content of potassium available to plants (according to PN-R-04023, 1996) (Table 2). The application of PM resulted in a very high increase in the AP and AK content. The contents of phosphorus and potassium available to plants were 182.9 mg P/kg and 249.2 mg K/kg, respectively, as class I of soils with a very high content of these nutrients.

The soil investigated after 10 years of PM application was very abundant in phosphorus available to plants and its application in successive years would be irrational and pose a serious threat due to the pollution with surface waters phosphates. The threat connected with the eutrophication of surface waters concerns mostly soils exposed to water erosion (Smith et al. 2007). The study by Bielińska and Mocek-Płóciniak (2015) recorded a high accumulation of available phosphorus in goose farms soils. For that reason phosphatases taking part in phosphorus biotransformation are considered to be a good indicator of organic phosphorus mineralization potential and the biological activity of soil.

The total content of Zn_{tot} in the control field ranged from 27.8 to 31.7 mg/kg, Cu_{tot} from 7.0 to 8.7 mg/kg, Fe_{tot} from 4.1 to 5.0 g/kg and Mn_{tot} from 250 to 307 mg/kg (Table 3). A comparison of the total content of the analysed metals only for Zn_{tot} showed a significantly higher total content in the soil fertilized with PM (Table 4). Studied soil samples were not contaminated by trace elements (Journal of Laws, item 1359. 2016) and their contents were not higher than the admissible concentrations in arable soils. Trace elements in poultry droppings come mostly from special animal feed additives enhancing health and feeding

Table 3. Heavy metals in soil

Parameter	Soil fertilized with poultry manure (*n* = 10) – after 10 years				Soil non-fertilized with poultry manure (*n* = 5)			
	min.	max.	SD	*CV* (%)	min.	max.	SD	*CV* (%)
Zn_{tot}	34.8	40.9	2.08	5.5	27.8	31.7	1.52	5.0
Cu_{tot}	8.0	10.3	0.76	8.6	7.0	8.7	0.62	7.8
Fe_{tot}	4.4	5.6	0.40	7.8	4.1	5.0	0.37	7.9
Mn_{tot}	266	371	32.8	10.7	250	307	23.9	8.4

SD – standard deviation; *CV* – coefficient of variation; tot – total content

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Table 4. Mean values of the statistical analysis (Anova, Tukey's test)

Parameter	Fertilized soil (n = 10)	Non-fertilized soil (n = 5)	Significance level
Zn_{tot}	37.9	30.2	0.0002
Cu_{tot}	8.8	7.98	ns
Fe_{tot}	5.1	4.68	ns
Mn_{tot}	307	283	ns

ns – not significant; tot – total content

Table 5. Values of (relative changes (RCh)) (%) and resistance of soil (RS) for the activity of alkaline phosphatase (AlP), acid phosphatase (AcP), dehydrogenases (DHA) and catalase (CAT)

Parameter	CAT	DEH	AlP	AcP
RCh	–21.7	–28.0	100	50
RS	0.64	0.56	0	0.33

effectiveness (Bolan et al. 2010). Applying high rates of fertilizers can result in the accumulation of metals in soil (Schomberg et al. 2009), which is especially important in terms of their phytotoxicity.

A change in the enzymatic activity of soil induced by PM fertilization was confirmed by the values of resistance of soil. The highest RS value was noted for the activity of AlP (RS = 0.64) (Table 5). Orwin and Wardle (2004) describe the RS values close to 1.0 as a lack of effect (maximum resistance) of the factor in their study on the enzyme. It can be thus stated that the application of PM inconsiderably affected the activity of both phosphatases, as compared with CAT and DHA (Table 5). As for a decreasing resistance, enzymes can be ordered as AlP > AcP > CAT > DHA.

The activity of AlP and AcP facilitated the calculation of the enzymatic pH index. According to Dick et al. (2000), the soil pH value for which the value of ratio (AlP/AcP) is 0.50 can be considered optimal for plants growth and development. The value of ratio (AlP/AcP) was higher in the soil fertilized with PM than in the control soil (Table 6).

There was observed an increase in the activity of DHA, which is seen from the value of RCh coefficient (100%). The activity of DHA is commonly applied to evaluate the factors with an unfavourable effect on soil microorganisms. The results of the analysis of variance showed a significant effect of the PM application on the activity of the studied oxydoreductases (Table 2). A significant activation of CAT was found following the application of PM. Martens et al. (1992), investigating the activity of 10 enzymes depending on the type of fertilizer (e.g.: poultry manure, barley straw, sewage sludge), recorded a significant increase in the enzymatic activity in fertilized soil. It was found that BIF value was clearly increasing due to the poultry manure fertilization (Table 6), while the biochemical value of soil activity calculated from the content of TOC and the activity of the enzymes studied (B12) differed inconsiderably in the soils fertilized and non-fertilized with PM. The value of index B13 considering the amount of clay, however, was higher in the soil without an application of organic fertilizer. With the statistical analysis of the results there was found a significantly positive correlation between the activity of AcP and the content of phosphorus available to plants (r = 0.77; P < 0.05), which suggests that the enzyme was the adequate parameter determining the soils analysed in terms of the AP content, unlike the AcP activity. It must have been related to the acid reaction of the soil. The activity of AcP was also positively correlated with TOC (r = 0.76; P < 0.05). A positive dependence was also reported between TOC and AP (r = 0.53; P < 0.05). Organic matter plays a protective function for the enzymes which, as a result, undergo immobilization. It has a positive effect on the stabilization of protein structure, decreasing the sensitivity to negative changes of the environmental factors.

Table 6. Values of enzymatic indices: pH value, soil fertility (BIF) and soil activity (B12 and B13)

Fertilization	AlP/AcP	BIF	B12	B13
With poultry manure	0.522	0.483	3.02	2.02
Without poultry manure	0.467	0.255	2.98	2.68

AlP – alkaline phosphatase; AcP – acid phosphatase

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REFERENCES

Adeli A., Sistani K.R., Tewolde H., Rowe D.E. (2007): Broiler litter application effects on selected trace elements under conventional and no-till systems. Soil Science, 172: 349–365.

Bielińska E.J., Mocek-Płóciniak A. (2015): Biochemical and chemical indices of soil transformations on goose farms in years 1996–2011. Archives of Environmental Protection, 41: 80–85.

Bolan N.S., Szogi A.A., Chuasavathi T., Seshadri B., Rothrock Jr.M.J., Panneerselvam P. (2010): Uses and management of poultry litter. World's Poultry Science Journal, 66: 673–698.

Chaer G., Fernandes M., Myrold D., Bottomley P. (2009): Comparative resistance and resilience of soil microbial communities and enzyme activities in adjacent native forest and agricultural soils. Microbial Ecology, 58: 414–424.

Dick W.A., Cheng L., Wang P. (2000): Soil acid and alkaline phosphatase activity as pH adjustment indicators. Soil Biology and Biochemistry, 32: 1915–1919.

Hanč A., Tlustoš P., Száková J., Balík J. (2008): The influence of organic fertilizers application on phosphorus and potassium bioavailability. Plant, Soil and Environment, 54: 247–254

He Z.Q., Endale D.M., Schomberg H.H., Jenkins M.B. (2009): Total phosphorus, zinc, copper, and manganese concentrations in cecil soil through 10 years of poultry litter application. Soil Science, 174: 687–695.

Horswill P., O'Sullivan O., Phoenix G.K., Lee J.A., Leake J.R. (2008): Base cation depletion, eutrophication and acidification of species-rich grasslands in response to long-term simulated nitrogen deposition. Environmental Pollution, 155: 336–349.

Jackson B.P., Bertsch P.M., Cabrera M.L., Camberato J.J., Seaman J.C., Wood C.W. (2003): Trace element speciation in poultry litter. Journal of Environmental Quality, 32: 535–540.

Johnson J.L., Temple K.L. (1964): Some variables affecting the measurements of 'catalase activity' in soil. Soil Science Society of America Journal, 28: 207–209.

Kingery W.L., Wood C.W., Delaney D.P., Williams J.C., Mullins G.L. (1994): Impact of long-term application of broiler litter on environmentally related soil properties. Journal of Environmental Quality, 23: 139–147.

Marinari S., Masciandaro G., Ceccanti B., Grego S. (2000): Influence of organic and mineral fertilizers on soil biological and physical properties. Bioresource Technology, 72: 9–17.

Martens D.A., Johanson J.B., Frankenberger W.T.Jr. (1992): Production and persistence of soil enzymes with repeated addition of organic residues. Soil Science, 153: 53–61.

Nannipieri P., Giagnoni L., Landi L., Renella G. (2011): Role of phosphatase enzymes in soil. In: Bunemann E.K., Obreson A., Frossard E. (eds.): Phosporus in Action. Soil Biology 26. Berlin, Heidelberg, Springer Verlag, 215–241.

Orwin K.H., Wardle D.A. (2004): New indices for quantifying the resistance and resilience of soil biota to exogenous disturbances. Soil Biology and Biochemistry, 36: 1907–1912.

Rós A.B., Hirata A.C.S., Narita N. (2013): Cassava roots yield and soil chemical and physical properties according to chicken manure fertilization. Pesquisa Agropecuaria Tropical, 43: 247–254.

Schomberg H.H., Endale D.M., Jenkins M.B., Sharpe R.R., Fisher D.S., Cabrera M.L., McCracken D.V. (2009): Soil test nutrient changes induced by poultry litter under conventional tillage and no-tillage. Soil Science Society of America Journal, 73: 154–163.

Smith D.R., Owens P.R., Leytem A.B., Warnemuende E.A. (2007): Nutrient losses from manure and fertilizer applications as impacted by time to first runoff event. Environmental Pollution, 147: 131–137.

Stefanic F., Ellade G., Chirnageanu J. (1984): Researches concerning a biological index of soil fertility. In: Nemes M.P., Kiss S., Papacostea P., Stefanic C., Rusan M. (eds.): Proceeding of the 5th Symposium of Soil Biology. Bucharest. Romanian National Society of Soil Science, 35–45.

Tabatabai M.A., Bremner J.M. (1969): Use of *p*-nitrophenol phosphate for assay of soil phosphatase activity. Soil Biology and Biochemistry, 1: 301–307.

Thalmann A. (1968): Zur Methodik der Bestimmung der Dehydrogenaseaktivität im Boden mittels Triphenyltetrazoliumchlorid (TTC). Landwirdschaft Forschung, 21: 249–258.

Wyszkowska J., Borowik A., Kucharski M., Kucharski J. (2013): Applicability of biochemical indices to quality assessment of soil polluted with heavy metals. Journal of Elementology, 18: 733–756.

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