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Research Article

EFFECT OF DIFFERENT SUBSTANCES ON SOME PROPERTIES OF SOIL CONTAMINATED WITH HEATING OIL

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ABSTRACT
The aim of the study was to determine the effect of the application of different substances (nitrogen, compost, bentonite, zeolite and calcium oxide) to soil on its selected properties after prior contamination with heating oil: 0, 5, 10, 15 and 20 g kg^{-1} d.m. of soil. Heating oil contamination and the application of different substances had a significant effect on the tested soil properties. In the series without additives, heating oil caused an increase in soil pH and a decrease in hydrolytic acidity, the total exchange bases and cation exchange capacity. Bentonite and calcium oxide had the strongest effect of all the substances on soil properties. They induced a rise in soil pH, an increase in the total exchange bases and cation exchange capacity and a decrease in hydrolytic acidity. The effect of other substances, particularly nitrogen and compost, on the tested soil properties was significantly lower. On the soil contaminated with heating oil, the effect of individual substances on the degree of base saturation was relatively small because it did not exceed 8% in all of the test series.

Keywords: heating oil contamination, nitrogen, compost, bentonite, zeolite, calcium oxide, soil properties.

INTRODUCTION

Intensive development of industry, construction and the increase in diverse needs of population in developed countries involves the need to obtain, produce, transport and store rising quantities of fuels [Nadim et al. 2000, Wyszkowski et al. 2004]. Unfortunately, this is not harmless to the environment because of the entailed possibility of its pollution, which is the result of different kinds of events, mainly failures [Nadim et al. 2000]. One of these fuels is heating oil, most often used for heating buildings. If the soil environment is contaminated, the effects can be substantial and sometimes even hard to reverse. Oil derivatives have a very strong effect not only on physicochemical soil properties [Baran et al. 2002, Kucharski, Jastrzębska 2005, Ziółkowska, Wyszkowski 2010], but they also cause a loss of microbiological and biochemical balance in the soil [Wyszkowska, Wyszkowski 2010], which often becomes unfit for plant cultivation. Therefore, it becomes necessary to make an attempt to restore soil balance, e.g. by the application of different kinds of substances, bioremediation and phytoremediation or the use of more costly *ex situ* methods.

The aim of the study was to determine the effect of the application of different substances (nitrogen, compost, bentonite, zeolite and calcium oxide) to soil on its selected properties after prior contamination with heating oil.

MATERIALS AND METHODS

The study was performed in the greenhouse of the University of Warmia and Mazury in Olsztyn (north-eastern Poland) on soil with the granulometric composition of loamy sand. The soil properties were as follows: pH at 1 mole

KCl · dm^{-3} – 4.52; hydrolytic acidity (HA) – 25.4 mmol(+) · kg^{-1}; the total exchange bases (TEB) – 29.1 mmol(+) · kg^{-1}; cation exchange capacity (CEC) – 54.5 mmol(+) · kg^{-1}; the degree of cation saturation (BS) – 53.4%; C_{org} content – 11.28 g · kg^{-1}; the content of available forms of: phosphorus – 71.88 mg P · kg^{-1}; potassium – 118.60 mg K · kg^{-1} and magnesium – 104.18 mg Mg · kg^{-1}. The soil was contaminated with heating oil in the amounts of: 0; 5; 10; 15 and 20 g · kg^{-1} DM. The study was conducted in five series: without the substances and with the application of nitrogen (200 mg N · kg^{-1} soil in the form of 46% urea), compost (3%), bentonite and zeolite (2% relative to soil mass) and 50% calcium oxide in a dose corresponding to one full hydrolytic acidity. Macro- and micronutrients were also applied to all the pots in the same amounts (in mg · kg^{-1} soil): N – 100 ($CO(NH_2)_2$), P – 30 (KH_2PO_4); K – 100 (KH_2PO_4 + KCl); Mg – 50 ($MgSO_4 \cdot 7H_2O$); Mn – 5 ($MnCl_2 \cdot 4H_2O$); Mo – 5 [$(NH_4)_6Mo_7O_{24} \cdot 4H_2O$]; B – 0.33 ($H_3BO_3$). During the establishment of the experiment, heating oil, compost, bentonite and calcium oxide, as well as macro- and micronutrients in a form of aqueous solutions, were mixed with 9 kg soil and transferred to polyethylene pots. Spring barley (*Hordeum vulgare* L.) cv. Rebel was sown in the prepared pots as well as white mustard (*Sinapis alba* L.) cv. Bardena after its harvest in the flowering phase. The moisture content was maintained at 60% of the capillary water capacity during the study. Soil samples for the tests were collected at the time of white mustard harvest in the flowering phase.

The following were determined in the soil, after prior drying and screening through a 1 mm mesh sieve: pH – by the potentiometric method in an aqueous KCl solution with a concentration of 1 mole · dm^{-3}, hydrolytic acidity (HA) and the total exchange bases (TEB) – by the Kappen method [Lityński et al. 1976]. Cation exchange capacity (CEC) and the degree of soil base saturation (BS) were computed based on hydrolytic acidity (HA) and the total exchange bases (TEB) by the following formulas: CEC = TEB + HA; BS = TEB · CEC^{-1} · 100. Moreover, the following were determined in the soil before the experiment was established: organic carbon (C_{org}) content – by the Tiurin method [Lityński et al. 1976], available phosphorus and potassium content – by the Egner-Riehm method [Lityński et al. 1976], available magnesium content – by the Schachtschabel method [Lityński et al. 1976]. A two-factor analysis of variance (ANOVA) from the Statistica package [StatSoft, Inc. 2010] and Pearson's simple correlation coefficients (to determine the relationship between soil heating oil contamination and the tested soil properties) were used for statistical analysis of the obtained test results.

RESULTS AND DISCUSSION

Heating oil contamination and the application of different substances had a significant effect on the tested soil properties (Tables 1 and 2). In the series without additives, pH was positively correlated with increasing heating oil doses. The pH rose under increasing heating oil doses in the soil with a dose of 20 g · kg^{-1} soil. In the series with the respective additives, the relationship between heating oil doses and pH was not always so clearly directed as in the series without additives. In the series without additives, hydrolytic acidity in the studied soil decreased under increasing heating oil doses. The highest heating oil dose (20 g · kg^{-1} soil) caused a decrease by 22% compared to the object without the tested oil derivative. The effect of increasing heating oil doses on the total exchange bases and cation exchange capacity was negative. No relationship was detected between increasing heating oil doses and the degree of base saturation for the soil under white mustard.

Contamination of soils with oil derivatives has a significant effect on soil properties. Experiments by Kucharski and Jastrzębska [2005] indicate that heating oil caused a decrease in pH, the sum of base cations, cation exchange capacity and the degree of sorption complex base saturation, which is partly consistent with the results of own research. In a study by Baran et al. [2002], point sources of contamination with oil derivatives induced an increase in pH, the sum of base cations and cation exchange capacity.

All the alleviating substances applied to the soil caused changes in the tested properties in the objects contaminated with heating oil (Figure 1).

Comparing the effect of the substances in the soil contaminated with heating oil in the amount of 5–20 g · kg^{-1} soil, CaO and, to a slightly lower degree, bentonite, showed the most stimulating effect on soil pH compared to the series without additives. Bentonite and calcium oxide, as the only substances, contributed to a decrease in hydrolytic acidity in the soil by 39% and 31%, compared to the series without additives (Figure 1). Zeolite and

Table 1. pH and hydrolytic activity in soil after plants harvest

Dose of heating oil in g · kg⁻¹ of soil	Kind of substance neutralizing effect of heating oil						
	Without additions	Nitrogen	Compost	Bentonite	Zeolite	CaO	Average
pH							
0	5.34	4.76	5.11	6.84	5.35	6.33	–
5	5.20	5.60	5.25	6.58	5.34	6.52	–
10	5.32	5.27	5.53	6.71	5.32	7.01	–
15	5.40	5.23	5.34	6.65	5.46	6.95	–
20	5.86	5.27	5.46	6.55	5.36	6.83	–
r	0.768**	0.342	0.747**	-0.683*	0.444	0.779**	–
LSD for: heating oil dose – 0.13**; kind of neutralizing substance – 0.14**; interaction – 0.31**							
Hydrolytic activity [mmol · kg⁻¹ of soil]							
0	31.0	24.9	29.6	17.5	30.1	24.3	26.2
5	28.4	23.9	26.1	16.4	30.2	19.2	24.0
10	26.6	28.4	32.6	16.7	31.2	18.4	25.6
15	28.0	29.9	30.9	15.6	28.4	19.1	25.3
20	24.3	28.5	29.8	17.2	29.3	17.5	24.4
Average	27.7	27.1	29.8	16.7	29.8	19.7	25.1
r	-0.883**	0.814**	0.337	-0.305	-0.514	-0.820**	-0.419
LSD for: heating oil dose – 0.8**; kind of neutralizing substance – 0.8**; interaction – 1.9**							

Explanation: r – correlation coefficient; significant for: ** – P≤0.01, * – P≤0.05.

Table 2. Total exchange bases (TEB), cation exchange capacity (CEC) and base saturation (BS) in soil after plants harvest

Dose of heating oil in g · kg⁻¹ of soil	Kind of substance neutralizing effect of heating oil						
	Without additions	Nitrogen	Compost	Bentonite	Zeolite	CaO	Average
Total exchange bases (TEB) [mmol · kg⁻¹ of soil]							
0	105.6	96.2	77.5	117.2	119.6	100.0	102.7
5	94.4	87.4	93.6	130.0	115.1	101.5	103.7
10	85.8	88.9	90.3	134.6	106.8	112.9	103.2
15	86.9	85.3	81.7	132.5	102.6	115.4	100.7
20	96.7	75.2	92.7	132.7	105.0	116.8	103.2
Average	93.9	86.6	87.2	129.4	109.8	109.3	102.7
r	-0.496	-0.920**	0.410	0.756**	-0.914**	0.943**	-0.262
LSD for: heating oil dose - n.s.; kind of neutralizing substance - 6.7**; interaction - 14.9**							
Cation exchange capacity (CEC) [mmol · kg⁻¹ of soil]							
0	128.5	121.4	100.9	129.4	142.2	116.5	123.1
5	117.2	106.8	116.7	144.4	140.4	116.5	123.7
10	107.5	109.9	111.1	151.5	134.2	128.5	123.8
15	106.9	107.5	101.1	147.5	133.0	128.4	120.7
20	117.3	99.5	113.3	144.1	132.5	131.8	123.1
Average	115.5	109.0	108.6	143.4	136.4	124.3	122.9
r	-0.586	-0.859**	0.205	0.616*	-0.941**	0.924**	-0.391
LSD for: heating oil dose - n.s.; kind of neutralizing substance - 7.1**; interaction - 15.8*							
Base saturation (BS) [%]							
0	82.1	79.2	76.7	90.6	84.1	85.8	83.1
5	80.5	81.8	80.2	90.0	82.0	87.1	83.6
10	79.8	80.9	81.3	88.9	79.6	87.9	83.0
15	81.3	79.0	80.7	89.8	77.2	89.9	83.0
20	82.4	75.6	81.8	92.1	79.3	88.6	83.3
Average	81.2	79.3	80.1	90.3	80.4	87.9	83.2
r	0.215	-0.674*	0.840**	0.381	-0.856**	0.857**	-0.127
LSD for: heating oil dose - n.s.; kind of neutralizing substance - 1.1**; interaction - 2.4**							

Explanation: r – correlation coefficient; significant for: ** – P≤0.01, * – P≤0.05.

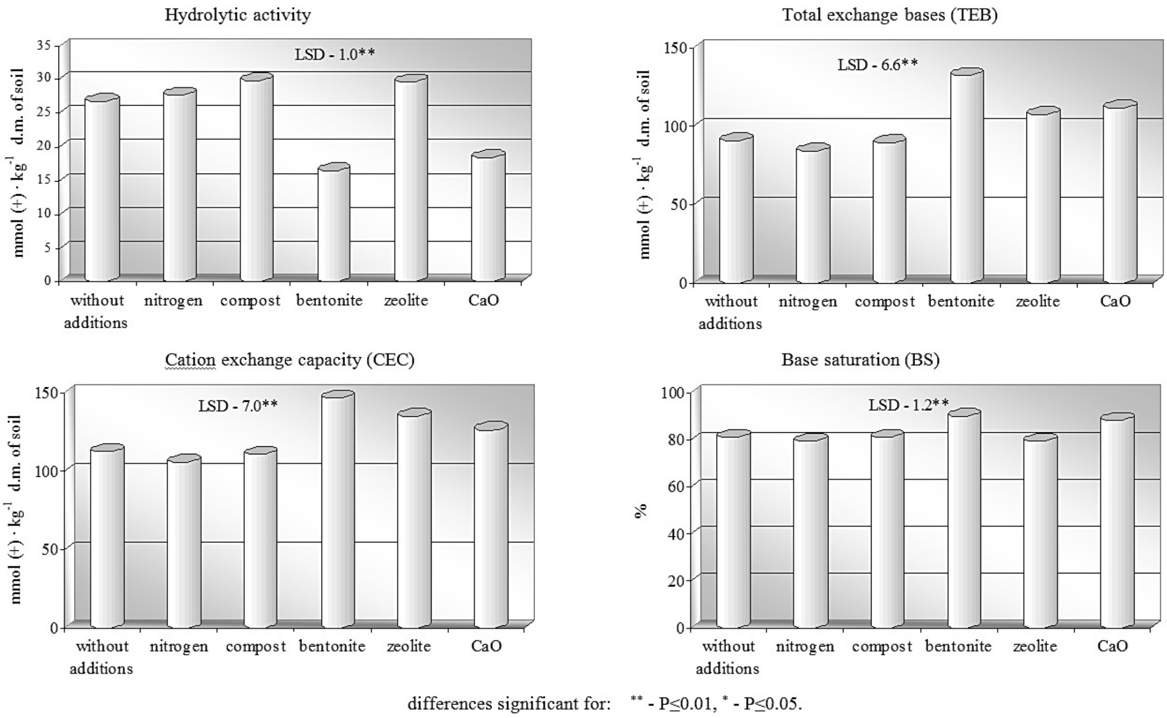

Figure 1. Soil properties after plants harvest (average from series contaminated with 5–20 g heating oil per kg of soil)

compost caused an increase in hydrolytic acidity in the soil, but only by 11%. The addition of nitrogen had no substantial effect on the tested property.

In the soil contaminated with heating oil, bentonite and calcium oxide showed the most stimulating effect and contributed to an increase in the total exchange bases by 46% and 23% and in cation exchange capacity by 26% and 13% compared to the series without additives (Figure 1). An increase in the total exchange bases by 18% and cation exchange capacity by 20% compared to the series without additives was recorded after the application of zeolite.

In the soils contaminated with heating oil, the effect of individual substances on the degree of base saturation was relatively low because it did not exceed 5% in all the test series (Figure 1). An exception was the application of bentonite and calcium oxide, which increased the value of the tested index by 8% and 7%, respectively, compared to the series without the alleviating substances.

The application of neutralizing additives to soil usually has a positive effect on the properties of soil contaminated with small quantities of oil derivatives. Organic substances act particularly favorably, as indicated by the studies of Riffaldi et al. [2006], Quintern et al. [2006], Wyszkowski and Ziółkowska [2009]. Organic substances, especially compost, have a positive effect on the sorption properties of soil and accelerate the decomposition of oil derivatives [Ziółkowska, Wyszkowski 2010]. The positive effect of bentonite and CaO on soil pH was confirmed by Wyszkowski and Ziółkowska [2011] who found that in soil contaminated with gasoline and diesel fuel these additives contributed to an increase in pH, the total exchange bases and exchange capacity. Bentonite, calcium oxide and compost decreased hydrolytic acidity in contaminated soil and contributed to a rise in the degree of base saturation. This creates more optimal conditions for a proper element cycle in the soil environment and plant growth [Ziółkowska, Wyszkowski 2010]. When soil is highly contaminated with oil derivatives, plant cultivation is not possible [Ogboghodo et al. 2004].

CONCLUSIONS

1. Heating oil contamination and the application of different substances had a significant effect on the tested soil properties.
2. In the series without additives, heating oil caused an increase in soil pH and a decrease in hydrolytic acidity, the total exchange bases and cation exchange capacity.
3. Bentonite and calcium oxide had the strongest effect of all the substances on soil properties. They induced a rise in soil pH,

an increase in the total exchange bases and cation exchange capacity and a decrease in hydrolytic acidity.

4. The effect of the other substances, particularly nitrogen and compost, on the tested soil properties was significantly lower. On the soil contaminated with heating oil, the effect of individual substances on the degree of base saturation was relatively small because it did not exceed 8% in all of the test series.

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