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EFFECT OF COMPOST, BENTONITE AND CALCIUM OXIDE ON CONTENT OF SOME MACROELEMENTS IN PLANTS FROM SOIL CONTAMINATED BY PETROL AND DIESEL OIL*

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Abstract

The aim of the study was to determine how soil contamination with petrol and diesel oil affected content of some macroelements in spring oilseed rape (*Brassica napus* var. *oleifera*) and oat (*Avena sativa* L.) and to determine whether application of compost, bentonite or calcium oxide could reduce the impact of petroleum-derived products on the properties of the plants. The soil formed from sandy loam was polluted with the following amounts of petrol and diesel oil: 2.5, 5.0 and 10 $cm^3 \cdot kg^{-1}$ of soil. The results of the tests showed that contamination of soil with diesel oil at the amount between 2.5 and 10 $cm^3 \cdot kg^{-1}$ of soil disturbed the plants' chemical composition. Irrespective of the application of compost, bentonite or calcium oxide, the highest doses of petrol and especially diesel oil decreased the content of most macroelements in spring oilseed rape and, to a smaller degree, in oat. Enrichment of soil with compost, bentonite or calcium oxide modified the content of macroelements in plants, mainly that of sodium under the effect of bentonite. Significant correlations, mainly between the content of some macroelements in spring oilseed rape and oats versus plant yield and content of other elements in plants, as well as some properties of soil were observed.

Key words: petrol and diesel oil contamination, compost, bentonite, calcium oxide, spring oilseed rape, oat, macroelements content.

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WPŁYW KOMPOSTU, BENTONITU I TLENKU WAPNIA NA ZAWARTOŚĆ NIEKTÓRYCH MAKROSKŁADNIKÓW W ROŚLINACH Z GLEBY ZANIECZYSZCZONEJ BENZYNĄ I OLEJEM NAPĘDOWYM

Abstrakt

Celem badań było określenie, w jaki sposób zanieczyszczenie gleby benzyną i olejem napędowym wpływa na zawartość niektórych makroskładników w rzepaku jarym (*Brassica napus* var. *oleifera*) i owsie (*Avena sativa* L.) oraz czy stosowanie kompostu, bentonitu i tlenku wapnia mogłoby zmniejszyć oddziaływanie substancji ropopochodnych na badane cechy roślin. Doświadczenia przeprowadzono na glebie wytworzonej z piasku gliniastego zanieczyszczonej rosnącymi dawkami benzyny i oleju napędowego: 2,5, 5,0 i 10 $cm^3 \cdot kg^{-1}$ gleby. W wyniku badań wykazano, że zanieczyszczenie gleby olejem napędowym w dawkach od 2,5 do 10 $cm^3 \cdot kg^{-1}$ gleby modyfikuje skład chemiczny roślin. Najwyższe dawki benzyny i oleju napędowego, niezależnie od aplikacji kompostu, bentonitu i tlenku wapnia, zmniejszały zawartość większości makroskładników w rzepaku jarym, i w mniejszym stopniu w owsie. Wzbogacenie gleby w kompost, bentonit i tlenek wapnia modyfikowało zawartość makroskładników w roślinach, głównie sodu, po zastosowaniu bentonitu. Istotne korelacje stwierdzono głównie między zawartością niektórych makroskładników w rzepaku jarym i owsie oraz plonem roślin i zawartością innych składników w roślinach, a także niektórymi właściwościami gleby.

Słowa kluczowe: zanieczyszczenie benzyną i olejem napędowym, kompost, bentonit, tlenek wapnia, rzepak jary, owies, zawartość makroskładników.

INTRODUCTION

Petroleum-derived products, which are widespread the natural environment, contribute to soil degradation by deteriorating soil, air and water chemical properties (WANG, BARTHA 1990, IWANOW et al. 1994, SZTOMPKA 1999). Petroleum-derived products include aliphatic, oleic and naphthenic hydrocarbons (CHI, KRISHNAMURTHY 1995) and water-soluble aromatic hydrocarbons, such as benzene, toluene, xylene (KRAHL et al. 2002). Polycyclic aromatic hydrocarbons (PAH) and other aromatic hydrocarbons are hardly mobile and can have a long-term effect on soil, plants or ground waters (SPARROW, SPARROW 1988, RACINE 1993, WYSZKOWSKA et al. 2002a,b). Contaminants penetrating soil disturb its structure and modify its physicochemical and biological properties (SZTOMPKA 1999, BUDNY et al. 2002, CARAVACA, RODÁN 2003). Soil enzymatic and microbiological activities often respond to soil pollution with petroleum products (CARAVACA, RODÁN 2003, WYSZKOWSKA, WYSZKOWSKI 2006). Polycyclic aromatic hydrocarbons are toxic to soil organisms, plants (BUDNY et al. 2002, WYSZKOWSKA et al. 2002a,b, DELILLE et al. 2003) and people (KRAHL et al. 2002). These contaminants can show potential carcinogenic and mutagenic activity (KRAHL et al. 2002). The content of available macro- and microelement forms in soil contaminated with petroleum-derived products (WYSZKOWSKI, ZIÓŁKOWSKA 2007) and the uptake by plants of macroelements changes so that the content of nutrients in particular plant organs fluctuates (WYSZ-

KOWSKI et al. 2004). It is, therefore, extremely important to restore soil contaminated with petroleum-derived products to its original state.

The aim of the study was to determine the effect of petrol and diesel oil soil contamination on the content of some macroelements in spring oilseed rape (*Brassica napus* var. *oleifera*) and oat (*Avena sativa* L.), and to verify whether soil amendment with compost, bentonite and calcium oxide could reduce the impact of petroleum-derived products on the properties of the plants.

MATERIAL AND METHODS

The experiment was conducted in a greenhouse at the University of Warmia and Mazury in Olsztyn (Poland), in polyethylene pots (with 4 replications). Soil material used for the trials was taken from the arable humus soil horizon and, under natural conditions, it was proper Eutric Cambisols soil according to WRB (1998) formed from sandy loam (1.0-0.1 mm – 50%; 0.1-0.02 mm – 39%; <0.02 mm – 8%), characterised by following properties: pH in 1 M KCl dm^{-3} – 5.10; hydrolytic acidity (HA) – 30.8 mmol $(H^+)\cdot kg^{-1}$; exchangeable cation bases – Ca^{++}, Mg^{++}, K^+ and Na^+ (ECB) – 88.0 mmol(+)$\cdot kg^{-1}$; cation exchange capacity (CEC) – 118.8 mmol(+)$\cdot kg^{-1}$; base saturation (BS) – 74.1%; C_{org} content – 8.48 $g\cdot kg^{-1}$; content of available: phosphorus – 34.1 $mg\cdot kg^{-1}$; potassium – 75.2 $mg\cdot kg^{-1}$ and magnesium – 36.7 $mg\cdot kg^{-1}$. During the study, increasing doses of petrol and diesel oil were applied in the following amounts: 0; 2.5; 5 and 10 $cm^3\cdot kg^{-1}$ d.m. of soil. Afterwards, some objects were enriched with compost (3% of the soil mass), bentonite (2%) or calcium oxide (in a dose equal one full hydrolytic acidity – 1.47 g $Ca\cdot kg^{-1}$ of soil). Compost was prepared from leaves (44%), manure (33%) and peat (23%) composted for six months. The concentration of macroelements in these substances (in $g\cdot kg^{-1}$) was as follows: compost: P – 2.32, K – 1.33, Mg – 1.47, Ca – 15.86, Na – 0.12; bentonite: P – 0.47, K – 2.43, Mg – 5.03, Ca – 26.72, Na – 12.11; calcium oxide: P – 0.10, K – 0.77, Mg – 2.65, Ca – 347.99, Na – 0.07. Additionally, macro- and microelements were added to all pots, in the following amounts (in $mg\cdot kg^{-1}$ of soil): N – 150 $CO(NH_2)_2$; P – 30 (KH_2PO_4); K – 70 (KH_2PO_4 + KCl); Mg – 50 ($MgSO_4.7H_2O$); Mn – 5 ($MnCl_2.4H_2O$); Mo – 5 ($(NH_4)_6Mo_7O_{24}\cdot 4H_2O$); B – 0.33 ($H_3BO_3$). The mineral fertilizers, in the form of aqueous solution, as well as petroleum-derived substances, compost, bentonite and calcium oxide, wherever appropriate, were introduced to the soil once prior to sowing spring oilseed rape, by mixing the substances with the whole mass of soil per pot. The soil samples thus prepared (each 9.5 kg) were placed in pots, where their moisture level was brought up to 60% of capillary water capacity. Prior to mixing and placing in pots, the soil was passed through a sieve with a mesh size 1 cm^2 and mixed with mineral fertilizers and in some objects with diesel oil as well as compost, bentonite and CaO. Afterwards, Polish cultivar Mazowiecki spring oilseed rape (*Brassica napus* var. *oleifera*) was sown, which, after the harvest, was followed by Polish cv. Borowik oats (*Avena sativa* L.). After emergence, 8 plants of spring oilseed rape per pot and 15 plants of oats per pot were left to grow. Immediately after harvesting the main crop in the flowering stage (58 day of vegetation) and collecting plants samples for chemical analyses, oats as an aftercrop was sown. The harvest of oats was carried out in the panicle stage (52 day of vegetation), after which plant samples were collected. The experiment was conducted in four replications. During the experiment (110 days), the moisture of soil was maintained at the level of 60% capillary water capacity.

After the vegetation period, the aerial parts of plants were measured for each pot and the plant material was sampled for laboratory analyses. The samples were cut, dried and ground. Next, they were mineralised in 25 cm^3 of concentrated H_2SO_4 with the addition of 1 g of d.m of hydrogen peroxide as a catalyst. The mineralised samples were transferred into conical flasks, which were replenished with distilled water to the volume of 200 cm^3 and assayed for macroelement content. The plant material was analysed for phosphorus by colorimetry (CAVELL 1955). Potassium, calcium and sodium were determined with atomic emission spectroscopy (AES) (SZYSZKO 1982). Magnesium was assayed with atomic absorption spectroscopy (AAS) (SZYSZKO 1982). Prior to plant sowing, the following soil properties were determined: pH (exchangeable acidity) potentiometrically, using aqueous solution of KCl at the concentration of 1M KCl dm^{-3} (LITYŃSKI et al. 1976), hydrolytic acidity – exchangeable H^+ and Al^{+++} (HA) and exchangeable cation bases – Ca^{++}, Mg^{++}, K^+ and Na^+ (ECB) with Kappen method (LITYŃSKI et al. 1976), content of organic carbon (C_{org}) with Tiurin method, using potassium dichromate with diluted sulphuric acid (LITYŃSKI et al. 1976), the content of available phosphorus and potassium – by Egner-Riehm method (LITYŃSKI et al. 1976), the content of available magnesium – by Schachtschabel method (LITYŃSKI et al. 1976). Based on the hydrolytic acidity and exchangeable cation bases, the cation exchange capacity (CEC) and base saturation (BS) were calculated from the following formulas: $CEC = ECB + HA$, $BS = (ECB \cdot CEC^{-1}) \cdot 100$. The results were analysed statistically using three-factor ANOVA and two-factor analysis of variance with Statistica software (StatSoft Inc. 2005). Finally, based on the results, Pearson's simple correlation coefficients between the variables tested experimentally were calculated for all replications.

RESULTS AND DISCUSSION

Effect of petrol and diesel oil on content of some macroelements in plants

The present study has demonstrated that the actual effect of petrol and diesel oil on the content of the macroelements in plants depended on the degree of contamination, application of a neutralizing substance (compost, bentonite and calcium oxide) as well as on the species of a crop, which determined the duration of contamination impact (Tables 1-5, Figure 1). The correlations between doses of petroleum-derived products and content of macroelements in plants were stronger for spring oilseed rape (grown as the main crop) than for oats (the aftercrop). The correlations were stronger

Table 1

Effect of petrol and diesel oil contamination on phosphorus (P) content in aerial parts of plants, in ($g \cdot kg^{-1}$ d.m.)

Dose of Pet or DO ($cm^3 \cdot kg^{-1}$ of soil)	Contamination							
	petrol (Pet)				diesel oil (DO)			
	kind of substance neutralizing effect of Pet and DO							
	without additions	compost	bentonite	CaO	without additions	compost	bentonite	CaO
Spring oilseed rape (*Brassica napus* var. *oleifera*) – main crop								
0	3.15	4.14	3.87	4.25	3.15	4.14	3.87	4.25
2.5	4.66	4.59	4.71	4.69	4.05	4.04	3.72	3.36
5.0	6.18	5.52	5.02	4.55	3.87	4.08	4.17	3.94
10.0	4.90	4.05	5.27	4.17	3.14	5.16	5.96	4.10
r	0.560	-0.057	0.899**	-0.346	-0.212	0.854**	0.920**	0.127
LSD	*a* – 0.04 **, *b* – 0.06 **, *c* – 0.06 **, $a \cdot b$ – 0.08 **, $a \cdot c$ – 0.08 **, $b \cdot c$ – 0.12 **, $a \cdot b \cdot c$ – 0.16 **							
Oats (*Avena sativa* L.) – aftercrop								
0	1.42	1.51	1.69	1.49	1.42	1.51	1.69	1.49
2.5	1.42	1.62	1.49	1.55	1.33	1.52	1.88	1.52
5.0	1.31	1.50	1.42	1.45	1.67	1.71	1.79	1.36
10.0	1.24	1.39	1.50	1.33	1.45	1.47	1.88	1.49
r	-0.954**	-0.737**	-0.582	-0.872**	0.267	-0.086	0.668*	-0.150
LSD	*a* – 0.02**, *b* – 0.03 **, *c* – 0.03 **, $a \cdot$b – 0.04 **, $a \cdot c$ – 0.04 **, $b \cdot c$ – 0.05 **, $a \cdot b \cdot c$ – 0.07 **							

LSD for: *a* – petroleum substance, *b* – petroleum substance dose, *c* – neutralizing substance
**significant at *p*=0.01, *significant at *p*=0.05, *r* – correlation coefficient

Table 2

Effect of petrol and diesel oil contamination on potassium (K) content in above-ground parts of plants, in ($g \cdot kg^{-1}$ d.m.)

Dose of Pet or DO ($cm^3 \cdot kg^{-1}$ of soil)	Contamination							
	petrol (Pet)				diesel oil (DO)			
	kind of substance neutralizing effect of Pet and DO							
	without additions	compost	bentonite	CaO	without additions	compost	bentonite	CaO
Spring oilseed rape (*Brassica napus* var. *oleifera*) – main crop								
0	16.60	20.07	17.99	19.66	16.60	20.07	17.99	19.66
2.5	20.49	18.47	22.63	21.42	17.15	19.55	15.88	14.93
5.0	26.50	21.25	21.85	18.92	20.50	23.78	15.67	17.87
10.0	25.20	15.90	22.01	17.38	23.36	31.73	31.46	26.80
r	0.813**	-0.665*	0.603*	-0.772**	0.977**	0.956**	0.810**	0.741**
LSD	*a* – 0.32 *, *b* – 0.46 **, *c* – 0.46 **, $a \cdot b$ – 0.65 **, $a \cdot c$ – 0.65 **, $b \cdot c$ – 0.92 **, $a \cdot b \cdot c$ – 1.29 **							
Oats (*Avena sativa* L.) – aftercrop								
0	16.55	16.03	18.66	17.13	16.55	16.03	18.66	17.13
2.5	16.86	18.12	19.70	17.81	24.61	24.40	20.62	23.35
5.0	16.74	18.53	19.56	18.23	27.47	27.22	22.00	24.58
10.0	23.49	25.75	22.04	23.76	29.49	26.80	23.98	24.89
r	0.889**	0.964**	0.954**	0.939**	0.886**	0.778**	0.986**	0.787**
LSD	*a* – 0.38 **, *b* – 0.53 **, *c* – 0.53 **, $a \cdot b$ – 0.75 **, $a \cdot c$ – 0.75 **, $b \cdot c$ – 1.07 **, $a \cdot b \cdot c$ – 1.51 **							

LSD for: *a* – petroleum substance, *b* – petroleum substance dose, *c* – neutralizing substance
**significant at p=0.01, *significant at p=0.05, *r* – correlation coefficient

in the objects with petrol than in the variants with diesel oil. In the first series of experiments (without compost, bentonite or CaO), petrol stimulated the content of calcium (r=0.877) and magnesium (r=0.969) in aerial parts of spring oilseed rape (main crop). In the soil samples mixed with 10 cm^3 petrol$\cdot kg^{-1}$, calcium content in spring oilseed rape was 118% and magnesium content was 37% higher than in the non-contaminated objects. Identical effects were produced by 5 cm^3 petrol$\cdot kg^{-1}$ of soil on the content of phosphorus (r=0.560), potassium (r=0.813) and sodium (r=0.813). For these objects, the increase reached 96, 60 and 185%, respectively, compared to the control variant (without petrol). The highest dose of petrol (10 $cm^3 \cdot kg^{-1}$ of soil) resulted in a decrease in the content of phosphorus, potassium and sodium in spring oilseed rape. Diesel oil (without any organic substance or CaO added) stimulated only the potassium content (r=0.977) in the aerial

Table 3

Effect of petrol and diesel oil contamination on sodium (Na) content in aerial parts of plants ($g \cdot kg^{-1}$ d.m.)

Dose of Pet or DO ($cm^3 \cdot kg^{-1}$ of soil)	Contamination							
	petrol (Pet)				diesel oil (DO)			
	kind of substance neutralizing effect of Pet and DO							
	without additions	compost	bentonite	CaO	without additions	compost	bentonite	CaO
Spring oilseed rape (*Brassica napus* var. *oleifera*) – main crop								
0	1.14	1.47	6.01	1.62	1.14	1.47	6.01	1.62
2.5	2.01	1.28	10.38	1.47	2.11	2.53	6.25	1.23
5.0	3.25	2.51	10.39	1.56	1.22	1.40	5.78	0.91
10.0	2.98	2.51	12.43	2.06	1.15	0.79	13.63	0.70
r	0.813**	0.811**	0.885**	0.809**	-0.284	-0.633*	0.865**	-0.951**
LSD	*a* – 0.06 **, *b* – 0.09 **, *c* – 0.09 **, $a \cdot b$ – 0.12 **, $a \cdot c$ – 0.12 **, $b \cdot c$ – 0.18 **, $a \cdot b \cdot c$ – 0.25 **							
Oats (*Avena sativa* L.) – aftercrop								
0	7.67	7.67	17.26	10.41	7.67	7.67	17.26	10.41
2.5	4.91	7.45	16.03	8.96	2.56	3.61	17.29	3.51
5.0	6.18	7.51	16.20	7.69	1.60	1.76	17.47	1.49
10.0	0.77	5.69	14.75	4.05	1.51	2.42	14.86	5.22
r	-0.910**	-0.907**	-0.946**	-0.997**	-0.769**	-0.755**	-0.843**	-0.446
LSD	a – 0.14 **, b – 0.20 **, c – 0.20 **, a·b – 0.28 **, a·c – 0.28 **, b· c – 0.39 **, a· b·c – 0.56 **							

LSD for: *a* – petroleum substance, *b* – petroleum substance dose, *c* – neutralizing substance
**significant at p=0.01, *significant at p=0.05, *r* – correlation coefficient

parts of spring oilseed rape, where the increase was 41%. Similar correlations were found for phosphorus (2.5 $cm^3 \cdot kg^{-1}$ of soil), sodium (2.5 $cm^3 \cdot kg^{-1}$ of soil), calcium (5 $cm^3 \cdot kg^{-1}$ of soil) and magnesium (5 $cm^3 \cdot kg^{-1}$ of soil). This effect was particularly strong, which was evidenced by the increase in calcium (105%) and magnesium (103%). The application of 10 cm^3 of diesel oil per 1 kg of soil caused considerable decrease in phosphorus, sodium, calcium and magnesium, particularly in aerial parts of spring oilseed rape.

The effect of petroleum-derived products on the content of macroelements in aerial parts of oats (aftercrop) was weaker (Tables 1-4). In the first (control) series, the content of phosphorus, sodium and magnesium in aerial parts of oats decreased by 13% (*r*=-0.954), 90% (*r*=-0.910) and 22% (*r*=-0.944), respectively, in objects with petrol The content of sodium, calcium and magnesium content decreased by nearly 80% (r=-0.769), 21% (r=-0.663) and 14%

Table 4

Effect of petrol and diesel oil contamination on calcium (Ca) content in above-ground parts of plants ($g \cdot kg^{-1}$ d.m.)

Dose of Pet or DO ($cm^3 \cdot kg^{-1}$ of soil)	Contamination							
	petrol (Pet)				diesel oil (DO)			
	kind of substance neutralizing effect of Pet and DO							
	without additions	compost	bentonite	CaO	without additions	compost	bentonite	CaO
Spring oilseed rape (*Brassica napus* var. *oleifera*) – main crop								
0	8.47	9.71	9.48	12.37	8.47	9.71	9.48	12.37
2.5	8.70	10.85	11.70	13.03	15.08	16.31	12.05	12.77
5.0	9.92	11.59	11.45	10.89	17.38	17.24	15.87	16.27
10.0	9.96	11.26	12.73	12.78	10.61	18.9	15.58	17.34
r	0.877**	0.739**	0.882**	0.012	0.100	0.853**	0.857**	0.930**
LSD	*a* – 0.23 **, *b* – 0.33 **, *c* – 0.33 **, $a \cdot b$ – 0.46 **, $a \cdot c$ – 0.46 **, $b \cdot c$ – 0.65 **, $a \cdot b \cdot c$ – 0.92 **							
Oats (*Avena sativa* L.) – aftercrop								
0	5.54	4.69	4.74	6.22	5.54	4.69	4.74	6.22
2.5	5.48	5.16	4.16	6.87	5.34	5.65	4.32	6.43
5.0	5.73	5.85	4.14	6.22	6.01	6.63	4.09	6.51
10.0	5.65	4.69	3.85	6.69	4.40	5.14	3.87	6.21
r	0.594	-0.022	-0.899**	0.336	-0.663*	0.182	-0.947**	-0.139
LSD	*a* – n.s., *b* – 0.24 **, *c* – 0.24 **, $a \cdot b$ – 0.34 *, $a \cdot c$ – 0.34 **, $b \cdot c$ – 0.68 **, $a \cdot b \cdot c$ – n.s.							

LSD for: *a* – petroleum substance, *b* – petroleum substance dose, *c* – neutralizing substance
**significant at p=0.01, *significant at p=0.05, *r* – correlation coefficient

(r=-0.577) in oats cultivated in soil contaminated with 10 cm^3 of diesel oil per 1 kg of soil. The highest petrol and diesel oil doses increased only potassium in oat, whereas the middle diesel oil dose (5 $cm^3 \cdot kg^{-1}$ of soil) depressed only the content of phosphorus. Further increases in petrol and diesel oil doses had a negative effect on the content of phosphorus and potassium in oats.

The study presented in this paper has revealed some strong and significant correlations between the content of macroelements in spring oilseed rape and oats versus plant yield and content of other elements in plants, as well as some properties of soil (Table 6). Such relationships are confirmed especially by correlation coefficients calculated between the content of potassium, sodium and calcium and other elements in plants and properties of soil.

Table 5

Effect of petrol and diesel oil contamination on magnesium (Mg) content in aerial parts of plants ($g \cdot kg^{-1}$ d.m.)

Dose of Pet or DO ($cm^3 \cdot kg^{-1}$ of soil)	Contamination							
	petrol (Pet)				diesel oil (DO)			
	kind of substance neutralizing effect of Pet and DO							
	without additions	compost	bentonite	CaO	without additions	compost	bentonite	CaO
Spring oilseed rape (*Brassica napus* var. *oleifera*) – main crop								
0	2.32	2.64	2.17	3.14	2.32	2.64	2.17	3.14
2.5	2.60	2.55	2.92	2.69	4.48	4.15	2.73	2.64
5.0	2.60	2.93	3.06	2.53	4.70	4.27	3.23	2.95
10.0	3.17	2.83	3.28	2.54	3.47	4.84	4.19	4.00
r	0.969**	0.639*	0.874**	-0.795**	0.280	0.878**	0.999**	0.758**
LSD	*a* – 0.04 **, *b* – 0.06 **, c – 0.06 **, *a*·*b* – 0.08 **, *a*·*c* – 0.08 **, *b*·*c* – 0.12 **, a·b·c – 0.16 **							
Oats (*Avena sativa* L.) – aftercrop								
0	3.69	2.95	2.76	2.93	3.69	2.95	2.76	2.93
2.5	3.45	3.25	2.88	3.48	3.18	3.58	2.73	2.98
5.0	3.50	3.91	2.88	3.23	3.60	3.52	3.11	2.86
10.0	2.86	2.73	2.73	3.10	3.17	2.97	2.86	2.97
r	-0.944**	-0.183	-0.315	0.038	-0.577	-0.163	0.379	0.125
LSD	*a* – n.s., *b* – 0.07 **, *c* – 0.07 **, *a*·*b* – 0.11 **, *a*·*c* – 0.11 **, *b*·*c* – 0.15 **, *a*·*b*·*c* – 0.21 **							

LSD for: *a* – petroleum substance, *b* – petroleum substance dose, *c* – neutralizing substance
**significant at p=0.01, *significant at p=0.05, n.s. – non-significant, *r* – correlation coefficient

These results are confirmed by the literature on the effect of petroleum-derived compounds on plants (IWANOW et al. 1994, AMADI et al. 1996, WYSZKOWSKI et al. 2004). The negative effect of such pollutants is a product of the behaviour of petroleum-derived compounds in soil, where they block air spaces that allow air and water to enter soil layers, which causes soil lumping and deteriorates physical, chemical and biological properties of soil. The organic carbon to nitrogen ratio in soil contaminated with petroleum-derived products is typically unfavorable. Therefore, reactions of mineral and organic nitrogen compounds in soil are inhibited. The rate of ammonification and nitrification decreases (IWANOW et al. 1994, AMADI et al. 1996) while bacteria and fungi develop intensively and consume macroelements. The content of plant available macroelements in soil decreases (XU, JOHNSON 1997). Such a development has been confirmed in the present study and in earlier re-

Table 6

Person's simple correlation coefficient between content of macroelements in plants and yield and some properties of soil

Variable	Content in plants									
	spring oilseed rape (*Brassica napus var. oleifera*)					oats (*Avena sativa* L.)				
	P	K	Na	Ca	Mg	P	K	Na	Ca	Mg
Plants										
Yield	-0.075	-0.508**	0.009	-0.654**	-0.726**	-0.275*	0.408**	-0.432**	-0.081	0.182
N	0.730**	0.530**	0.276*	0.127	0.148	0.491**	0.113	0.413**	-0.283*	0.005
P	X	0.646**	0.456**	0.111	0.173	X	0.062	0.545**	-0.290*	-0.110
K	0.646**	X	0.227	0.341**	0.527**	0.062	X	-0.444**	0.012	-0.125
Na	0.456**	0.227	X	-0.019	0.010	0.545**	-0.444**	X	-0.559**	-0.380**
Ca	0.111	0.341**	-0.019	X	0.840**	-0.290*	0.012	-0.559**	X	0.437**
Mg	0.173	0.527**	0.010	0.840**	X	-0.110	-0.125	-0.380**	0.437**	X
Soil										
pH KCl	0.061	-0.103	0.329**	0.155	-0.198	0.089	-0.273*	0.424**	0.196	-0.397**
HA	-0.171	0.070	-0.425**	-0.156	0.179	-0.116	0.361**	-0.582**	-0.041	0.445**
ECB	0.233	0.028	0.435**	0.087	-0.139	-0.290*	-0.182	0.274*	-0.061	-0.235
CEC	0.194	0.061	0.317*	0.034	-0.084	-0.378**	-0.071	0.093	-0.086	-0.101
BS	0.258*	-0.055	0.445**	0.158	-0.198	-0.040	-0.390**	0.541**	0.009	-0.401*
$N-NO_3$	-0.065	-0.068	-0.087	-0.249*	-0.005	0.037	0.538**	-0.259*	-0.244	0.085
$N-NH_4$	-0.045	0.195	-0.130	0.496**	0.568**	0.376**	0.710**	0.012	-0.146	-0.294*
C_{org}	0.014	0.419**	-0.230	0.569**	0.615**	-0.020	0.012	-0.274*	0.132	0.407**
$P_{available}$	0.132	0.019	0.103	0.203	0.085	0.107	-0.154	0.194	0.291*	-0.157
$K_{available}$	0.031	0.393**	0.173	0.600**	0.675	0.433**	0.640**	0.087	-0.347**	-0.260*
$Mg_{available}$	0.036	0.144	0.553**	-0.024	0.139	0.426**	0.571**	0.307*	-0.667**	-0.277*

**significant at p=0.01, *significant at *p*=0.05

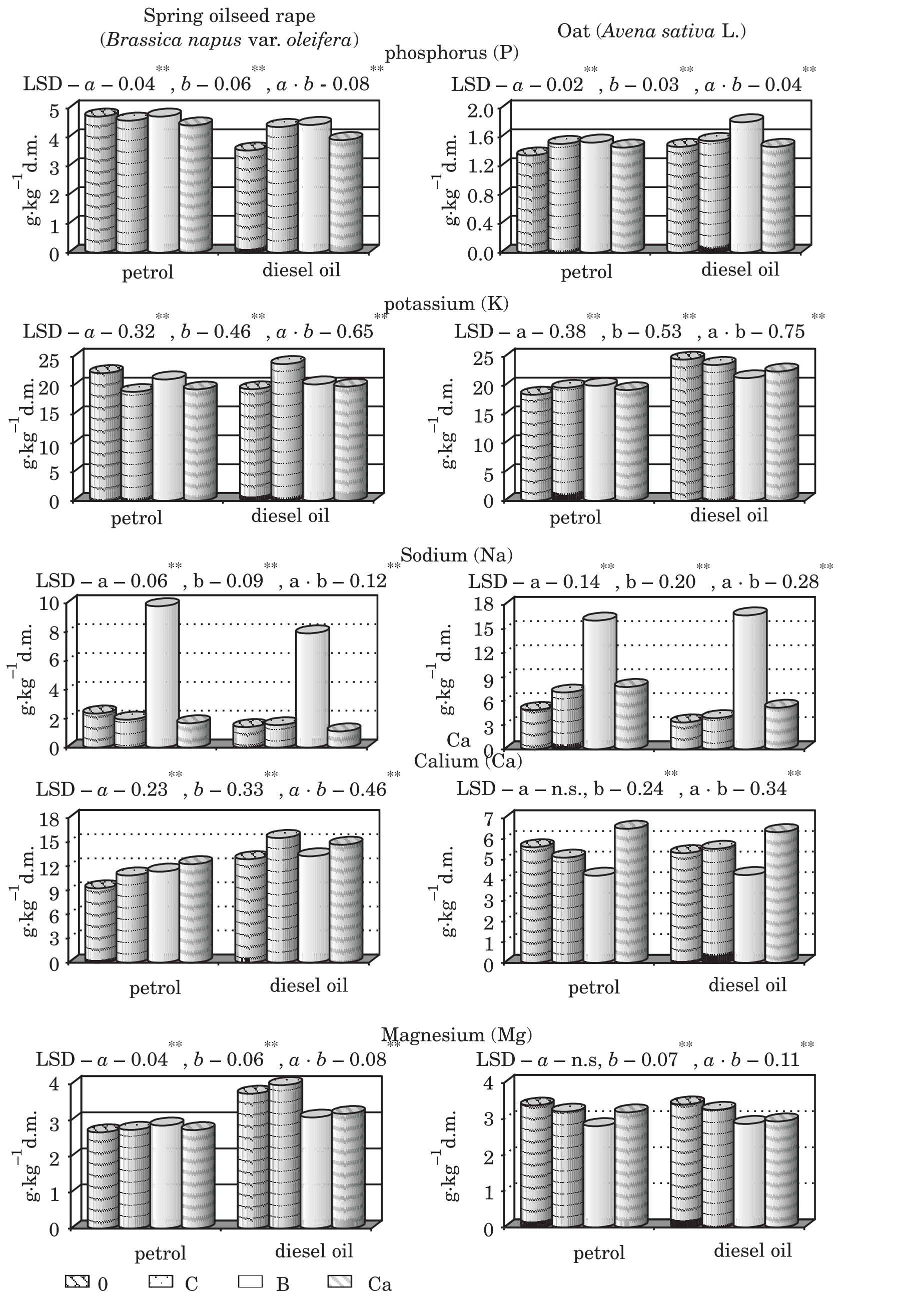

Fig. 1. Comparison of the effect of a neutralizing substances on the content of some macroelements of plants, in g·kg^{-1} d.m. (average for series):
0 – without substances, C – with compost, B – with bentonite, Ca – with calcium oxide
LSD for: a – kind of a petroleum substances, b – addition of a neutralizing substances
**significant for p=0.01, *significant for p=0.05, n.s. non-significant

search (Wyszkowski, Wyszkowska 2005), in which limited content of macroelements in oats from soil contaminated by high doses of diesel oil was demonstrated. Another experiment reported by Wyszkowski and Wyszkowska (2005) indicates correlation between the enzymatic activity of soil and the content of nitrogen and phosphorus in plants. However, this correlation was strongly modified by the presence of diesel oil, nitrogen and sawdust in soil.

The effect of petrol and diesel oil on macroelements in plants is determined by many factors, of which plant variety seems to be the most important. In the study by Dimitrov and Mitowa (1998) only 3 out of 7 experimental plant species contained modified levels of some macroelements when cultivated on diesel oil-contaminated soil in comparison to uncontaminated soil. According to Wyszkowski and Wyszkowska (2005), content of most macroelements in aerial parts of maize on diesel oil-contaminated soil is likely to increase.

Role of compost, bentonite and calcium oxide in modification of the influence petroleum-derived products on plants' chemical composition

A very important factor which modified content of macroelements in plants was the addition of compost, bentonite or calcium oxide (Tables 1-4, Figure 1). On average, irrespective of the degree of soil contamination, all components introduced to soil in order to alleviate possible negative effects of petroleum-derived products significantly modified the content of macroelements in aerial parts of both plants. Obviously, the effect of the neutralizing substances varied depending on the dose of petrol and diesel oil added to soil. The effect of a neutralizing substance (compost, bentonite and calcium oxide) on the content of the majority of macroelements was stronger in spring oilseed rape than in oats. Compost, bentonite or CaO more strongly contributed to increasing the content of sodium, calcium and magnesium than phosphorus and potassium in plants. Bentonite was the effective in increasing sodium in aerial parts of both plants, especially spring oilseed rape. In the bentonite-treated series, the highest increase in sodium content in spring oilseed rape (*ca* 9-fold in petrol objects and *ca* 7-fold in diesel oil objects) was observed in either uncontaminated objects or polluted with the highest doses of petrol and diesel oil. Calcium oxide and, to a lesser degree bentonite (only in spring oilseed rape), increased the content of calcium in plants. As for magnesium, the correlation was reverse. The results obtained after the application of compost were less consistent.

The application of compost and other substances to soil usually have a positive effect on soil properties, plants' growth and chemical composition (Vouillamoz, Milke 2001). Compact soils rich in humus are far more tolerant to degradation than sandy soils (Wyszkowski et al. 2004). Organic substance improves absorbance of petroleum products and has influence on the biological life of soil (Małachowska-Jutsz et al. 1997) and consequently on plants.

Liming improves properties of soil. Bentonite added to soil forms a compact barrier, which prevents petroleum products from reaching deeper horizons of the soil profile. Moreover, content of elements available to plants rise, which is of importance for plant growth and development (WYSZKOWSKI et al. 2004, WYSZKOWSKI, WYSZKOWSKA 2005).

CONCLUSIONS

1. Irrespective of the application of compost, bentonite or calcium oxide, the highest doses of petrol and especially diesel oil decreased the content of most macroelements in spring oilseed rape and, to a smaller degree, in oats.

2. Enrichment of soil contaminated with petroleum-derived products with organic matter, bentonite or calcium oxide improved chemical composition of plants, which was demonstrated as increased content of some macroelements in plants. These neutralizing substances added to soil increased its tolerance to eco-toxic effects of petrol and diesel oil.

3. Enrichment of soil with compost, bentonite or calcium oxide modified the content of macroelements in plant, mainly sodium when bentonite was used.

4. Some strong and significant correlations between the content of macroelements in spring oilseed rape and oats versus plants yield and content other elements in plants, as well as some properties of soil were observed.

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