Effect of soil contamination with diesel oil on yellow lupine yield and macroelements content

M. Wyszkowski, J. Wyszkowska, A. Ziółkowska

University of Warmia and Mazury in Olsztyn, Poland

ABSTRACT

The study has been undertaken to assay the effect of soil contamination with diesel oil on yellow lupine yield and macroelement contents as well as to examine the relationships between the accumulation of macroelements versus the yellow lupine yielding and some yield quality characteristics. The influence of soil pollution with refinery products depended on the type of soil, diesel oil concentration in soil and mineral fertilisation. Increasing contents of soil pollution with diesel oil promoted higher concentrations of phosphorus, sodium, magnesium and calcium in aboveground parts and roots of yellow lupine. More severe contamination was also responsible for depressed yield of yellow lupine aboveground parts and roots as well as accumulation of nitrogen in aboveground parts and potassium in roots of the crop. The addition of nitrogen to soil diversified the yielding and content of macroelements in yellow lupine. The direction these changes took depended on the plant organ, type of soil and degree of diesel oil contamination.

Keywords: soil; diesel oil contamination; nitrogen application; yellow lupine yield; macroelements content

Pollution of the soil environment with petroleum and refinery products is one of the factors expressing anthropopression. Due to its toxicity, widespread presence and complex nature, this type of pollution is a serious problem, one reason being that as the modern civilisation, urbanisation and mechanisation develop, the use of petroleum and petroleum-based products grows. Contamination of soils with crude oil and refinery products is becoming an ever-increasing problem, especially in the light of several breakdowns of oil pipelines and wells reported recently. Nonetheless, major points of soil pollution with refinery products are petrol stations, garages servicing cars and tractors, seaport areas (Michalcewicz 1995). Other areas of concern are mining and distribution of petroleum-based products (Song and Barhta 1990, Amadi et al. 1996, Jørgensen et al. 2000). Besides, heavier use of machinery in agriculture leads to higher consumption of diesel oil. Certain negligence when transporting, collecting or storing refinery products together with unsatisfactory care while disposing of old or used petroleum products lead to considerable pollution of the natural environment (Leahy and Colwell 1990).

Petroleum and refinery products penetrating soil cause its degradation (Sztompka 1999). Once they enter an ecosystem, petroleum-based products initiate a series of processes, affecting both its biotic and abiotic elements (Małachowska-Jutsz et al. 1997). Crude oil and products derived from this raw material are composed of aliphatic, oleic, naphthenic and aromatic hydrocarbons (Chi Yuan and Krishnamurthy 1995), which modify physical and chemical properties of soil and its structure. These compounds are largely responsible for changed fertility of soil (Tyczkowski 1993, Iwanow et al. 1994). Soil polluted by petroleum-based products loses its biological activity and may not be able to recover it over ten years (Sparrow and Sparrow 1988, Racine 1993, Wyszkowska et al. 2001). Moreover, diesel oil has a negative effect on the biochemical and physicochemical characteristics of soils (Tyczkowski 1993, Kucharski and Wyszkowska 2001, Wyszkowska et al. 2002).

Since contamination of soil with refinery products deteriorates its biochemical and physicochemical properties, it also limits the growth and development of plants, whose nutritive and technological value can be low and often questionable. In this connection, the present study has been undertaken to determine the effect of soil contamination with diesel oil on yellow lupine yielding and macroelements content and to assess the relationship between the accumulation of macroelements and lupine yield and some yield quality characteristics.

MATERIAL AND METHODS

The trials were conducted in the greenhouse, in plastic pots containing 3.2 kg soil each. Four replications were performed. Two types of soil were tested: Eutric Cambisol soil derived from light loamy sand and Eutric Cambisol soil derived from light loam (Table 1). Before the experiment was established,

Table 1. Some physicochemical properties of the soils used in the experiments

Type (kind) of soil	Granulometric composition (mm)			C (g/kg)	pH_{KCl}	Hh	S
	1.0–0.1	0.1–0.02	< 0.02			mmol(+)/kg of soil	
Eutric Cambisol (light loamy sand)	54	33	13	6.2	6.3	10.8	65.5
Eutric Cambisol (light loam)	62	12	26	7.6	6.5	12.4	81.5

C = organic carbon content, Hh = hydrolytic acidity, S = total exchange bases

the soil was mixed with mineral fertilisers and with diesel oil where required (0, 1.69, 3.38, 5.07, 6.76, 8.45 and 10.14 g/kg of soil). Diesel oil characterized with the following properties: water content – max. 200 mg/kg, solid contamination content – max. 24 mg/kg, sulphur content – max. 0.5 g/kg, mass density in 15°C – max. 860 kg/m^3, stickiness in 40°C – max. 4.5 mm^2/s (PN-EN 590). The trials were performed in two series: 0 and 250 mg N/kg in the form of $CO(NH_2)_2$ (half the dose applied 18 days before sowing and the other half on the day of sowing). In all pots, the soil was enriched with the following amounts of macro- and microelements necessary for the proper growth and development of plants (quantities expressed in mg/kg of soil): P – 75 (K_2HPO_4); K – 140 (K_2HPO_4 + KCl); Mg – 40 ($MgSO_4.7H_2O$); Zn – 5 ($ZnCl_2$); Cu – 5 ($CuSO_4.5 H_2O$); Mn – 5 ($MnCl_2.4 H_2O$); Mo – 5 ($Na_2MoO_4.2 H_2O$); B – 0.33 (H_3BO_3). During the first 18 days the soil was not sown. After 18 days the soil was sown with cv. Juno yellow lupine (7 plants per pot). For the whole vegetation period lasting 76 days, the soil moisture was maintained at a fixed level of 60% of the capillary water holding capacity.

Plant material samples were taken during the harvest of yellow lupine plants. The samples were then shredded, dried and ground. While preparing chemical analyses, 1 g of plant dry matter was ashed in 25 cm^3 concentrated H_2SO_4 with the addition of 5 cm^3 hydrogen peroxide as a catalysing agent. The samples were then transferred to conical flask and filled up to 200 cm^3 with distilled water. In the plant samples determined total content of macroelements. Nitrogen was determined by Kjeldahl method (Bremner 1965), phosphorus by vanadium-molybdenum colorimetric method (Calvell 1955), magnesium by atomic absorption spectrometry – AAS (Szyszko 1982) and potassium, calcium and sodium by atomic emission spectrometry – AES (Szyszko 1982).

The results were elaborated statistically using two-factor analysis of variance ANOVA. Pearson's simple correlation coefficients were also computed for diesel oil doses versus yield of lupine plants, number and weight of root nodules, content of macroelements, using Statistica software (StatSoft 2001).

RESULTS AND DISCUSSION

Apart from their indirect effect via soil (Racine 1993, Iwanow et al. 1994, Wyszkowska et al. 2002), hydrocarbons from refinery products can also affect plants directly, smearing root plants with oily substances and thus limiting transpiration and respiration by plants, reducing permeability of cell membranes, and upsetting metabolic conversions leading to changes in the chemical composition, and lastly through the toxic influence of some hydrocarbons on plants (Pezeshki et al. 2000). The prevailing opinion found in the relevant references is that petroleum-based products have adverse impact on yields of various plant species and in high doses they can depress germination of plants and cause necrosis of seedlings (Sparrow and Sparrow 1988, Amadi et al. 1996). This assumption has been confirmed by the authors' own studies.

The yield of yellow lupine was correlated with the degree of soil contamination by diesel oil, type of soil, nitrogen fertilisation and plant organ (Figure 1). It has to be added that diesel oil exerted a stronger effect on the aboveground parts rather than the roots of plants. The highest dose of the contaminant (10.14 g/kg of soil) in the treatment without nitrogen depressed the yield of aboveground parts of plants grown in light loamy sand by 80% and that of plants grown in light loam by 82%. The yields of root weight were depressed by 66 and 28%, respectively. The addition of nitrogen reduced the negative impact of diesel oil on yellow lupine yielding only in the objects with the smallest concentration of the pollutant (1.69 g/kg of soil). In the objects polluted with higher doses of diesel oil, the introduction of nitrogen did not reduce the toxicity of this refinery product. In contrast, its toxic effect was even more pronounced.

The relevant literature contains evidence suggesting that refinery products, including diesel oil, are toxic to plants (Sparrow and Sparrow 1988, Iwanow et al. 1994, Amadi et al. 1996, Kucharski and Wyszkowska 2001, Wyszkowska et al. 2001). The negative impact of petroleum-based products can be attributed to the fact that as these substances continue to penetrate soil deeper and deeper, they

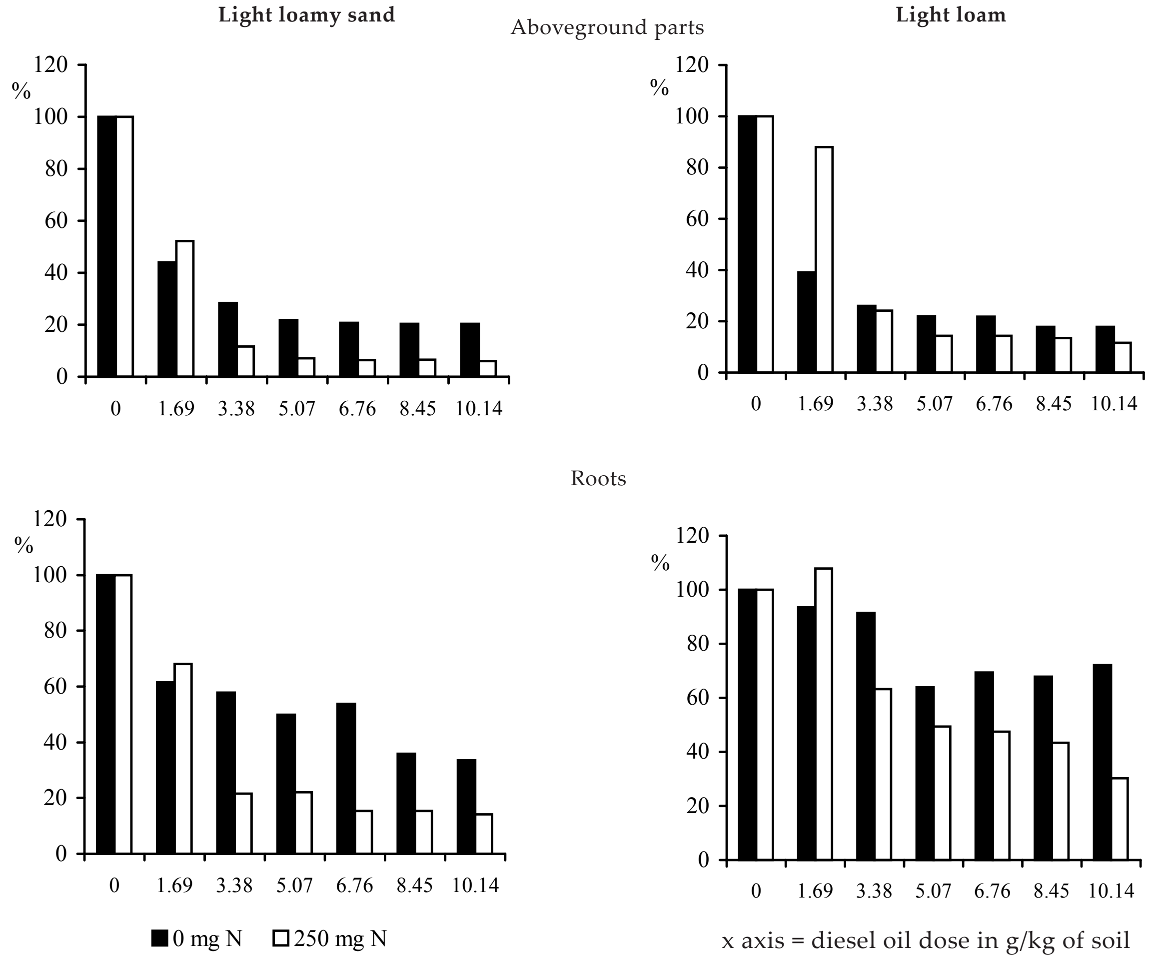

Figure 1. Changes of yield of yellow lupine in dependence of diesel oil dose (g/kg of soil)

block air spaces that allow air and water to enter soil layers. As a result, the soil is becoming more compact, its physical, chemical and biological properties are deteriorating, and finally its productive potential is diminishing.

The tests (Tables 2 and 3, Figure 2) show that soil contamination with diesel oil significantly affected the accumulation of nitrogen, potassium, magnesium and calcium, both in aboveground parts and in roots of yellow lupine plants.

The concentration of nitrogen in yellow lupine aboveground parts and roots was strongly dependent on the type of soil and nitrogen application (Table 2). The high average nitrogen content in aboveground parts and roots of yellow lupine was observed on the soil of light loamy sand granulometric composition. In the series without fertilisation, increasing doses of diesel oil caused decreased nitrogen content in aboveground parts of plants grown in either type of soil. It was only in the objects with light loam soil polluted by the highest dose of diesel oil that a significant increase in the nitrogen concentration was observed (versus the control, unpolluted combinations). Under the effect of the most severe soil contamination with diesel oil (10.14 g/kg of soil), the concentration of nitrogen in yellow lupine aboveground parts was determined to decline by 63% in light loamy sand and by 45% in light loam. There was one exception, however. The content of nitrogen was observed to have increased in the light loam soil treated with 250 mg N/kg. The series without nitrogen fertilisation contaminated with the diesel dose of 10.14 g/kg of soil in both types of soil caused a comparable decrease in the content (reaching 45%) of this macroelement relative to the control objects (without diesel oil). When applying the highest dose of diesel oil in the nitrogen fertilised series, an increase in the nitrogen accumulation in roots was observed, equal to 61% in light loamy sand and to 10% in light loam compared with the control.

Another reason why refinery products have an unfavourable effect on the state of soil is the greasy texture of hydrocarbons, whose excessive presence in soil is also responsible for the prevailing amounts

Table 2. Content of nitrogen, phosphorus and potassium in yellow lupine (g/kg dry matter)

Diesel oil dose (g/kg of soil)	Aboveground parts				Roots			
	light loamy sand		light loam		light loamy sand		light loam	
	0 mg N	250 mg N	0 mg N	250 mg N	0 mg N	250 mg N	0 mg N	250 mg N
Nitrogen (N)								
0	17.02	16.29	12.47	6.80	8.79	7.19	8.84	7.32
1.69	17.33	15.11	14.59	10.75	8.67	6.76	9.16	6.17
3.38	15.47	14.24	10.64	11.12	8.06	9.46	7.00	7.89
5.07	10.59	16.23	9.00	11.15	7.83	10.31	7.36	9.14
6.76	7.31	13.83	7.26	12.83	7.39	14.13	7.18	8.74
8.45	6.29	13.23	7.64	9.02	6.38	14.46	5.43	8.53
10.14	6.31	8.96	6.81	7.99	4.87	11.58	4.90	9.82
	11.47	13.99	9.77	9.95	7.43	10.55	7.12	8.23
Average	12.73		9.86		8.99		7.68	
	11.30				8.34			
LSD	a = 0.44**, b = 0.44**, c = 0.82**, a × b = 0.62**, a × c = 1.17**, b × c = 1.17**, a × b × c = 1.65**				a = 0.29**, b = 0.29**, c = 0.54**, a × b = 0.41**, a × c = 0.77**, b × c = 0.77**, a × b × c = 1.09**			
Phosphorus (P)								
0	3.63	3.19	2.45	2.16	3.37	2.73	2.97	1.93
1.69	4.27	3.34	2.79	1.85	4.15	2.98	2.28	2.76
3.38	5.02	4.47	3.61	2.05	4.13	3.07	2.13	2.36
5.07	5.82	4.35	4.06	2.64	4.24	4.02	3.27	2.42
6.76	6.29	4.93	3.77	3.00	3.94	4.59	2.90	2.99
8.45	6.38	5.06	4.04	3.20	3.64	4.45	4.02	2.27
10.14	6.06	5.63	3.41	3.35	3.69	3.87	2.49	3.01
	5.35	4.43	3.45	2.61	3.88	3.67	2.87	2.53
Average	4.89		3.03		3.78		2.70	
	3.96				3.24			
LSD	a = 0.11**, b = 0.11**, c = 0.21**, a × b = n.s., a × c = 0.29**, b × c = 0.29**, a × b × c = 0.41**				a = 0.18**, b = 0.18**, c = 0.34**, a × b = n.s., a × c = n.s., b × c = 0.48**, a × b × c = 0.68**			
Potassium (K)								
0	23.91	22.85	20.73	17.57	16.39	10.75	11.43	9.43
1.69	23.58	28.03	20.51	18.26	17.77	12.67	11.90	8.51
3.38	23.31	33.85	20.94	26.46	15.01	12.44	11.10	10.59
5.07	24.58	31.80	23.41	26.03	14.67	12.22	10.46	10.91
6.76	26.74	32.07	23.83	32.97	13.25	9.88	9.12	6.11
8.45	30.45	30.28	26.45	31.70	12.46	8.43	7.87	6.60
10.14	29.98	31.77	22.82	34.19	10.65	12.27	7.09	6.46
	26.08	30.09	22.67	26.74	14.31	11.24	9.85	8.37
Average	28.09		24.71		12.78		9.11	
	26.40				10.94			
LSD	a = 0.76**, b = 0.76**, c = 1.41**, a × b = n.s., a × c = 2.00**, b × c = 2.00**, a × b × c = 2.83**				a = 0.22**, b = 0.22**, c = 0.42**, a × b = 0.31**, a × c = 0.59**, b × c = 0.59**, a × b × c = 0.84**			

LSD: a = kind of soil, b = nitrogen dose, c = diesel oil dose

n.s. = non-significant differences at $p = 0.05$, *significant at $p = 0.05$, **significant at $p = 0.01$

Table 3. Content of sodium, magnesium and calcium in yellow lupine (g/kg dry matter)

Diesel oil dose (g/kg of soil)	Aboveground parts				Roots			
	light loamy sand		light loam		light loamy sand		light loam	
	0 mg N	250 mg N	0 mg N	250 mg N	0 mg N	250 mg N	0 mg N	250 mg N
Sodium (Na)								
0	4.13	2.07	1.50	1.30	12.57	11.08	12.04	11.37
1.69	4.62	2.79	1.29	1.35	14.02	13.85	13.37	10.39
3.38	2.32	4.82	1.43	4.27	12.27	14.58	12.72	12.77
5.07	2.77	4.48	1.69	3.80	11.65	16.18	14.32	13.74
6.76	3.19	3.95	1.81	4.34	12.03	12.56	14.30	14.41
8.45	4.35	3.07	1.94	4.49	13.08	12.34	12.39	12.32
10.14	4.11	2.81	2.59	5.38	11.77	12.99	12.34	13.16
	3.64	3.43	1.75	3.56	12.48	13.37	13.07	12.60
Average	3.53		2.66		12.93		12.83	
	3.10				12.88			
LSD	a = 0.14**, b = 0.14**, c = 0.26**, a × b = 0.20**, a × c = 0.37**, b × c = 0.37**, a × b × c = 0.52**				a = n.s., b = 0.23**, c = 0.42**, a × b = 0.32**, a × c = 0.60**, b × c = 0.60**, a × b × c = 0.85**			
Magnesium (Mg)								
0	2.87	3.21	2.35	2.90	2.81	3.66	2.82	4.07
1.69	3.25	3.31	3.15	3.18	3.55	4.81	4.50	5.14
3.38	3.64	4.28	3.77	3.14	3.25	5.42	4.73	6.20
5.07	3.82	3.92	4.13	3.24	3.82	5.14	5.24	5.04
6.76	3.75	3.82	3.99	3.29	3.83	3.74	5.81	5.41
8.45	4.19	3.52	3.88	3.20	3.95	3.33	4.80	4.96
10.14	4.38	3.43	3.75	3.00	3.36	3.69	4.94	5.30
	3.70	3.64	3.57	3.14	3.51	4.26	4.69	5.16
Average	3.67		3.36		3.88		4.93	
	3.51				4.41			
LSD	a = 0.09**, b = 0.09**, c = 0.17**, a × b = 0.13**, a × c = 0.24**, b × c = 0.24**, a × b × c = 0.34**				a = 0.05**, b = 0.05**, c = 0.10**, a × b = 0.08**, a × c = 0.14**, b × c = 0.14**, a × b × c = 0.20**			
Calcium (Ca)								
0	7.96	12.05	8.93	11.14	2.73	2.05	2.91	1.65
1.69	10.12	16.14	12.16	12.76	3.60	3.55	2.34	1.91
3.38	13.51	18.39	12.63	13.86	2.94	4.42	2.72	2.57
5.07	15.34	17.57	18.46	14.06	3.07	4.28	3.30	2.96
6.76	16.09	15.57	20.47	15.35	3.11	5.13	2.90	2.67
8.45	16.79	13.35	21.18	15.13	3.22	4.90	2.05	2.47
10.14	17.90	13.19	20.82	14.44	2.98	5.45	2.32	3.47
	13.96	15.18	16.38	13.82	3.09	4.25	2.65	2.53
Average	14.57		15.10		3.67		2.60	
	14.84				3.13			
LSD	a = 0.42*, b = 0.42**, c = 0.79**, a × b = 0.60**, a × c = 1.12**, b × c = 1.12**, a × b × c = 1.57**				a = 0.28**, b = 0.28**, c = 0.52**, a × b = 0.39**, a × c = 0.73**, b × c = 0.73**, a × b × c = 1.04**			

LSD: a = kind of soil, b = nitrogen dose, c = diesel oil dose

n.s. = non-significant differences at $p = 0.05$, *significant at $p = 0.05$, **significant at $p = 0.01$

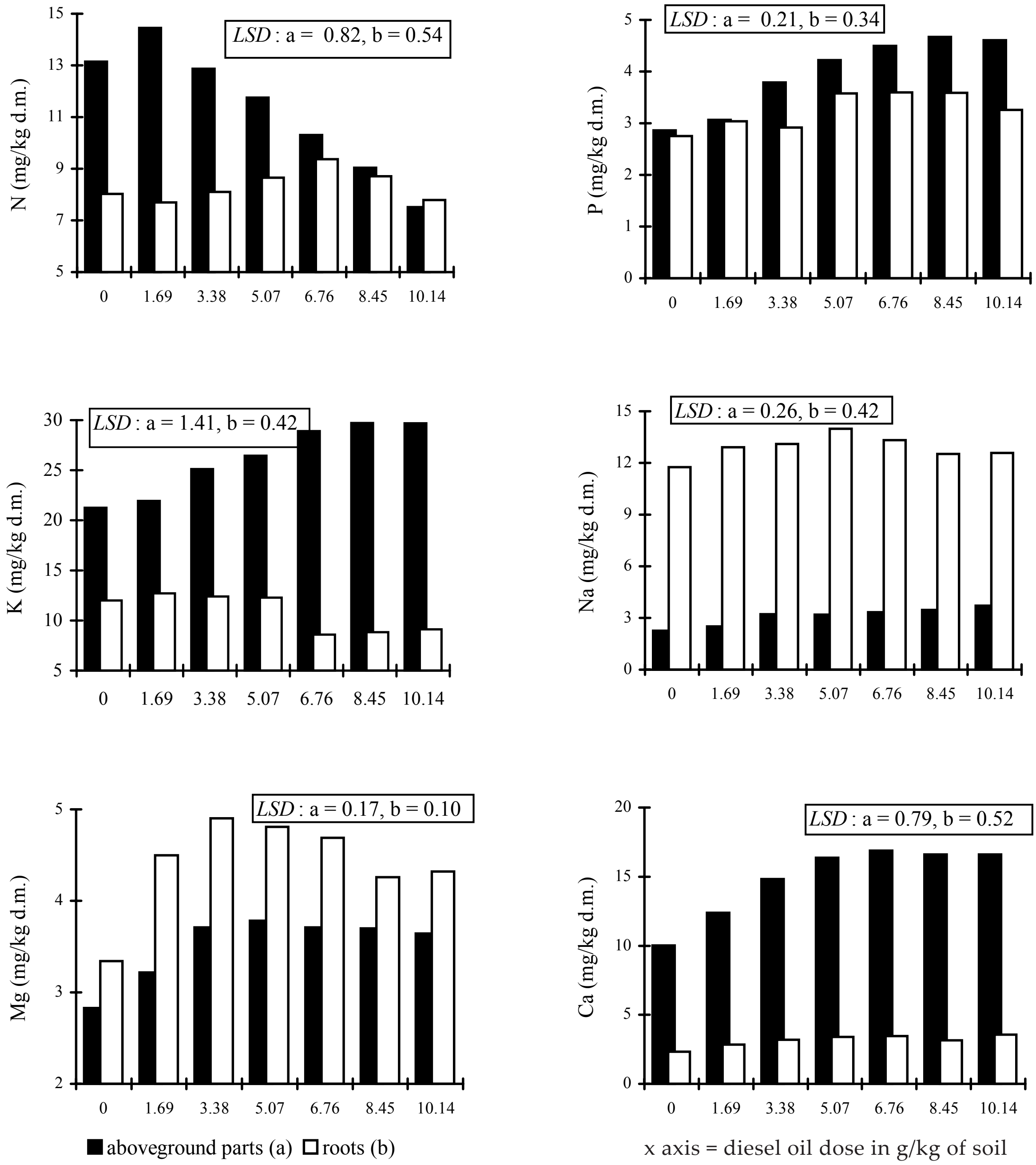

Figure 2. Content of macroelements in yellow lupine, irrespective of the kind of soil and nitrogen dose (g/kg dry matter)

of organic carbon over those of nitrogen in soil. In this situation, petroleum derived compounds inhibit conversion of mineral and organic nitrogen compounds in soil, thus depressing the processes of ammonification and nitrification (Iwanow et al. 1994, Amadi et al. 1996). The fact that nitrification processes are retarded has also been indicated by the results reported by Rimowsky et al. (1998). When this happens is because, bacteria and fungi growing on a hydrocarbons medium in soil consume all available nitrogen, restricting the uptake of these elements by plants, as has been confirmed by the authors' own research and several investigations (Małachowska-Jutsz et al. 1997, Xu and Johnson 1997). The experiments realised by Dimitrov and Mitova (1998) showed a large range of variability in the nitrogen uptake by plants growing in soils contaminated with diesel oil depending on plant species. Out of 7 tested plant species, 3 were determined to contained elevated concentrations of nitrogen relative to the plants from unpolluted soils.

As regards phosphorus, it was revealed that the highest doses of the petroleum-based product tested were responsible for increased P and K accumulation in aboveground parts of yellow lupine (Table 2,

Table 4. Significantly Pearson's simple correlation coefficients between the macroelements content and diesel oil dose and yield and chemical composition aboveground parts and roots of yellow lupine

Variable		N	P	K	Na	Mg	Ca
Aboveground parts							
Diesel oil dose		–0.45	0.48	0.55	0.35	0.59	0.67
Yield		0.31	–0.43	–0.58	–0.42	–0.57	–0.61
Length of stems		0.28	–0.31	–0.73	–0.53	–0.44	–0.53
Content	N					–0.28	–0.47
	P			0.46	0.27	0.65	0.33
	K		0.46		0.73	0.30	0.36
	Na		0.27	0.73			
	Mg	–0.28	0.65	0.30			0.74
	Ca	–0.47	0.33	0.36		0.74	
Roots							
Diesel oil dose			0.28	–0.37		0.35	
Yield		–0.42		0.43	–0.29	–0.44	–0.30
Nodules quantity		–0.28		0.53		–0.43	–0.25
Nodules mass				0.53		–0.47	
Content	N		0.38				
	P	0.38		0.34		–0.36	–0.44
	K		0.34			–0.37	–0.46
	Na					0.54	
	Mg		–0.36	–0.37	0.54		0.40
	Ca		–0.44	–0.46		0.40	

Figure 2). The increase was correlated with the amount of nitrogen available to plants in soil. In the soil of light loamy sand, it reached 67% in the unfertilised series and 77% in the N fertilised series. In light loam, the respective results were 39 and 45%. The highest dose of diesel oil (10.14 g/kg of soil) caused the maximum increase in potassium contents, reaching 25% in the series without N, 39% in the objects fertilised with 250 mg N/kg in a pot filled with light loamy sand and as much as 95% in light loam. Diesel oil contamination of soil was also responsible for higher accumulation of phosphorus in yellow lupine roots, but the increase was less regular in the objects filled with light loam than those containing light loamy sand. The unfertilised series in light loam was an exception, as it was determined to have a lower P content. Increasing doses of diesel oil resulted in depressed K contents in yellow lupine roots, except the object polluted with the dose of diesel oil equal 3% mwc established in light loamy sand, in which the effect of contamination was irregular.

The concentration of sodium in yellow lupine aboveground parts was clearly varied among roots (Table 3, Figure 2). The presence of diesel oil in soil was not indifferent to the accumulation of sodium in yellow lupine plants. In general, this influence was positive, both in aboveground parts and in the roots, except the series without nitrogen fertilisation, in which it was irregular. The application of readily available nitrogen to soil stimulated the uptake of sodium in the diesel oil polluted objects compared to the control (not contaminated with diesel oil). The highest increase in the concentration of this element (3-fold higher than in the control) was determined in the aboveground parts of plants harvested from the soil polluted with the maximal dose of diesel oil (10.14 g/kg of soil) in the series with 250 mg N/kg in light loam.

In nearly all the objects, both in the roots and in the aboveground parts of plants, yellow lupine was determined to have been capable of accumulating more magnesium and calcium when grown in the soil contaminated with increasing diesel oil doses compared to the control combinations (Table 3, Figure 2). The increase in magnesium accumulation was significantly larger in the objects without nitrogen than in those fertilised with this element, especially in the roots of yellow lupine plants grown in light loam. It should be emphasised that higher magnesium contents in yellow lupine plants from the unfertilised series were determined also in the soil contaminated with the high doses of diesel oil, whereas in the objects fertilised with nitrogen such an effect was shown in the case of medium diesel oil doses (3.38–6.76 g/kg of soil). Nevertheless, it has to be said that considerably high Ca contents were determined in the aboveground parts of yellow lupine plants from the unfertilised objects, in contrast to their roots. Irregular fluctuations in the content of calcium in the roots of yellow lupine plants from the series without nitrogen set in light loam were exceptional.

Bacteria and fungi in soil consume available phosphorus and other macroelements, restricting the uptake of these elements by plants, as has been confirmed by the authors' own research and several investigations (Małachowska-Jutsz et al. 1997, Xu and Johnson 1997). The studies carried out by Dimitrov and Mitova (1998) did not reveal any distinct modification in the content of phosphorus and calcium in plants harvested from unpolluted objects versus those grown in diesel oil contaminated soils.

The simple correlation coefficients obtained suggest that the content of macroelements was significantly correlated with the soil contamination with diesel oil (Table 4). The correlations were mostly positive, except the nitrogen content in aboveground parts and potassium content in roots, where the dependences were negative. The concentration of most of the macroelements, apart from nitrogen in aboveground parts and potassium in roots of yellow lupine, was significantly and adversely correlated with the yield of aboveground parts, length of stems, and number and mass of root nodules. It is worth stressing that the negative correlations resulted from the fact that oil diesel exerted strong influence on yellow lupine, which led to a large decline in yields of aboveground parts and mass of roots and root nodules. The relationships between the content of each macroelement and the accumulation of the remaining ones in yellow lupine were mostly positive.

Degrading impact of refinery products on soil depends on their load per area unit as much as on the quality of soil. Compact soils rich in humus are far more tolerant to degradation than sandy soils. Besides, compact soil rather than a light one can absorb larger quantities of a petroleum-based substance and deform its structure to a higher extent. In more compact soils, it is less easy to maintain continuous supply of oxygen and sufficient moisture. This has been proven by the authors' own research, in which diesel oil produced stronger effects in light loamy sand than in light loam, especially in terms of the development of roots of yellow lupine.

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ABSTRAKT

Vliv kontaminace půdy naftou na výnos lupiny žluté a obsah makroživin

Cílem pokusu bylo zjistit vliv kontaminace půdy naftou na výnos lupiny žluté a obsah makroživin v pletivech a stanovit vztah mezi akumulací prvků v biomase a její tvorbou, včetně kvalitativních parametrů. Rostoucí úroveň znečištění podporovala růst obsahu fosforu, hořčíku a vápníku v nadzemní biomase a kořenech lupiny. Vyšší úroveň znečištění vedla současně k výnosové depresi nadzemí hmoty i kořenů a k hromadění dusíku v nadzemní biomase a draslíku v kořenech lupiny. Přihnojení dusíkem ovlivnilo výnos a obsah makroživin. Změny ve složení závisely na části rostliny, půdním typu a úrovni kontaminace. Obsahy živin v nadzemní biomase i v kořenech rostlin významně korelovaly s výnosem rostlin, délkou stonku a hmotností kořenových hlízek, stejně jako i s obsahem a příjmem dalších prvků rostlinami.

Klíčová slova: půda; kontaminace naftou; hnojení dusíkem; výnos lupiny žluté; obsah makroživin

Corresponding author:

Dr. Mirosław Wyszkowski, University of Warmia and Mazury in Olsztyn, Department of Environmental Chemistry, 10-718 Olsztyn, Pl. Łódzki 4, Poland
e-mail: miroslaw.wyszkowski@uwm.edu.pl