The effects of mineral treatment and the amendments by organic and organomineral fertilisers on the crop yield, plant nutrient status and soil properties

K. Gondek, B. Filipek-Mazur

H. Kołłątaj Agricultural University of Cracow, Poland

ABSTRACT

The studies were carried out as a pot experiment comprised of mineral treatments with farmyard manure, slurry and liquid organomineral fertiliser (Damishum) and finally the unfertilised control. Mineral fertilisation and liquid organomineral fertiliser better affected the crop yield in comparison with organic treatments in the first year of the experiment, whereas in the subsequent two years with a consecutive affect of organic fertilisers. According to the expectations the biggest nitrogen concentrations were found in crops receiving mineral treatment and organomineral fertiliser. Phosphorus content depended on crop species and applied fertiliser. Potassium and magnesium contents immediately after treatment were the highest in the objects receiving organic treatment (farmyard manure and slurry). In the subsequent years no visible tendency in both element contents was noticed. Among the cultivated crops rape revealed the biggest amounts of cadmium in the above ground parts. Lead concentrations in the above ground parts of the cultivated crop did not reveal any diversification among the objects. Copper accumulated mainly in the crop root systems, except rape, whereas zinc concentration depended on the plant species and applied fertilisation. The treatment caused a decrease in the soil pH and an increase in hydrolytic acidity value. Mineral and organomineral fertilisation caused a pronounced decline in organic carbon content in the soil, whereas farmyard manure raised it. Similar dependencies were found for the total nitrogen concentrations. The applied treatment increased the contents of mobile forms of cadmium, lead and zinc but had no significant effect on changes of mobile copper form contents.

Keywords: fertilisation; plant; yield; chemical composition; macroelements; heavy metals

The development of mankind has been always connected with plant production, which supplied food, raw materials for processing and energy. Intensification of plant production (Mangova and Rachovska 2004, Skupinová et al. 2004) and growing demands concerning its quality inclined fertiliser producers to look for new technologies of production. Technological progress in this field allowed to obtain higher concentrations of so called pure component in a fertiliser and to introduce a bigger number of nutrients, including microelements.

The application of mulitcomponent fertilisers entails many measurable advantages *inter alia*: homogenous chemical composition of soil, possibility of supplying to the soil all essential nutrients and considerable cost-effectiveness in their distribution and application (Stępień and Mercik 2001).

Intensification of fertilisation (Hřivna et al. 2002) and a wide range of fertilisers, imposes the necessity for detailed analysis on the effect of their application upon crop yielding (Faber et al. 1988), nutritional value of the obtained yield (Domska et al. 2001) and soil properties (Stępień and Mercik 2001).

The objective of the study was to determine yield-forming efficiency of organic and mineral treatment and to learn its effect on mineral content in plants and some soil properties.

MATERIAL AND METHODS

The studies were carried out as a pot experiment comprising 4 treatments and the control object. Mixed farmyard manure, slurry from pigs and Damishum (liquid multi-component fertiliser produced in Slovakia) were used for the experiment (Table 1). Damishum treatment added to the experimental design aimed at determining this fertilisers effect on the amount and quality of plant yield in comparison to classical mineral and organic fertilisation usually applied in Poland. The experimental design is presented in Table 2. The

Table 1. Chemical composition of materials used in experiment

Determination		FYM	Slurry	Damishum*
Dry mass (g/kg)		269	179	–
Organic matter	g/kg dry mass	371	128	49
Total N		25.4	36.9	155.6
P		6.90	6.40	20.96
K		13.00	21.20	1.66
Mg		6.40	8.90	< 0.01
Ca		21.40	2.40	0.07
Na		1.20	1.70	1.13
Cu	mg/kg dry mass	164.00	30.40	0.56
Zn		460.00	397.50	2.72
Mn		357.00	292.50	7.10
Cr		11.10	14.10	0.28
Fe		5080	893	36
Cd		2.10	0.30	< 0.01
Pb		15.10	4.10	0.04
Ni		10.00	4.90	0.70

*aqueous solution

experiment was set up in PVC pots with 5 kg of air-dried soil each. The soil contained 69% of < 0.02 mm particles – silty clay (FAO-ISRIC 1989). The soil reaction expressed in pH measured in 1 mol/dm^3 KCl solution was 4.11 and hydrolytic acidity determined with Kappen's method was 73.40 mmol(+)/kg (Ostrowska et al. 1991). The soil contained 1.90 g/kg total nitrogen determined by Kjeldahl's method (Ostrowska et al. 1991) and 14.10 g/kg organic carbon assessed by Tiurin's method (Ostrowska et al. 1991). The contents of available phosphorus and potassium forms fell within the medium values range and were 73.99 mg/kg of phosphorus and 134.04 mg/kg of soil dry mass of potassium. The total heavy metal concentrations in the soil prior to the research outset ranged within the natural contents limits and were as follows: 18.02 mg Cu, 35.18 mg Pb, 158.38 mg Zn, 53.96 mg Cr, 0.83 mg Cd and 39.98 mg Ni/kg of soil dry mass.

Fertiliser doses (applied in the first year of the experiment) were calculated on the basis of their nitrogen concentrations (Table 2). In the object receiving mineral treatment nitrogen was applied as NH_4NO_3 (pure salt), the complementary phosphorus and potassium treatments were applied on all objects except the control, phosphorus as $Ca(H_2PO_4)_2.H_2O$ and potassium as KCl.

Maize, KLG 2210 cv., planted 6 plants/pot, was cultivated in the first year of the experiment. During vegetation nitrogen deficiency symptoms were noticed. In order to supplement it, a top dressing with NH_4NO_3 dosed 0.5 g/pot was applied. The plants were harvested after 102 days of vegetation at the cob formation stage. In the second year of the experiment, after supplementary mineral treatment was applied, winter rape, Górczański cv. was grown with 12 plants/pot. Winter rape, one sowed in spring and one assembled on green forage. After 52 days of vegetation the plants were harvested at the leaf rosette phase. Another crop grown also in the second year of the experiment was sunflower, Lech cv. planted after a supplementary nitrogen treatment with 0.5 g N-NH_4NO_3/pot and cultivated with a density of 9 plants/pot. After 62 days of vegetation the plants were harvested at the flowering phase. In the third year of the experiment, after a supplementary mineral treatment, oat, Dragon cv. was grown with a density of 25 plants/pot. Oats cultivation until full harvest maturity was determined by a desire to obtain grain generative yield to determine the accumulation of the studied heavy metals. The plants were harvested after 89 days of vegetation at the full maturity stage. During vegetation in all years of the experiment the soil moisture was maintained at 60% of the soils maximum water capacity.

In the fertilisers and plant material, separately from each pot, soil dry matter was assessed after drying at 70°C in a dryer with hot air flow. Further analyses were conducted on dried and ground material. Macroelements (N, P, K, Ca, Mg and Na) were determined in the fertilisers by the method used for plant material analyses (Ostrowska et al. 1991). The total nitrogen was assayed by Kjeldahl's method in Kjeltec II Plus apparatus after sample wet mineralisation in concentrated sulphuric acid in an open system using the set produced by Tecator (Ostrowska et al. 1991). The contents of phosphorus, potassium, calcium, magnesium and sodium and heavy metal concentrations were determined after sample dry mineralisation in

Table 2. Plant cultivars and doses of mineral fertilizers

Year	Plants	Fertilisation (g/pot)		
		N	P	K
1999	maize	1.00*	1.81**	1.20**
2000	rape	1.00	–	1.20
	sunflower	0.50	–	–
2001	oat	0.50	–	1.00

*form of organic fertilizers, **supplemented mineral a muffle furnace (at 500°C for 5 h) and ash solution in nitric acid (1:2). Phosphorus was assayed by colorimetry method using DU 640 spectrophotometer (Beckman), potassium, sodium and calcium (only in the fertilisers) were determined by flame photometry (FES), magnesium, zinc and copper by absorption spectrometry (AAS) in PU 9100X Philips apparatus (Ostrowska et al. 1991). In the same solutions cadmium and lead were assessed by ICP-AES method using JY 238 Ultrace apparatus produced by Jobin Yvon.

Each year when vegetation was completed, the soil was sampled from the individual treatments and subjected to chemical analysis. The following parameters were determined in samples of the air-dried soil: soil pH by potentiometer method, hydrolytic acidity by Kappen's method and organic carbon content by Tiurin's method (Ostrowska et al. 1991). Selected heavy metals (Cd, Pb, Cu and Zn) were extracted from the soil using 1 mol/dm^3 NH_4NO_3 solution for 24 hours. The forms extracted in this way are considered by Zeien and Brümmer as so called mobile forms (Zeien and Brümmer 1989). In the obtained extracts studied element concentrations were determined by ICP-AES method using JY 238 Ultrace apparatus.

All chemical analyses were conducted in two simultaneous replications and considered reliable if arithmetic mean error for two assays and did not exceed 5%.

The obtained results were elaborated statistically using one factor ANOVA and the significance of differences between arithmetic means were assessed by *t*-Student test at $P < 0.05$ significance level. The coefficient of correlation was computed according to Spearman's rank order correlation (Stanisz 1998).

RESULTS AND DISCUSSION

Table 3 shows dry mass yields of the cultivated plants. Yields of maize above ground parts (stem + leaves) were diversified among the objects. The highest were obtained on the objects fertilised with mineral salts (157.38 g/pot) and liquid Damishum fertiliser (132.77 g/pot). In comparison to farmyard manure and slurry treatments they were significantly higher. In relation to the combination with mineral fertilisation, yields were markedly higher in the objects where Damishum was used. Similar dependencies were observed for cobs and the roots of maize. The total yields of maize (roots, stem + leaves, cob) fertilised with multi component liquid fertiliser were significantly bigger in comparison with those obtained on farmyard manure and slurry treatments, but also markedly lower than with mineral treatment, where the highest yields were obtained in the first year of the experiment. In the second year of the studies, rape cultivation produced comparable yields of above ground parts on all experimental treatments and root yields in the object receiving multi-component fertiliser were significantly bigger in comparison with those ob-

Table 3. Yield of plants dry mass (g/pot)

Plants		Control	Mineral fertilisation	FYM	Slurry	Damishum	$LSD_{p < 0.05}$
Maize	cob	0.00	28.27	4.75	3.96	12.87	2.00
	leaf + stem	39.65	157.38	110.49	121.42	132.77	10.55
	roots	4.01	23.20	11.29	14.68	21.57	1.10
	total	43.66	208.85	126.53	140.06	167.21	10.45
Rape	above ground parts	9.89	41.47	44.42	43.50	41.63	3.30
	roots	2.64	8.11	7.86	8.20	8.53	0.53
	total	12.53	49.58	52.28	54.70	50.16	3.25
Sunflower	above ground parts	9.80	58.64	67.50	70.14	65.83	5.15
	roots	0.80	3.81	4.41	6.12	3.96	0.65
	total	10.60	62.45	71.91	76.36	69.79	5.18
Oat	grain	4.05	24.85	25.75	26.99	25.89	1.71
	straw	4.96	22.82	23.78	22.60	22.28	1.06
	roots	1.02	4.58	4.68	5.25	4.77	0.57
	total	10.03	52.25	54.21	54.84	52.94	3.59

tained as a result of farmyard manure treatment. The yields of the sunflower above ground parts were considerably lower on mineral treatment as compared to the other objects. The mass of sunflower roots was similar on all treatments, except slurry, where it was significantly higher. The biggest grain yield was detected in the object fertilised with slurry and the difference was significant in relation to mineral treatment. The yields of oat grain fertilised with Damishum and farmyard manure were similar. Identical dependencies were detected for root yields. Straw yields from the individual treatments did not differ markedly and on an average were 22.87 g/pot of straw dry mass. On the basis of conducted research it was demonstrated that mineral and liquid Damishum fertiliser treatment better affected crop yield than organic fertilisation (farmyard manure and slurry) in the first year of the experiment. On the other hand, in the subsequent two years consecutive effect of organic fertilisers became apparent, visible as higher crop yield on these treatments. The dependency resulted from several year (2–4 year) activity of organic fertilisers. Mineral and Damishum treatment in the second and third year of the experiment influenced the plant yield less.

The results of nitrogen concentrations in cultivated crops show on this diversification depending on treatment and plant species (Table 4). Immediately after fertilisation, comparable nitrogen contents were detected in maize cobs receiving mineral treatment, farmyard manure and Damishum. In maize stem and leaves, significantly more nitrogen was found in plants from mineral and Damishum treatments, whereas for the roots the results were higher for farmyard manure and Damishum objects. The above ground parts of rape were more nitrogen abundant than maize tops. Liquid Damishum fertiliser acted identically (upon nitrogen concentration in rape) as mineral treatment but significantly better in comparison with farmyard manure and slurry fertilisation. Nitrogen content in rape roots was markedly bigger in plants receiving organic fertilisers and Damishum as compared to plat roots treated with mineral components. In the second year of the studies sunflower was also grown. The nitrogen content in the sunflower's above ground parts was considerably lower in plants fertilised with Damishum as compared to plants from the other treatments. A decrease in this content was on an average 17% in comparison with the mineral treatment, farmyard manure or slurry. A similar dependency was detected for the sunflower root system. Nitrogen content in oat grain cultivated in the second year of the consecutive fertiliser effect was much higher than this element concentration in dry mass of this plant straw and roots. The highest contents of this element were detected in the grain of plants fertilised with farmyard manure and with Damishum. Oat grain from the other objects had markedly less nitrogen. Nitrogen concentrations in oat straw were between 1.82 g/kg in Damishum

Table 4. Content of nitrogen and phosphorus (g/kg dry mass) in plant biomass

Treatment	Control		Mineral fertilisation		FYM		Slurry		Damishum		$LSD_{p < 0.05}$ for content	
	N	P	N	P	N	P	N	P	N	P	N	P
Maize												
Cob	–	–	11.68	2.60	11.88	2.63	9.20	3.15	11.34	2.75	0.12	0.12
Leaf + stem	3.73	2.05	5.74	1.45	3.92	2.18	3.21	2.20	5.68	1.58	0.72	0.46
Roots	8.61	1.55	6.92	1.30	7.45	1.88	6.93	2.05	8.18	1.60	0.57	0.48
Rape												
Above ground parts	10.18	2.45	17.40	2.73	15.76	2.50	15.87	2.73	17.35	3.13	1.98	0.34
Roots	7.79	3.20	8.91	6.45	10.70	3.15	10.02	4.00	10.54	3.88	0.95	0.27
Sunflower												
Above ground parts	8.15	2.68	6.94	2.00	6.89	1.98	7.00	2.00	5.81	1.70	0.79	0.69
Roots	4.52	1.80	4.98	1.33	4.19	1.93	3.77	1.58	3.75	1.85	0.62	0.76
Oat												
Grain	10.94	6.69	11.69	3.87	14.61	4.18	13.35	4.35	14.55	4.07	1.00	0.26
Straw	2.55	6.55	2.01	2.16	2.01	1.61	2.22	1.89	1.82	1.05	0.33	0.26
Roots	2.86	0.82	2.95	1.47	3.25	1.25	3.29	1.66	3.56	1.15	0.35	0.25

treatment and 2.55 g/kg dry mass in straw from the control. In oat roots nitrogen content was the biggest on organic and Damishum treatments but a significant increase in this component content in comparison with mineral treatment was found only under the influence of the consecutive effect of liquid Damishum fertiliser. In the authors' own investigations nitrogen content in plants was diversified in all objects, despite supplementing its dose to a uniform level on all treatments. According to expectations the most nitrogen was found in plants receiving mineral treatments. It was caused by a relatively easier uptake of this element from these fertilisers than from organic ones. Nitrogen in farmyard manure and slurry occurred mainly in organic forms and its availability depended on mineralisation rate.

The highest concentration of phosphorus was detected in cobs, stems and leaves of plants maize fertilised with slurry (Table 4). In comparison to slurry treatment phosphorus level in the above ground parts of the plants from the other treatments was lower in cobs by between 12 and 17% and between 1 and 34% in leaves and stems. A similar relationship was observed in maize roots. Phosphorus content in rape above ground parts did not reveal any diversification among mineral treatment, farmyard manure or slurry. Significantly bigger quantities of this component were found in rape above ground parts fertilised with Damishum. Phosphorus concentration in rape roots was higher than detected in the above ground parts and reached the highest value 6.45 g P/kg dry mass in the roots of plants receiving mineral treatment. A similar relationship was not found for sunflower roots where phosphorus concentrations in the above ground parts and roots of the fertilised plants were approximate and did not exceed 2.00 g P/kg dry matter. In the third year of the experiment a significantly better effect of farmyard manure and slurry on phosphorus content in oat grain was determined (in comparison with mineral treatment). The consecutive effect of liquid Damishum fertiliser was comparable with mineral fertilisation. Mineral treatment best influenced the phosphorus content in oat straw. The lowest value of phosphorus was detected in the straw of oats fertilised with Damishum. Oat roots accumulated the most of the phosphorus from slurry treatment whereas the least, in the case of straw with the Damishum treatment. Besides nitrogen phosphorus also is of great importance for yield and quality of the plants (Mallarino et al. 1999, Colomb et al. 2000). Phosphorus content depended on plant species and the applied fertilisation. Maize cultivated in the first year with organic treatment was characterised by bigger phosphorus concentrations than maize fertilised with minerals and Damishum. It was caused by a higher soil pH on organic treatments, which determines the chemical sorption of phosphates. After the third year of the study plants grown on mineral treatment, where soil reaction was the lowest, contained the least of phosphorus.

Potassium content in maize cobs, in comparison with mineral treatment, was significantly bigger on farmyard manure and slurry treatments, whereas markedly smaller amounts of this component were found in maize cobs fertilised with Damishum (Table 5). Leaves, stem and roots of maize were characterised by higher potassium content than cobs. On the basis of obtained results higher concentrations of this component were detected in plants receiving mineral treatment and Damishum, whereas smaller ones were found on organic treatments. In the first year of consecutive effect higher concentrations of potassium were detected in the above ground parts of rape fertilised with Damishum, the increase was significant in relation to the control, whereas it proved insignificant as compared to the other treatments. Rape roots accumulated less potassium with a similar dependency among the other objects. Potassium contents in the above ground parts of the sunflower were smaller and applied fertilisation did not diversify the content, which on an average for plants from individual treatments was 13.23 g/kg. A similar relationship 3.24 g/kg was determined for sunflower roots at mean contents for plants from treatments. In oat grain potassium content did not reveal any marked differences on individual treatments or on the control. Average potassium content in oat grain was 6.03 g/kg dry mass. Oat straw contained on an average over four times larger quantities of this component than grain and fertilisation did not cause any marked differences in it. A significant decline in potassium concentration was observed as a result of the consecutive effect of Damishum. The potassium content in oat roots from treatments was smaller than in the control, without any significant differences.

Magnesium content in maize cobs was higher on farmyard manure and slurry treatments (Table 5). Stems and leaves of maize had more of this component except the mentioned objects and the biggest magnesium amounts were detected in the plants receiving mineral and Damishum fertilisation. On all treatments similar magnesium concentrations were detected in maize roots, except plants fertilised with Damishum. Among the crops cultivated in the subsequent years of the experiment the biggest amounts of magnesium was discovered in the above ground parts of the sunflower (mean 7.99 g/kg), rape (mean 4.97 g/kg) and oat grain (mean 1.34 g/kg) and oat straw (mean 1.40 g/kg). Similar relationships were found for the roots of the discussed plants but at lower contents. The biggest concentrations of this element in the roots of plants grown in the control object resulted from a relatively low plant yield. Potassium and magnesium fertilisation is of some importance for yielding and quality of plants (Mallarino et al. 1999). The content of potassium and magnesium immediately after the fertilisation were the highest in organic treatments (farmyard manure and slurry). In the subsequent years no marked tendency in both element concentrations was observed.

From among the cultivated plants rape was characterised with the lowest content of cadmium in the above ground parts (Table 6). In the first year of the experiment cadmium contents in the maize above ground parts were as follows: 0.17–0.33 mg/kg in cobs and 0.37–0.57 mg/kg dry mass in stems and leaves. In the maize roots over 5 times more cadmium was determined than in cobs and over twice as much than in stem and leaves. Rape from treatments accumulated between 3.15 mg/kg (farmyard manure) and 5.81 mg/kg dry mass (Damishum). These values were too high from the perspective of animal forage quality. Lower contents of cadmium (comparable to those found in maize roots) were determined in rape roots, however the biggest value was assayed in the root systems of plants fertilised with Damishum. In the first year of the experiment cadmium contents in maize above ground parts were as follows: 0.17–0.33 mg/kg in cobs and 0.37–0.57 mg/kg dry mass in stems and leaves. In maize roots over 5 times more cadmium was determined than in cobs and over twice as much than in the stem and leaves. Rape from treatments accumulated between 3.15 mg/kg (farmyard manure) and 5.81 mg/kg dry mass (Damishum). Lower contents of cadmium (comparable to those found in maize roots) were determined in rape roots, however the biggest value was assayed in the root systems of plants fertilised with Damishum (Table 6). Sunflower above ground parts from treatments contained significantly less cadmium than detected in the plants form the control, which resulted from a big concentration of this element in a relatively low yield. The most cadmium was found in the above ground parts of plants receiving Damishum and the content was markedly smaller than detected in the above ground parts of plants receiving mineral and slurry treatment. Significantly more cadmium (in comparison with the control) was found in the root system of plants fertilised with farmyard manure and minerals. The least quantities of cadmium were found in oat grain from the control. In oat grain from the other objects cadmium concentrations were significantly larger, particularly on organic and Damishum treatments. Oat straw accumulated more of this element at similar dependencies. The most cadmium was found in the oat root system. Root system of plants fertilised with the other fertilisers accumulated markedly more cadmium (in comparison with the contents found on mineral

Table 5. Content of potassium and magnesium (g/kg dry mass) in plant biomass

Treatment	Control		Mineral fertilisation		FYM		Slurry		Damishum		$LSD_{p < 0.05}$ for content	
	K	Mg	K	Mg	K	Mg	K	Mg	K	Mg	K	Mg
Maize												
Cob	–	–	7.85	1.78	8.88	2.60	8.90	2.78	3.48	2.10	0.90	0.29
Leaf + stem	5.95	2.60	9.60	4.35	11.70	2.05	11.03	2.45	9.87	4.53	1.74	0.50
Roots	11.91	1.03	15.11	1.03	12.14	1.10	12.52	1.10	14.71	1.33	3.70	0.19
Rape												
Above ground parts	27.47	6.07	31.86	4.30	32.34	5.27	32.31	4.63	35.18	4.59	3.33	0.47
Roots	21.36	1.95	23.44	1.44	20.14	1.29	24.21	1.68	26.26	1.70	0.66	0.08
Sunflower												
Above ground parts	21.90	8.07	13.46	7.84	13.62	8.26	12.93	8.08	12.91	7.71	2.16	0.51
Roots	3.63	0.94	3.52	2.97	3.49	3.80	2.84	3.64	3.12	3.15	1.05	0.93
Oat												
Grain	6.04	0.26	6.02	1.32	6.10	1.33	5.98	1.43	6.01	1.38	0.41	0.20
Straw	27.91	1.37	29.12	1.31	29.26	1.45	28.65	1.43	16.22	1.43	0.24	0.09
Roots	10.24	3.31	7.65	0.63	7.12	0.93	7.09	0.83	7.05	0.86	0.13	0.02

Table 6. Content of cadmium and lead (mg/kg dry mass) in plant biomass

Treatment	Control		Mineral fertilisation		FYM		Slurry		Damishum		$LSD_{p < 0.05}$ for content	
	Cd	Pb	Cd	Pb	Cd	Pb	Cd	Pb	Cd	Pb	Cd	Pb
Maize												
Cob	–	–	0.17	0.19	0.32	0.26	0.33	0.30	0.19	0.13	0.03	0.04
Leaf + stem	0.57	2.45	0.50	2.26	0.39	2.41	0.37	3.26	0.37	1.56	0.08	0.58
Roots	1.67	3.01	1.37	3.06	1.53	2.64	1.09	2.44	1.44	2.58	0.17	0.56
Rape												
Above ground parts	1.54	1.20	4.55	1.11	3.15	1.21	4.04	1.19	5.81	1.20	0.34	0.36
Roots	1.18	0.81	0.93	0.70	0.81	0.86	1.10	1.00	1.36	1.06	0.35	0.46
Sunflower												
Above ground parts	9.07	3.06	2.77	0.83	2.29	0.57	2.40	0.74	2.01	0.47	0.40	0.29
Roots	1.13	0.65	1.47	0.66	1.41	0.63	1.28	0.59	1.24	0.58	0.22	0.12
Oat												
Grain	0.68	1.18	1.19	1.05	1.46	1.31	1.71	1.39	1.59	2.21	0.10	0.18
Straw	1.56	3.80	1.81	4.25	1.80	4.92	1.98	5.62	1.99	5.41	0.21	0.41
Roots	0.86	0.60	2.31	2.66	2.56	4.44	1.59	4.36	2.73	4.69	0.19	1.08

treatment). The quoted results confirm the findings of Logan and Chaney (1983) who detected bigger cadmium uptake under conditions of pot experiment than under field conditions. According to Chaney (1982) cadmium is the element, which does not undergo the effect of soil-plant barrier, which denotes that plants tolerate in their tissues (and do not reveal any symptoms of its toxicity) the quantities of this element harmful for animals consuming the plants. The fact was also confirmed by experiments carried out by Kuboi et al. (1987) who tested the relationship between accumulation ability and the tolerance of various plant species to cadmium. They demonstrated that spinach was the plant tolerant to this element as it took up big amounts of it. On the other hand, Kabata-Pendias and Pendias (1993) demonstrated that at its increased uptake cadmium accumulated mostly in the roots. According to the above quoted authors and also to Morslet et al. (1986), cadmium blocking in roots most probably involves forming cadmium bonds with sulfhydryl groups and proteins to form so called phytochelatines.

Lead content in the above ground parts of the cultivated plants did not reveal any diversification among treatments, neither did it exceed the limit value of 25 mg/kg dry mass assumed as permissible in forage plants (Anke 1987). The biggest amounts of lead in the above ground parts were found in stems and leaves of maze where the contents ranged between 1.56 and 3.26 mg/kg dry mass and in oat straw, where between 3.80 and 5.26 mg/kg dry mass were found. Maize cobs had the least of this metal, i.e. between 0.13 and 0.30 mg/kg dry mass. Most of the lead was detected in maize and oat roots (Table 6). Lead content depended on its concentration in the substratum and specific features of plants. Like copper, lead was also arrested in roots, which might have resulted from the formation of slightly soluble lead forms in the root system Dutka et al. (1991). Investigating trace metal contents in oat and maize cultivated in soil fertilised with mixed municipal and industrial sewage sludge found that lead concentration in these plants did not clearly change in effect of applied doses of sewage sludge. Maize contained more lead than oat.

Copper accumulated in plants mainly in their root systems, except rape (Table 7). Copper contents in the above ground parts of plants cultivated immediately after fertilisation and in the first year of consecutive effect of fertilisation were lower than in oat grain grown in the third year of the studies. Generally the above ground parts of maize and sunflower from mineral and organic treatments contained more of this element than on Damishum treatment. A reverse relationship was detected for rape and oats. Plant root system did not accumulate any excessive amounts of copper. Most of the copper was found in maize roots

Table 7. Content of copper and zinc (mg/kg dry mass) in plant biomass

Treatment	Control		Mineral fertilisation		FYM		Slurry		Damishum		$LSD_{p < 0.05}$ for content	
	Cu	Zn	Cu	Zn	Cu	Zn	Cu	Zn	Cu	Zn	Cu	Zn
Maize												
Cob	–	–	3.07	32.00	3.48	35.70	3.60	37.05	2.51	42.70	0.47	4.23
Leaf + stem	1.91	46.60	1.69	35.20	1.79	29.00	1.54	32.10	1.39	33.05	0.35	5.80
Roots	15.27	64.81	5.00	41.28	9.11	49.52	10.26	46.10	6.16	45.21	1.55	6.22
Rape												
Above ground parts	2.60	61.83	3.68	90.13	3.37	87.43	3.66	103.8	4.81	124.0	0.52	11.86
Roots	3.00	48.33	2.63	46.05	2.63	42.57	3.39	43.73	3.23	55.70	0.41	5.44
Sunflower												
Above ground parts	21.59	283.3	4.18	96.85	4.50	84.45	4.36	85.23	3.28	72.70	0.54	7.40
Roots	15.05	243.5	5.81	7665	5.92	60.18	5.67	62.25	4.87	78.48	1.19	16.37
Oat												
Grain	4.88	49.96	4.44	37.70	5.95	45.47	6.09	48.13	6.54	47.51	0.56	2.50
Straw	2.01	35.69	2.53	25.76	2.70	31.44	2.80	39.88	2.76	39.04	0.18	3.26
Roots	2.41	47.04	5.03	61.00	5.75	65.14	6.96	63.35	8.92	68.67	0.87	6.84

grown immediately after the applied treatment. Considering copper content in the cultivated crops it should be stated that the element accumulated mainly in the root systems, except rape. Copper contents determined in the plants resulted from its small concentration in the applied fertilisers. This elements availability is also very strongly modified by organic matter contents, which reveals big copper bonding abilities. The antagonism between copper and calcium and small mobility of this metal in plant might also have a significant effect upon copper content in plants. However, it should be clearly stated that plants, irrespective of applied fertilisation blocked copper translocation on the root system level where a higher concentration of this metal was found.

Zinc concentration in plants was diversified and depended on the plant species and applied fertilisation (Table 7). More zinc accumulated in the monocotyledonous root systems (maize and oat). The dicotyledonous (rape and sunflower) had more zinc in their above ground parts. The effect of liquid Damishum fertiliser was comparable with slurry activity. The zinc distribution in individual plant parts was diversified and depended on the cultivated plant. An excess of zinc was found in plants from the control and mineral and farmyard manure treatments.

Heavy metal concentrations in plants depended on many factors, *inter alia* on the way of their uptake. The discussed elements, including cadmium, lead and zinc are absorbed passively and their contents depend on their soil concentrations. In the case of copper both passive and active uptake is possible. Studies conducted by Gambuś (1997) reveal barriers in the way the metal is transported from roots to the above ground parts. According to Gambuś (1997) they generally act efficiently in all plant species in relations to lead and copper. However, in regards to cadmium and zinc they apparently depend on the cultivated plant species. According to Chu and Wong (1987) and Galler (1992) these barriers exist also in the way the metal is transported among the above ground parts.

Mean values of soil pH from individual fertiliser combinations decreased significantly after the first year of the experiment on mineral treatments and objects where Damishum liquid fertiliser was applied. In relation to the control and the above-mentioned combinations, farmyard manure effect proved positive, whereas slurry did not influence significantly a change in soil reaction (Table 8). In the results of fertilisation applied in the subsequent two years of the experiment, a marked decline in soil pH was noted in relation to the control and the decline was even bigger under the influence of mineral and Damishum treatment than farmyard manure and slurry. Presented research results have not been fully confirmed in the literature on the subject. Mazur et al. (1998) found that slurry treatment only to a small extent affects changes in soil reaction whereas fertilisation with farmyard manure influences an increase in pH value. In the presented research the above-mentioned relationship was confirmed only in the first year immediately after applied farmyard manure and slurry treatment. The lack of consistency of the presented results with those given by Mazur et al. (1998) might have been caused by a supplementary treatment with nitrogen and particularly with potassium (as KCl) applied in the second and third year of the experiment and also may be due to various soils used for the experiments. On the other hand, results concerning soil pH under the influence of mineral treatment proved consistent with other findings (Mazur et. al. 1998).

The value of hydrolytic acidity was markedly higher in the soil of all treatments than in the control soil (Table 8). Like in the case of the reaction a similar effect of farmyard manure and slurry and also of mineral treatment and Damishum was noticed upon soil hydrolytic acidity. Results concerning hydrolytic acidity are consistent with those obtained by Mazur et al. (1998) for slurry and mineral treatment. In the case of farmyard manure fertilisation the above-mentioned authors detected slight changes in hydrolytic acidity value in relation to the control.

Fertilisation applied in the experiment diversified organic carbon contents in the soil (Table 8). The changes depended on the quantity of organic substance supplied to the soil with the fertilisers. The biggest decline in organic C content was detected in the soil of Damishum treatment in the first and second year of the experiment, which was due to the fact that organic compounds which undergo fast mineralisation were supplied to the soil with the fertiliser, whereas the direct and consecutive effect of farmyard manure proved the best and the increase in soil organic carbon determined in individual years proved significant in relation to the control and other fertiliser combinations. An increase in organic carbon contents under the influence of farmyard manure treatment has been confirmed by the results of research carried out by Jarecki and Krzywy (1991). The quoted authors have not corroborated an increase in organic carbon content under the influence of slurry fertilisation.

The contents of determined cadmium in mobile forms were increasing in the subsequent years of the experiment and on an average were almost by 68% higher in the soil after the third year of studies in comparison with the soil content after the first year. Most of the cadmium mobile forms were found in the soil of Damishum treatment (Table 9). The greatest cadmium mobility in this object might have been conditioned by low soil reaction and the lowest content of organic carbon, as confirmed by significant correlation coefficients, respectively ($r = -0.55$; $P < 0.05$) and ($r = 0.53$; $P < 0.05$). Diversification of this element mobility among the treatments was more pronounced immediately after the applied fertilisation (1st year of the experiment), whereas over the subsequent years the differentiation was weakened. Cadmium mobility to a considerable degree depends on soil pH (Niemyska-Łukaszuk 1995, Gambuś and Rak 2000). In the presented studies soil reaction declined over subsequent years of the experiment and favoured cadmium compound solubility. A successive increase in mobile cadmium form content might have been also affected by organic substance contents in relation to which cadmium shows big affinity. Gorlach and Gambuś (1991) also found a considerable influence of organic substance on cadmium desorption.

The content of lead mobile forms was generally small (Table 9) and the differences in this metal soil contents after the first year were insignificant. Marked diversification of lead mobile form contents was observed in the second and third year of the experiment. Attention should be paid to successive increase of these forms of lead in the subsequent years on mineral and Damishum treatments. On farmyard manure and slurry treatments the increase in lead mobile form contents in the second year was

Table 8. Changes in values of soil pH, hydrolitic acidity and organic carbon in soil

Treatment	pH_{KCl}			Hh [mmol(+)/kg]			Organic C (g/kg)		
	1999	2000	2001	1999	2000	2001	1999	2000	2001
Control	4.30	4.03	4.16	58.8	59.1	58.0	16.1	15.0	17.6
Mineral fertilisation	4.11	3.42	3.62	70.9	86.4	86.1	15.6	18.0	18.8
FYM	4.38	3.60	3.76	61.2	75.5	78.8	20.5	19.9	22.4
Slurry	4.26	3.49	3.69	63.3	82.3	73.0	15.6	17.1	22.5
Damishum	4.02	3.52	3.69	75.7	83.0	74.1	14.3	12.0	18.0
$LSD_{p < 0.05}$	0.06	0.10	0.05	1.87	5.54	2.01	3.49	2.23	0.60

Table 9. Changes in the contents of heavy metal mobile form in soil (mg/kg dry mass of soil)

Treatment	Cd			Pb			Cu			Zn		
	1999	2000	2001	1999	2000	2001	1999	2000	2001	1999	2000	2001
Control	0.33	0.42	0.52	0.26	0.33	0.11	0.27	0.37	0.29	6.98	7.79	7.94
Mineral fertilisation	0.38	0.44	0.56	0.25	0.55	0.54	0.32	0.28	0.44	8.94	9.70	10.97
FYM	0.30	0.45	0.58	0.24	0.46	0.33	0.33	0.31	0.35	8.70	10.86	11.37
Slurry	0.31	0.43	0.56	0.19	0.78	0.33	0.33	0.48	0.46	9.30	11.00	10.93
Damishum	0.38	0.42	0.61	0.17	0.44	0.52	0.32	0.53	0.45	9.61	10.22	12.68
$LSD_{p < 0.05}$	0.02	0.02	0.03	0.09	0.15	0.07	0.09	0.21	0.05	n.s.	n.s.	0.65

n.s. = not significant

followed by significant (in relation to the contents determined in the soil of mineral and Damishum treatments) decline in this elements mobile forms in the third year. The obtained results of lead mobile form contents significantly correlated with the soil reaction value ($r = –0.84$; $P < 0.05$). Lead is generally a small mobile element in the soil, which also has been pointed out in the present work. The element reveals a big affinity for forming complex ions, which regulate lead sorption and desorption processes. Lead is also very strongly bound by clayey minerals and organic matter (Kabata-Pendias and Pendias 1993, Mocek and Owczarzak 1993, Gorlach and Gambuś 2000). In the presented research a considerable decrease in soil pH, which according to Kabata-Pendias and Pendias (1993) considerably affects lead compound solubility did not cause any changes in this element mobility. No noted increase in the leads mobile form contents could have been caused by the kind of soil (heavy loam) used for the experiment, whose components strongly absorbed the element.

The content of copper mobile forms remained on a similar level in soils of individual fertiliser combinations and did not fluctuate much in the subsequent years of the experiment (Table 9). Soil components affecting copper mobility, like in case of lead, include clayey minerals, soil pH, iron and manganese hydroxides, however, soil organic substance is the most important. Despite a considerable amount of copper supplied to the soil with slurry and farmyard manure no significant differences in this element mobility in soil were observed. In the studies conducted by Jakubus et al. (1996) on the effect of long-term mineral and organic fertilisation on the contents of *inter alia* various fractions of copper in soil, it was found that this treatment did not cause any excessive copper accumulation in soil and at the same time farmyard manure treatment diminished the share of easily soluble fractions in total contents, whereas mineral treatment increased this share. In the present research no such dependency was found.

The concentrations of zinc mobile forms were on a much higher level than the other element contents (Table 9). In the first and second year of the experiment a difference among these zinc form concentrations in soil of individual treatments were insignificant, but this element mobility increased successively in the subsequent years, which might have been due to a change in soil reaction with which mobile forms of this element revealed significant correlation ($r = –0.68$; $P < 0.05$). In the third year considerable differences in Zn mobile forms were observed among treatments. The most zinc was determined in the soil fertilised with Damishum (12.68 mg Zn/kg) and farmyard manure (11.37 mg Zn/kg). The differences in comparison with the other treatments were statistically significant. Zinc belongs to the most mobile elements in soil (Kabata-Pendias and Pendias 1993). Its solubility diminishes proportionately to an increase in soil reaction. In the presented experiment decreasing soil reaction advanced zinc compound solubility, which has been confirmed also by a significant dependency between the reaction and mobile zinc form contents in soil. Also Jakubus et al. (1996) pointed to significant dependency of soil reaction and zinc mobile fraction content.

REFERENCES

Anke M. (1987): Toxizitatsgrenzwerte fur Spurenelemente in Futtermitteln. In: Schwermetalie in der Umwelt. Kolloqium Institute Pflanzenernährung, Jena, 2: 110–127.

Chaney R.L. (1982): Fate of toxic substances in sludges applied to cropland. Proc. Int. Symp. On land application of sewage sludge. Association for Utilization of Sewage Sludge, Tokyo, Japan: 259–324.

Chu L.M., Wong M.H. (1987): Heavy metal contents of vegetable crops treated with refuse compost and sewage sludge. Plant and Soil, *103*: 191–197.

Colomb B., Kiniry J.R., Debaeke P. (2000): Effect of soil phosphorus on leaf development and senescence dynamics of field-grown maize. Agronomy Journal, *92*: 428–435.

Domska D., Bobrzecka D., Wojtkowiak K., Warzechowska A., Sokołowski Z. (2001): Influence of fertilization technique on triticale yield and grain quality. Folia of University of Agriculture, Stetin, 223, Agriculture, *89*: 35–40. (In Polish)

Dutka S., Piotrowska M., Gałczyńska B., Bolibrzuch E. (1991): Heavy metal contents in oats (*Avena sativa* L.) and maize (*Zea mays* L.) cultivated in soils with sewage sludge. In: The effect of sewage sludge treatment on trace metal concentrations in plants. Wyd. IUNG, Puławy, *R(277)*: 5–18. (In Polish)

Faber A., Kęsik K., Winiarska A. (1988): Assessing effectiveness of Polish multicomponent foliar fertilisers in pot and field experiments. In: Foliar enrichment and plant protection in the light of research and experiences of agricultural practice. Wyd. IUNG, Puławy: 170–179. (In Polish)

FAO-ISRIC Soil Database (SDB). 1989.

Galler J. (1992): Schwermetalltransfer in der Nahrungskette. Der Forderungsdienst/Beratungsservice, *9*: 61–69.

Gambuś F. (1997): Heavy metals uptake by various cultivated plant species. Part II. Heavy metals accumulation by plants. Acta Agraria et Silvestria, Series Agraris, *35*: 31–44. (In Polish)

Gambuś F., Rak M. (2000): Influence of soil properties on cadmium compounds solubility. Zeszyty Problemowe Postepów Nauk Rolniczych, *472*: 251–257. (In Polish)

Gorlach E., Gambuś F. (1991): Desorption and phytotoxicity of heavy metals depending of soil properties. Rocznik Gleboznawczy, *XLII*: 207–214. (In Polish)

Gorlach E., Gambuś F. (2000): Potentially toxic trace elements in soil (excess, harmfulness and counteracting). Zeszyty Problemowe Postepów Nauk Rolniczych, *427*: 275–296. (In Polish)

Hřivna L., Richter R., Lošák T., Hlušek. (2002): Effect of increasing doses of nitrogen and sulphur on chemical composition of palnts, yields seed quality in winter rape. Rostlinná Výroba, *48*: 1–6.

Jakubus M., Czekała J., Blecharczyk A. (1996): The effect of long term fertilisation on microelement fractions in soil. Zeszyty Problemowe Postepów Nauk Rolniczych, *434*: 443–448. (In Polish)

Jarecki M., Krzywy E. (1991): Formation of carbon, nitrogen and other chemical component contents in soil under the influence of farmyard manure and slurry treatment. Rocznik Gleboznawczy, *XLII*: 37–44. (In Polish)

Kabata-Pendias A., Pendias H. (1993): Biogeochemistry of trace elements. Wydawnictwo Nauk PWN, Warszawa. (In Polish)

Kuboi T., Noguchi A., Yazaki J. (1987): Relationship between tolerance and accumulation characteristics of cadmium in higher plants. Plant and Soil, *104*: 275–280.

Logan T.J., Chaney R.L. (1983): Utilization of municipal waste water and sludge on land-metals. University California, Riverside: 235–326.

Mallarino A.P., Bordoli J.M., Borges R. (1999): Phosphorus and potassium placement effects on early growth and nutrient uptake of no-till corn and relationships grain yield. Agronomy Journal, *91*: 37–45.

Mangova M., Rachovska G. (2004). Technological characteristics of newly developed mutant common winter wheat lines. Plant, Soil and Environment, *50*: 84–87.

Mazur T., Wojtas A., Mazur Z., Sądej W. (1998): Comparison between organic and mineral treatment effect on reaction and acidity of soil. Zeszyty Problemowe Postepów Nauk Rolniczych, *456*: 251–255. (In Polish)

Mocek A., Owczarzak W. (1993). Binding of Cu, Pb, Zn on humus in soil contaminated by the copper smelting plants. Zeszyty Problemowe Postepów Nauk Rolniczych, *411*: 293–298.

Morslet A.F., Smits W.T.M., Limonard T. (1986): Histochemical demonstration of heavy metal tolerance in ecomycorrhizal fungi. Plant and Soil, *96*: 417–420.

Niemyska-Łukaszuk J. (1995). The effect of soil granulometric compostin and reaction on the contents of available heavy metal forms. Zeszyty Problemowe Postepów Nauk Rolniczych, *418*: 459–464. (In Polish)

Ostrowska A., Gawliński S., Szczubiałka Z. (1991): Methods of analysis and assessment of soil and plant properties. IOŚ, Warszawa. (In Polish)

Skupinová S., Vejl P., Sedlák P., Bardová M., Srbek L., Klápště P., Zouhar M., Tesařová B. (2004). Using DNA markers for characterisation of tomato resistance against root nematode *Meloidogyne incognita.* Plant, Soil and Environment, *50*: 59–64.

Stanisz A. (1998): Staightforward course of statistics basing on programme Statistica PL examples from medicine. Wydawnictwo Statsoft, Polska. (In Polish)

Stępień W., Mercik S. (2001): Influence of single or multiple nutrient fertilizers on soil and plants grown in 5-year crop rotation. Folia of University of Agriculture, Stetin, 223, Agriculture, *89*: 165–168. (In Polish)

Zeien H., Brümmer G.W. (1989): Chemische Extraktionen zur Bestimmung von Schwermetallbindungsformen in Boden. Mitteilungen der Deutschen Bodenkundlichen Gesellschaft, *59*: 505–510.

Received on May 17, 2004

ABSTRAKT

Vliv minerálního, organického a organominerálního hnojení na výnos a nutriční složení rostlin a na změnu půdních vlastností

V nádobovém pokusu byl sledován přídavek minerálních hnojiv, hnoje, kejdy a kapalného organominerálního hnojiva (Damishum). Minerální hnojení a hnojení organominerálním hnojivem zvýšilo výnos rostlin významněji v porovnání s organickým hnojením v prvním roce pokusu. V následujících pokusných letech se lépe projevila aplikace organických hnojiv. V souladu s předpoklady byly nejvyšší obsahy celkového dusíku nalezeny v rostlinách pěstovaných na variantách hnojených minerálně a organominerálně. Obsah fosforu v rostlinách významně závisel na pěstované rostlině a použitém hnojivu. Obsahy draslíku a hořčíku v rostlinách byly nejvyšší po přímé aplikaci organických hnojiv (hnůj, kejda). Nejvyšší množství kadmia z pěstovaných rostlin hromadila v nadzemních částech řepka. Obsah olova v nadzemních částech rostlin se nelišil mezi pěstovanými rostlinami. Měď se především hromadila v kořenech rostlin s výjimkou řepky, zatímco obsah zinku závisel na pěstované rostlině a použitém hnojivu. Aplikace hnojiv vedla ke snížení hodnoty pH půdy a ke zvýšení hydrolytické kyselosti. Hnojení minerálním a organominerálním hnojivem vedlo k výraznému poklesu obsahu půdního organického uhlíku, zatímco hnůj jeho obsah zvyšoval. Podobné interakce byly zjištěny i v případě celkového obsahu dusíku. Hnojení zvyšovalo obsah mobilních forem kadmia, olova a zinku, ale nemělo významný vliv na změny obsahu mobilní mědi.

Klíčová slova: hnojení; rostliny; výnos; chemické složení; makroživiny; těžké kovy

Corresponding author:

Dr. Ing. Krzysztof Gondek, Department of Agricultural Chemistry, H. Kołłątaj Agricultural University of Cracow, Al. Mickiewicza 21, 31-120 Cracow, Poland
e-mail: rrgondek@cyf-kr.edu.pl