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MAGNESIUM AND CALCIUM CONTENT AND REMOVAL IN CROPS GROWN IN SOIL FERTILIZED WITH DIFFERENT FORMS OF WASTE

Teresa Bowszys*, Jadwiga Wierzbowska, Dorota Pilejczyk, Paweł Sternik

Department of Agricultural Chemistry and Environmental Protection, University of Warmia and Mazury in Olsztyn
*Corresponding author. E-mail: teresa.bowszys@uwm.edu.pl

ABSTRACT

Our objective has been to determine the effect of farmyard manure as well as composted municipal waste and sewage sludge on the content of Mg and Ca in crops and on the removal of these elements from the soil by the harvested biomass. The research covered two cycles of a rotation of four crops: potato, spring barley, winter oilseed rape and winter wheat. Farmyard manure, municipal sewage sludge composted with straw, sewage sludge (dried and granulated), sewage sludge compost Dano and composted green waste were applied once in a rotation cycle, in a dose of 10 Mg d.m.·ha^{-1} (under potato), or twice, split into two doses, each of 5 Mg d.m.·ha^{-1} (under potato and winter oilseed rape). In the other years, the crops were supplied only mineral fertilization. Neither the type of organic fertilizer (manure or composts produced from sewage sludge and municipal waste) nor the application dosage (once or twice during the crop rotation) modified significantly the content of magnesium and calcium in plants. However, the Mg removal in the crop yield was modified by the applied fertilization. Composted sewage sludge increased the removal of Mg by 11-18% compared to that caused by NPK fertilization. The Mg uptake in treatments fertilized with composted municipal waste was similar to that in the NPK fertilized treatment. The total removal of calcium in the crop yields from treatments fertilized with composted sewage sludge was approximately the same as in the NPK treatment, but 10% (1st rotation cycle) and 40% (2nd rotation cycle) higher than the removal of this element from the FYM treated plot.

Key words: magnesium, calcium, content and removal in crops, fertilization, waste.

INTRODUCTION

The problem of sewage sludge and municipal waste recycling gains importance, as more and more are generated worldwide (*Environment* 2014; Mosquera-Losada et al., 2010). Advances in the civilization development lead to increasing amounts of waste products and changes in their chemical composition. Depending on where they are generated, waste products may contain large quantities of harmful substances, heavy metals, PAHs, PCBs, microbial and parasitic contaminants. One of the most sensible solutions for waste recycling in nature is to use by-products for agricultural purposes. Whenever the use of organic and mineral fertilization is limited, composts produced from sewage sludge or municipal waste can become an inexpensive source of nutrients for crops, also preventing depletion of soil nutrients.

Numerous studies on the chemical composition of sewage sludge demonstrated that this type of waste can turn into a rich source of organic matter and nutrients for plants (Arvas et al., 2011; Dusza et al., 2009; Fernandez et al., 2007; Flavel and Murphy, 2006; Kahiluoto et al., 2015; Mtshali et al., 2014; Sądej et al., 2007). Raw sewage sludge and municipal waste, as well as composts made from these raw materials are rich in nutrients and can therefore be used as unconventional soil improvers or substrates for cultivation of ornamental plants (Dobrowolska and Janicka, 2014; Hargreavers et al., 2007; Roca-Perez et al., 2009). However, before they are applied in the natural environment, they must be stablised and prepared by submitting to biological, chemical and thermal processing or to other technological processes that will control their susceptibility to putrefaction and eliminate any risk to the environment or to human health (Bień et al., 2011). For gaining an in-depth and thorough knowledge of the ecological consequences of waste application in farming, it is necessary to perform broad

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basic and experimental research that will allow us to elaborate guidelines for safe and rational use of composts.

The objective of our study has been to determine the influence of composts made from municipal waste and sewage sludge on the content of magnesium and calcium in crops and on the removal of these elements from soil with the harvested biomass yield.

MATERIAL AND METHODS

The experiment comprised two cycles of a rotation composed of four crops: potato, spring barley, winter oilseed rape and winter wheat. The field trials were conducted in 2004-2007 (1st cycle) and 2008-2011 (2nd cycle). The experiment consisted of 13 treatments fertilized with: NPK, farmyard manure (10 and 2x5 Mg d.m.·ha^{-1}); municipal sewage sludge composted with straw (10 and 2x5 Mg d.m.·ha^{-1}); dried and granulated sewage sludge (10 and 2x5 Mg d.m.·ha^{-1}); sewage sludge compost (10 and 2x5 Mg d.m.·ha^{-1}); Dano compost from mixed municipal waste (10 i 2x5 Mg d.m.·ha^{-1}); compost made from green waste (10 and 2x5 Mg d.m.·ha^{-1}). Manure and composts in doses of 10 Mg d.m.·ha^{-1} were applied only once in a rotation cycle (under potato in 2004 and in 2008), while doses of 5 Mg d.m.·ha^{-1} were supplied twice per rotation: under potato (2004, 2008) and under winter oilseed rape (2006, 2010). In the plots fertilized with manure and organic substances, nitrogen was balanced, depending on the soil content of N-total, with up to 150 kg·ha^{-1} under potato and up to 120 kg·ha^{-1} under winter oilseed rape. Spring barley (2005 and 2009) and winter wheat (2007 and 2011) were supplied only mineral fertilization consisting of N – 120 kg·ha^{-1}, P – 26 kg·ha^{-1} and K – 100 kg·ha^{-1}. The experiment was set up on proper grey-brown podsolic soil developed formed from sandy clay loam, classified as good wheat complex (2A gp. gc:gl). Prior to the onset of the experiment, the soil was characterized by high availability of phosphorus (45.3 mg·kg^{-1}), moderate availability of potassium (124.5 mg·kg^{-1}) and low availability of magnesium (48.3 mg·kg^{-1}), while its pH in 1 mol·dm^{-3} KCl was 5.04.

Table 1. Content of magnesium and calcium in manure and organic substances used in the experiment (g·kg^{-1})

Component	Farmyard manure (FYM)	Municipal sewage sludge composted with straw	Dried and granulated sewage sludge	Sewage sludge compost	Dano compost from mixed municipal waste	Compost made from green waste
Mg	1,1	1,9	3,7	7,8	3,32	2,95
Ca	3,6	17,8	15,1	33,9	17,7	12,6

The content of magnesium and calcium in manure and composts is specified in Table 1. Results of chemical analyses were submitted to statistical processing supported by Statistica 10®. The Tukey's HSD (Honestly Significant Differences) test was employed for verification of significance of differences, at the level of significance α=0.05.

RESULTS AND DISCUSSION

The content of magnesium in the crops grown in the first rotation cycle, depending on a species and fertilization, was from 23% to 40% higher than in the plants grown in the subsequent four-year rotation cycle (Tables 2 and 3). The content of magnesium in potato tubers in the 1st and 2nd rotation from the treatments fertilized with manure or composts was higher than from the plots supplied only NPK. Significantly positive influence of the composts on the content of magnesium in spring barley grain was verified only in the 1st rotation under the residual effect of dried and granulated sewage sludge.

The subsequent application of 5 Mg d.m.·ha^{-1} of fertilizer waste under winter oilseed rape induced, in comparison to the NPK treatment, a significant increase in the concentration of magnesium in seeds and straw of oilseed rape in both rotation cycles (from 3.99 to 4.12 mg·kg^{-1} d.m. of seeds and from 0.90 to 0.92 mg·kg^{-1} d.m. of straw in the 1st rotation and from 3.26 to 3.42 mg·kg^{-1} s.m. of seeds and from 0.95 to 1.17 mg·kg^{-1} d.m. of straw in the 2nd rotation). Also, a positive albeit non-significant residual effect of the second half-dose of the fertilizer substances was detected in relation to the magnesium concentration in wheat.

Table 2. Content of magnesium in 1st rotation crops (g·kg^{-1} d.m.)

Crops	Method of use	NPK	Farmyard manure	Municipal sewage sludge composted with straw	Dried and granulated sewage sludge	Sewage sludge compost	Dano compost from mixed municipal waste	Compost made from green waste	Mean
Potato tubers	a	1.09	1.24	1.19	1.35	1.29	1.23	1.09	1.21
	b		1.11	1.16	1.30	1.24	1.15	1.14	1.17
	mean		1.17	1.17	1.33	1.27	1.19	1.11	1.19
Spring barley grain	a	1.30	1.36	1.30	1.39	1.35	1.33	1.36	1.34
	b		1.41	1.31	1.28	1.30	1.42	1.29	1.33
	mean		1.39	1.30	1.34	1.33	1.37	1.33	1.34
Spring barley straw	a	0.79	0.81	0.80	0.91	0.81	0.76	0.77	0.81
	b		0.83	0.80	0.81	0.91	0.79	0.87	0.83
	mean		0.82	0.80	0.86	0.86	0.77	0.82	0.82
Winter oilseed rape seeds	a	3.99	4.10	4.02	4.04	3.97	4.04	4.10	4.04
	b		4.24	4.11	4.13	4.20	4.05	4.10	4.12
	mean		4.17	4.07	4.08	4.09	4.4	4.10	4.08
Winter oilseed rape straw	a	0.90	0.86	0.89	0.91	1.00	0.79	0.71	0.87
	b		0.89	0.92	1.04	1.07	0.91	0.75	0.92
	mean		0.87	0.91	0.97	1.04	0.85	0.73	0.90
Winter wheat grain	a	1.42	1.34	1.43	1.43	1.38	1.38	1.35	1.39
	b		1.36	1.37	1.40	1.41	1.39	1.43	1.40
	mean		1.35	1.40	1.42	1.40	1.39	1.39	1.39
Winter wheat straw	a	0.86	0.86	0.90	0.99	0.92	0.92	0.90	0.91
	b		0.86	0.93	0.94	0.98	0.97	0.96	0.93
	mean		0.86	0.91	0.96	0.95	0.95	0.93	0.92

HSD P<0.05	Potato tubers	Barley grain	Barley straw	Oilseed rape seeds	Oilseed rape straw	Wheat grain	Wheat straw
Fertilizer	0.07	n.s.	n.s.	0.14	0.18	n.s.	0.09
method of use	0.03	n.s.	n.s.	0.05	n.s.	n.s.	n.s.
Fertilizer* method of use	0.10	0.13	0.14	n.s.	n.s.	n.s.	n.s.

a – 10 Mg d.m.·ha^{-1} once during the crop rotation; b – 2x5 Mg d.m.·ha^{-1} twice during the crop rotation.

Dependence of the content of nutrients on the composition of sewage sludge and the processing technology used in their conversion to fertilizer has been demonstrated by Dusza et al. (2009) and Kalembasa et al. (1999). Gondek (2012) and Kaczor et al. (2006) showed a beneficial influence of soil nourishment with sewage sludge, manure or mineral and organic fertilizers, which consisted in higher concentrations of magnesium and calcium in plants compared to the control treatments. According to Keskin et al. (2010) and also

Wysokiński and Kalembasa (2011) fertilization of grasslands with sewage sludge increased the content of nitrogen and potassium while having no effect on the concentrations of phosphorus, calcium and magnesium in awnless brome (*Bromus inermis* Leyss).

Table 3. Content of magnesium in 2nd rotation crops ($g \cdot kg^{-1}$ d.m.)

Crops	Method of use	NPK	Farmyard manure	Municipal sewage sludge composted with straw	Dried and granulated sewage sludge	Sewage sludge compost	Dano compost from mixed municipal waste	Compost made from green waste	Mean
Potato tubers	a	0.89	0.97	1.01	0.93	0.91	0.96	1.05	0.96
	b		1.02	0.94	0.99	1.02	0.96	1.01	0.98
	mean		1.00	0.98	0.96	0.97	0.96	1.03	0.97
Spring barley grain	a	1.07	1.07	1.11	1.14	1.08	1.06	1.00	1.09
	b		1.04	1.0	1.09	1.10	1.14	1.11	1.09
	mean		1.06	1.10	1.12	1.09	1.10	1.09	1.09
Spring barley straw	a	0.53	0.54	0.54	0.64	0.65	0.57	0.59	0.58
	b		0.50	0.52	0.55	0.57	0.60	0.59	0.55
	mean		0.52	0.53	0.60	0.61	0.59	0.59	0.57
Winter oilseed rape seeds	a	3.26	3.36	3.34	3.39	3.36	3.46	3.35	3.36
	b		3.47	3.49	3.47	3.41	3.36	3.49	3.42
	mean		3.41	3.42	3.43	3.39	3.41	3.42	3.39
Winter oilseed rape straw	a	0.95	0.95	0.91	1.06	1.13	1.08	1.01	1.01
	b		1.33	1.32	1.16	1.15	1.19	1.12	1.17
	mean		1.14	1.11	1.11	1.14	1.13	1.07	1.01
Winter wheat grain	a	0.99	1.02	0.99	0.99	1.01	1.05	0.97	0.99
	b		1.04	1.00	1.02	1.02	1.04	1.02	1.01
	mean		1.03	1.00	1.01	1.02	1.05	0.99	1.00
Winter wheat straw	a	0.75	0.68	0.80	0.72	0.74	0.73	0.71	0.73
	b		0.74	0.70	0.74	0.72	0.73	0.77	0.74
	mean		0.71	0.76	0.73	0.73	0.73	0.74	0.73

HSD P<0.05	Potato tubers	Barley grain	Barley straw	Oilseed rape seeds	Oilseed rape straw	Wheat grain	Wheat straw
Fertilizer	0.07	0.05	0.08	n.s.	0.18	0.06	n.s.
Method of use	n.s.	n.s.	n.s.	n.s.	0.06	n.s.	n.s.
Fertilizer* method of use	0.09	0.08	n.s.	n.s.	0.25	n.s.	0.09

a – 10 Mg d.m.$\cdot ha^{-1}$ once during the crop rotation; b – 2x5 Mg d.m.$\cdot ha^{-1}$ twice during the crop rotation.

The total average removal of magnesium with the yield of the crops grown in the 1st rotation cycle (71.63 $kg \cdot ha^{-1}$) was 51% higher than in the 2nd rotation (47.36 $kg \cdot ha^{-1}$). Plants supplied NPK fertilizers alone took up the least of this element (69.49 kg $Mg \cdot ha^{-1}$ in the first rotation cycle and 44.94 kg $Mg \cdot ha^{-1}$ in the second one (Figures 1 and 2). Significantly the highest uptake of magnesium was achieved in the treatments fertilized with dried and granulated sewage sludge (1st rotation 77.55; 2nd rotation 52.29 $kg \cdot ha^{-1}$).

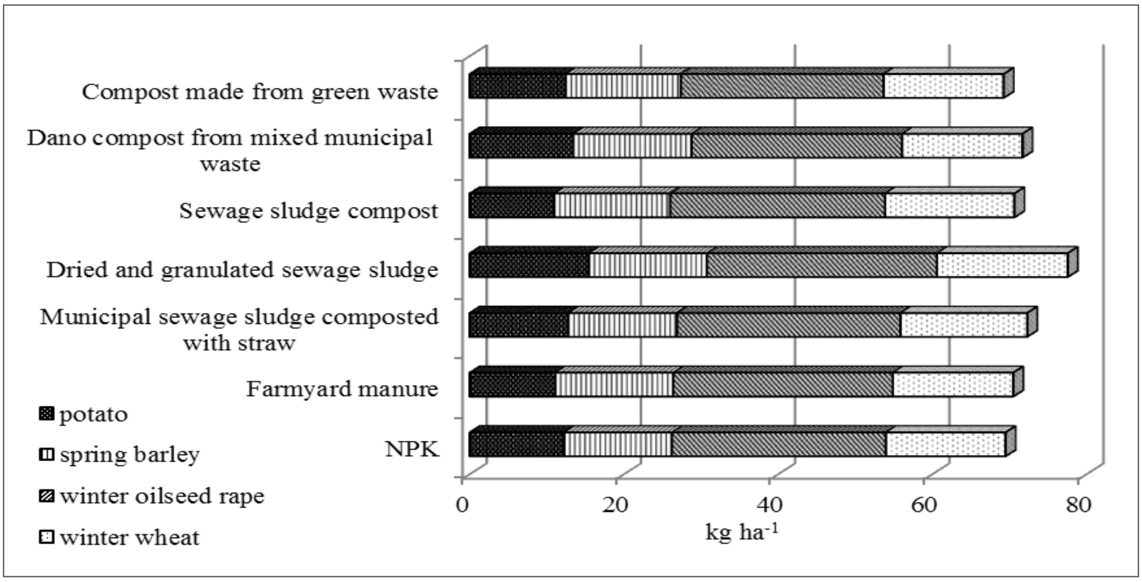

Figure 1. Removal of magnesium with yields of crops in the 1st rotation

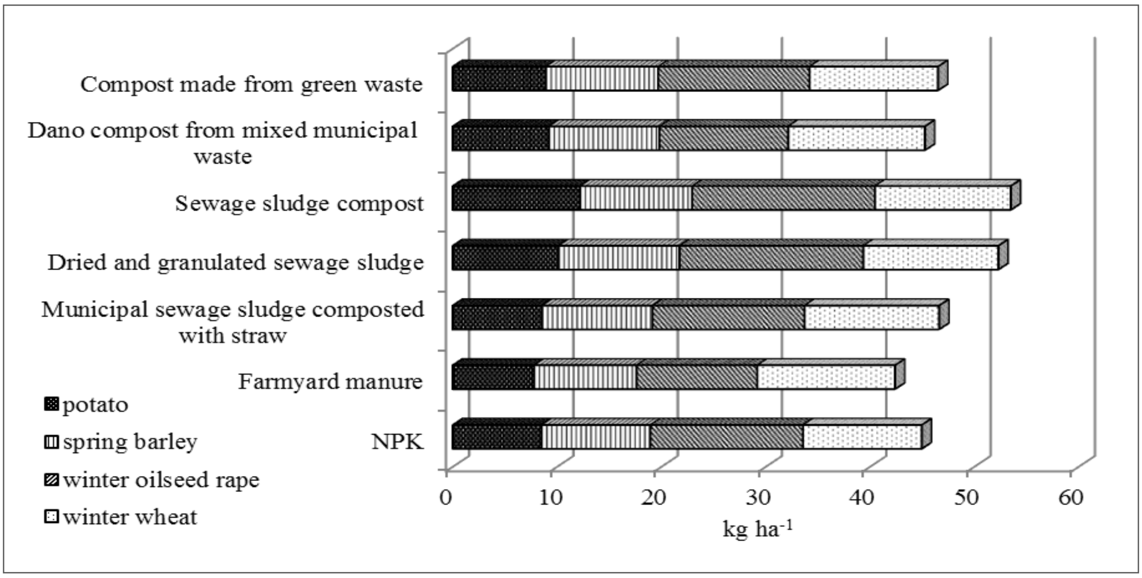

Figure 2. Removal of magnesium with yields of crops in the 2nd rotation

A higher content of calcium, by an average 13% more, was detected in the crops from the 2nd rotation (Tables 4 and 5). Potato tubers grown in the first year of the experiment were much poorer in calcium (0.58 mg·kg^{-1} d.m. on average), but responded significantly better to the fertilization with manure and composts than to the application of NPK fertilizers. The most significant influence on the Ca concentration in potato tubers was produced by composted municipal waste, such as Dano compost and composted green waste (0.63 mg·kg^{-1} d.m.). A significantly beneficial residual effect on the calcium content in spring barley grain occurred in the 1st rotation only after dried, granulated and composted sewage sludge had been supplied.

In the second rotation cycle, such an effect followed an application of Dano compost. In turn, the content of calcium in winter oilseed rape and in winter wheat from either rotation cycle was only slightly modified by the applied fertilization.

Table 4. Content of calcium in 1st rotation crops (g·kg^{-1} d.m.)

Crops	Method of use	NPK	Farmyard manure	Municipal sewage sludge composted with straw	Dried and granulated sewage sludge	Sewage sludge compost	Dano compost from mixed municipal waste	Compost made from green waste	Mean
Potato tubers	a	0.53	0.52	0.65	0.60	0.56	0.62	0.64	0.59
	b		0.60	0.54	0.56	0.61	0.64	0.59	0.58
	mean		0.56	0.59	0.58	0.59	0.63	0.62	0.58
Spring barley grain	a	0.41	0.44	0.41	0.46	0.46	0.42	0.45	0.43
	b		0.40	0.42	0.45	0.48	0.45	0.42	0.43
	mean		0.42	0.41	0.46	0.47	0.44	0.44	0.43
Spring barley straw	a	5.02	4.66	5.44	5.54	5.06	5.02	5.15	5.13
	b		4.43	4.59	5.05	5.47	4.39	5.60	4.94
	mean		4.55	5.01	5.30	5.27	4.70	5.38	5.03
Winter oilseed rape seeds	a	2.76	2.70	2.72	2.82	2.59	2.65	2.41	2.66
	b		2.94	2.51	2.45	2.85	2.77	2.81	2.73
	mean		2.82	2.62	2.64	2.72	2.71	2.61	2.70
Winter oilseed rape straw	a	10.85	9.75	10.46	9.70	12.00	9.75	8.80	10.19
	b		9.25	9.89	11.09	10.80	9.22	8.61	9.96
	mean		9.50	10.18	10.39	11.40	9.49	8.71	10.07
Winter wheat grain	a	0.62	0.63	0.59	0.71	0.58	0.52	0.62	0.61
	b		0.61	0.58	0.62	0.57	0.52	0.59	0.59
	mean		0.62	0.58	0.67	0.57	0.52	0.61	0.60
Winter wheat straw	a	2.07	1.70	1.72	2.32	2.28	1.91	1.99	2.00
	b		1.83	2.18	2.42	2.10	2.03	1.98	2.09
	mean		1.77	1.95	2.37	2.19	1.97	1.98	2.04

HSD P<0.05	Potato tubers	Barley grain	Barley straw	Oilseed rape seeds	Oilseed rape straw	Wheat grain	Wheat straw
Fertilizer	0.05	0.05	0.75	n.s.	1.66	n.s.	0.29
Method of use	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Fertilizer* method of use	0.08	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

a – 10 Mg d.m.·ha^{-1} once during the crop rotation; b – 2x5 Mg d.m.·ha^{-1} twice during the crop rotation.

The studies conducted by Bowszys et al. (2006 a, b) suggest that sewage sludge composts, especially in the first year, raise the plant content of calcium and magnesium, while any supplement of other substances (straw) diminishes this effect. On the other hand, Wen et al. (1999) did not observe an increase in the Mg or Ca content in crops induced by manure or sewage sludge. Krzywy-Gawrońska (2012) demonstrated that the biomass of Virginia fanpetals contained more P, Mg and S when grown in soil nourished with sewage sludge, with or without brown coal ash, than in soil supplied calcium carbonate or ash from incineration of coal high in calcium.

Table 5. Content of calcium in 2nd rotation crops ($g \cdot kg^{-1}$ d.m.)

Crops	Method of use	NPK	Farmyard manure	Municipal sewage sludge composted with straw	Dried and granulated sewage sludge	Sewage sludge compost	Dano compost from mixed municipal waste	Compost made from green waste	Mean
Potato tubers	a	1.31	1.12	1.18	1.15	1.33	1.23	1.26	1.23
	b		1.11	1.79	1.51	1.42	1.16	1.23	1.32
	mean		1.11	1.48	1.33	1.24	1.19	1.24	1.27
Spring barley grain	a	0.46	0.50	0.47	0.47	0.49	0.54	0.47	0.49
	b		0.52	0.57	0.52	0.48	0.54	0.48	0.51
	mean		0.51	0.52	0.49	0.49	0.54	0.48	0.50
Spring barley straw	a	3.57	3.24	4.03	4.64	4.07	3.63	3.53	3.81
	b		2.93	3.66	3.75	3.37	3.08	4.19	3.51
	mean		3.08	3.85	4.19	3.72	3.35	3.86	3.66
Winter oilseed rape seeds	a	3.39	3.08	3.65	3.33	3.55	3.44	3.49	3.42
	b		3.22	3.43	3.40	3.97	3.78	4.01	3.60
	mean		3.15	3.54	3.36	3.76	3. 61	3.75	3.51
Winter oilseed rape straw	a	13.84	13.17	13.76	14.57	14.20	15.06	13.60	14.04
	b		13.43	15.69	14.38	15.60	13.96	13.48	14.34
	mean		13.30	14.72	14.48	14.90	14.51	13.54	14.18
Winter wheat grain	a	0.74	0.74	0.75	0.74	0.66	0.74	0.75	0.73
	b		0.74	0.74	0.67	0.74	0.74	0.75	0.73
	mean		0.74	0.75	0.71	0.70	0.74	0.74	0.73
Winter wheat straw	a	3.98	3.89	3.65	4.18	5.00	4.23	4.46	4.20
	b		3.82	4.40	4.59	4.75	4.26	4.21	4.29
	mean		3.85	4.03	4.39	4.87	4.24	4.33	4.24

HSD P<0.05	Potato tubers	Barley grain	Barley straw	Oilseed rape seeds	Oilseed rape straw	Wheat grain	Wheat straw
Fertilizer	n.s.	0.06	0.87	0.43	n.s.	n.s.	0.56
Method of use	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Fertilizer*method of use	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.

a – 10 Mg $d.m. \cdot ha^{-1}$ once during the crop rotation; b – 2x5 Mg $d.m. \cdot ha^{-1}$ twice during the crop rotation.

The removal of calcium (129 $kg \cdot ha^{-1}$) with the yields of crops was similar in both rotations (Figures 3 and 4). Compared with the treatments supplied green waste compost, the removal of this element with the crop yields was much higher in treatments fertilized with dried, granulated or composted sewage sludge (135 $kg \cdot ha^{-1}$ in the first rotation and 146 $kg \cdot ha^{-1}$ in the second rotation).

Bowszys et al. (2006 b) demonstrated a positive effect of compost made of municipal waste on yield of plants, which largely determines the uptake of nutrients. Helios et al. (2014) also reported a significant influence of sewage sludge application on plant yields although the yield structure and its content of macroelements were unaffected. Černý et al. (2010) completed a long-term experiment, in which they showed that yields of potato, wheat and barley increased considerably under the influence of sewage sludge compared to manure fertilization.

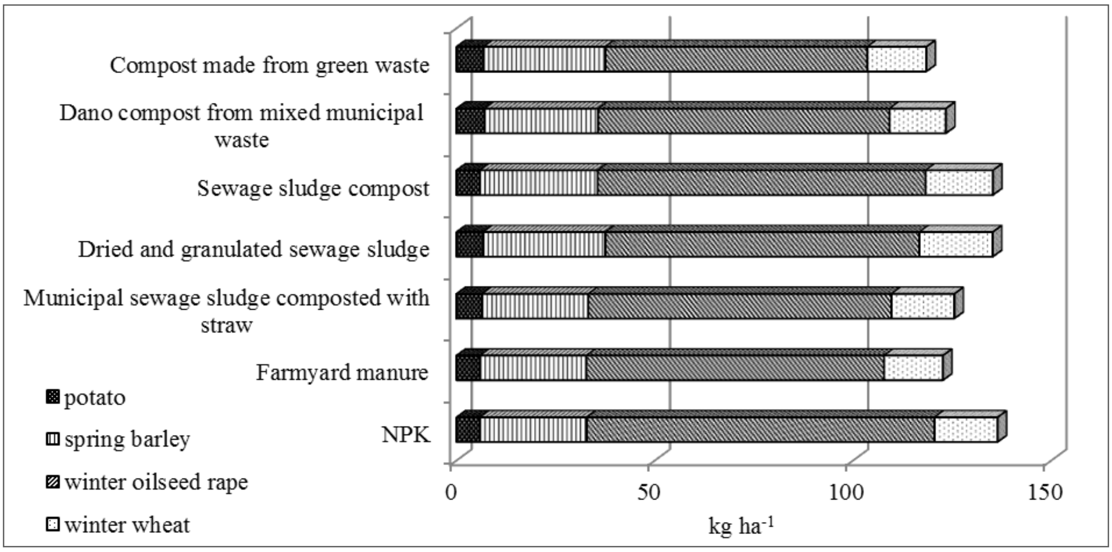

Figure 3. Removal of calcium with yields of crops in the 1st rotation

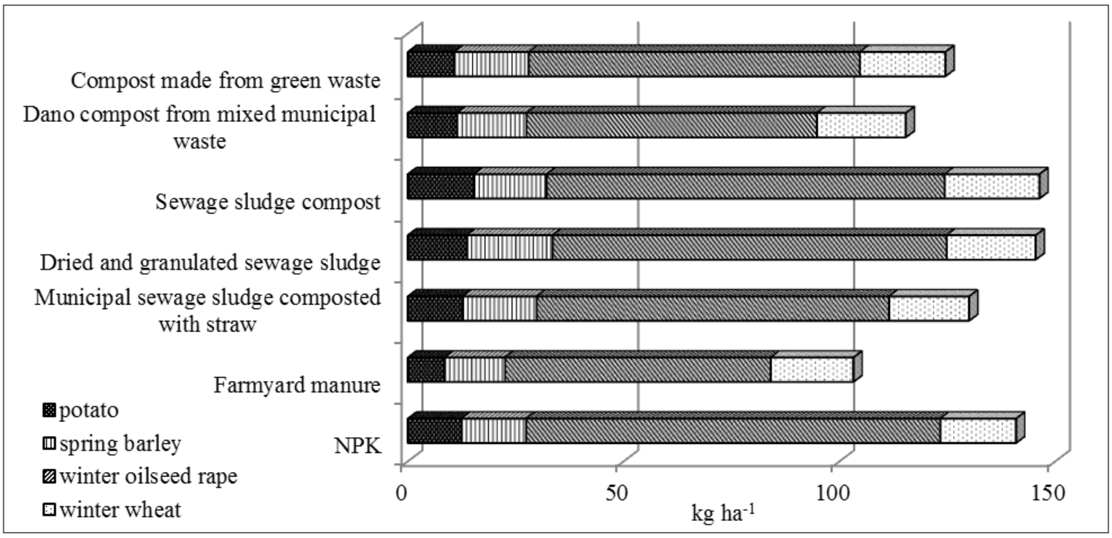

Figure 4. Removal of calcium with yields of crops in the 2nd rotation

CONCLUSIONS

Manure and composts made of sewage sludge or municipal waste as well as their application technology in a rotation cycle only slightly modified the content of magnesium and calcium in plants.

The removal of magnesium with the crops' yields was modified by the tested fertilization. Composted sewage sludge increased the magnesium removal by 11 to 18% compared to the NPK treatment. The plots fertilized with municipal waste compost demonstrated a similar uptake of magnesium by biomass as in the NPK treatment.

The total removal of calcium with the crops' yields from the treatments fertilized with sewage sludge compost was similar to that in the NPK treatment but 10% (1st rotation) and 40% (2nd rotation) higher than in the plots fertilized with manure.

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