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Original Research

Manganese Content in Biomass of Spring Wheat, Soil, and Soil Effluents after Fertilization with Municipal Sewage Sludge and Compost of Municipal Wastes

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Abstract

Our investigations aimed at determining the content of manganese in spring wheat biomass, soil, and soil effluents after fertilization with municipal sewage sludge and compost of municipal wastes. The investigations were conducted for three years as a pot experiment on soil material with granulometric composition of medium silt loam. The sewage sludge was stabilized and originated from a municipal mechanical-biological treatment plant. It was manufactured of plant and other biodegradable wastes using MUT-Kyberferm technology. During the three-year period of the experiment, on non-limed and limed soil only fertilization with municipal sewage sludge produced a better effect, apparent as the amount of wheat grain biomass, in comparison with mineral salt treatment, farmyard manure and composts of plant wastes. Fertilization with farmyard manure, sewage sludge and compost did not modify significantly manganese concentrations in wheat grain, straw, and roots. Soil liming had a better effect on manganese content in wheat. The content of mobile manganese forms was significantly higher in the non-limed soil, irrespective of the applied fertilization. In both experimental series (0 Ca and + Ca) the greatest number of mobile manganese forms was found in the soil of the mineral treatment. Among the treatments where fertilizers were used, the biggest amounts of manganese in the soil effluents (from both experimental series), were assessed after the application of compost from plant wastes. Liming had a crucial influence on diminishing manganese concentration in water draining away from soil.

Keywords: manganese, spring wheat, sewage sludge, compost, soil, soil effluents

Introduction

The use of organic waste on farms for agricultural purposes has been identified as a standard of good agricultural practice. These wastes constitute considerable resources of fertilizer components and organic matter, which is connected with their biological (mainly plant) origin [1, 2]. Environmental application of wastes requires a detailed analysis of their chemical composition and microbial load to enable assessment of environmental hazards, or sometimes proper treatment of wastes to transform them into useful material which, if properly managed, would produce a positive effect [3]. Contrary to mineral fertilizers, organic wastes are a valuable source of nutrients not only for plants, but also for microorganisms and soil fauna [4, 5]. However, it should be remembered that environmental use of wastes

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may be limited due to their negative effect on, among others, soil properties and chemistry of plants and waters, but also due to their sanitary hazard [6-9]. In order to diminish the risk of environmental contamination, detailed provisions for introducing waste substances into the environment were stated in appropriate regulations [10-12].

Due to nutrient and organic matter resources, sewage sludge and composts produced from municipal wastes have the best chances of being used in agriculture. Fertilizer use of these materials may significantly contribute to increase the resources and improve the quality of organic substance in soils. Undoubtedly it will lead to an improvement of physical, chemical, and biological soil properties [13, 14].

Various wastes must be used in agriculture most cautiously. It is not permissible to apply wastes in agriculture only for their liquidation or detoxication without first analyzing their chemical composition and microbial load. Appropriate principles and technologies of their application must be developed that would consider their effect on individual elements of the natural environment [2, 15, 16].

Our three-year investigations aimed to assess manganese content in spring wheat biomass, soil, and soil effluents after fertilization with municipal sewage sludge, and compost produced from municipal wastes.

Table 1. Some properties of soils before the establishment of the experiment.

Granulometric composition Ø	1.0-0.1 mm	$g \cdot kg^{-1}$	260
	0.1-0.02 mm		300
	<0.02 mm		440
pH H_2O			6.33
pH KCl			5.70
Hydrolytic acidity		$mmol(+) \cdot kg^{-1}$ d.m.	23.9
Sum of alkaline cation			233.5
Organic C		$g \cdot kg^{-1}$ d.m.	19.3
Total Mn		$mg \cdot kg^{-1}$ d.m.	1567
Total Cr		$mg \cdot kg^{-1}$ d.m.	21.3
Total Zn		$mg \cdot kg^{-1}$ d.m.	89.5
Total Pb		$mg \cdot kg^{-1}$ d.m.	31.1
Total Cu		$mg \cdot kg^{-1}$ d.m.	8.12
Total Cd		$mg \cdot kg^{-1}$ d.m.	0.75
Total Ni		$mg \cdot kg^{-1}$ d.m.	12.8
Total Hg		$mg \cdot kg^{-1}$ d.m.	0.39

Experimental Procedures

Assessment of the effect of fertilizing with municipal sewage sludge and compost produced from municipal and other biodegradable wastes on manganese content in spring wheat, soil, and soil effluents was conducted in a pot experiment in a vegetation hall. The experimental soil material was medium silt loam with 440 $g \cdot kg^{-1}$ of <0.02 mm granulometric fraction, collected from the 0-20 cm layer of arable land. Characteristics of selected physical and chemical soil properties were given in Table 1.

The experiment was conducted for three years in polyethylene pots, 38 cm high and 28 cm in diameter, containing 22.0 kg of air-dried soil material and equipped with the effluent removal system. The soil effluent removal system was composed of a perforated hose-pipe with attached container and of sand and gravel filtration layer. The experiment was conducted in three replications and two series: non limed (0 Ca) and limed (+ Ca), comprising 5 treatments: 0 – soil without fertilizers, M – soil fertilized with mineral salts [N, P, and K introduced in form N-NH_4NO_3, P-$Ca(H_2PO_4) \cdot H_2O$, K-KCl], SM – soil fertilized with pig farmyard manure, SS-soil fertilized with municipal sewage sludge, and C – soil fertilized with composts produced from plant and other biodegradable wastes (identified in the Waste Catalogue code 20 02 01).

Pig manure, after 6 months of storage obtained from a private farm, was used for the experiment. The sewage sludge was stabilized and originated from a municipal mechanical-biological treatment plant located in the southern part of the Małopolska Voivodeship. At biological stage of sewage treatment the method of activated sludge treatment in aeration chambers was used. Sewage sludge used for the experiment was subjected to oxygen stabilization in separate open chambers in which the aeration process was conducted constantly at ambient temperature. After this period sewage sludge was dewatered on filtration beds. The dewatering process lasted 3 months. The compost used for the experiment was produced from plant and other biodegradable wastes using MUT-Kyberferm technology [17] in the following proportions: 25% grass, 20% chips, 20% leaves, 10% organic waste from markets, 5% tobacco dust, and 20% wastes from coffee manufacturing. The compost was obtained from a composting plant in Kraków. The characteristics of selected properties of farmyard manure, municipal sewage sludge, and compost of plant wastes are presented in Table 2.

Prior to the experiment, the soil was gradually moistened to 30% of maximum water capacity. After moistening, a part of the soil material was limed separately in each pot. Liming was done with chemically pure CaO and the dose was established on the basis of soil total hydrolytic acidity. CaO dose was 0.68 $g \cdot kg^{-1}$ d.m. soil. Subsequently, both limed and nonlimed soil material was left for 4 weeks and water losses were supplemented periodically. Afterward, the mineral fertilizers, farmyard manure and organic materials were mixed with soil. Nitrogen dose supplied in mineral salts, farmyard manure, and organic materials was 0.14 g $N \cdot kg^{-1}$ soil d.m. Phosphorus and potassium were supplemented to equal levels introduced with fertilization on all treatments (except the control), phosphorus to 0.10 g $P \cdot kg^{-1}$ soil d.m. in a water solution of $Ca(H_2PO_4)_2 \cdot H_2O$, and potassium to 0.15 g $K \cdot kg^{-1}$ soil d.m. as water KCl solution. In the second and third year of the experiment supplementary doses of nitrogen, phospho-

Table 2. Chemical composition of materials used in the experiment.

Determination		Swine manure (SM)	Municipal sewage sludge (SS)	Compost made of plant waste (C)
Dry matter g·kg^{-1}		186	573	458
pH H_2O		6.58	7.63	7.44
Organic matter g·kg^{-1} d.m.		686	501	479
Total forms				
N	g·kg^{-1} d.m.	26.3	38.9	37.3
P		20.1	15.3	6.1
Ca		3.0	15.9	24.6
Na		3.4	0.6	0.9
Mn	mg·kg^{-1} d.m.	416	250	301
Cr	mg·kg^{-1} d.m.	5.82	37.09	14.98
Zn	mg·kg^{-1} d.m.	555	2034	158
Pb	mg·kg^{-1} d.m.	3.36	29.53	9.68
Cu	mg·kg^{-1} d.m.	290	125	27
Cd	mg·kg^{-1} d.m.	1.31	2.07	1.18
Ni	mg·kg^{-1} d.m.	11.34	20.27	7.74
Hg	mg·kg^{-1} d.m.	0.21	0.94	0.29

rus, and potassium were used equally in all treatments (0.10 g N, 0.02 g P, and 0.14 g K·kg^{-1} soil d.m.). These components were supplied as chemically pure salts [N – NH_4NO_3; P – $Ca(H_2PO_4)\cdot H_2O$; K – KCl].

In each year of the experiment spring wheat "Nawra" c.v. was cultivated at plant density of 28 seeds per pot. Wheat was harvested at full grain maturity. The plant vegetation period was 109 days in the first year, 104 days in the second, and 96 days in the third. During the experiment the plants were watered with distilled water to 50% of maximum water capacity.

In order to determine selected soil chemical properties, soil material samples were collected each year and from each pot separately after spring wheat vegetation was completed.

The soil lump in a pot was leached with distilled water to assess manganese content in soil effluents.

After the harvest, wheat plants were divided into roots, straw, and ears. The ears were then threshed mechanically to obtain grain biomass. In order to assess dry mass yield, the individual parts were dried (at 70ºC) with hot air flow to obtain constant weight. The plant material (separately grain, straw, and roots) was crushed in the laboratory, milled, and then mineralized in a muffle furnace (at 450ºC for 5 hrs.). The remains were solved in a diluted nitric acid 1:2 (v/v) solution [18].

In the soil material collected from the pots, dried, and sifted through a sieve with 1 mm mesh, pH was assessed by a potentiometer in a soil suspension and 1 mol·dm^{-3} KCl solution. Mean values of soil pH from individual years of the experiment on treatments were calculated after converting pH values into hydrogen ion concentration. Manganese concentration was assessed after extraction with 1 mol·dm^{-3} NH_4NO_3 solution [19].

During the vegetative period, the soil lump in pots was leached with distilled water every 30 days, which simulated a 36 mm rainfall. The resultant soil effluent was collected from each washing and kept in a refrigerator at 4ºC. Total manganese concentration in soil effluents was determined after evaporating 100 cm^3 of the soil effluent and dissolving the remains in a diluted nitric acid 1:2 (v/v) [20].

The concentrations of manganese in the obtained solutions after plant material and soil effluent mineralization, and in soil extracts was determined using the ICP-AES method on JY 238 Ultrace apparatus (France) and the concentrations assessed in the plant and soil material were converted into material dry weight.

Chemical analysis of the plant and soil material and soil effluents were conducted in all three replications. In order to verify the assessment results obtained for the plant and soil material, plant reference material – NCS DC73348 (China National Analysis Center for Iron & Steel) or soil reference – EnviroMAT, SS-2 (SCP Science) was added to each analyzed series. The result was considered reliable if the relative standard error did not exceed 5%.

Two-way ANOVA (fertilization x liming) in a completely randomized design using F-Fisher test was conducted for the obtained results. The significance of differences between arithmetic means was verified on the basis of homogenous groups determined by Duncan test at the sig-

Table 3. Total (from three years) dry-matter (DM) yield grain, straw, and roots of spring wheat. Different letters within columns show significant differences among treatments ($\alpha<0.05$; Duncan's multiple range test).

Treatment	Yields g DM·pot^{-1}					
	0 Ca			+ Ca		
	grain	straw	roots	grain	straw	roots
0	128.3 a	116.2 a	7.74 a	125.3 a	121.2 a	7.04 a
M	175.0 b	176.6 c	13.18 c	173.4 b	169.1 bc	11.73 c
SM	183.6 b	169.7 bc	10.98 b	173.8 b	158.6 b	10.18 b
SS	202.7 c	175.2 c	11.24 b	183.0 b	171.2 bc	10.50 b
C	183.1 b	164.2 bc	11.50 b	177.1 b	168.4 bc	10.90 b

0 – soil without fertilization, M – soil with addition of mineral salts, SM – soil with addition of swine manure, SS – soil with addition of municipal sewage sludge, C – soil with addition of compost made of plant waste

nificance level $\alpha<0.05$. All statistical calculations and graphic presentations of the results were made using the Statistica PL package [21].

Results and Discussion

The total for 3-years quantities of wheat grain, straw, or roots obtained on the treatments where fertilizers were applied were significantly higher than for those harvested on the non-fertilized objects, irrespective of the experiment series (0 Ca or + Ca) (Table 3).

The highest amounts of grain, both on the non-limed (0 Ca) and limed (+ Ca) series, were gathered from the treatment where municipal sewage sludge was applied (Table 3). However, statistically proved difference in the amount of grain biomass in comparison with the other fertilized treatments was registered only for the yield from the non-limed series (0 Ca).

The amounts of wheat straw biomass were the greatest, irrespective of the experimental series (0 Ca or + Ca), on the treatments where mineral or municipal sewage sludge were used as fertilizers (Table 3).

Amounts of root biomass differed significantly between the treatments where organic materials or mineral salts were used (Table 3). The largest wheat root biomass quantity was registered on the mineral salt treatments in both series (0 Ca and + Ca).

Fertilizer effectiveness of organic materials is determined mainly by the rate of their mineralization, leading to release of mineral components crucial for plant growth and development [22]. The most important fertilizer element affecting crop yield is nitrogen, but disturbed relations between other nutrients may directly influence plant mineral balance and condition biological value of the obtained yield. In the case of organic materials originated from wastes, an additional factor that may inhibit plant growth and development is usually the higher trace element concentration than in the soil, including heavy metals revealing a phytotoxic effect. During the three-year period of the experiment, irrespective of the type of the applied fertilization, only municipal sewage sludge treatment produced a better result, expressed by wheat grain biomass amount, in comparison with mineral salts or fertilization with farmyard manure and compost produced from plant wastes. A similar dependence was noted for straw, although the difference between the amount of biomass harvested from municipal sewage sludge treatment and on the pots where mineral fertilizers were used was not significant. No such advantageous effect of any applied organic material as compared with mineral treatment was assessed for roots. The results of the research conducted so far demonstrated a favourable influence of sewage sludge or composts produced from municipal wastes on plant yield [23]. It was mainly determined by trace element concentrations and, in the case of composts, also their maturity. As demonstrated by Maćkowiak et al. [23], compost fertilization usually affects plant growth and development to a lesser degree than application of mineral fertilizers. On the other hand, Gondek [24] revealed that sewage sludge fertilization tested in a three-year experiment better affected maize biomass yield than treatment with mineral salts, although soil granulometric composition proved an important factor affecting biomass amount. Delgado et al. [25] also proved a favourable effect of fertilization with composted sewage sludge on maize biomass amount. Wiater et al. [26] obtained worse direct effect of a granulate produced from sewage sludge on maize yield in comparison with mineral treatment, but the residual effect of sewage sludge fertilizer activity was better.

Bigger amounts of manganese were assessed in wheat grain of the non-limed series (0 Ca), irrespective of the applied fertilization (Fig. 1). Wheat fertilization with farmyard manure, sewage sludge, and compost did not cause any significant differences in manganese concentrations in grain in either non-limed or limed series.

The mean for three years of manganese content in wheat straw was the highest both in the non-limed (0 Ca) and limed (+ Ca) series on mineral treatment, but Mn content in wheat straw from the non-limed series (0 Ca) was over twice higher than that assessed in the straw from the same object in the limed series (+ Ca) (Fig. 2).

No significant differences in manganese content in root biomass from individual treatments were registered irrespective of the experimental series (0 Ca or + Ca) (Fig. 3). Manganese concentrations in wheat roots from fertilized objects were significantly lower than determined in root biomass from the objects that did not receive fertilization. This might result from the analyzed element cumulation in a relatively lower biomass yield.

Piotrowska and Gałczyńska [27] and Patorczyk-Pytlik [28] revealed that an excessive accumulation of heavy metals in plants happens when big doses of sewage sludge or composts, heavily loaded with these elements, are used for fertilization. As reported by Ohki [29], it may lead to inhibition of growth and development of some plant organs. Results show that, irrespective of the experimental series (0 Ca or + Ca), manganese concentration in maize biomass

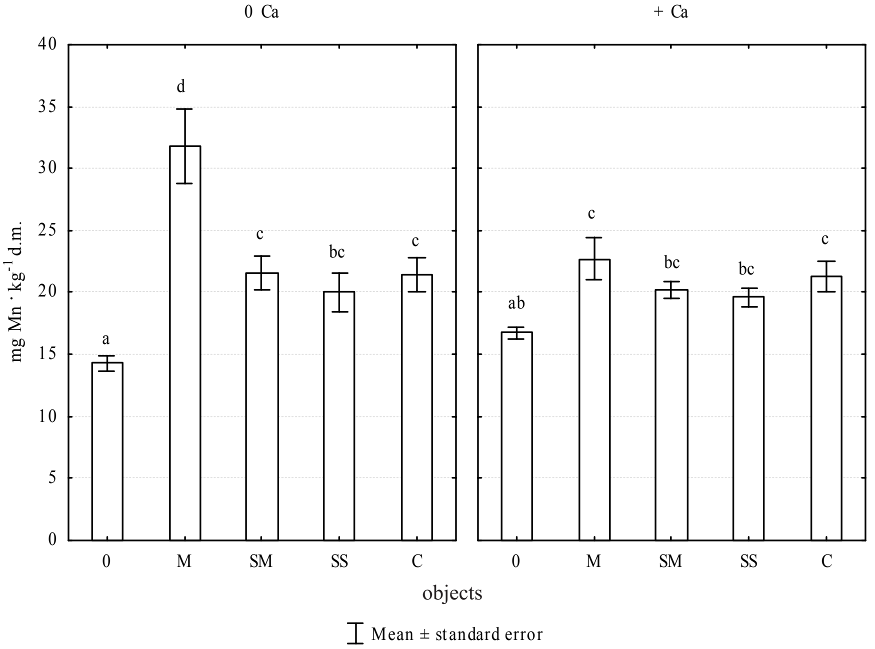

Fig. 1. Average content of manganese in grain of spring wheat.
Different letters show significant differences among treatments (α<0.05; Duncan's multiple range test).
0 – soil without fertilization, M – soil with addition of mineral salts, SM – soil with addition of swine manure, SS – soil with addition of municipal sewage sludge, C – soil with addition of compost made of plant waste.

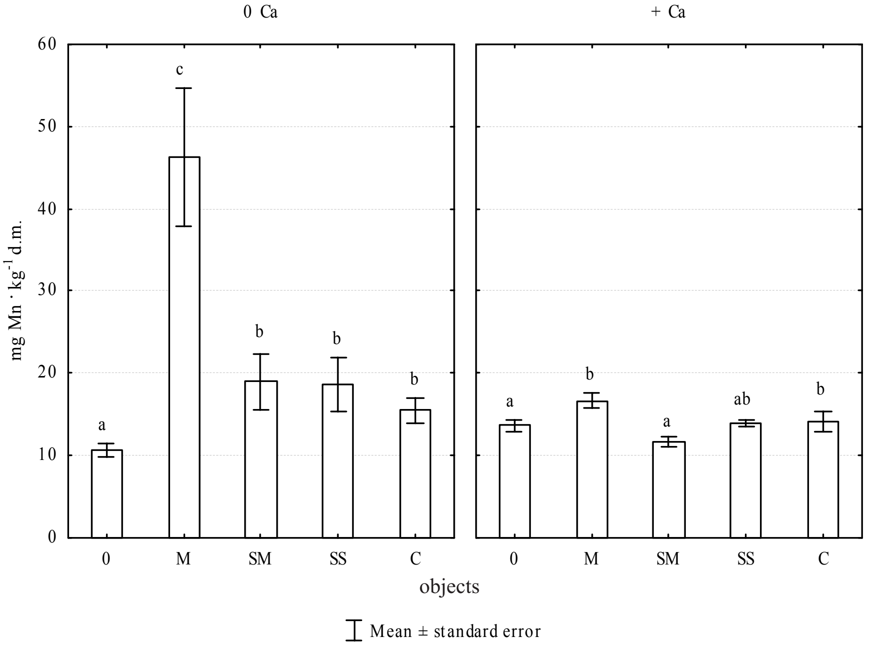

Fig. 2. Average content of manganese in straw of spring wheat.
Different letters show significant differences among treatments (α<0.05; Duncan's multiple range test)
0 – soil without fertilization, M – soil with addition of mineral salts, SM – soil with addition of swine manure, SS – soil with addition of municipal sewage sludge, C – soil with addition of compost made of plant waste.

was higher in the treatments where nitrogen, phosphorus and potassium were applied in mineral form. Also, Reszel and Głowacka [30] obtained bigger contents of manganese in maize fertilized with mineral materials in comparison with this element content assessed in plants fertilized with sewage sludge. Numerous investigations show that manganese content in plants is conditioned mainly by soil pH, which determines this element's bioavailability [31, 32]. Research conducted by Rabikowska and Piszcz [33] on the influence of mineral fertilization with nitrogen on utilization of, among others, manganese from farmyard manure, clearly demonstrate that the smallest quantities of manganese were absorbed by plants fertilized with farmyard manure each year, and particularly bigger doses of this fertilizer caused a bigger manganese uptake by all plants cultivated in the experiment.

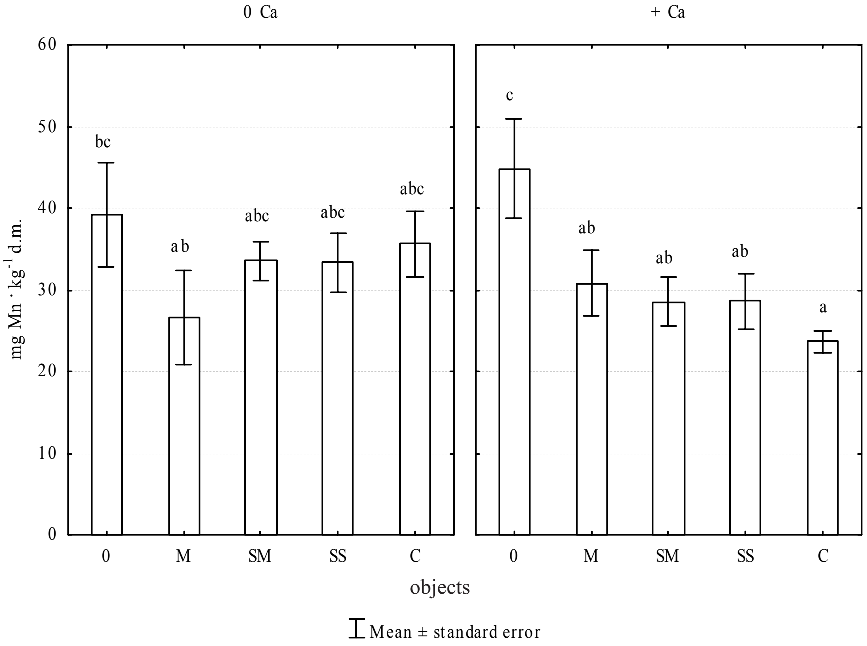

Fig. 3. Average content of manganese in roots of spring wheat.

Different letters show significant differences among treatments ($\alpha<0.05$; Duncan's multiple range test).

0 – soil without fertilization, M – soil with addition of mineral salts, SM – soil with addition of swine manure, SS – soil with addition of municipal sewage sludge, C – soil with addition of compost made of plant waste.

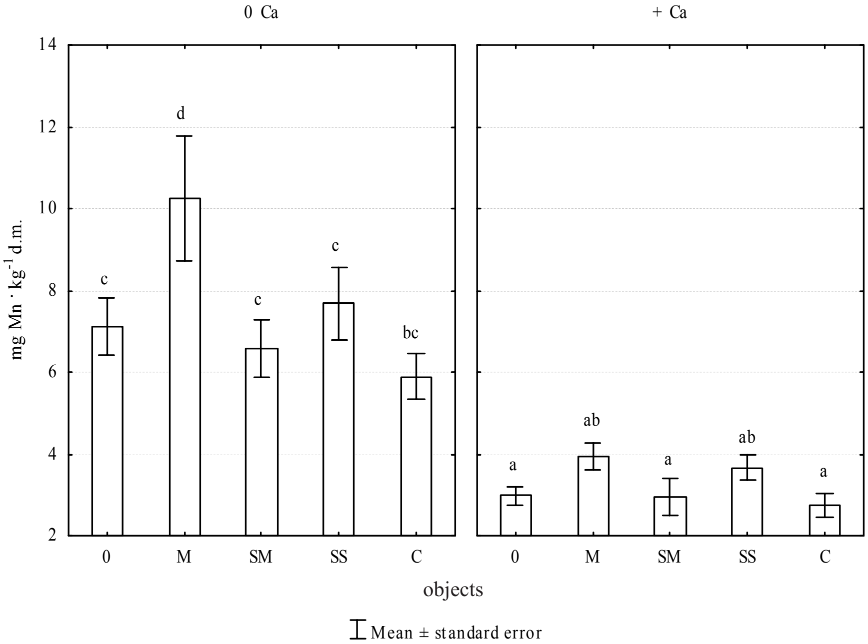

Fig. 4. Average content of manganese (extraction of 1 mol·dm^{-3} NH_4NO_3) in soil.

Different letters show significant differences among treatments ($\alpha<0.05$, Duncan's multiple range test).

0 – soil without fertilization, M – soil with addition of mineral salts, SM – soil with addition of swine manure, SS – soil with addition of municipal sewage sludge, C – soil with addition of compost made of plant waste.

The average for three years' content of manganese mobile forms was significantly the highest in the soil from treatments in the non-limed series (Fig. 4). In both experimental series the greatest number of manganese mobile forms were found in soil from objects where mineral fertilizers were used. In the soil from these treatments the lowest pH values measured in KCl and soil suspensions were assessed (Fig. 5). Considering all applied organic materials, the highest average (for three years) contents of manganese mobile forms were determined in the soil from treatments where municipal sewage sludge was applied, irrespective of the experimental series (0 Ca or + Ca). Heavy metal

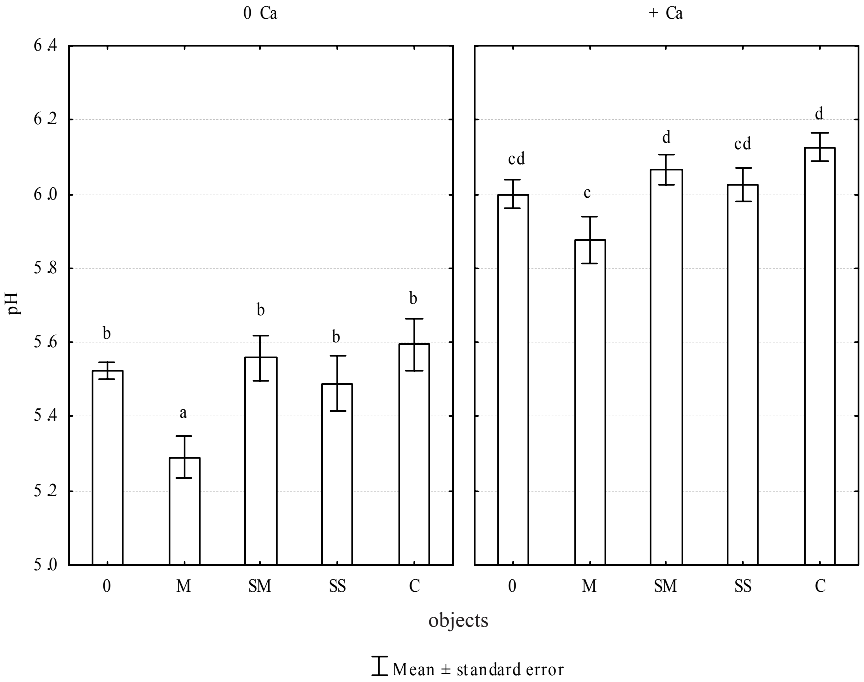

Fig. 5. Soil pH.
Different letters show significant differences among treatments (α<0.05, Duncan's multiple range test).
0 – soil without fertilization, M – soil with addition of mineral salts, SM – soil with addition of swine manure, SS – soil with addition of municipal sewage sludge, C – soil with addition of compost made of plant waste.

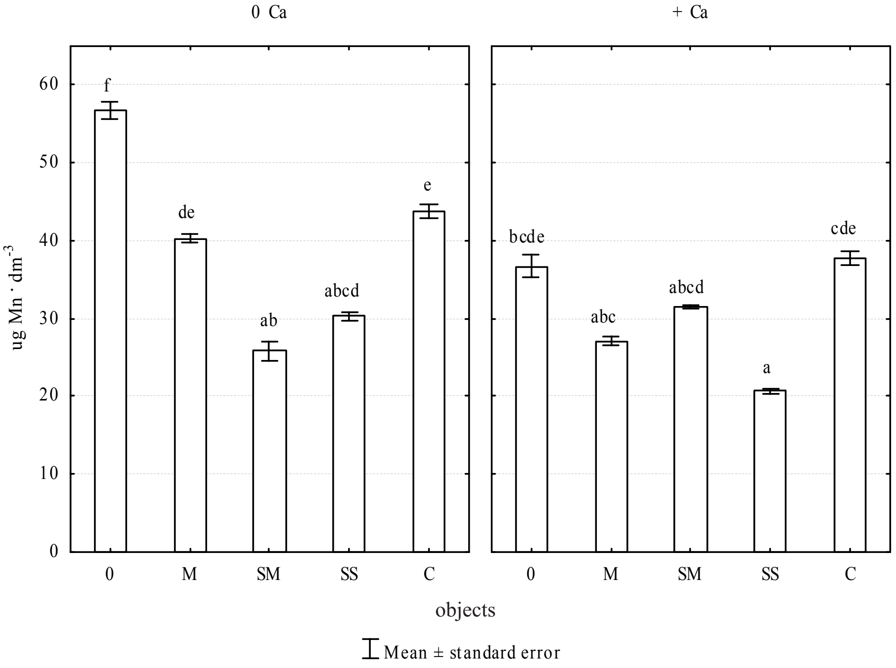

Fig. 6. Average content of manganese in soil leakages.
Different letters show significant differences among treatments (α<0.05, Duncan's multiple range test).
0 – soil without fertilization, M – soil with addition of mineral salts, SM – soil with addition of swine manure, SS – soil with addition of municipal sewage sludge, C – soil with addition of compost made of plant waste.

release into soil solution depends on soil properties and chemistry of the element itself [30, 34]. In this study liming significantly decreased soil acidification, regardless of fertilization. The highest content of manganese mobile forms was assessed in the soil fertilized with mineral salts in both series (0 Ca and + Ca), which was enhanced by soil acidification. Presented research results have been confirmed by the results obtained by Godo and Reisenauer [35]. Gondek [36] also demonstrated that after the application of organic materials and irrespective of the soil granulometric composition, the content of manganese mobile forms was markedly lower than the content determined in the soil from mineral salt treatments. Jakubus et al. [37] revealed that soil pH has a marked effect on manganese content in water-soluble fraction. Moreover, the same authors stated that farmyard manure fertilization caused a decrease in readily soluble manganese forms, whereas mineral fertilization increased this share. According to Hsu and Lo [38], manganese bioavailability from organic materials after their application to soil is conditioned by the rate of mineralization of organic matter to which considerable amounts of manganese are bound [39].

In the soil effluents (from both experimental series), the greatest quantities of manganese were found after the application of compost produced from plant wastes (Fig. 6). Soil liming had a crucial effect on diminishing manganese concentrations in water draining away from all treatments in this series. According to Bożym and Wacławek [40], trace element content in soil effluents is considerably affected by pH and precipitation amount, and the forms of elements present in the substrate. Even though under conditions the quantity and parameters of water used to wash the soil lump remained unchanged, yet changes occurring in soil (mainly progressive acidification over a longer period of time) may cause an increase in the amount of trace elements leached from soil. A significant effect of liming on a reduction of manganese leaching from soil was previously registered in research conducted by Ruszkowska et al. [41].

Conclusions

1. Considering organic materials and regardless of the applied liming, only fertilization with municipal sewage sludge produced a better effect expressed by the amount of wheat grain biomass in comparison with fertilization using mineral salts, farmyard manure, and compost from plant waste over a three-year period of research.
2. Wheat fertilization with organic materials did not markedly diversify manganese concentrations in grain, straw, and wheat roots. Bigger quantities of manganese were assessed in grain and straw of plants cultivated in non-limed soil, irrespective of applied fertilization. An opposite dependence was found in roots.
3. The contents of mobile manganese forms was significantly higher in the soil from treatments of non-limed series. In both experimental series the biggest amount of mobile manganese forms was assessed in the soil from treatment receiving mineral fertilizers.
4. The highest concentrations of manganese in soil effluents (from both experimental series) and among the treatments where fertilization was conducted after the application of compost based on plant wastes. Liming has a crucial effect on diminishing manganese content in water draining away from the soil.

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