CHALLENGES OF MODERN TECHNOLOGY | Vol. 9, No 1, 2018, 3-17 DOI: 10.5604/01.3001.0013.6122

The rate of release of macronutrients from new organic-mineral fertilizers

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The rate of release of macronutrients from new granulated organic-mineral fertilizers formed from spent mushroom substrate was investigated in the conditions of a microplot experiment in the laboratory. Nitrate(V) and ammonium were estimated using a colorimetric method using a flow autoanalyzer after extraction in 1% solution K_2SO_4 and in 0.01 mol · dm - 3 $CaCl_2$, pH-value – by potentiometric method after extraction with 1 mol · dm - 3 KCl, available P and K by the Egner-Riehm method. New granulated organic-mineral fertilizers formed from spent mushroom substrate had an impact on the pH-value seven days after application. This tendency was intensified in the following weeks. New granulated organic-mineral fertilizers were a source of available form of nitrogen (nitrate(V), ammonium), potassium and phosphorus.

Key words: spent mushroom substrate, organic-mineral fertilizers, rate of macronutrient release, sewage sludge

Introduction

The challenges facing modern agriculture also include taking care of the environment, providing good quality of the soil and obtaining optimal yields. Generally, Polish soils are characterized by very acidic, acidic or slightly acidic reaction, lower content of soil organic matter, low content of macronutrients and low water retention capacity. 56.6 % of them are classified into the light agronomic category of soils. An unfavorable relationship between the N : P : K content in applied mineral fertilizers and the decreasing consumption of calcium fertilizers has been observed in Poland in recent years. It is important to regulate soil pH. The availability of toxic metals depends on the pH-value of the soil and the content of organic matter. Adjusting the pH-value has a positive influence on the growth of crop, yield and reduction of nitrogen and phosphorus losses. This increased the availability of macronutrients for plants [1]. 38 % of soil in Poland are characterized by a pH-value < 5.5 (Fig. 1). The content of macronutrients in Polish soils were estimated by the Research Laboratories of the National Chemistry-Agriculture Station on samples taken from 37,000 of farms per year [2]. The content of macronutrients and the pH-value of the soil characterized for Poland was estimated based on their results (Fig. 1, Fig. 2) according to [3]. Adjusting the pH-value is necessary for 32 %, needed for 17.2 % and recommended for 13.4 % of them [1]. The estimation of the nitrogen content in the soil is very important for developing a fertilization and environmental protection plan. The content of mineral nitrogen in the soil was characterized by a high dispersion according to the results of analysis of soil samples collected in Poland (in 2015). The ammonium content ranged from 0.43 to 42.6 mg · kg $^{-1}$ (average 8.82 mg · kg $^{-1}$) and the nitrate(V) content ranged from 0.00 to 110.58 mg · kg $^{-1}$ (average 10.19 mg · kg $^{-1}$) [4].

It is necessary to protect the natural environment, taking care for the soil fertility and optimal supply of nutrients for crops according to [1]. The decrease in livestock population [5] caused a decline in the availability of organic fertilizers such a farmyard manure. It has a negative impact on the organic matter content in the soil. An alternative to farmyard manure are composts, classified as organic fertilizers (according to [6, 7]). Their production is a good way to disposal organic wastes, because wastes with an organic carbon content above 5 % could be naturally managed in agriculture according to [8]. One kind of them is spent mushroom substrate (SMS). About 5-6 kg of this waste is generated by the production of 1 kg of *Agaricus bisporus* [9]. It is important to manage this waste, because Poland is the European leader in the production of mushroom (third place in the world). Two countries, China and the USA, are the largest global producers of *Agaricus bisporus*. 302 916 Mg of mushroom was produced in our country in 2017 [10]. 1 514 580 - 1 817 496 Mg of this waste was generated that year. Spent mushroom substrate (SMS) is used after mushroom harvest (fresh mushroom substrate) or after the composting process (spent mushroom compost SMC) [11]. Compost production is a good solution for management of organic wastes (e.g. municipal solid wastes, sewage sludge). The composting process had a positive impact on the elimination of *Salmonella enteritidis* bacteria [12]. Composts based on SMS are used for fertilization. They had the positive impact on soil properties and yield of test-plants [13, 14]. This tendency was observed by other researchers [15, 16] and in own investigations, but organic-mineral fertilization had a stronger impact on yielding and soil [17, 18, 19]. The application

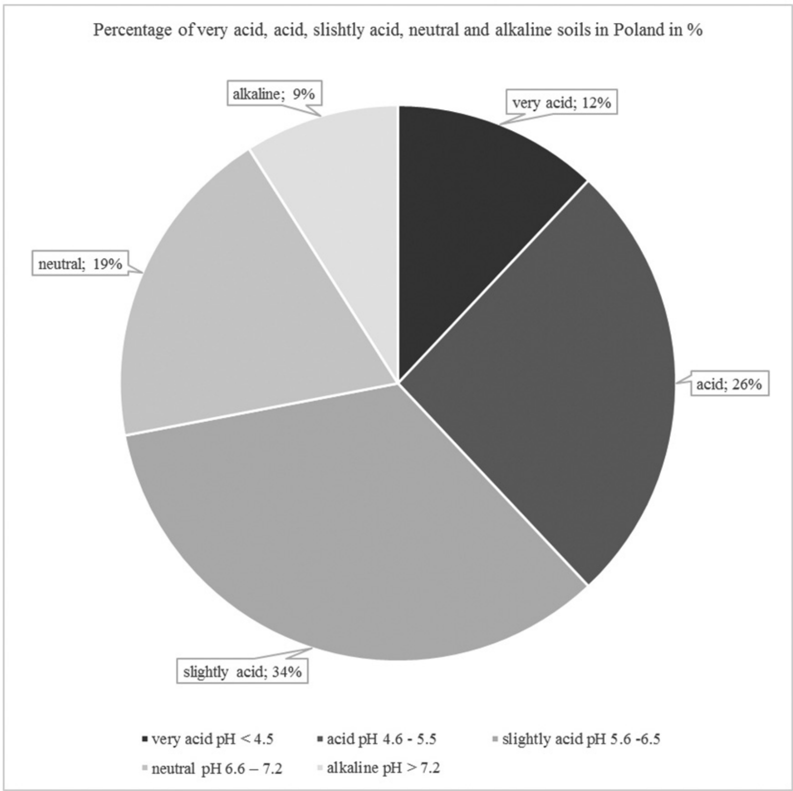

Figure 1. Structure of soil pH-value in Poland in 2014-2017 (according to [3])

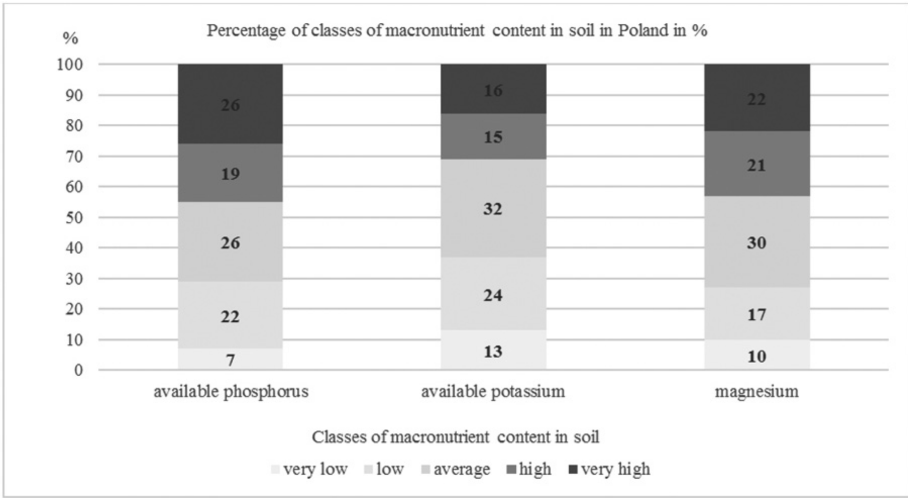

Figure 2. Classes of P, K and Mg content in soil in Poland in 2014-2017 (according to [3])

of SMS and mineral fertilization with nitrogen and potassium fertilizers had a greater impact on the orchard grass [20] and soil properties [21]. Organic-mineral fertilization resulted in a higher yield and content of macronutrients in the test-plant (e.g. higher potassium content in *Lolium multiflorum* [22] or magnesium in common cabbage *Brassica oleracea* L. and corn *Zea mays* L. [19]). According to [13] composts based on SMS should be produced with the supplementation of potassium fertilizers. Otherwise, plantations must be additionally top-dressing with potassium [13,20], which unnecessarily generates costs and is disadvantageous for the natural environment (e.g. depletion of natural resources, exhaust emissions, time-consuming) [23].

The quality of yields is depended on the different mineralization level of nitrogen in each variant of used fertilizers: compost, farmyard manure, organic-mineral fertilizer [24]. The rate of release of nitrogen and other macronutrients ions release is important for yielding and environmental protection. Organic-mineral fertilizers are characterized by rapid mineralization of nitrogen from inorganic fertilizer and constant release of this macronutrient in organic fertilizers [25]. The content of available phosphorus in the soil increased on objects fertilized with SMS and mineral fertilization compared to only SMS. The similar tendency was observed between objects with mineral fertilization only compared to other fertilized with farmyard manure and mineral fertilizers. SMS had an impact on the increase of available phosphorus in the soil [26]. Plants cultivated at objects with sewage sludge (supplemented with mineral potassium fertilizers) contained less of potassium compared on to others cultivated at farmyard manure (an identical dose of potassium was applied to all objects) [27].

It is very important to adjust the rate of release of nutrients from fertilizers to the current needs of plants. Slow-release fertilizers, called controlled release fertilizers, are characterized by the slow rate of release of macronutrients. They must meet each of the following three criteria: 1) no more than 15% of the components were released within 24 hours, 2) no more than 75% of the components were released within 28 days, 3) at least 75% of ingredients were released in the "Release time" declared by their producer [28]. The durability of the fertilizer pellet is important from the point of view of the dynamics of nitrogen and phosphorus release to the soil. Too soft pellets disintegrate quickly and the released biogens can be washed away into the profile (it is the risk of water pollution) [23]. Therefore, a prerequisite to use new granulated organic-mineral fertilizers in a sustainable way is to quantify the amount of available forms of nitrogen, phosphorus and potassium and their rate of release into the soil.

The Aim of the Investigation

The aim of this investigation is an evaluation of the rate of nitrogen, phosphorus and potassium from new granulated organic-mineral fertilizers formed from SMS and to estimate their impact on the pH-value of soil within four weeks.

Methods and materials

The release of nutrients from granulated organic-mineral fertilizers on soil properties is investigated under the conditions of a microplot experiment within four weeks. The research was based on a laboratory experiment at the Experimental Station of the Faculty of Agriculture and Biology – Warsaw University of Life Sciences in Skierniewice, Middle Mazovian Lowland, Central Part of Poland (latitude: N 51° 58', longitude: E 20° 10'). Glass beakers (capacity: 1000 cm^{-3}) were used as objects in the microobject experiment. They were filled soil from an experimental untreated field (without fertilization) on light soil. 500 g of air-dry soil was used to set up one object. Humidity accounted for 60% of the field water capacity. The loss of water due to evaporation was regularly supplemented with demineralized water using the weight method. Microplots were incubated in laboratory conditions – temperature 20°C. The dose of fertilizer applied to one object contained 0.6 g of nitrogen. The total number of objects was 28: six granulated organic-mineral fertilizers formed from SMS and the control object without fertilization (all in four replications). After the first, second, third and fourth week of the micoplot experiment 1 object from each combination was prepared for analysis. The experiment started on June 30 and completed on July 28, 2011. The soil used in this experiment was from the unfertilized object (the control field without fertilization since 1923). It had been classified as Luvisols [29]. Soil textural composition was loamy sand (in the layer 0-30 cm, the content of particles was as follows: <0.002 mm – 7%, 0.002-0.05 mm – 6% and >0.05 mm – 87%). The pH-value of the soil used in the experiment was 3.91. This soil contained 26.1 mg · kg^{-1} of $P_{available}$ and 84.0 mg · kg^{-1} of $K_{available}$.

Granulated organic-mineral fertilizers OM1-OM6 were formed from composts made of SMS (Compost A) or SMS mixed with sewage sludge in the ratio 5:1 (Compost B). They were supplemented with mineral fertilizers (Tab. 1) before the granulation. Their percentage contents of used ingredients (Tab. 1) were presented in (Fig. 3). These fertilizers were granulated using a modified Testmer drum granulator.

Compost A (SMC) was characterized by a higher value of pH compared to compost B (made of mixed SMS and sewage sludge), but the opposite tendency was observed for granulated organic-mineral fertilizers formed from them. OM1-OM4 had lower pH-value in comparison to OM5 and OM6 (Fig. 4).

Granulated organic-mineral fertilizers contained more nitrogen, phosphorus or potassium, and less organic coal, calcium and magnesium compared to composts used to form them (Tab. 2).

Table 1. Ingredients of granulated organic – mineral fertilizers

Fertilizer	Compost		Mineral fertilizers				
			Nitrogen fertilizers			Phosphorus fertilizer	Potassium fertilizer
	A	B	urea $CO(NH_2)_2$	ammonium nitrate NH_4NO_3	ammonium sulfate $(NH_4)_2SO_4$	single superphosphate $Ca(H_2PO_4)_2{\cdot}H_2O$	high-potassium salt (KCl - 48%K)
OM1	+	-	+	-	-	+	+
OM2	+	-	-	+	-	+	+
OM3	+	-	-	-	+	+	+
OM4	+	-	-	+	-	-	-
OM5	-	+	-	-	-	-	-
OM6	-	+	-	-	+	-	-

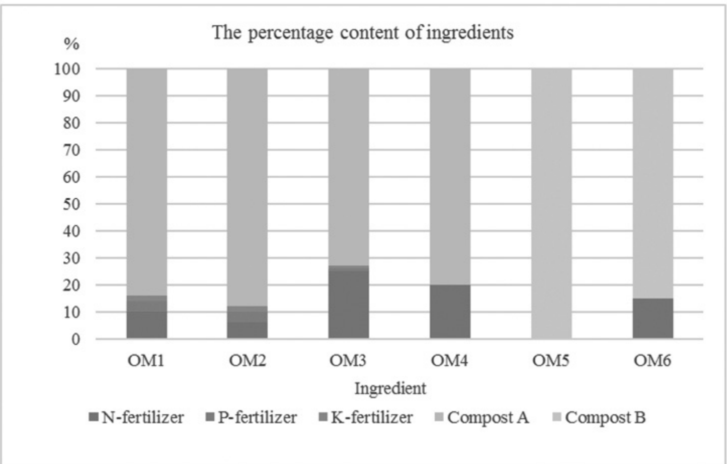

Figure 3. Ingredients used to form new granulated organic-mineral fertilizers

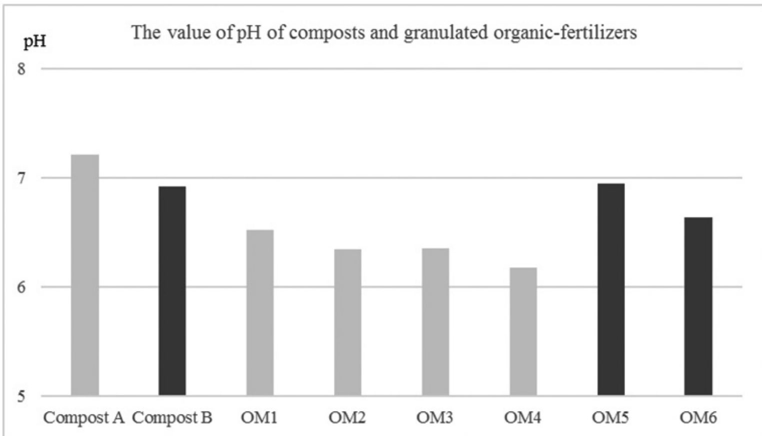

Figure 4. The value of pH of new granulated organic-mineral fertilizers and composts used to form them

Table 2. The content of macronutrients in granulated organic-mineral fertilizers and composts used to form them

Kind of fertilizers	C_{org}	N	P	K	Ca	Mg
	%					
Compost A	25.22	1.35	0.62	0.39	6.20	0.40
Compost B	41.13	2.20	0.71	0.27	4.48	0.42
OM1	21.20	7.60	1.82	2.27	7.00	0.31
OM2	22.43	2.50	1.85	2.70	7.13	0.43
OM3	18.28	5.00	0.67	1.16	5.86	0.32
OM4	20.47	8.30	0.93	0.39	4.11	0.35
OM5	41.13	2.20	0.71	0.27	4.48	0.42
OM6	34.82	6.30	0.95	0.36	4.22	0.37

Table 3. The content of macronutrients in the dose of granulated organic-mineral fertilizers for each object

Fertilizer	applied dose	N	C_{org}	P	K	Ca	Mg
	g						
OM1	7.89	0.60	1.67	0.14	0.18	0.55	0.02
OM2	24.00	0.60	5.38	0.44	0.65	1.71	0.10
OM3	12.00	0.60	2.19	0.08	0.14	0.70	0.04
OM4	7.23	0.60	1.48	0.07	0.03	0.30	0.03
OM5	27.27	0.60	11.22	0.19	0.07	1.22	0.11
OM6	9.52	0.60	3.32	0.09	0.03	0.40	0.04

Samples of soil were collected after each week of the experiment and then the nitrate(V) and ammonium ions were analyzed in soil using the colorimetric method using a flow auto-analyzer (extraction in 1% solution K_2SO_4 according to [30] and with extraction in 0.01 mol · dm^{-3} $CaCl_2$), (this method with $CaCl_2$ was proposed by V.J.G. Houba, I. Novozamsky, J. Uittenbogaard and J.J. van der Lee in 1983 for the extraction of soluble nitrogen from the soil with the ratio 10:1 of extraction solution to soil with the duration of 2 hours [31]). The soil samples were air dried, sieved to < 2 mm (fragments of the granules were separated) and characterized for: pH – by potentiometric method after extraction in 1 mol · dm^{-3} KCl [32] using pHmeter Schott, available P and K by Egner-Riehm (DL) method [33, 34], using AAS SOLAAR M6 ThermoElementar for potassium and spectrophotometer Genesys 10 Thermo Electron for phosphorus. The results were classified according to classes of soil pH-value (estimated in 1 mol · dm^{-3} KCl) and the content of macronutrients for NO_3^-, NH_4^+ and available P and K.

The results of chemical analyzes were statistically processed by the method of analysis of variance (ANOVA) using Statgraphics Stratus software program. The Tukey's test was used to assess differences between mean values at the significance level $\alpha \leq 0.05$. Estimation of soil pH-value based on the content of ions H^+ (the least significant difference LSD and standard deviation SD were calculated on $[H^+]$ according to the equation: pH = - log 10 $[H^+]$).

Results

All of granulated organic-mineral fertilizers had a positive impact on increasing the soil pH-value. They changed soil pH class from very acidic to slightly acidic (OM1) or acidic (OM2, OM4, OM5 and OM6). Objects fertilized by OM6 remained in a very acidic class, but noted differences were statistically significant compared to the control object without fertilization (Tab. 4). Other granulated organic-mineral fertilizers were characterized by the stronger impact on the pH-value of the soil. The differences between them were not statistically significant (Tab. 4). All granulated organic-mineral fertilizers had a positive impact on the pH-value of the soil in the first week after application (Fig. 5).

There was observed statistically significant differences between composts used to form fertilizers ($LSD_{0.05}$ for factor 2.34141E-05 [H+], two homogenous groups – first group: OM1-OM4 and the second: OM5-OM6). OM5 and OM6 contained sewage sludge. Objects with the compost made only of SMS (SMC) had a stronger impact on the pH-value of the soil. However, the kind of used nitrogen mineral fertilization did not have a statistically significant

Table 4. Impact of granulated organic-mineral fertilizers on the pH-value of the soil

Fertilizer combination	HG	pH-value of the soil (soil pH class)					
		week				Mean	SD
		I	II	III	IV	for fertilizer [H^+]	
Control	a	3.91 (very acidic)	3.85 (very acidic)	3.95 (very acidic)	3.98 (very acidic)	3.92 (very acidic)	1.63431E-05
OM1	c	6.10 (slightly acidic)	6.07 (slightly acidic)	5.73 (slightly acidic)	5.92 (slightly acidic)	5.93 (slightly acidic)	4.90784E-07
OM2	c	4.39 (very acidic)	4.33 (very acidic)	4.78 (acidic)	4.99 (acidic)	4.54 (acidic)	1.78797E-05
OM3	c	5.32 (acidic)	5.19 (acidic)	4.85 (acidic)	4.28 (very acidic)	5.02 (acidic)	4.52566E-06
OM4	c	6.19 (slightly acidic)	5.74 (slightly acidic)	5.40 (acidic)	5.30 (acidic)	5.63 (slightly acidic)	1.87868E-06
OM5	c	4.45 (very acidic)	5.15 (acidic)	5.03 (acidic)	5.13 (acidic)	4.83 (acidic)	1.38056E-05
OM6	b	4.07 (very acidic)	3.93 (very acidic)	4.15 (very acidic)	4.18 (very acidic)	4.43 (very acidic)	2.3207E-05
HG for week		a	a	a	a		
Mean for week		4.61375E-05	4.15134E-05	3.09258E-05	3.05398E-05		
SD for week		5.31997E-05	5.39311E-05	4.21896E-05	3.94534E-05		
Total mean		3.72791E-05					
Total SD		4.54309E-05					
$LSD_{0,05}$ for fertilizer [H^+]		3.1814E-05					
$LSD_{0,05}$ for week [H^+]		7.02535E-05					

HG – homogenous groups

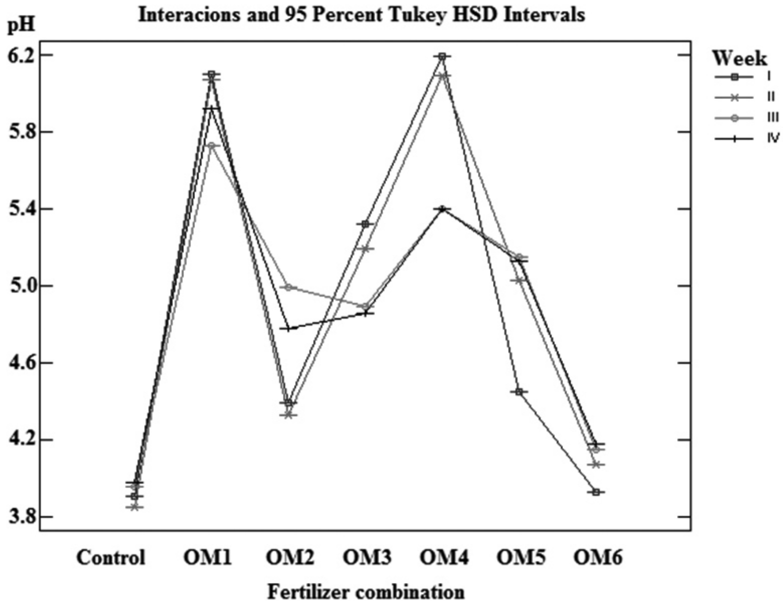

Figure 5. Interactions between the fertilizer combination and the week of the experiment on the pH-value of the soil (generated using Statgraphics Stratus)

impact on the pH-value ($LSD_{0.05}$ for factor mineral fertilizer 5.59291E-05 [H+], one homogenous group).

The kind of the granulated organic-mineral fertilizers had statistically significant impact on the rate of release of nitrate(V). It was observed especially on the object with OM4. The similar tendency was observed on OM2. These fertilizers were formed with the addition of ammonium nitrate (NH_4NO_3). The rate of NO_3^- release increased in the following weeks on objects with OM4 and OM2 (Tab. 5). It was due to the use of ammonium nitrate for supplementation (Tab. 5). Other fertilizers were characterized by a slower rate release of nitrate(V). The impact of OM3 and OM6 supplemented with ammonium sulfate $(NH_4)_2SO_4$ was higher compared to the control object without fertilization, but these differences were not statistically significant. OM5 and OM1 were characterized by a stronger, but similar impact on the change of soil nitrate(V) content. The least content of nitrate(V) (NO_3^-) in soil was noted on the control object without fertilization (Tab. 5, Fig. 6). The content of this form of nitrogen in soil was analyzed using $CaCl_2$ and K_2SO_4 extraction. However, the differences between the methods were not statistically significant. Fertilizers were different with the rate of macroelement release in individual weeks. More nitrate(V) was released from OM4 and OM2 last week compared to the first, but these differences were not statistically significant (Tab. 5, Fig. 6). OM5 and OM6 (fertilizers formed from the compost containing sewage sludge) had a less impact in comparison to others formed from SMC (Tab. 5).

There was observed statistically significant differences between composts used to form fertilizers ($LSD_{0.05}$ for factor 24.15, two homogenous groups – the first group: OM1-OM4, mean: 49.16 +/- 46.31 and the second: OM5-OM6, mean: 19.23 +/- 16.65). OM5 and OM6 contained sewage sludge. Objects with the compost made exclusively of SMS had a stronger impact on the content of nitrate(V) in the soil. The kind of used nitrogen mineral fertilizer had a statistically significant impact on the content of this form of nitrogen ($LSD_{0.05}$ for factor mineral fertilizer 26.62, two homogenous groups – the first: OM1, OM3, OM5 and OM6, mean for urea 28.43 +/- 2.44, mean for ammonium sulfate 6.03 +/- 3.00, mean for OM5 34.76 +/- 6.35 and the second: OM2 and OM4, mean for ammonium nitrate 79.91 +/- 47.98).

The kind of granulated organic-mineral fertilizers had a statistically significant impact on the rate of release of NH_4^+ (Tab. 6). All fertilizers used had a positive impact on the increase in the content of ammonium ions in the soil. However, these differences were statistically significant for OM1, OM3, OM4 and OM6 compared to the control object without fertilization. This was noted especially for OM4. The similar tendency was observed for OM6 and OM3 (and for OM2). These fertilizers were formed using mineral nitrogen fertilization: ammonium nitrate (NH_4NO_3) was used for OM2 and OM4 and ammonium sulfate $(NH_4)_2SO_4$ for OM3 and OM6. OM4 was characterized by the highest influence on the content of NH_4^+ in the soil. It was statistically significant. The impact of OM3 and OM6 was higher in comparison to the control object without fertilization, but these differences were not statistically significant. OM5 and OM1 were characterized by a stronger, but similar impact on the change of ammonium content

Table 5. The rate of release of nitrate(V) (NO_3^-) from granulated organic-mineral fertilizers

Fertilizer combination	HG	Nitrate(V) content in the soil mg $NO_3^- \cdot kg^{-1}$					
		Week				Mean	SD
		I	II	III	IV	for fertilizer	
Control	a	1.384	1.483	1.956	2.805	1.907	0.780326
OM1	abc	27.810	30.102	29.415	26.399	28.431	2.44107
OM2	c	57.817	53.616	40.673	49.803	50.477	18.4739
OM3	ab	8.569	7.554	7.258	10.097	8.369	2.26354
OM4	d	50.949	75.703	147.876	162.868	109.349	51.0969
OM5	bc	33.951	37.475	34.060	33.572	34.764	6.3484
OM6	ab	4.221	4.246	3.247	3.047	3.690	1.30059
HG for week		a	a	a	a		
Mean for week		26.386	30.025	37.783	41.227		
SD for week		23.122	27.873	49.495	54.679		
HG for method	$CaCl_2$	a					
	K_2SO_4	a					
Mean for method	$CaCl_2$	38.136					
	K_2SO_4	29.574					
SD for method	$CaCl_2$	42.924					
	K_2SO_4	37.984					
Total mean		33.855					
Total SD		40.391					
$LSD_{0,05}$ for fertilizer		31.851					
$LSD_{0,05}$ for week		41.215					
$LSD_{0,05}$ for method		21.717					

HG – homogenous groups

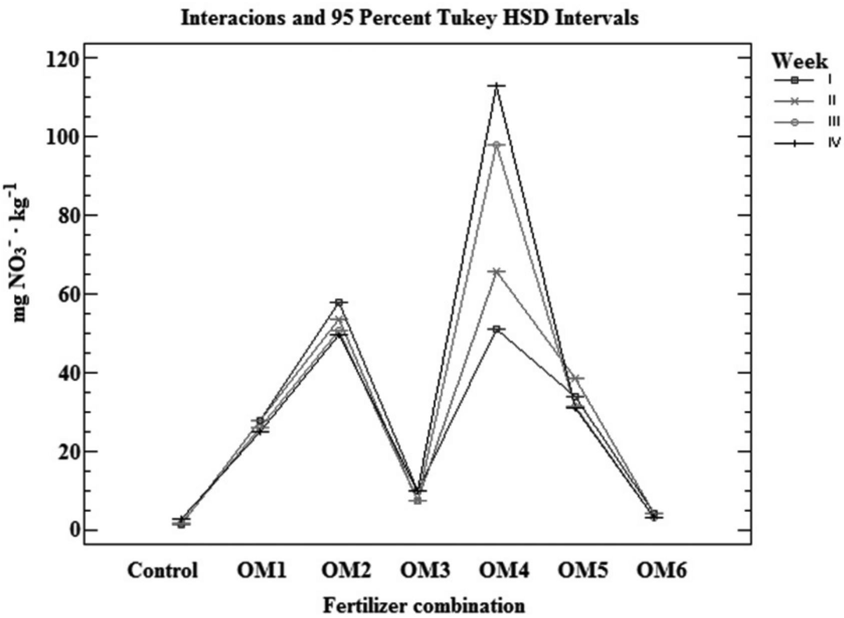

Figure 6. Interactions between the fertilizer combination and the week of the experiment on the rate of release of NO_3^- (generated using Statgraphics Stratus)

in the soil. The least content of ammonium (NH_4^+) in the soil was noted on the control object without fertilization (Tab. 6, Fig. 7). The content of this form of nitrogen in the soil was analyzed using $CaCl_2$ and K_2SO_4 for extraction. However, the differences between methods were not statistically significant. Fertilizers were different among themselves in the rate of this ion release in individual weeks. More ammonium was released from OM4 and OM6 last week compared to the first, but for OM1, OM2, OM3 and OM5 these values were similar during the experiment (Tab. 6, Fig. 7).

Table 6. The rate of release of ammonium (NH_4^+) from granulated organic-mineral fertilizers

Fertilizer combination	HG	Ammonium ions content in the soil mg $NH_4^+ \cdot kg^{-1}$					
		Week				Mean	SD
		I	II	III	IV	for fertilizer	
Control	a	0.082	0.104	0.157	0.107	0.113	0.047
OM1	bc	31.682	31.826	30.618	25.866	29.998	4.846
OM2	ab	14.970	14.457	15.578	14.230	14.591	2.213
OM3	bc	31.056	29.396	34.105	35.344	32.475	6.232
OM4	d	45.123	45.330	70.063	88.462	62.245	30.175
OM5	ab	12.548	15.331	15.949	13.905	14.433	3.525
OM6	c	32.683	32.902	30.680	46.491	35.689	8.344
HG for week		a	a	a	a		
Mean for week		23.896	24.192	28.164	32.058		
SD for week		15.219	15.609	24.562	30.265		
HG for method	$CaCl_2$	a					
	K_2SO_4	a					
Mean for method	$CaCl_2$	28.628					
	K_2SO_4	25.528					
SD for method	$CaCl_2$	21.557					
	K_2SO_4	22.664					
Total mean		27.078					
Total SD		21.971					
$LSD_{0,05}$ for fertilizer		18.913					
$LSD_{0,05}$ for week		22.402					
$LSD_{0,05}$ for method		11.851					

HG – homogenous groups

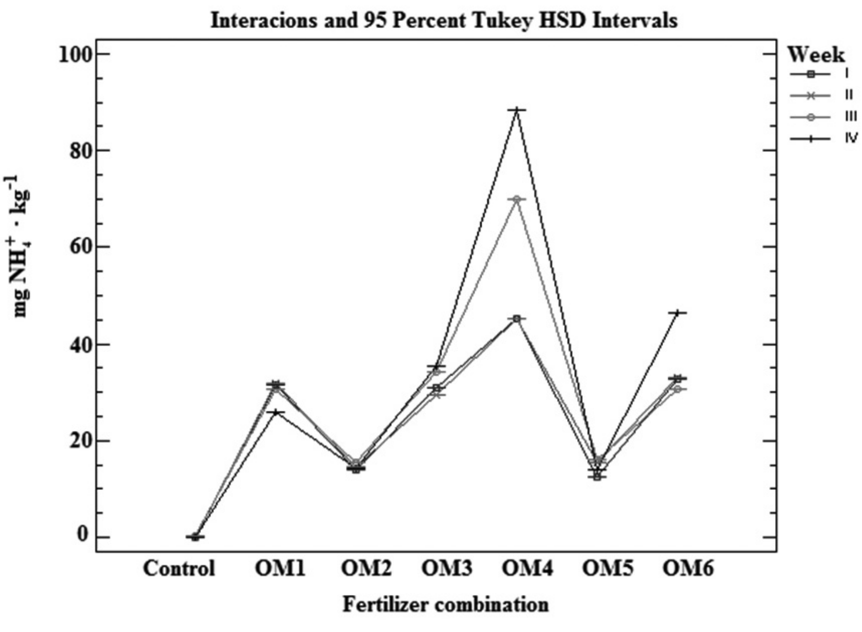

Figure 7. Interactions between the fertilizer combination and the week of the experiment on the rate of release of NH_4^+ (generated using Statgraphics Stratus)

Composts used to form granulated organic-mineral fertilizers were characterized by the similar impact on the rate of release of ammonium. The differences between them were not statistically significant ($LSD_{0.05}$ for factor 12.44). Supplementation with nitrogen mineral fertilizers had an impact on the diversity of the rate of ammonium release ($LSD_{0.05}$ for factor 22.42, two homogenous groups – the first: OM1, OM3, OM5 and OM6, the second: OM1, OM2, OM3, OM4, OM6, mean for urea 30.00 +/- 4.85, mean for ammonium sulfate 34.08 +/- 7.31, mean for OM5 14.43 +/- 3.52 mean for ammonium nitrate 38.42 +/- 32.13). OM2 and OM4 with ammonium nitrate were

Table 7. The rate of release of available phosphorus from granulated organic-mineral fertilizers

Fertilizer combination	HG	Available P in the soil Soil class of available phosphorus mg P · kg^{-1}					
		week				Mean for fertilizer	SD
		I	II	III	IV		
Control	a	23.88	23.46	26.55	25.52	24.84	1.4
		(low)	(low)	(low)	(low)	(low)	
OM1	ab	28.20	38.90	32.31	37.04	34.11	4.8
		(low)	(low)	(low)	(low)	(low)	
OM2	b	37.04	42.19	48.16	49.60	44.24	5.8
		(low)	(low)	(medium)	(medium)	(medium)	
OM3	b	34.76	31.28	45.46	43.74	38.82	6.9
		(low)	(low)	(medium)	(low)	(low)	
OM4	b	34.58	33.75	38.07	38.49	36.21	2.4
		(low)	(low)	(low)	(low)	(low)	
OM5	ab	31.49	31.28	40.13	32.31	33.80	4.2
		(low)	(low)	(low)	(low)	(low)	
OM6	b	50.01	35.60	43.22	46.51	43.83	6.2
		(medium)	(low)	(low)	(medium)	(low)	
HG for week		a	a	a	a		
Mean for week		34.28	33.78	39.03	39.03		
SD for week		8.25	6.05	7.59	8.38		
Total mean		36.5511					
Total SD		7.636					
$LSD_{0,05}$ for fertilizer		11.248					
$LSD_{0,05}$ for week		11.244					

HG – homogenous groups

characterized by the stronger impact in comparison to OM3 and OM6 with ammonium sulfate and OM1 with urea. Organic-mineral fertilizers containing nitrogen mineral fertilizers had the higher influence on the rate of release of ammonium compared to OM5 formed from Compost B only.

The pH-value of the soil had a strong impact on the content of NO_3^- and NH_4^+ in the soil. The lowest content was recorded on very acidic soils. This tendency was observed for both forms of nitrogen. The increase of pH-value resulted in the increase of the content of nitrate(V) ($LSD_{0.05}$ for the classes of the pH-value of the soil 32.89, total mean 33.86 +/- 40.39, two homogenous groups). The average content of nitrate(V) in very acidic soil 15.25 +/- 22.70 mg NO_3^- · kg^{-1}, in acidic soil 49.07 +/- 54.13 mg NO_3^- · kg^{-1} and in slightly acidic 40.06 +/- 19.55 mg NO_3^- · kg^{-1}. The similar tendency was observed for ammonium ($LSD_{0.05}$ for classes of the pH-value of the soil 15.03, total mean 27.08 +/- 21. 79, two homogenous groups). The average content of NH_4^+ in very acidic soil 16.76 +/- 16.39 mg NH_4^+ · kg^{-1}, in acidic soil 33.04 +/- 27.61 mg NH_4^+ · kg^{-1} and in slightly acidic 35.07 +/- 9.57 mg NH_4^+ · kg^{-1}.

All granulated organic-mineral fertilizers had a positive impact on the increase of phosphorus content in the soil, but these differences between them were not statistically significant. The soil class of available forms of this macronutrient was changed only for OM2, OM3 and OM6 by one or two weeks. The lowest content of phosphorus was observed on the control object without fertilization. These differences were not statistically significant compared to OM1 and OM5 (Tab. 7). Generally, the soil content of available P increased with time (Fig. 8). However, the differences between the weeks were not statistically significant (Tab. 7). Most phosphorus was applied on the objects fertilized with OM2 (less was used on the objects with OM5 and OM1) (Tab. 3).

The rate of phosphorus release (forms available for plants estimated by the Egner-Riehm method) was similar on objects fertilized with fertilizers formed from both kinds of composts ($LSD_{0.05}$ for factor 5.83). However, OM5 and OM6, containing sewage sludge, had a stronger impact on the increase of soil content of this form of the investigated macronutrient. Supplementation with a single superphosphate for OM1, OM2 and OM3 influenced the value of phosphorus content, but these differences were not statistically significant compared to OM4, OM5 and OM6 formed without that mineral fertilizer ($LSD_{0.05}$ for factor 5.48).

Granulated organic-mineral fertilizers had an impact on the increase of researched form of phosphorus in the soil. All of them changed the content of phosphorus within the soil class. OM2 was characterized by the statistically significant strongest influence in comparison to other fertilizers. OM1 and OM3 had a lower impact than OM2. Their impact was stronger compared to OM4, OM5 and OM6. These fertilizers were formed without supplementa-

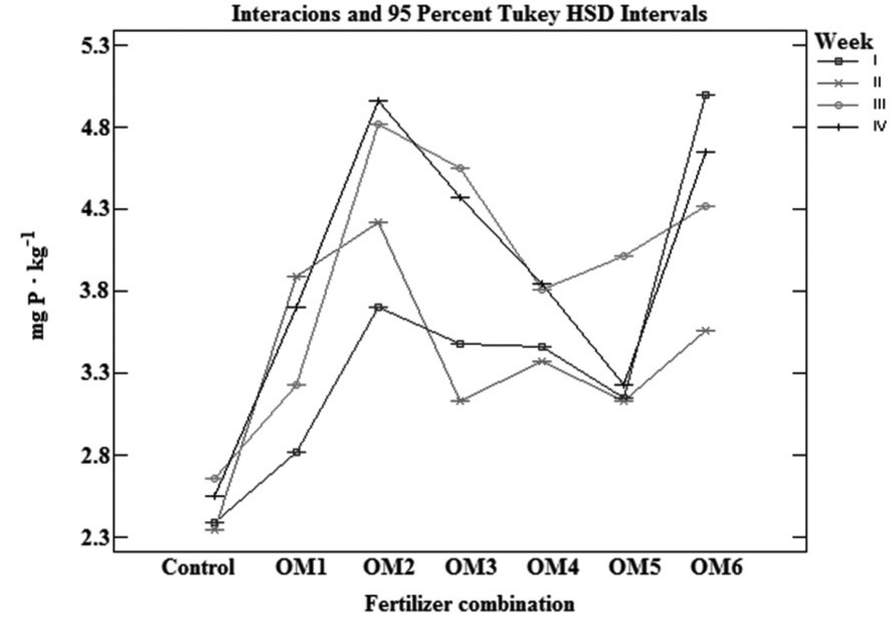

Figure 8. Interactions between the fertilizer combination and the week of the experiment on the rate of release of available form of phosphorus (generated using Statgraphics Stratus)

tion with single superphosphate $Ca(H_2PO_4)_2 \cdot H_2O$. They caused the increase of the content of the researched form of phosphorus in the soil, but these differences were not statistically significant in comparison to control object without fertilization (Tab. 7, Fig. 8).

OM1, OM2 and OM3 had a statistically significant stronger impact on the increase of the available potassium content in the soil compared to other organic-mineral fertilizers. They were supplemented with potassium salt. OM1, OM2 and OM3 contained more of this macronu-

Table 8. The rate of release of available potassium from granulated organic-mineral fertilizers

Fertilizer combination	HG	Available K in the soil (soil class of available potassium) mg K · kg^{-1}					
		week				Mean for fertilizer	SD
		I	II	III	IV		
Control	a	26.0 (very low)	28.0 (very low)	80.0 (low)	89.0 (low)	55.6 (low)	33.4
OM1	bc	271.0 (very high)	234.0 (very high)	284.0 (very high)	396.0 (very high)	296.2 (very high)	69.8
OM2	d	561.0 (very high)	676.0 (very high)	619.0 (very high)	898.0 (very high)	688.5 (very high)	147.3
OM3	c	350.0 (very high)	303.0 (very high)	405.0 (very high)	609.0 (very high)	416.8 (very high)	134.8
OM4	abc	253.0 (very high)	230.0 (very high)	196.0 (high)	374.0 (very high)	263.2 (very high)	77.5
OM5	abc	216.0 (very high)	242.0 (very high)	231.0 (very high)	351.0 (very high)	260.0 (very high)	61.6
OM6	ab	138.0 (medium)	139.0 (medium)	176.0 (high)	252.0 (very high)	176.3 (very high)	53.5
HG for week		a	a	a	a		
Mean for week		259.3	264.6	284.4	424.1		
SD for week		168.5	202.1	178.3	261.2		
Total mean		308.1					
Total SD		205.8					
$LSD_{0,05}$ for fertilizer		210.2					
$LSD_{0,05}$ for week		303.4					

HG – homogenous groups

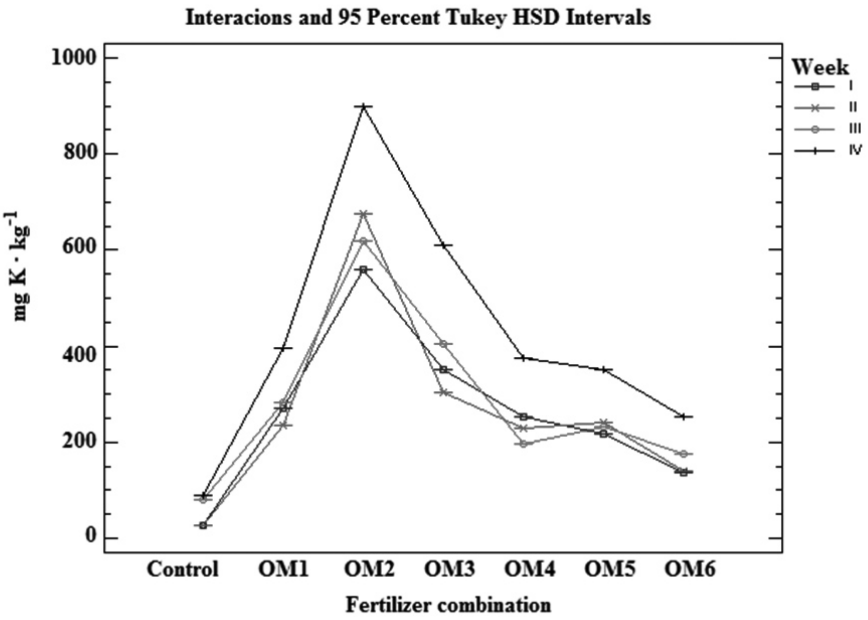

Figure 9. Interactions between the fertilizer combination and the week of the experiment on the rate of release of available form of potassium (generated using Statgraphics Stratus)

trient in comparison to compost A and compost B used to form them (Tab. 2) Other granulated organic-mineral fertilizers were formed using ammonium nitrate (for OM4), ammonium sulfate (for OM6) and composts (for OM4, OM5 and OM6). The differences between them were statistically significant ($LSD_{0.05}$ for factor 129.49, two homogenous groups, the first: OM1, OM2, OM3, mean 467.17 +/- 203.88, the second: OM4, OM5 and OM6, mean 233.17 +/- 72.25). Most potassium was applied on the objects fertilized with OM2, less on objects with OM1 and OM3, and the least on objects with OM4, OM5 and OM6 (Tab. 3). Both composts were characterized by a similar impact on the rate of release of this macronutrient from investigated fertilizers ($LSD_{0.05}$ for factor 152.44, single homogenous group).

New organic-mineral fertilizers were diversified in terms of the rate of granule disintegration. OM1 was characterized by the hardest granules. They were resistant to disintegration. OM2 and OM5 had similar properties. OM3, OM4 and OM6 were characterized by the tendency to easily disintegration (Tab. 9).

Discussion

Fertilizers based on SMS or mixture of SMS and sewage sludge had a positive impact on the change of pH-value of the soil. According to [14] composts had a stronger impact compared to farmyard manure. Organic-mineral fertilizers had a significant influence on the pH-value of the soil. This was already observed in the first week (Tab. 4, Fig. 5). The kind of the compost used to form them strongly differentiates their effect on the deacidification of the soil. OM5 and OM6 (organic-mineral fertilizers containing sewage sludge) differed from other fertilizers in their impact on the pH-value of the soil. This tendency was observed by Szulc *et al.* [14]. Compost based on SMS and sewage sludge had a stronger impact compared to other made exclusively from SMS [14]. This tendency was recorded only for OM3 compared to OM5 and OM6. OM1, OM2 and OM4 formed from SMC and the addition of mineral fertilizers were characterized by a higher influence on the deacidification of the soil (Tab. 4, Fig. 5).

The change of pH-value of soil had positive impact on the soil. Adjust the pH-value of the soil reduces the emission of nitrogen oxides and nutrient leaching. It has a strong influence on the decrease of available forms of trace elements for plants. Adjusting the pH-value has an effect on yielding and growth crops [1].

Nitrogen

The content of nitrate(V) and ammonium in the soil increased after applying new granulated organic-mineral fertilizers. The soil from the control object during the experiment was classified into classes with very low content of these forms of nitrogen in accordance with the normative content of N_{min} developed by [35]. The nitrate(V) content could be classified into the following classes: very high for OM1, OM2, OM4 and OM5, high or very high for OM3 and low or medium for OM6 (Tab. 5) and the ammonium content was very high (Tab. 6). Changes in mineral N on the objects fertilized with OM5 were probably related to the mineralization of organic matter derived from organic matter contained in the compost made of SMS and sewage

Table 9. The rate of disintegration of the granules with their organoleptic assessment after the end of the experiment

Fertilizer	The rate of granules disintegration			
	week			
	I	II	III	IV
OM1	The number of applied granules on the object			
	14	13	11	12
	The number of granules and their fragments from the object after finishing			
	19 big fragments + 2 smaller ones	15 big fragments + 3 smaller ones	15 big fragments	12 big fragments
	Organoleptic estimation of granules after finishing			
	hard granules, hard to crush, they did not break under the pressure of the nail	hard granules, but they broke under the pressure of the nail	granules did not break, but they bent slightly	very hard granules, they did not break under the pressure of the nail
OM2	The number of applied granules on the object			
	32	36	33	47
	The number of granules and their fragments from the object aft er finishing			
	38 big fragments	41 big fragments + 1 smaller one	38 big fragments	49 big fragments
	Organoleptic estimation of granules after finishing			
	hard granules, but they broke under the slight pressure of the nail	hard granules, they did not break under the pressure of the nail	very hard granules did not break under the pressure of the nail	granules broke up easily
OM3	The number of applied granules on the object			
	13	12	12	13
	The number of granules and their fragments from the object afte r finishing			
	25 big fragments + 1 smaller one	23 big fragments	14 big fragments	18 big fragments
	Organoleptic estimation of granules after finishing			
	hard granules, but they broke under the pressure of the nail	granules disintegrated very easily	granules broke up very easily	granules broke up easily
OM4	The number of applied granules on the object			
	20	24	25	30
	The number of granules and their fragments from the object after finishing			
	25 big fragments + 1 smaller one	23 big fragments	25 big fragments	30 big fragments
	Organoleptic estimation of granules after finishing			
	granules broke easily under the pressure of the nail	granules broke easily under the pressure of the nail	soft granules broke up under the pressure of the nail	granules disintegrated easily under the pressure of the nail
OM5	The number of applied granules on the object			
	41	29	39	39
	The number of granules and their fragments from the object after finishing			
	29 big fragments	45 big fragments + 4 smaller ones	42 big fragments	44 big fragments
	Organoleptic estimation of granules after finishing			
	hard granules, they did not break under the pressure of the nail	hard granules, they did not disintegrated, but they broke easily under the pressure of the nail	granules were resistant to strong pressure of the nail	granules disintegrated easily under the slight pressure of the nail
OM6	The number of applied granules on the object			
	27	29	25	31
	The number of granules and their fragments from the object after finishing			
	31 big fragments + numerous small fragments	37 big fragments + numerous small fragments	30 big fragments	32 big fragments + numerous small fragments
	Organoleptic estimation of granules after finishing			
	granules were easily disintegrated under the pressure of the nail	granules were easily disintegrated under the pressure of the nail	granules were very easily disintegrated under the pressure of the nail	granules were very easily disintegrated under the pressure of the nail

sludge [36]. According to [37] granulated organic-mineral fertilizers based on sewage sludge were characterized by slow rate of release nitrate(V) and ammonium forms of nitrogen compared to sewage sludge and mineral fertilizers. The lowest content of nitrate(V) was recorded on very acidic soil. These values were higher on objects with a higher class of the pH-value of the soil. The similar tendency was observed by [38]. Their contents depended on the pH-value of the soil. The nitrate(V) content increased with the increase of the pH-value of the soil [38]. The similar tendency was observed for ammonium, but the opposite trend was observed by [38].

Organic-mineral fertilizers were characterized by the different rate of release of nitrate(V). OM1, OM3, OM5 and OM6 were characterized by the similar release of nitrate(V) in all weeks of the experiment. OM2 had the highest content NO_3^- in the first week and the lowest in the fourth week (Fig. 6). Fertilizers with polyvinyl alcohol were characterized by a similar impact on the change of nitrate(V) in water extracts in this same time [39]. Objects fertilized with OM4 were characterized by the lowest content NO_3^- in the fourth week and the lowest in the first (Fig. 6). The similar tendency was observed by [40]. The rate of release of nitrate(V) from SMS was variable over time. It depended on the kind of wastes used to made fertilizers [40]. Fertilized objects were characterized by a higher content of nitrate(V) between the first and fourth weeks compared to the unfertilized control object. This tendency was observed by [40] in the case of two fertilizers (SMS from *Agaricus bisporus* and SMS from *Pleurotus*) and opposite trend in the third (a mixture of two type of SMS from *Agaricus bisporus* and *Pleurotus*) [40].

The nitrate(V) content on the objects fertilized with OM3 was higher than on objects with OM6 and on the control object without fertilization, but lower compared to other fertilizers (Tab. 6). Similar values from 10.5 to 11.9 mg $NH_4^+ \cdot kg^{-1}$ were noted by [21] after harvests on the objects with direct and residual impact of SMS and SMS with mineral fertilizers.

Organic-mineral fertilizers were characterized by the different rate of release of ammonium. OM2 was characterized by the similar release of nitrate(V) in all weeks of the experiment. Objects fertilized with OM1 contained less ammonium in the fourth week compared to the first (Fig. 7). OM3, OM4, OM5 and OM6 had the highest content NH_4^+ in the fourth week and the lowest in the first week (Fig. 7). The similar tendency was observed by [40] (for two fertilizers: SMS from *Agaricus bisporus* and a mixture of SMS from *Agaricus bisporus* and *Pleurotus*, but the opposite trend for SMS from *Pleurotus*) and [39] (for fertilizers with shellac and polyvinyl acetate). The rate of release of ammonium from SMS was variable over time. It depended on the kind of wastes used to made fertilizers [40]. Fertilized objects were characterized by the higher nitrate (V) content between the first and fourth weeks compared to the unfertilized control object. This tendency was observed by [40] for three fertilizers [40]. The ammonium content on the objects fertilized with OM2 and OM4 was the lowest compared to other fertilizers and higher in comparison to the control object without fertilization (Tab. 6). Similar values were noted by the [21] after the harvest.

The control object was characterized by the lower content of nitrate(V) and ammonium (Tab. 5, Tab. 6) compared to the results recorded by [21]. The laboratory experiment with granulated organic-mineral fertilizers based on the soil from the unfertilized object since 1923, but the farm field regularly fertilized was used by Anna Majchrowska-Safaryan [21].

Phosphorus

The content of phosphorus in the soil was increased after applying fertilizers. The soil class of available P was changed on objects with OM2, OM3 and OM6 (Tab. 7). The similar tendency was observed by [14] on objects fertilized with composts based on SMS. The soil class of the investigated macronutrient changed from medium to high. Soil samples in that experiment were collected after the harvest of test plants (after a long time from the application of these organic fertilizers) [14]. Objects fertilized with new organic-mineral fertilizers were characterized by the higher content of available phosphorus compared to the control object without fertilization (Tab. 7). Fertilization with SMS and mineral fertilizers had a stronger influence than with SMS only. This tendency was observed in subsequent years [21].

Potassium

New granulate organic-mineral fertilizers had a higher impact on the content of available form of potassium in the soil compared to the control object. The class of potassium availability was medium or very high compared to the control object without fertilization (Tab. 8). All recorded differences were statistically significant (Fig. 9, Tab. 8). This tendency was observed on objects fertilized with SMC and compost made of SMS and sewage sludge. However, the differences recorded by [14] were not statistically significant. The soil class of available potassium was change from low to medium (in the first and in the second week on objects fertilized with OM6) or very high (on objects fertilized with other fertilizers) (Tab. 8). The supplementation with potassium mineral fertilizer had a significant influence on the content of the investigated macronutrient. The kind of compost used to form granulated organic-mineral fertilizers was characterized by a similar impact on the release of potassium. This tendency was observed for composts based on SMS by [14]. The higher content of available potassium was recorded on the objects with OM2 (Tab. 8). This was due to the highest content of this macronutrient in the fertilizer dose (Tab. 3). This tendency was recorded by [41]. Potassium fertilization caused the increase in the content of the investigated macronutrient in the soil. This macronutrient is characterized by the higher effect on the object with the less content of it in soil [41]. Objects fertilized with new organic-mineral fertilizers were characterized by the higher content of available potassium compared to the control object without fertilization (Tab. 9). Fertilization with SMS and mineral fertilizers had the stronger influence than exclusively SMS. This tendency was observed in subsequent years [21].

Granules of OM3, OM4 and OM6 disintegrated quickly (Tab. 9). This could create a danger of groundwater pollution [23]. OM1 was characterized by the most beneficial durability of the fertilizer pellet form. This is important for the dymanics of macronutrient release. It has a positive effect on yielding and crop health. The rate of release of macronutrients does not pose a risk of groundwater pollution. OM2 and OM5 were similar to OM1 (Tab. 9) [23].

The physical-mechanical parameters of new granulated organic-mineral fertilizers like particle hardness of granules, abrasion resistance, hygroscopicity evaluation, bulk densities, total porosities, abrasion fragility, crushing strength, critical relative humidity and water sorption from moist porous media should be investigated in laboratory conditions. This is an issue for further research, because their results are important for the implementation of new granulated organic-mineral fertilizers for production. The estimation of these properties could find application in the fertilizer industry. However, these results are important for engineer constructors of machines used in the production and application of granulated organic-mineral fertilizers formed from waste-based composts.

Conclusions

New granulated organic-mineral fertilizers were characterized by rapid deacidification of the soil already after seven days of application. This tendency was observed in the following weeks. The change of the pH-value of the soil had a positive impact on the soil properties. These fertilizers were the source of available macronutrients for plants: nitrate(V), ammonium, phosphorus and potassium. Classes of soil richness in the investigated forms of nitrogen changed to higher. The similar tendency was observed for potassium. The content of phosphorus was higher, although it did not change the soil class. It is recommended to estimated their physical-mechanical properties.

Acknowledgements
The research supported by Warsaw University of Life Sciences, Project No. 505-10-01260050, Poland.

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