Journal of Elementology ISSN 1644-2296

Szulc W., Rutkowska B., Kuśmirek E., Spychaj-Fabisiak E., Kowalczyk A., Dębska K. 2019. *Yielding, chemical composition and nitrogen use efficiency determined for white cabbage (Brassica oleracea* L. var. *capitata* L.*) supplied organo-mineral fertilizers from spent mushroom substrate.* J. Elem., 24(3): 1063-1077. DOI: 10.5601/jelem.2019.24.1.1778

RECEIVED: 5 December 2018
ACCEPTED: 3 February 2019

ORIGINAL PAPER

YIELDING, CHEMICAL COMPOSITION AND NITROGEN USE EFFICIENCY DETERMINED FOR WHITE CABBAGE (*BRASSICA OLERACEA* L. VAR. *CAPITATA* L.) SUPPLIED ORGANO-MINERAL FERTILIZERS FROM SPENT MUSHROOM SUBSTRATE*

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Abstract

An amount of over 1 800 thousand tonnes of spent mushrooms substrate is generated every year in Poland. This waste is characterized by a high content of organic matter, macro- and micronutrients. For this reason, spent mushroom substrate should be used in agriculture primarily to improve the balance of organic matter and to enrich the soil with available forms of nutrients. The aim of this study was to develop a technology of producing a new granulated organo-mineral fertilizer from spent mushroom substrate and assess its quality for possible use in horticultural production. Granulated organo-mineral fertilizers were produced from composted spent mushroom substrate, and two fertilizers were produced from compost made from fresh spent mushroom substrate mixed with sewage sludge. Prior to granulation, different amounts of mineral fertilizers were added to the compost. The evaluation of the fertilization value of the granulated organo-mineral fertilizers was conducted on the basis of a microplot experiment established on sandy soil at the Experimental Station of the Warsaw University of Life Sciences. The tested plant was white cabbage (*Brassica oleracea* L. var. *capitata* L.). Organo-mineral fertilization effects a significant increase of soil pH, organic carbon content and total nitrogen content in soil, in addition to which it increased the soil content of phosphorus, potassium and magnesium.

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* This study was supported by the project No 8762/E-385/SPUB/2016/1 „Wydziałowa Stacja Doświadczalna im. prof. Mariana Górskiego w Skierniewicach – od 1922 r. wieloletnie doświadczenia agrotechniczne", sponsored by Ministry of Science and Higher Education, Poland.

The tested fertilization regime significantly affected the yield of cabbage, which increased by 90 to 103% relative to the control. Nitrogen use efficiency (NUE) for the tested organo--mineral fertilizers ranged from 15.9 to 33.0%, and agronomic efficiency (AE) varied from 1.6 to 51.1 kg DW kg^{-1} N.

Keywords: mushroom compost, organo-mineral fertilizer, soil properties, white cabbage.

INTRODUCTION

Depletion of the humus content of soil necessitates search for an inexpensive and safe safe source of organic matter. Spent mushrooms substrates may serve the purpose (Scotti et al. 2015, Mi et al. 2016, Garcia et al. 2017).

With its production of 7076.8 thousand Mg of mushrooms, China is the biggest mushroom producer in the world. The second place is occupied by the USA (406.2 thousand Mg). In the European Union, Poland is the largest producer of mushrooms, with the total production volume of over 335 thousand Mg. Large quantities of substrate remaining after mushroom production create a waste management problem for producers. It is estimated that about 5-6 kg of spent substrate is generated to grow 1 kg of mushrooms, and therefore finding environmentally and economically sustainable solutions for spent mushroom substrate has become an increasing concern (Czop, Pikoń 2017).

Substrate for the cultivation of mushrooms is usually made from horse manure or poultry litter and animal bedding. Moreover, the mushroom substrate contains other additions such as gypsum, winter cereal straw and casing soil made from a mixture of peat and alkalinizers. Spent mushroom substrates are characterized by high levels of organic carbon and macro- and microelements, but the use of these nutrients by plants is relatively low and amounts to 20-25% N, 20-40% P and 65-85% K in the first year after an application to soil (Lou et al. 2017). These proportions usually are insufficient to meet crops' requirements. Therefore, using spent mushroom substrate in agriculture entails additional mineral fertilization (Lou et al. 2017).

According to Antille at al. (2013), an organo-mineral fertilizer can be defined as 'a fertilizer obtained by blending, chemical reaction, granulation or dissolution in water of inorganic fertilizers having a declarable content of one or more primary nutrients with organic fertilizers or soil improver.' Conversion of spent mushroom substrate into organic-mineral fertilizers enables production of substances with a positive effect on crop yield and soil properties. Additionally, this process allows us to overcome to a certain extent the growing problem of waste from mushroom production. Organo--mineral fertilizers release nutrients slowly owing to the organic fraction that protects the inorganic components by means of binding and absorption, thereby slowing the rate of release of plant nutrients. The addition of mineral nutrients facilitates faster growth and development of plants at the beginning of their growing season (Antille et al. 2013, Kominko et al. 2017, Oliveira et al. 2017). The use of such fertilizers is recommended in particular on sandy soils with a low capacity of the sorption complex. Implementation of organo-mineral fertilizers stabilizes the organic carbon content of soil, reduces nutrient losses from mineral fertilizers, and simultaneously helps to reduce consumption of mineral fertilizers in agriculture (Atere, Olayinka 2012, Kominko et al. 2017, Oliveira et al. 2017).

The focus of the study was to develop a technology of producing new granulated organo-mineral fertilizers from spent mushroom substrate and to assess their quality for possible use in horticultural production. The evaluation of fertilizers was carried out in a micro-plot experiment with white cabbage. The yield and chemical composition of plants as well as selected soil properties were examined in this experiment.

MATERIAL AND METHODS

Fertilizers production

Granulated organo-mineral fertilizers (OM1-OM4) were produced on the basis of composted spent mushroom substrate. Prior to granulation, different amounts of mineral fertilizers, such as urea ($CO(NH_2)_2$), ammonium nitrate (NH_4NO_3), ammonium sulphate ($(NH_4)_2SO_4$), single superphosphate ($Ca(H_2PO_4)_2 \cdot H_2O$), high-potassium salt (KCl-48% K), were added to the compost produced from the spent mushroom substrate (Table 1). The resulting mixtures were granulated using a Testmer drum granulator.

For the production of the remaining two fertilizers (OM5 and OM6), compost made from fresh spent mushroom substrate mixed with sewage sludge at a 5:1 ratio (Table 1). Fertilizer No. 5 (OM5) was produced by granulating the compost without any addition of mineral fertilizers. To produce fertilizer No. 6 (OM6), ammonium sulphate was added to the compost from spent mushroom substrate with added municipal sewage sludge (Table 1), and the resulting mixture was granulated.

Microplot experiment

The assessment of the fertilization value of the granulated organo-mineral fertilizers produced on the basis of spent mushroom substrate was conducted based on a three-year (2013-2015) microplot experiment located at the Experimental Station of the Faculty of Agriculture and Biology of the Warsaw University of Life Sciences, situated in Skierniewice (latitude 51°58′ North, and longitude 20°10′ East). The plant cultivated in the experiment was white cabbage (*Brassica oleracea* L. var. *capitata* L.) of the cultivar Discover F_1.

Table 1

Proportions of the components in the mixtures used for the production of organo-mineral fertilizers (w/w %)

Organo--mineral fertilizer	Additives mineral fertilizers				Compost from spent mushroom substrate	Compost from spent mushroom substrate and sewage sludge (5:1)
	nitrogen form		$Ca(H_2PO_4)_2$	KCl		
OM1	$CO(NH_2)_2$	10	4	2	84	-
OM2	NH_4NO_3	6	4	2	88	-
OM3	$(NH_4)_2SO_4$	25	1	1	73	-
OM4	NH_4NO_3	20	-	-	80	-
OM5	-	-	-	-	-	100
OM6	$(NH_4)_2SO_4$	15	-	-	-	85

Stoneware pots (1.2 m long and 40 cm wide) filled with soil were treated as microplots. The experiment was established on Luvisols (FAO, 2014) with three replications. Soil textural composition was loamy sand (in the layer 0-30 cm, the content of particles was as follows: <0.002mm – 7%, 0.002-0.05 mm – 6%, and >0.05 mm – 87%). The soil's basic physicochemical properties are presented in Table 2 and the weather conditions are illustrated in Figure 1.

The experiment included the following fertilization combinations: control plot (no fertilization), mineral fertilization, composted spent mushroom substrate (compost) and six organo-mineral fertilizers (OM1-OM6) – Table 1. The above fertilizers were applied in two doses corresponding to 100 kg N ha^{-1} and 200 kg N ha^{-1}. Mineral fertilization was applied in doses N – 100 kg ha^{-1} (ammonium nitrate), P – 50 kg ha^{-1} (single superphosphate), K – 150 kg ha^{-1} (high-potassium salt) and N – 200 kg ha^{-1}, P – 100 kg ha^{-1}, K – 300 kg ha^{-1}.

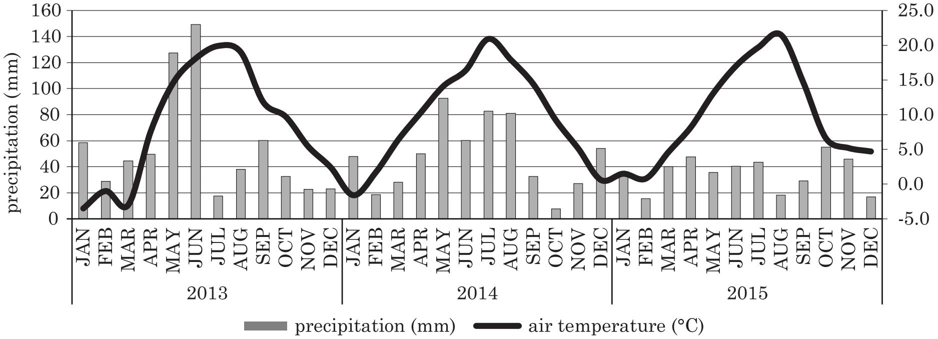

Fig. 1. Meteorological conditions at the Experimental Station in Skierniewice

The applied fertilization corresponded to the nutritional requirements of the tested plant. Every year, seedlings were planted on the second week of March and transplanted at the beginning of May. During the vegetative growth of the cabbage plants, all treatments were carried out according to agrotechnical recommendations. The cabbage was harvested at the beginning of September (at the BBCH stage 49 – heads reach typical size, shape and firmness).

Analytical methods

During harvest, the fresh weight of the plants was determined and then the plant material was dried in a dryer to constant weight and ground in an electric mill (Retsch ZM200). Samples of plant material were analyzed for: total nitrogen content – by a modified Kjeldahl method, using a Gerhardt Vapodest 30 apparatus for rapid steam distillation, phosphorus content – by the vanadium-molybdenum method, using a Thermo Electron Genesys 10 UV spectrophotometer, potassium – by the AAS method, using a Thermo Elemental SOLAAR M6 spectrometer.

Samples of the spent mushroom substrate, municipal sewage sludge, composts and organo-mineral fertilizers were analyzed for: dry matter content – by the oven-dry method, pH – in distilled water, by the potentiometric method with a Schott pH meter, organic carbon content – by dry distillation, with a LECO 2000 apparatus, total nitrogen content – by a modified Kjeldahl method, using a Gerhardt Vapodest 30 apparatus for rapid steam distillation, phosphorus content – by the vanadium-molybdenum method, using a Thermo Electron Genesys 10 spectrophotometer, K, Ca, Mg – by AAS, using a Thermo Elemental SOLAAR M6 spectrometer, Mn, Cu, Ni, Cr, Cd, Pb, Zn – by ICP, using a Thermo Elemental IRIS Advantage ICP-OES.

Soil samples for the basic chemical and physical soil analyses were taken after harvesting the plants, with a Egner's soil probe sampler from the depth of 0-20 cm, according to ISO 10381-1:2002. Soil samples were air dried and sieved to < 2 mm. Soil samples were characterized for: pH – by potentiometric method after extraction with 1 mol dm^{-3} KCl (ISO 10390:2005), total organic carbon after dry combustion (ISO 10694: 1995), total nitrogen by a modified Kjeldahl method (ISO 11261: 1995), available P and K by the Egner-Riehm (DL) method (PN-R-04023:1996, PN-R-04022:1996). Mn, Cu, Ni, Cr, Cd, Pb, Zn content after extraction in 1 mol dm^{-3} HCl (10 g of soil was shaken with 100 ml HCl on a rotary shaker for 2 h at 120 rounds min^{-1}) by Inductively Coupled Plasma Atomic Emission Spectrometry (ICP-AES).

The accuracy of the analytical methods was verifed based on certifed reference materials: Enviromat SS-1 (SCP Science) and BCR 281 Rye Grass (LGC Promochem).

Data analysis

Nitrogen use was defined as nitrogen use efficiency (NUE) and agronomic efficiency (AE), which were calculated from the following formulas:

NUE = YN FN^{-1} (kg yield kg^{-1} N applied);

AE = (YN – Y0) FN^{-1} (kg yield increase kg^{-1} N applied);

where:

FN – amount of applied N (kg ha^{-1});

YN – crop yield in a treatment with applied N (kg ha^{-1});

Y0 – crop yield in a treatment with no N (kg ha^{-1});

The results of the chemical analyses were processed statistically by the multifactor analysis of variance (ANOVA) using Statistica ver. 10. The Tukey's test was used to assess the differences between mean values at a significance level of $p < 0.05$.

RESULTS AND DISCUSSION

The chemical composition of the fertilizers varied and depended on the added components from which they were produced (Table 2). The fertilizers

Table 2

Chemical composition of granulated organo-mineral fertilizers

Fertilizer	pH	C_{org}	N	P	K	Ca	Mg
		(g kg^{-1})					
Compost	7.21	352.1	13.51	6.15	3.92	62.0	3.96
OM1	6.52	212.0	76.0	18.2	22.7	70.0	3.1
OM2	6.34	224.3	25.0	18.5	27.0	71.3	4.3
OM3	6.35	182.8	50.0	6.7	11.6	58.6	3.2
OM4	6.17	204.7	83.0	9.3	3.9	41.1	3.5
OM5	6.94	411.3	22.0	7.13	2.71	44.8	4.2
OM6	6.63	348.2	63.0	9.5	3.6	42.2	3.7
	Cu	Zn	Mn	Ni	Cd	Pb	Cr
	(mg kg^{-1})						
Compost	23.51	139.00	231.48	11.63	0.26	3.11	37.12
OM1	25.47	152.07	222.71	10.00	0.27	3.75	31.34
OM2	26.55	149.67	256.11	12.52	0.29	3.70	40.23
OM3	21.21	130.07	262.51	6.36	0.21	3.12	27.41
OM4	20.60	158.02	227.01	7.72	0.25	3.56	34.65
OM5	54.32	372.82	302.31	14.73	0.49	6.50	43.61
OM6	52.77	356.97	235.16	12.05	0.49	5.58	30.54

were characterized by a slightly acidic to neutral reaction and a high calcium content. The highest organic carbon content was found in fertilizers OM5 and OM6 produced from the compost with sewage sludge added, and the lowest was in fertilizer OM3 produced from the compost from spent mushroom substrate with the addition of ammonium sulphate.

All of the tested fertilizers influenced significantly an increase in the soil pH relative to the control (Figure 2). The soil reaction changed from strongly

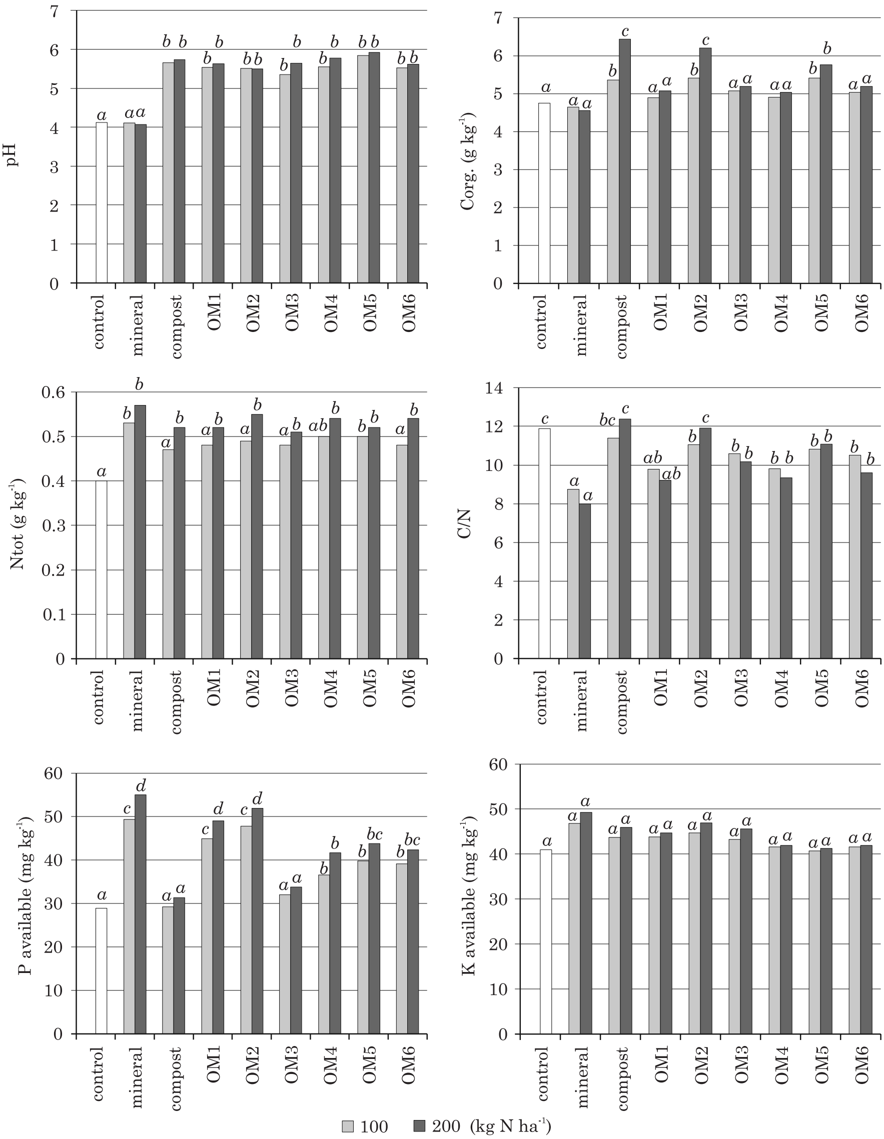

Fig. 2. Effect of organo-mineral fertilizers on selected soil properties. Letters denote significant differences among treatments at $p = 0.05$ level

acidic to acidic, or slightly acidic. The highest soil pH values were obtained in the plots where the compost from spent mushroom substrate was used and in the plots fertilized with the compost from spent mushroom substrate with the addition of sewage sludge (OM5). The de-acidifying effect of the tested fertilizers was probably associated with the substantial amounts of calcium in their chemical composition, which ranged from 40 to 70 g kg^{-1} (Table 2). In other studies, it had been shown that fertilization with spent mushroom substrates regulated the pH-value of the soil environment both in the first and subsequent years of the experiment (Lou et al. 2017).

A significant increase in the soil C_{org} content was found only as a result of using the compost from spent mushroom substrate and fertilizers OM2 and OM5 (Figure 2). It should be emphasized that fertilizer OM2 was an organo-mineral fertilizer in which the proportion of the compost from spent mushroom substrate was the highest among all the fertilizers tested. The OM5 was a compost from spent mushroom substrate with sewage sludge in which the C_{org} content was the highest (Table 2). A significant increase in the soil C_{org} content under the influence of the higher fertilizer dose was obtained only in the plots fertilized with the compost from spent mushroom substrate and fertilizer OM2. Other authors, too, had pointed to an increase in the organic carbon content of the soil as a result of using composted spent mushroom substrates (Jordan et al. 2008, Medina et al. 2012). At the same time, these authors had shown that the organic carbon content of soil did not change much over time following the use of composted spent mushroom substrate.

The total nitrogen content in the soil increased with the application of the tested fertilizers relative to the control. A significant increase in the amount of this element in the soil was found as a result of using the higher dose of all the tested fertilizers, corresponding to 200 kg ha^{-1} of nitrogen. The lower dose of the compost and fertilizers such as OM1-OM3 and OM6 did not influence the content of N_{tot} in soil (Figure 2). An increase in the total nitrogen content of the soil resulting from the use of spent mushroom substrates had also been reported by other authors, who showed that it was related to the slow mineralization rate of spent mushroom substrates. At the same time, their studies demonstrated that nitrogen losses from soils fertilized with spent mushroom substrates were considerably lower than from soils fertilized with mineral fertilizers (Medina et al. 2012, Holbeck et al. 2013, Lou et al. 2017).

The reduction in the soil C/N ratio was observed under the influence of the tested fertilizers compared with the control (Figure 2). Organic fertilization promotes faster accumulation of nitrogen in the soil than of carbon, which is the reason for the narrowing of the C/N ratio of the soil (Yan et al. 2012). The lowest C/N ratios were found in the plots fertilized with fertilizers OM1 and OM4, i.e. fertilizers which supplied the largest amounts of nitrogen (Table 3). With a composted spent mushroom substrate, stabilized organic matter is introduced into the soil, where it undergoes slow mineralization,

Table 3

Content of macroelements in cabbage depending on fertilization

Combination	Dose (kg N ha^{-1})	N	P	K
		(g kg^{-1} DW)		
Control		12.61^{b}	2.72^{b}	18.85^{a}
Compost	100	15.26^{c}	3.68^{c}	23.16^{bc}
	200	15.94^{c}	4.03^{c}	24.07^{c}
Mineral	100	14.22^{cd}	3.11^{c}	23.18^{c}
	200	18.04^{d}	3.96^{c}	25.07^{d}
OM1	100	9.35^{a}	2.44^{b}	22.16^{b}
	200	10.07^{a}	2.51^{b}	23.44^{c}
OM2	100	9.60^{a}	2.39^{b}	23.40^{bc}
	200	10.28^{a}	2.58^{b}	24.79^{c}
OM3	100	9.56^{a}	2.10^{a}	21.23^{b}
	200	10.04^{a}	2.30^{ab}	23.44^{c}
OM4	100	9.70^{a}	1.99^{a}	20.39^{ab}
	200	10.52^{a}	2.19^{a}	21.34^{b}
OM5	100	12.86^{b}	3.42^{c}	23.62^{c}
	200	13.46^{b}	3.75^{c}	24.38^{c}
OM6	100	10.06^{a}	2.15^{a}	20.33^{a}
	200	10.86^{a}	2.26^{ab}	21.35^{b}
Optimal content*		18.0	3.0	15.0

* according to Hochmuth et al. (2012);
Letters denote significant differences among treatments at p = 0.05 level.

and this may explain the absence of significant changes in the soil C/N ratio between the fertilized plots and the control plot (Medina et al. 2012).

The available phosphorus content of the soil in the plots where the tested fertilizers were used increased in comparison with the control plot (Figure 2). The highest content of the available P of the soil was found as a result of using fertilizers OM1 and OM2, which contained the most phosphorus (Table 2). In contrast, the level of available forms of this element in the soil was not significantly increased in the plots fertilized with the compost from spent mushroom substrate and with the fertilizer with the lowest P content (OM3). Other authors had shown that in mature composts more than 70% of total P occurred in an inorganic form, which may have had an effect on increasing the amounts of readily available forms of phosphorus in the soil following the use of such fertilizers (Sharpley, Moyer 2000, Eghball 2003, Zvomuya et al. 2006, Jordan et al. 2008). Composts are generally characterized by high availability of phosphorus. In the first year of their application, the amount of available phosphorus compounds released into the soil can represent up to 60% of the amount of this element released as a result of using mineral phosphorus fertilizers (Sinaj et al. 2002, Miller et al. 2010, Olson et al. 2010).

The available potassium content of the soil underwent very small changes under the influence of the applied fertilization. None of the tested fertilizers showed a significant effect on the content of available potassium in the soil (Figure 2). In spent mushroom substrates, from 62 to 72% of potassium occurs in an easily available form and can be taken up by plants in the first year after application (Stewart et al. 2000). Other studies had shown a significant increase in the available potassium content of the soil as a result of using spent mushroom substrate (Courtney, Mullen 2008).

The nitrogen content of cabbage was not greatly influenced by the experimental factors, but the highest amounts of this element were found in the plants from the plots fertilized with the compost from spent mushroom substrate and with fertilizer OM5, and also in the plants from the control plot. At the same time, the yields of cabbage obtained from those plots were the lowest (Table 4). The nitrogen content of the cabbage plants increased with the higher fertilizer dose. In the experiment, the cabbage plants were characterized by a low nitrogen content, which ranged from 9.08 to 16.91 g kg^{-1} DW (Table 3). A similar nitrogen content of cabbage plants

Table 4

Yield, nitrogen use efficiency (NUE) and agronomic efficiency (AE)

Combination	Dose (kg N ha^{-1})	Yield (g DW per microplot)	NUE (%)	AE (kg DW kg^{-1} N)
Control		71.4^{a}	-	-
Compost	100	73.4^{a}	17.5^{a}	1.6^{a}
	200	84.2^{a}	17.6^{a}	5.1^{a}
Mineral	100	137.1^{b}	83.5^{f}	52.3^{e}
	200	163.6^{c}	81.6^{f}	36.7^{cd}
OM1	100	133.0^{b}	27.3^{c}	49.0^{de}
	200	151.6^{bc}	24.9^{b}	31.9^{c}
OM2	100	132.8^{b}	29.8^{de}	48.9^{d}
	200	152.3^{bc}	26.5^{b}	32.2^{c}
OM3	100	134.5^{b}	30.7^{e}	50.2^{e}
	200	154.4^{c}	25.9^{b}	33.0^{c}
OM4	100	135.6^{b}	33.0^{e}	51.1^{e}
	200	156.4^{c}	29.7^{de}	33.8^{c}
OM5	100	87.6^{a}	18.0^{a}	12.9^{b}
	200	96.5^{a}	15.9^{a}	10.0^{b}
OM6	100	127.1^{b}	30.1^{e}	44.3^{d}
	200	144.3^{b}	26.5b	29.0^{c}

Letters denote significant differences among treatments at p = 0.05 level.

fertilized with urea at 100 and 200 kg N ha^{-1} had been observed by FREYMAN et al. (1991).

The nitrogen content determined in the white cabbage was below the critical content for plant growth and development. The critical levels of nitrogen in cabbage plants reported in the literature vary, depending on the developmental stage of the plant and the organ analyzed. The nitrogen content of the outer leaves of cabbage at harvest considered to be critical for plant growth and development is about 18 g kg^{-1} DW The content of nitrogen exceeding 30 g kg^{-1} DW is considered to be too high, as it causes deterioration in cabbage crop quality (HOCHMUTH et al. 2012).

Similarly to nitrogen, the highest amounts of P were found in the plants fertilized with the compost from spent mushroom substrate and with fertilizer OM5 (Table 3). The content of phosphorus in plants from these objects was significantly higher in comparison with the remaining combinations. The lowest amounts of phosphorus were found in the plants fertilized with the OM4 – without the addition of phosphorus. In these conditions, the yield of cabbage was the highest. DOMAGAŁA-ŚWIĄTKIEWICZ and SADY (2010) showed that the enhanced plant growth after nitrogen application caused dilution of phosphorus without any competition occurring in its uptake. In all the fertilizer combinations tested, no increase in the phosphorus content was observed in cabbage plants as a result of using the higher dose of fertilizers. Comparing the phosphorus content obtained in cabbage dry matter in this experiment with the critical content for growth and development of this plant reported by HOCHMUTH et al. (2012), it was found that only the applications of the compost from spent mushroom substrate and fertilizer OM5 ensured that the plants contained more than 3.0 g P kg^{-1} DW, which is evidence of good nutrition in terms of phosphorus uptake. In the other fertilizer combinations, the phosphorus content of the cabbage plants was slightly lower than optimal.

The lowest potassium content was determined in the cabbage plants from the control combination. As a result of using the tested organo-mineral fertilizers, the potassium content of plants was observed to increase in comparison with the control. It was shown that the potassium content of cabbage from the combinations OM4 and OM6 was similar to that in plants from the control object and lower than in plants from the other fertilizer combinations (Table 3). However, the potassium content of cabbage plants usually increased with the dose of the fertilizers used. According to the research by HOCHMUTH et al. (2012), a potassium content below 12.0 g kg^{-1} DW is considered critical for the growth and development of white cabbage, while a content above 30.0 g kg^{-1} DW is considered excessive. It can be concluded that, regardless of the type and dose of the fertilizers applied, the cabbage plants cultivated in the experiment were characterized by an optimum potassium content.

Cabbage is one of the most popular vegetable crop in Poland, with the total annual production around 1000 thousand tonnes. The average yield of cabbage in Poland is about 50 Mg ha^{-1} of fresh matter (GUS 2017). However, the yield of cabbage can be very differentiated and depends on many agrotechnical factors, mainly fertilization (Kołota, Chohura 2015). The lowest yields of cabbage were obtained from the control plot and the plots fertilized with the compost from spent mushroom substrate and the compost produced from spent mushroom substrate with the addition of sewage sludge (OM5). As a result of using the organo-mineral fertilizers, the yields of cabbage increased significantly in comparison with the yields both from the control plot and from the plots fertilized with the composts (Table 4). Zahradník and Petříkova (2007) and Olaniyi and Ojetayo (2011) had also shown a significant increase in cabbage yields as a result of using organo-mineral fertilizers compared with the yields obtained when fertilizing with composts. The relatively low yields resulting from the use of composts were attributed by these authors to the slow release of nutrients from those fertilizers, which did not ensure that the high nutritional needs of cabbage plants were satisfied. At the same time, the presence of readily available forms of nutrients in organo-mineral fertilizers had a beneficial effect on cabbage yields.

The value of nitrogen use efficiency from the tested organo-mineral fertilizers ranged from 15.9 to 33.0% and, apart from the compost, was lower at the higher nitrogen dose (Table 4). The largest NUE was achieved for the mineral fertilization (over 80%), and the smallest – from the compost and OM5 (16-18%). The NUE values in remaining objects ranged from 25 to 33%. According to Mazur and Mazur (2006), the use of nitrogen from organic fertilizers in the first year of their application is 25-35% and decreases in following years to 15-25%. Chatterjee et al. (2014) showed that the highest use of nitrogen by cabbage (58.88%) was obtained using combined organic-mineral fertilization where the share of nitrogen from mineral fertilizers was 75%, and organic nitrogen 25%.

The lowest agronomic efficiency was found for the compost from spent mushrooms substrate (1.6-5.1 kg DW kg^{-1} N), and the highest one – for mineral fertilization (37-52 kg DW kg^{-1} N). In the other fertilizer combinations in which organic-mineral fertilizers were applied, AE ranged from 10-13 for OM5 to 30-50 kg DW kg^{-1} N for the remaining variants. The value of this indicator was higher at the lower nitrogen dose. An opposite relationship was found only in the case of compost (Table 4). Katroschan et al. (2014) showed that the AE of organic cabbage fertilization was 42.7-52.4 kg DW kg^{-1} N.

CONCLUSIONS

1. Organo-mineral fertilizers based on spent mushroom substrate have a beneficial effect on soil properties. As a result of the applied fertilization, the soil's reaction changes within a wide range from strongly acidic to acidic,

or slightly acidic. The beneficial effect of using organo-mineral fertilizers is manifested by an increase in the organic carbon content and total nitrogen content of the soil, which, depending on a fertilizer combination, range respectively from 5 to 24% C_{org} and 25 to 32% N_{tot} relative to the control combination. Organo-mineral fertilization increases the levels of plant available forms of nutrients in the soil, such as available phosphorus – from 1 to 79%, and available potassium – from 1 to 12% in relation to the unfertilized object.

2. Organo-mineral fertilization significantly affected the yield of cabbage, which, depending on a fertilizer combination and fertilizer dose, increased by 90 to 103% relative to the control combination.

3. The amounts of N, P and K in the tested plants depended on a fertilizer combination, whereas a fertilizer dose did not significantly affect the chemical composition of cabbage plants. The amounts of nitrogen and phosphorus in the dry matter of white cabbage plants decrease relative to the control combination. The potassium content of cabbage plants increased as a result of the application of the tested fertilizers.

4. Nitrogen use efficiency (NUE) and agronomic efficiency (AE) values were dependent on the fertilizing combination and the nitrogen dose. The highest NUE and AE values were observed in response to the application of OM4 (80% spent mushroom substrate and 20% NH_4NO_3) in a dose of 100 kg N ha^{-1}.

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