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EFFECTS OF SPENT MUSHROOM SUBSTRATE ON SELECTED PHYSICAL PROPERTIES OF SOIL PLANTED WITH WHITE CABBAGE

R. Rosa, PhD, D. Sc. [1]
ORCID ID: 0000-0001-6344-538X
J. Franczuk, PhD, D. Sc. [1]
ORCID ID: 0000-0002-8440-850X
A. Rutkowska, PhD [1]
ORCID: 0009-0003-7952-1529
A. Andrejiová, PhD, Ing. Doc. [2]
ORCID: 0000-0001-5484-440X
O. Dydiv, Cand. Sc. [3]
ORCID: 0000-0003-4155-5945
[1] University of Siedlce, Poland
[2] Slovak University of Agriculture in Nitra, Slovak Republic
[3] Lviv National Environmental University

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The long-term use of mineral fertilizers in agriculture can have detrimental effects on the natural environment. One potential solution to mitigate these negative impacts is to incorporate natural and organic materials to enrich the soil. A traditional natural fertilizer that has been utilized for centuries around the world, including Poland, is manure. However, systemic changes in Polish agriculture over the past two decades have led to a shortage of this resource. As a result, there is a pressing need to explore alternative sources of organic matter for soil enhancement. One promising option is the use of organic waste materials, such as spent mushroom substrate (SMS). This substrate is a by-product of the cultivation of edible mushrooms, particularly champignons (*Agaricus bisporus*). Given the scale of mushroom production in Poland, it is estimated that Polish farms generate between 1.6 and 2.0 million tons of this waste, which requires safe disposal and management. Across Europe, the annual production of mushroom substrate exceeds 3 million tons. In a recent experiment, the introduction of spent mushroom substrate provided more organic matter, as well as macro and micronutrients, to the soil compared to farmyard manure (FYM). Measurements taken before the harvesting of cabbage revealed that the physical properties of the soil - namely, topsoil bulk density, porosity, and subsoil moisture - remained consistent between plots treated with SMS and FYM, both of which demonstrated significantly better conditions than the control plot with no organic fertilizer. When plowed in prior to planting cabbage seedlings, both SMS and FYM notably increased the marketable yield of cabbage heads in comparison to the control. The yield-enhancing effects of the two organic fertilizers were found to be quite similar.

Keywords: *Brassica oleracea* L. var. *capitata* L. f. *alba*, farmyard manure, mushroom substrate, organic fertilizers, soil properties, yielding.

Роса Р., Франчук Ж., Рутковська А., Андрійова А., Дидів О. Вплив відпрацьованого грибного субстрату на окремі фізичні властивості ґрунту за вирощування капусти білоголової

Зауважено, що тривале застосування мінеральних добрив у сільському господарстві негативно впливає на природне середовище. Одним із потенційних шляхів зменшення цього негативного впливу є використання природних і органічних матеріалів для збагачення ґрунту. Основним природним добривом, яке століттями застосовується в усьому світі, зокрема й у Польщі, є гній. Проте системні зміни в польському сільському господарстві за останні два десятиліття призвели до його дефіциту. Тому необхідно шукати альтернативні джерела органічної речовини, що постачається в ґрунт. Досліджено, що відмінним джерелом органічної речовини, яке покращує фізичний стан ґрунту та забезпечує поживними речовинами рослини, можуть бути органічні відходи, такі як відпрацьований грибний субстрат. Грибний субстрат використовується у вирощуванні їстівних грибів, переважно печериць (*Agaricus bisporus*). Враховуючи обсяги виробництва грибів у Польщі, зауважено, що польські грибні ферми виробляють 1,6-2,0 мільйона тонн відходів, які потребують безпечного поводження. У Європі кількість виробленого грибного субстрату перевищує 3 мільйони тонн на рік. Виявлено, що відпрацьований грибний субстрат (SMS) забезпечив надходження до ґрунту більшої кількості органічної речовини, а також макро- та мікроелементів, аніж традиційний гній (FYM). Визначені перед збиранням капусти фізичні властивості ґрунту – зокрема об’ємна маса орного шару, його пористість та вологість підорного шару – не відрізнялися між варіантами із застосуванням SMS і

FYM, проте були значно кращими порівняно з контролем без внесення органічних добрив. Заорані перед висаджуванням розсади капусти добрива SMS і FYM достовірно підвищили товарну врожайність головок порівняно з контролем. Ефективність обох органічних добрив щодо підвищення врожайності була подібною.

Ключові слова: *Brassica oleracea* L. var. *capitata* L. f. *alba*, гній з ферми, грибний субстрат, органічні добрива, властивості ґрунту, урожайність.

Problem setting. White cabbage is one of the most important vegetables, grown in Poland, Ukraine, and many other countries. Among vegetables cultivated in Poland, it ranks second with 571 200 tons harvested in 2024 [9]. Ukraine is the world's fifth-largest producer of cabbage [10]. The popularity of this vegetable is due to its versatile use and the possibility of long-term storage in a fresh state.

Due to its high soil, water, and nutritional requirements, white cabbage yields are the greatest on fertile soils, rich in organic matter, with pH close to neutral and sufficient moisture. The humus content of soils is important in cabbage cultivation. However, the amount of organic matter content of Polish soils is relatively low. This is due to the prevalence of light soils made of sand of various origins. More than half of Polish soils contain less than 2 % of organic matter, with 11 % containing more than 3.5 % [15]. Additionally, most species of vegetables, root crops, maize, cereals, and oilseed plants decrease organic matter content in soils. On the other hand, the cultivation of legumes and grasses and the application of organic fertilizers have a beneficial effect.

Analysis of recent research and publications. Every year, substantial amounts of nutrients are removed from the soil through crop cultivation, which necessitates supplementation. However, relying exclusively on basic mineral fertilizers and their overuse poses risks to the natural environment and accelerates the degradation of organic matter [26]. High organic matter (OM) content in the soil plays a crucial role in stabilizing its structure and reducing vulnerability to compaction as well as water and wind erosion [30]. OM serves as a structural binder that facilitates the formation of soil aggregates and pores, both of which are vital for effective water and air circulation. It is capable of retaining three to five, or even up to twenty times its own weight in water [6]. Furthermore, humus substances enhance the concentration of soil nutrients and improve their availability to plants [5]. Therefore, to maintain soil structure and nutrient levels, it is essential to systematically supplement the soil with organic matter. Potential sources include residues from catch crops and the introduction of exogenous organic matter, such as organic fertilizers and organic waste generated by human economic activities [20]. A particularly valuable resource for replenishing organic matter and providing nutrients is the substrate leftover from mushroom production (SMS). Incorporating it into the soil as an organic fertilizer is an increasingly popular method in waste management [31].

Problem statement. The aim of the experiment was to determine the effects of SMS on selected soil physical properties and the yield of white cabbage.

The main materials and methods. Between 2016 and 2018, a field experiment was conducted at the Agricultural Experimental Station in Zawady, located in central-eastern Poland (52°09′ N; 22°33′ E). The experiment was designed as a completely randomized layout with three replicates. The experimental factors included the incorporation of organic matter, such as pig manure (FYM) and mushroom substrate (SMS), as well as a control group (Control) that did not receive any organic fertilizers. The crop grown was white cabbage, cv. Kamienna Głowa, which followed winter triticale as a preceding crop.

Before the experiment, a sample of the soil was collected to determine its pH, humus, and macronutrient content. A month before planting cabbage, manure and mushroom substrate were applied to the appropriate experimental combinations. Their doses were calculated on the basis of their nitrogen content, with no more than 170 kg N ha-1 introduced into the soil. The FYM dose was 25 t·ha-1 with 20 t ha-1 of SMS. FYM and SMS samples were also collected to determine their pH and the content of dry matter, total carbon, total nitrogen, and macronutrients.

Before planting cabbage, mineral fertilizers were applied in the following amounts: 140 kg N ha-1, 95 kg P_2O_5 ha-1, and 370 kg K_2O ha-1. The doses were determined on the basis of soil mineral content and nutritional requirements of the late varieties of cabbage [27]. The whole dose of P and K fertilizers was applied before planting seedlings, but the N dose was divided into two equal parts – the first applied before planting seedlings, the other three weeks afterwards. Cabbage seedlings were planted at a spacing of 50 × 60 cm.

Three weeks after planting seedlings and then one week before the harvest, soil samples were collected from each combination to determine moisture content in the 0–20 cm and 20–40 cm layers. Additionally, a week before the harvest, soil samples were collected from each combination to determine the bulk density and solid-phase density of the soil. Cabbage was harvested in mid-October. Then the marketable yield (t ha-1) of cabbage heads was determined. Unsplit, hard, and properly developed heads were considered to be marketable.

Manure and mushroom substrate properties were determined in the following manner:

- pH with the potentiometric method,
- dry matter content (%) with the drying and weighing method, after drying the sample to a constant weight at 105 °C,
- total nitrogen and carbon content (%) with the PerkinElmer Series II 2400 Elemental Analyzer (TCD),
- organic matter content (%) was calculated according to the formula: OM = TC · 1.724 (TC is total carbon),
- total content of P, K, Ca, Mg, and Na ($g \cdot kg^{-1}$ DM) with Inductively Coupled Plasma Optical Emission Spectroscopy (ICP-OES), using the PerkinElmer Optima 8300 emission spectrometer.

In the soil material collected during the white cabbage growing period, the following were determined:

- soil moisture (%) with the drying and weighing method, after drying to a constant weight at 105 °C,
- soil bulk density (ρo) ($g\ cm^{-3}$) in metal cylinders with a volume of 100 cm^3,
- solid-phase density (ρs) ($g \cdot cm^{-3}$) with the pycnometric method,
- Total porosity (*Po*) was calculated according to the formula: $Po = (\rho s - \rho o) / \rho s \cdot 100$ (%).

The results were statistically analyzed using the analysis of variance appropriate for a completely random system. The significance of the differences between means was assessed by Tukey's test at a significance level of p=0.05 [32].

The field experiment was conducted on the Luvisol soil composed of a mixture of sand, clay and silt, and with loose sand as subsoil. Humus content in the soil before the experiment was on average 1.69 %, with pH in H2O ranging from 6.19 to 6.26. Throughout the experiment, the arable layer contained on average (mg): 37.8 N-NO3, 19.8 N-NH4, 62.4 P, 115.8 K, 769.6 Ca, and 67.3 Mg in 1 L of soil. Selected physical properties of the soil were as follows: solid-phase density 2.24 $g\ cm^{-3}$, bulk density 1.51 $g\ cm^{-3}$, and total porosity 35.03 %.

For the general assessment of pluviothermic conditions during the cabbage growing period Sielianinov's hydrothermal coefficient was calculated according to the methodology used by Skowera and Puła [28]. The coefficient values indicated that in July 2017, it was very dry, and June and August were quite dry (Table 1).

Hydrothermal coefficient: up to 0.4, extremely dry; 0.41–0.7, very dry; 0.71–1.0, dry; 1.01–1.3, rather dry; 1.31–1.6, optimal; 1.61–2, rather humid; 2.01–2.5, humid; 2.51–3, very humid; and >3, extremely humid [Skowera and Puła 2004].

September was moderately humid, and October was humid. Such conditions resulted in higher yields of white cabbage that year. The total precipitation during the 2017 growing period of 269.8 mm was the highest over the years of the experiment. The lowest amount of rainfall during the cabbage growth period (129.1 mm) was observed in 2018. June and August were very dry, July was quite dry, and September and October were dry. Such conditions resulted in very poor seedling survival, with a large number of them dying, cabbage's slow growth, and poor binding of heads. In 2016, total precipitation in June-October was 187.2 mm. The values of Sielianinov's hydrothermal coefficient indicated that June was dry, July and August were very dry, September was extremely dry, and October was extremely wet. The prevailing drought that year negatively affected the yield of cabbage.

Result and discussion. Spent mushroom substrate (SMS) pH ranged from 6.3 to 6.9, with 7.0 to 7.1 for manure (FYM) (Table 2). An SMS pH range of 6.2–6.8 was noted by such authors as Becher [1], Czop and Kłapcia [4], Gong et al. [7], Jordan et al. [12], and Uklańska-Pusz et al. [33]. Menget et al. [23] noted a lower pH of SMS (6.1), but Medina et al. [22] and Uzun [34] recorded much higher values (7.2–8.0).

The average SMS dry matter content was 30.5 %, 5.8 percentage points higher than in FYM (Table 2). According to other authors [3; 4; 12; 18 and 33], it ranged from 30.5 to 34.9 %. In the present experiment the content of organic matter (53.3 %) and total carbon (31.5 %) in SMS was greater than in FYM (by 2.6 and 1.5 percentage points, respectively). Increased organic matter (OM) content in SMS (64.5–71.0 %) was recorded, among others, by Jordan et al. [12] and Uklańska-Pusz et al. [33]. On the other hand, significantly lower values (22–34 %) were noted by Niżewski et al. [25].

The medium content of total nitrogen (TN) in both SMS and FYM was the same, with 2.7 % (Table 2). Similar SMS nitrogen content was reported by Wiśniewska-Kadżajan and Jankowski [35]. In many studies, it was lower and ranged from 1.5 to 2.6 % of DM [2; 7; 19; 23]. According to Majchrowska-Safaryan and Tkaczuk [19] and Uklańska-Puszet al. [33], as much as 94 % of nitrogen in mushroom substrate is in organic form.

Table 1

Sielianinov's hydrothermal coefficient during the growing period of white cabbage

Years	The months of the cabbage growing period				
	June	July	Aug	Sept	Oct
2016	0.72	0.56	0.61	0.28	3.02
2017	1.06	0.47	1.04	1.92	2.36
2018	0.61	1.12	0.40	0.71	0.94

Table 2

Selected properties of farmyard manure and spent mushroom substrate

Years	pH_{H2O}	Content (%)				C:N
		Dry matter	Total carbon (TC)	Organic matter (OM)	Total nitrogen (TN)	
Farmyard manure (FYM)						
2016	7.1	25.7	28.5	48.1	2.5	11.2
2017	7.0	24.6	30.3	51.2	2.7	11.1
2018	7.0	23.8	31.3	52.9	2.9	11.0
Mean	7.0	24.7	30.0	50.7	2.7	11.1
Spent mushroom substrate (SMS)						
2016	6.3	32.7	36.1	61.2	2.3	15.8
2017	6.9	29.8	30.6	51.7	2.8	10.9
2018	6.2	29.1	27.9	46.9	2.8	9.8
Mean	6.5	30.5	31.5	53.3	2.7	12.2

The average C:N ratio in mushroom substrate was 12.2:1, with 11.1:1 in manure (Table 2). Similar C:N ratios (11.0–13.5:1) were recorded by Becher [1], Becher and Pakuła [2], and Louet al. [16], with higher values (18-19:1) reported by Jordan et al. [12] and Menget al. [23]. According to Becher [1], C and N content and the C:N ratio in SMS varied and were dependent on the way the substrate was prepared and especially on its components. In addition, the author stated that the pH of SMS was similar to that of FYM, the former with slightly higher nitrogen content, similar carbon content, but a narrower C:N ratio.

The amount of N introduced to the soil with SMS and FYM was similar and amounted on average to 167.2 and 167.1 kg ha^{-1}, respectively. Manure enriched soil with significantly more P (54.9 vs. 31.7 kg ha^{-1}) and more Mg (38.9 vs. 33.1 k ha^{-1}) than mushroom substrate, but the latter provided significantly more K (151.0 vs. 49.2 kg ha^{-1}) and C (314.4 vs. 52.6 kg ha^{-1}) to the soil (Table 3).

The amounts of macronutrients in SMS varied to a great extent. Niżewski et al. [25] and Uklańska-Pusz et al. [33] recorded P content in SMS dry matter at 0.1–0.4 %, Gong et al. [7] at 0.7–0.8 %, and Meng et al. [23] at 2.3 %. The content of K was at the level of 2.5 % [23], 1.7–2.0 % [1; 12], and 1.0 % [33]. The content of Ca and Mg in SMS from Polish mushroom farms usually ranges from 6.0 to 15.0 % and from 0.2 to 0.52 %, respectively [21; 25].

According to many authors, substrate left over after cultivation of champignon and other cultivated fungi has a positive effect on the physical, chemical, and biological properties of soil [13; 14; 16]. In the present research, the moisture content of the 0–20 cm soil layer, measured after planting the seedlings, was on average 10.5 %, with 12.3 % in the 21–40 cm layer (Table 4). No significant differences in soil moisture were found between experimental combinations.

Prior to the cabbage harvest, the average moisture content in the 0–20 cm soil layer was recorded at 9.1%, exhibiting significant variation throughout the growing periods (refer to Table 4). During this time, soil moisture levels were primarily influenced by rainfall. In 2016, increased moisture in the top layer was attributed to the heavy rainfall in October. Both in 2016 and 2018, the moisture content in the 0–20 cm soil layer was significantly higher in plots treated with both FYM and SMS compared to the control group. However, in 2017, a year marked by substantial rainfall, no significant differences in soil moisture were observed between the control and the experimental units that received organic fertilizers.

Table 3

The amount of mineral components (kg·ha^{-1}) introduced into the soil with farmyard manure and spent mushroom substrate

Years	N	P	K	Ca	Mg
Farmyard manure (FYM)					
2016	163.2 a*	55.7 ab	52.5 a	57.3 a	41.7 a
2017	168.5 a	57.8 a	53.8 a	53.8 a	41.0 a
2018	169.6 a	51.3 b	41.4 b	46.8 a	34.2 b
Mean	167.1 A	54.9A	49.2 B	52.6 B	38.9 A
Spent mushroom substrate (SMS)					
2016	168.7 a	36.4 a	172.6 a	302.6 b	34.5 a
2017	167.5 a	30.5 b	140.1 b	401.5 a	37.0 a
2018	165.3 a	28.1 b	140.3 b	239.1 c	28.0 b
Mean	167.2 A	31.7 B	151.0 A	314.4 A	33.1 B

* Means marked with the same lowercase and uppercase letters in columns are not significantly different at $P \leq 0.05$

Table 4

Soil moisture (%) in white cabbage cultivation

Organic matter source	Soil layer 0–20 cm				Soil layer 21–40 cm			
	Years			Mean	Years			Mean
	2016	2017	2018		2016	2017	2018	
After planting white cabbage seedlings								
Control	10.6a*	11.3 a	9.7 a	10.5 a	11.4 a	12.4 a	12.2 a	12.2 a
Farmyard manure (FYM)	10.8 a	10.6 a	10.8 a	10.7 a	11.4 a	12.5 a	12.8 a	12.2 a
Spent mushroom substrate (SMS)	10.3 a	9.9 a	11.1 a	10.3 a	11.0 a	13.3 a	13.4 a	12.6 a
Mean	10.6 A	10.6 A	10.5 A	10.5	11.3 A	12.7 B	12.8 B	12.3
Before harvesting white cabbage								
Control	10.3 b	7.8 a	6.3b	8.1 b	11.8 a	8.8b	9.0 b	9.9 b
Farmyard manure (FYM)	13.1 a	7.5 a	8.3a	9.6 a	13.2 a	10.0ab	9.6 ab	11.0 a
Spent mushroom substrate (SMS)	12.4 from	7.8 a	8.5 a	9.5 a	12.7 a	11.6 a	11.1a	11.8 a
Mean	11.9 B	7.7 A	7.7A	9.1	12.6 B	10.1 A	9.9A	10.9

* Means marked with the same lowercase letters in columns and uppercase letters in rows are not significantly different at $P \leq 0.05$

The average moisture content for the 20–40 cm soil layer, assessed before the cabbage harvest, was 10.9% (Table 4). In 2016, this moisture content was significantly higher than in the subsequent years of 2017 and 2018. The impact of organic fertilizers on moisture levels in the 20–40 cm soil layer varied across the experimental years. In 2016, there were no significant differences in soil moisture between the different treatments. However, in 2017 and 2018, the application of SMS resulted in a greater increase in subsoil moisture compared to FYM. The control plots consistently displayed significantly lower moisture levels. Ma et al. [17] noted increases in soil moisture at various depths (15, 30, and 45 cm) following the application of shredded SMS, which were 6.3–8.1%, 10.7–17.2%, and 7.3–12.8% higher than in the control without SMS. Additionally, research by Harris [8] and Nakatsuka et al. [24] highlighted that incorporating SMS into the soil can enhance water retention, owing to its hydrophilic properties.

The density of the solid soil phase, determined before the harvest of white cabbage, amounted to an average of 2.25 g cm^{-3} and did not differ significantly. The density of the solid soil phase, determined before the harvest of white cabbage, amounted to an average of 2.25 g cm^{-3} and did not differ significantly across experimental years and combinations (Table 5). However, a significant effect of plowed-in organic matter on the bulk density of soil was observed. In SMS combinations it was 1.40 g cm^{-3} on average, significantly lower than in the control (1.47 g cm^{-3}). According to Table 6, in 2016, average soil bulk density (1.46 g cm^{-3}) was significantly higher than in 2018 (1.40 g cm^{-3}).

Table 5

Density of the solid phase of the soil (g·cm^{-3}) before harvesting white cabbage

Organic matter source	Years			Mean
	2016	2017	2018	
Control	2.28 a	2.30 a	2.18 a	2.25 a
Farmyard manure (FYM)	2.26 a	2.28 a	2.20 a	2.25 a
Spent mushroom substrate (SMS)	2.28 a	2.24 a	2.22 a	2.25 a
Mean	2.27 A	2.27 A	2.20 A	2.25

* Means marked with the same lowercase letters in columns and uppercase letters in rows are not significantly different at $P \leq 0.05$

Table 6

Bulk density of soil (g·cm^{-3}) before harvesting white cabbage

Organic matter source	Years			Mean
	2016	2017	2018	
Control	1.51 a*	1.47 a	1.45 a	1.47 a
Farmyard manure (FYM)	1.43 a	1.44 a	1.39 a	1.42 ab
Spent mushroom substrate (SMS)	1.45 a	1.38 a	1.37 a	1.40 b
Mean	1.46 B	1.43 AB	1.40 A	1.43

* Means marked with the same lowercase letters in columns and uppercase letters in rows are not significantly different at $P \leq 0.05$

Table 7

Total soil porosity (%) before harvesting white cabbage

Organic matter source	Years			Mean
	2016	2017	2018	
Control	33.56 a*	36.10 a	33.52 a	34.39 a
Farmyard manure (FYM)	36.47 a	36.65 a	37.08 a	36.73 a
Spent mushroom substrate (SMS)	36.59 a	38.62 a	38.17 a	37.79 a
Mean	35.54 A	37.12 A	36.26 A	36.30

* Means marked with the same lowercase letters in columns and uppercase letters in rows are not significantly different at $P \leq 0.05$

Table 8

Marketable yield of white cabbage (t·ha^{-1})

Organic matter source	Years			Mean
	2016	2017	2018	
Control	63.9 b	66.2 b	41.7 c	57.3 b
Farmyard manure (FYM)	78.7 a	78.8 a	50.3 bc	69.3 a
Spent mushroom substrate (SMS)	71.5 a	82.4 a	60.5 a	71.5 a
Mean	71.4 A	75.8 A	50.8 B	66.0

* Means marked with the same lowercase letters in columns and uppercase letters in rows are not significantly different at $P \leq 0.05$

Measured before the harvest, soil total porosity was similar throughout the experiment, with an average of 36.30 % (Table 7). In relation to the control, soil total porosity tended to increase, but not significantly, in combinations with FYM and SMS. Steward et al. [29] found that SMS improved properties of soil planted with root crops such as sweet corn (*Zea mays*), head cabbage, and potato (*Solanum tuberosum*) by reducing soil bulk density at a depth of 10 cm (by 0.05–0.25 g cm^{-3}), increasing the stability of soil aggregates (by 13–16 %) and water content (by 0–7 %). Nakatsuka et al. [24] also reported that after the SMS application, the porosity of the top soil layer and of the subsoil increased.

In the present research, the yield of marketable heads, average across 2016–2018, was 66.0 t ha^{-1} (Table 8). Different weather conditions in the consecutive growing periods affected the marketable yield. The highest yield (75.8 t ha^{-1}) was harvested in 2017, a year with the most favorable hydrothermal conditions for cabbage, and the lowest (50.8 t·ha^{-1}) in 2018, when they were the least favorable.

On average over the growing periods, FYM and SMS significantly increased the marketable yield of heads in relation to the control. In 2016–2017, the best yield-increasing effect was noted both for FYM and SMS, and in the very dry year of 2018 for SMS. The beneficial effect of spent substrate left over after the production of *Agaricus bisporus* on the growth and yields of cabbage was also indicated by the research of Szulc et al. [31]. They applied composted SMS to white head cabbage at a dose corresponding to 100 kg N ha^{-1} and noted a slight, 3 % increase in the yield compared to the control without organic and mineral fertilizers. However, a two-fold increase in the amount of SMS resulted in an 18.6 % increase in the cabbage yield relative to the control. According to Islam et al. [11], the yield of broccoli treated with SMS increased by 85.9 % compared to the control without organic fertilization.

Conclusions. Mushroom substrate introduced more organic matter into the soil than manure. Soil physical properties, i.e., moisture of the top and deeper soil layers, bulk density, and porosity, did not differ significantly between soil treated with FYM and SMS but were much more favorable than in the control without organic fertilizers. Because of the unfavorable content of organic matter in Polish soils and decreasing manure production, mushroom substrate could be a valuable source of organic matter in vegetable cultivation, stabilizing the physicochemical properties of the soil. In the present experiment, mushroom substrate was also a valuable source of plant nutrients, with almost 55% more macro- and micronutrients introduced into the soil than with manure. Because of the beneficial effect of mushroom substrate on soil physical properties and the white cabbage yield, it should be recommended as a valuable alternative to manure.

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