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Spent Cultivation Substrate (SCS) Management in Circular Farming System †

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Abstract: Spent cultivation substrate (SCS) is growing medium which stays after cultivation of mushrooms (SMS) or vegetables (SGS) and for many years was considered as a problematic waste product from farming. However recently in the new transition to sustainable, circular farming systems it is seen as a valuable product which could be recycled. The SMS was air characterised by high organic matter content, low bulk density, high pH and soluble slats content, rich in macro and micro elements and their content generally decreased in following order K, Ca, Na, Mg, Mn, Fe, Si, Se and Mo. The content of heavy metals was acceptable for both SMS and SGS. SGS could be potentially used in horticulture for subsequent greenhouse vegetables cultivation, if composted/co composted with additional waste products due to high mineral salt content and to eliminate potential pests.

Keywords: mushroom cultivation; sustainable agriculture; vegetable and herbs cultivation; bioeconomy; farm waste management; soil amendment

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1. Introduction

Mushroom and plant crop cultivation is normally performed through energy- and resource-intensive processes (based on fossil or mineral resources), in commercial specialized operations such as climate-controlled tunnels and greenhouses). These operations generate wastes and the CO_2 footprint of the produce is high [1]. During mushroom cultivation for 1 kg of grown mushrooms fruiting bodies 5 kg of spent mushroom compost (SMC) is given [2] SMCs from *Agaricus* are more degraded (more stabilised) than those from lignivorous fungi (e.g., *Pleurotus* and *Lentinula*) and therefore more suitable in growing media in greenhouse cultivation of vegetables [3,4]. Here, the mushroom growing composts were based on combined food waste and diary manure digestate from AD biogas plant and wheat straw. Digestates are rich in nutrients and can be used as a fertiliser, growing media additives for both, plant and mushroom production [5–11].

Bio-waste, which include park- and garden (green) waste are often collected and treated together with food waste in European composting and biogas plants [12]. According to a 2016 report from the European Compost Network, only about 25% of biowaste (of which 'more than 50% is green waste') is recycled into high quality compost and digestate [13]. However, using composts from waste streams as stand-alone growing media poses challenges, such as high pH, high salinity and nitrogen immobilisation [14]. Studies show that green compost can be improved through better aeration, selectivity of feedstock, control of quality and composting process [15,16]. Therefore, in the scope of the

VegWaMus CirCrop project we have focused on recycling spent mushroom substrate (SMS) into growing medium or growing medium additives for vegetables and subsequent mushroom cultivation. We also investigated reuse spent growing substrate (SGS) and crop waste from greenhouse tomato production into new cultivation substrate.

2. Materials and Methods

The spent mushroom substrate (SMS) after 120 days of *Agaricus subrufescens* cultivation comprise from combined food waste diary manure digestate based compost with wheat straw and casing layer—Norwegian black peat. Both components were thoroughly mixed and air dried.

Three types of spent growing substrates (SGS) from one year greenhouse tomato cultivation were examined. The growing substrates were based on garden compost produced from mostly green waste (Lindum AS, Norway), vermicompost, earth worms crust fed with combined food waste—diary manure digestate [17] and aged bark. The compost mixes were fertilised by liquid fraction of digestate. Spent Growing Substrate mix 1: (SGS1) 30:70 vermicompost: garden compost. Spent Growing Substrate mix 2: (SGS2) 30:35:35 vermicompost: aged bark: garden compost. Spent Control Substrate peat 1 (SCS1)—Peat + mineral fertigation.

The examined substrates were analysed for elemental content before and after crop cultivation and/or composting the changes in the initial constitution was evaluated. Chemical and physical features were measured such as pH, EC, dry matter content (DM), ash, organic matter content and compared.

2.1. Analysis of Substrate Ingredients, SMC and SGS

Fresh samples (300 g) of thoroughly mixed composts or raw materials were taken. From this, 30 g was taken for pH and 60 mL for EC (electrical conductivity) measurement. The remaining samples were dried and weighed for dry matter determination, combined and subsequently homogenized in a blender. This was used for ash content analysis.

pH, electrical conductivity (EC), dry matter (DM) and ash content were determined immediately after sampling. Minimum 10 g compost/substrate were dried at 120 °C in duplicate to determine dry matter. Thereafter the dried material was burned at 550 °C to determine volatile solids/ash content. DM, VS and Ash are given as the mean of the two samples. Calculations: DM (%) = Dried material (g)/Fresh material (g). Ash (%) = Burnt material (g)/Dried material (g). Organic matter content was determined by 'loss on ignition' method. pH: 30 mL fresh material was mixed with 100 mL distilled 20 °C water. The pH was measured after 30 min using a pH meter. EC: 60 mL of fresh material was mixed with 300 mL distilled 20 °C water. The EC was measured after 30 min using EC meter (Milwaukee 802 pH/EC/TDS meter). Organic nitrogen (N) was analyzed using Kjeldahl-N method according to method Int/NS-EN 13342:2000 by VestfoldLab, Sem, [18] or by EN13654-1 m by Eurofins, Moss [19].

2.2. Element Contents in Substrate

Samples of substrates were dried preliminary at 45 ± 2 °C for 120 h in an electric oven and ground in a laboratory mill. Accurately weighted 0.500 ± 0.001 g of a dry sample of substrate has been digested by concentrated nitric acid in close Teflon containers in the microwave sample preparation system. After digestion samples were filtered through paper filters and diluted with water to final volume of 15.0 mL. The inductively coupled plasma optical emission spectrometry (Agilent 5110 ICP-OES (Agilent, USA) has been used to elements determination. For multielement determination the common conditions were used. The detection limits have been determined on the level of 0.0X mg/kg dry weight (dw) or better for all elements determined. The uncertainty for total analytical procedure (including sample preparation) was below the level of 20%. Every individual sample was analyzed in triplicate. All element contents are given as milligram per kilogram dry matter (d.m.).

3. Results and Discussion

The air-dried SMS was characterised by high organic matter content, low bulk density, high pH and soluble salts content. SMS substrates was rich in macro and micro elements important from nutritional point of view and their content generally decreased in following order K, P, Na, Mg, Ca, Mn, Fe, Si, Se and Mo (Table 1). The amount of the nutrients was higher than in the initial mushroom compost before cultivation. Those features make SMS almost ideal as plant fertilizer or growing substrate additive. The advantage over chemical fertilizer is that SMS deliver slow-release of nutrients not causing the nutrient burn of the crops [20]. However, excessive application can cause increase of salinity of soils and substrates. If the digestate in the circular food-loop would use for mushroom cultivation, it would be very useful if SMS could be used as a plant stimulating growing medium. This would also be of interest for existing greenhouse vegetable growers seeking more sustainable solutions. In the study by [21], who substituted a high fraction of peat with a compost made from digestate solids, SMS and manure for tomato and pepper seedlings, they obtained better growth and quality of the seedlings, with reduced Fusarium wilt, when using this compost.

Table 1. Substrate composition before and after mushroom cultivation—summary of changes.

	Before Use	**After Use**
	Mushroom Compost	**SMS**
OM%	87.6	83.2
DM%	30.2	35.5
pH	8.8	5.5
EC (dS/m)	4.3	3.6
Ash%	12.4	16.8
K (mg/kg)	10,968	14,334
P (mg/kg)	3100	3900
Na (mg/kg)	1955	3123
Mg (mg/kg)	1275	2410
Ca (mg/kg)	1420	1660
Mn (mg/kg)	51.6	96.6
Fe (mg/kg)	28.8	57.9
Si (mg/kg)	45.9	40.6
Se (mg/kg)	1.1	2.9
Mo (mg/kg)	0.5	1.6

Digestates, depending on the feedstock, can be also rich in elements such non-essential and trace elements, heavy metals, various organic pollutants, and other unwanted compounds which puts its usefulness in direct food production in vegetables of mushrooms questionable [22–25]. Therefore, to prove usability of Over 60 elements were analyzed in the abovementioned composts, however we have taken the closer look into three, important for the human health and also highly accumulative in plants and mushrooms: cadmium (Cd), copper (Cu) and zinc (Zn) (Table 2). In all examined SCS the level of cadmium was acceptable, and ranged from 0.6 to 2.2 mg/kg. All but one, substrates were within the limit of class Eco. Also, levels of Cu were quite low, within limits even of class 0 (SMS-3.3 mg/kg) or class Eco. Similar trend was observed with zinc, where SMS showed the lowest levels of class 0, whereas SGS were within class Eco. Cadmium is toxic, which accumulates in body over time. There are naturally low concentrations of this element in the soil. Can be found in higher concentrations of P fertilizers and some rocks

[26]. Copper however is necessary compound for human health. In small quantities it is nutrition but when the values are high can be toxic. Cu- fertilizer used in areas with too low Cu content in soil. Often too high in animal manure. Zinc is one of the most important trace metals in human nutrition, however the intake is small quantities. It can be also very toxic if the ingestion will be too high, though. Added in pigs and salmon feeds, so that milk and salmon meat can often have too high values [27]. All examined SCS showed acceptable levels of heavy metals, ranging in limit values of class 0 to Eco (Table 2). Therefore, could be potentially used in horticulture for subsequent greenhouse vegetables cultivation [6].

Table 2. Some heavy metals levels in substrates after cultivation mg/kg with reference to limits and initial substrates.

	Cadmium Cd	Copper Cu	Zinc Zn
Limit value class 0	0.4	50	150
Limit value class Eco	0.7	70	200
Limit value class 1	0.8	150	400
Limit value class 2	2.0	650	800
Limit value class 3	5.0	1000	1500
Average digestate	0.32	60	250
Average garden compost	0.37	50	170
Peat substrate	0.38	470	250
Initial substrate mushroom cultivation	0.62	1.99	47
SGS mix 1	2.2	62	190
SGS mix 2	0.60	67	210
SMS mg/kg	0.72	3.30	109

Changes in substrates has been observed after one year of greenhouse tomato cultivation (Table 3). There was notable increase of the total nitrogen (tot-N), phosphorus (P) and calcium (Ca) content in both SGS. Strong decrease of amount of potassium (K) and chloride (Cl) was observed in both SGS. Notable decrease in amount of nitrate in SGS1, whereas in SG2 nitrate stayed at the same level. No accumulation of sodium (Na) was measured, however both substrates noticeable accumulated sulphur (S). Ash value stayed at the similar level.

Table 3. Substrate nutrients before and after tomato cultivation—summary of changes

	Before Use mg/L			After Use mg/L		
	Peat	**SGS1**	**SGS2**	**Peat**	**SGS1**	**SGS2**
tot-N, mg/kg fresh weight	3200	2500	2300	8896	10,002	12,104
Nitrate, mg/L	170	83	3.0	16	14	3.5
Ash%	95	40	45	92	38	45
Phosphorus (P), mg/L	200	59	53	5.0	585	466
Potassium (K), mg/L	1200	1000	740	10	197	132
Calcium (Ca), mg/L	2000	2000	1900	291	5850	4905
Sodium (Na), mg/L	280	270	170	25	246	196
Sulphur (S), mg/L	500	200	170	148	776	662
Chloride (Cl), mg/L	230	250	130	6.0	72	51

Organic growing media are easier to recycle, however when using food and green waste composts as peat-free plant growing media, there is a challenge that nutrient immobilisation and high pH and salts content limit plant growth. The initial substrates were much poorer in the nutrients than the SGS after cultivation, which may indicate either releasing of the immobilised nutrients or residues of the fertilisation after cultivation. Either way, richer initial substrate is an advantage. Some studies say that depending on the feedstock, compost from green waste can have to high salinity and therefore recommend not more than 20 to 50% of addition [28,29].

However, composting or co composting with additional waste products is recommended to eliminate potential pests and due to high mineral salt content. SGS has good composting potential with sufficiently high C/N ration and organic matter content (50–65%) to heat up during composting. Good quality compost from food and other organic wastes is rich in valuable nutrients, which can be cycled back into food production by use as an excellent soil amendment [15].

4. Conclusions

- The SMS features shows it could be used air dried as addition to plant cultivation medium.
- SMS could be also used as a substrate additive for other mushrooms cultivation or as a casing material.
- If used fresh, directly after cultivation both SCS should be composted or co composted with additional waste products to eliminate potential pests and due to high mineral salt content.
- After composting SGS could be potentially used in horticulture for subsequent greenhouse vegetables cultivation
- SGS can be also targeted for the direct use in outdoor agriculture and landscaping as soil fertility amendment

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