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Enhancing of the Composting Rate of Spent Mushroom Substrate by Rock Dust

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The composting of spent mushroom substrate yields a product that is valuable for agricultural utilization and soil reclamation. Experiments were conducted to determine if the inclusion of rock dust, a mineral waste, could accelerate the composting process. The composting model system consisted of a reactor with an integrated control system that controlled the temperature and oxygen concentration of the composting mass. The addition of rock dust increased indicators of microbial activity in the start-up period of the composting process, the mesophilic phase, resulting in increased temperature and protein, and higher oxygen requirements.

Introduction

The composting of the substrate remaining after the cultivation of mushrooms (*Agaricus bisporus*) has been widely studied (Van Griensven 1988; Chong and Rinker 1994; Szmidt and Chong 1995; Gerrits 1996). Mushroom producers don't reuse this substrate, known as spent mushroom substrate (SMS), because of disease incidence, nutrient depletion, and growth factor depletion. SMS has a rich and heterogeneous microbial population with remains of mushrooms, mycelia and bacteria. It has a high organic matter (OM) content and a low concentration of essential plant nutrients.

One of the uses SMS is the biological treatment (bioremediation) of contaminated soils (Buswell 1994). Other studies have been performed to assess the potential capacity of this material for being recomposted easily and therefore to have a second pasteurization (Szmidt 1994), which will enable it to be used as an alternative to peat in agriculture (Chong and Rinker 1994; Szmidt and Conway 1995). Limitation to the use of composted SMS in agriculture is its high electrical conductivity (EC) and incomplete sanitation of the material.

'Rockdust' (RD) is a generic term applied to any mineral primary material with a mesh size below 200. It is a common by-product of little commercial value obtained during quarrying and mining. The direct addition of certain type of rock dust to soil has been recommended due to its potential beneficial effects on increasing the cation exchange capacity, pH, and mineral content (Barker *et al.* 1998), or SMS to improve compost quality (Szmidt *et al.* 1998). Mineral waste has been reported to improves plant growth and health by increasing soil microbial activity (Campe 1997). The literature is unclear with respect to the best types of RD to be employed. Glacial materials and primary minerals such as dolerite or feldspars have been studied.

The composting mode utilized in the current study, is a complex sequence of aerobic biological processes (Hoitink and Keener 1993). Increases in the microbial population during composting are essential for adequately transforming waste, or by-product, into material suitable as a substrate, and fertilizer. These changes determine the quality of the final product and its applicability. The initial phase of microbial activity is critical in terms of nutrient availability, particularly nitrogen immobilization within the biomass, during the subsequent thermophilic phase (Fermor *et al.* 1985). One of the principal aspects that should be considered when determining the quality of compost is its bioactivity (e.g. the capability to protect plants against diseases through the establishment of suppressive microbial populations). Hence, the ability to modify and control the microflora is of great interest with regard to the composting process.

The purpose of this study was to determine the effect of a mineral waste such as rock dust, on microbial decomposition rate indicators during the first stage (start-up period) of the composting process using a composting simulator.

Materials and Methods

The spent mushroom substrate (SMS) used in this study was provided by Country Mushrooms Ltd, Kilmarnock, United Kingdom. The crop had been grown in a conventional manner using 30-liter bags filled with immature compost containing chicken manure, gypsum and straw and inoculated with mushroom spawn. The crop was covered with a surface layer of pH-adjusted peat prior to cropping. The organic waste (SMS) obtained after the cropping was mixed with a 1:1 (v:v) blended mix of two types of RD: 'glacial silt' from the extraction of sand and gravel (Collessie Quarry, Fife Sand and Gravel Ltd., Ladybank, Fife, UK), and 'quartz dolerite' (Cruiks Quarry, Tilcon Ltd., Inverkeithing, Fife, UK). The following treatments were applied:

Treatment 1: SMS alone.

Treatment 2: SMS + 20 kg RD/m^3 SMS (dry weight) (2 % w:v).

The composting was conducted in the reactor illustrated in Figure 1. It consisted of a cylinder chamber with an internal two-liter glass vessel (Dewar Flask & Container Dilvac). The internal and external atmospheres were connected by a T-valve, while the air was circulated by means of a pump (Anglicon Solo 2). The reactor was equipped with a temperature sensor and oxygen sensor (CAG-250E Ceramatec FIS-USA). The T-valve allowed the passage of external air to oxygenate the system when the oxygen concentration dropped below 5%. The admitted air was passed through a water bath at 37ºC to minimize cooling of the system by the external air. The air was not expelled from the system. Oxygen and temperature levels were recorded at 30-second intervals by a computer program, which integrated these data to maintain a preestablished oxygen level.

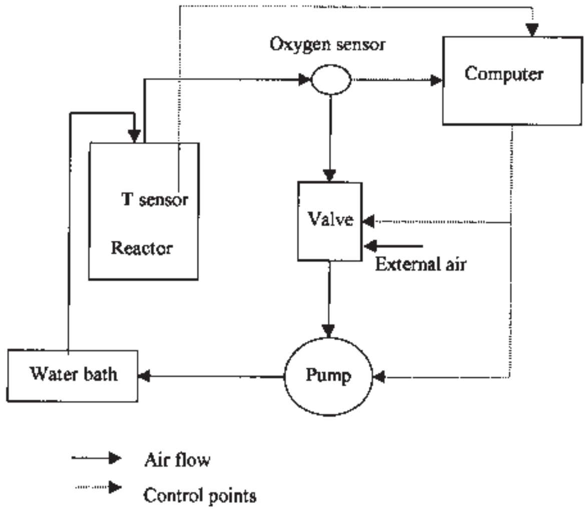

Figure 1. Diagram of the composting simulator system.

Four replicates per treatment were maintained for a period of four days. At the end of the process the concentrations of CO_2 and NH_3, produced during composting, were measured by detector tubes (2L Gastec 0.25-3.00% for CO_2) and (3L Gastec 1-30 ppm for NH_3). The both gases were extracted by a manual pump (Kitagawa 400).

The samples were analyzed for electrical conductivity (EC) and pH in an aqueous extract (1:6 w:v) of 5-g fresh sample, after 2 h agitation and centrifugation at 3500 rpm;

the ammonium and nitrate nitrogen contents of the same extract were measured, after filtering in ash free filter, by a colorimetric method and ion chromatography respectively (Sommers *et al.* 1992). The moisture content was determined by drying at 105ºC and the organic matter (OM) content by loss on ignition at 430ºC for 24 h (Navarro *et al.* 1991). Total nitrogen (TN) and total organic carbon (TOC) were determined by automatic microanalysis (Navarro *et al.* 1991). After $HNO_3/HClO_4$ digestion, P was determined colorimetrically by the method of Kitson and Mellon (1944); Na and K by flame photometry; and Ca, Mg, Fe, Cu, Mn and Zn by atomic absorption spectrophotometry.

The protein content was measured by Bradford's method (1976) in the following extracts:

1. An extract obtained by homogenizing 5 g of fresh sample (equal to about 1.5-g dry matter) with 50 ml of MOPS 10mM buffer pH 7.4 in a mortar. The suspension was then sonicated in a Soniprep 150 50Hz rod type sonicator (30 seconds on/30 seconds off for one hour), in order to break down the plant tissue and release the organic compounds (Riis *et al.* 1998)
2. Aqueous extract (1:20 w:v) of air dried samples.

Results and Discussion

Table 1 exhibits the main physical and chemical properties of the Spent Mushroom Substrate (SMS) and rock dust (RD). SMS is an organic waste characterized by a relatively high electric conductivity, and high OM and N contents, whereas the RD is characterized by a high mineral nutrient content.

Figure 2 shows the temperatures recorded for the both treatments (T_{SMS} = SMS treatment, T_{SMS+RD} = SMS+RD treatment) during the experiment. In the biooxidative phase of the composting process the internal temperatures increased immediately and soon reached values exceeding 40°C. The increase was greater for SMS+RD from 8 to 78 h, reaching a maximum of about 45ºC after 60 h of incubation, and then decreased below the temperatures recorded for SMS. The increase in temperature for SMS was slower but similar to that of SMS+RD at the end of the experiment.

TABLE 1.
Physical and chemical properties
of spent mushroom substrate (SMS)
and rock dust (RD).

	SMS	RD
Moisture (%)	72	6
Bulk density (g cm^{-3})	0.27	nd
pH	6.69	7.48
EC (µS cm^{-1})	6.95	4.85
OM (g kg^{-1})	686.8	11.8
TOC (g kg^{-1})	338.4	6.9
TN (g $kg-^{-1}$)	23.7	2.7
TOC/TN	14.28	2.56
N-Nitrate (mg kg^{-1})	96	nd
N-Ammonium (mg kg^{-1})	264	nd
P (g kg^{-1})	7.1	1.0
K (g kg^{-1})	10.8	18.0
Ca (g kg^{-1})	55.2	131.5
Mg (g kg^{-1})	3.1	16.0
Na (g kg^{-1})	2.8	13.0
Fe (g kg^{-1})	7.0	57.2
Cu (mg kg^{-1})	182	61
Mn (mg kg^{-1})	1800	845
Zn (mg kg^{-1})	200	96

nd: no detected

Microbial activity, as reflected by the temperature increase, was greater during almost all the SMS+RD treatment compared with SMS alone. This indicates that the degradation of organic compounds was also greater during the first stage of the composting process. The decrease in activity towards the end of the process was, perhaps, due to the low remaining concentration of easily biodegradable compounds (Paredes *et al.* 2000).

The increased microbial activity supposes an increased demand for oxygen during the aerobic process. Figure 3 illus-

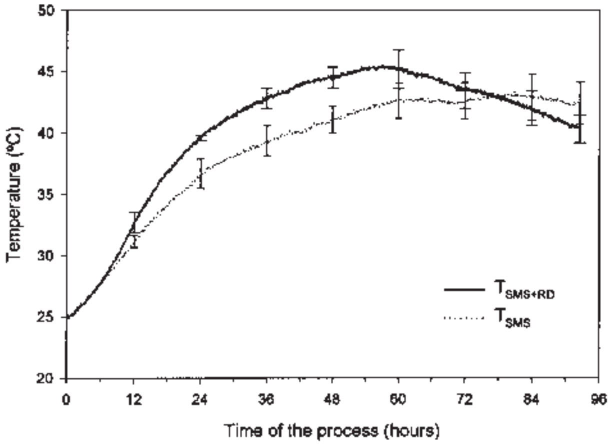

Figure 2. Evolution of temperature during the process. T_{SMS}: SMS treatment, T_{SMS+RD}: SMS+RD treatment.

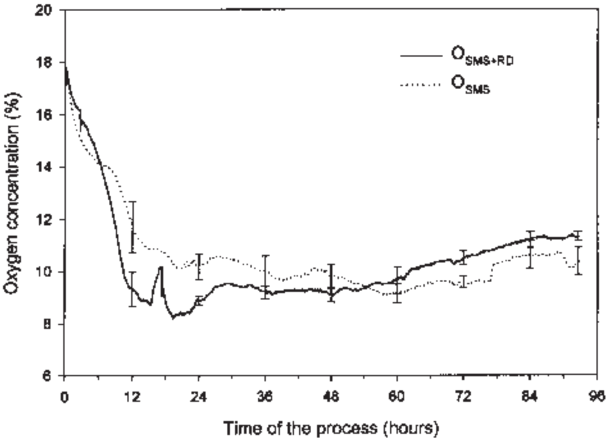

Figure 3. Levels in oxygen concentration in the internal air during the process. O_{SMS}: SMS treatment, O_{SMS+RD}: SMS+RD treatment.

trates the concentrations of oxygen in the internal atmosphere of the reactor (O_{SMS} = SMS treatment, O_{SMS+RD} = SMS+RD treatment). The consumption of oxygen was higher for SMS+RD from 8 to 56 h after start-up, mainly from 12 to 24 h. The oxygen levels in both treatments became similar at 54 h, whereas the temperature was similar at 72 h, which suggests that a lower requirement for oxygen (slower respiration) preceded the cooling phase. The RD increased microbial respiration as seen by the greater loss of biomass and increase in CO_2 with the RD (Table 2).

To assess which parameters govern the decomposition process in the two treatments, characteristics of the materials at the beginning and end of the process were analyzed. During the incubation period there were no observed significant differences in OM, TOC, and TN between the treatments (Table 3). However, the pH rose in both cases,

TABLE 2.
Final weight loss, and CO_2 and NH_3 release from the compost during the incubation process.

Treatment	Weight Loss (% of Start)	CO_2 (%)	NH_3 (mg kg^{-1})
SMS	1.96	2.0	0
SMS+RD	3.36	2.3	0

TABLE 3.
Characteristics of the samples of two treatments, at the start and the end of the process (mean of four replicates), and the relative effect of rock dust (RD) on each parameter (%). In brackets is the % with respect to the initial values when there was a significant difference.

Treatment	Time (h)	OM (%)	TOC (g kg^{-1})	TN (g kg^{-1})	pH	N-NH$_4$+ (mg kg^{-1})	N-NO$_3$ (mg kg^{-1})	Water Soluble Protein (%)	Sonicate Extract Protein (%)
SMS	Start (0)	68.7	338.4	23.7	6.69c	264b	96	0.51a	1.86ab
	End (96)	65.2	340.3	24.0	8.12a	1088a	146	0.37bc	2.03ab
					(21)	(312)	114	(27)	(9)
SMS+RD	Start (0)	63.1	328.7	21.8	6.85c	183b	201	0.44ab	1.79b
	End (96)	62.2	325.5	22.8	7.42b	1444a		0.29c	2.32a
					(8)	(689)		(34)	(30)
Relative effect of RD					-13	+373		7	+21
Sig		NS	NS	NS	***	***	NS	*	*

***, **, *: $P<0.001, 0.01, 0.05$. NS: Not significant. Values followed by the same letter are not statistically different according to the Waller-Duncan test at $P<0.05$.

probably as a consequence of the degradation of acid-type soluble compounds such as those with carboxylic and phenolic groups and the mineralization of organic soluble compounds, such as proteins, amino acids and peptides (Table 3) to inorganic compounds, such as NH_3 (Paredes *et al.* 2000).

No ammonia was detected in the internal air (Table 2) thus, was concluded that the ammonia produced was not lost by volatilization, despite the low TOC/TN ratio of the material (Table 1). This ammonium may have been immobilized, being incorporated into microbial tissue during growth of the microbial population, which likely occurred at the beginning of the bio-oxidative phase of composting (Bishop and Godfrey 1983).

No net nitrification occurred during the incubation (Table 3), and the temperatures (Bernal *et al.* 1996) probably favored ammonium retention. Bernal *et al.* (1993) also found that the addition of certain types of mineral wastes during the composting process reduces the amount of ammonia lost. Furthermore, a portion of the ammonium may have been resynthesized as organic nitrogen compounds in microbial tissue (Gerrits 1996). The increase in the protein fraction extracted with sonication (microbial nitrogen) supports this (Riis *et al.* 1998). The decrease in water-soluble protein and the increase in sonicate microbial protein (Table 3) were observed primarily in SMS+RD treatment, which is in accord with the higher activity associated with temperature and oxygen data. The protein nitrogen may have been apparently transferred from the soluble phase to the microbial tissue.

RD, an ostensibly inert material, can change composting process by modifying physical properties of substrates, as it happens in soil (Szmidt *et al.* 1998). Therefore, RD could have enhanced surface reactions, gas exchange and spatial effects, all of which could have favored the growth and activity of the indigenous microorganisms.

Conclusions

In the SMS+RD treatment, a microbial population with higher activity appears to have been established from the first stages of the mesophilic phase of the composting process. During the experiment, the SMS+RD treatment had a greater release of energy resulting in increased temperature, increased oxygen consumption and CO_2 released, and more production of ammonium. Therefore, the rock dust enhanced the activity during the mesophilic composting phase, due probably to changes in the physical properties of the material and to the addition of nutrients essential for the microbial growth and metabolism.

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