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Monitoring and optimizing the co-composting of dewatered sludge: A mixture experimental design approach

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ABSTRACT

The management of dewatered wastewater sludge is a major issue worldwide. Sludge disposal to landfills is not sustainable and thus alternative treatment techniques are being sought. The objective of this work was to determine optimal mixing ratios of dewatered sludge with other organic amendments in order to maximize the degradability of the mixtures during composting. This objective was achieved using mixture experimental design principles. An additional objective was to study the impact of the initial C/N ratio and moisture contents on the co-composting process of dewatered sludge. The composting process was monitored through measurements of O_2 uptake rates, CO_2 evolution, temperature profile and solids reduction. Eight (8) runs were performed in 100 L insulated air-tight bioreactors under a dynamic air flow regime. The initial mixtures were prepared using dewatered wastewater sludge, mixed paper wastes, food wastes, tree branches and sawdust at various initial C/N ratios and moisture contents. According to empirical modeling, mixtures of sludge and food waste mixtures at 1:1 ratio (ww, wet weight) maximize degradability. Structural amendments should be maintained below 30% to reach thermophilic temperatures. The initial C/N ratio and initial moisture content of the mixture were not found to influence the decomposition process. The bio C/bio N ratio started from around 10, for all runs, decreased during the middle of the process and increased to up to 20 at the end of the process. The solid carbon reduction of the mixtures without the branches ranged from 28% to 62%, whilst solid N reductions ranged from 30% to 63%. Respiratory quotients had a decreasing trend throughout the composting process.

1. Introduction

Wastewater sludge disposal is a major problem worldwide due to the continuously increasing amounts produced. Since the trend is to reduce landfilling of biodegradable waste in Europe, sludge pretreatment becomes necessary (EUC, 1999). According to Spinosa (2011), a precondition for biosolids landfilling is to produce a biologically stable and adequately dewatered material. Therefore, alternative techniques to treat sludge have been developed. Co-composting of municipal wastewater sludge with other organic substrates has been widely used over the past decades. Materials used as amendments in the process are the organic fraction of municipal solid waste, sawdust, wood chips and tree trimmings/branches. The addition of energy amendments, such as the organic fraction of municipal solid wastes, aims to enhance the overall degradation of a mixture. The addition of structural amendments, such as sawdust and wood chips, aims to reduce the moisture content of the mixture to near optimal levels and to increase the free air space (FAS) in order to facilitate oxygen transfer through the solid material (Haug, 1993).

Mixing of sludge with other organic materials is usually performed based on practical guidelines, sometimes using the initial C/N ratio and moisture content of the mixture as design parameters. The effect of initial physicochemical parameters (e.g. temperature, air flow rate, bulking agent content, bulking agent particle size, initial moisture content, C/N ratio) on the aerobic degradation of wastewater sludge mixtures has been studied (Gea et al., 2003, 2007; Liang et al., 2003; Pasda et al., 2005; Tremier et al., 2005; Banegas et al., 2007; Tremier et al., 2009; Mohajer et al., 2009, 2010). The initial C/N ratio, in particular, has been found to affect the composting process for several organic substrates (Nakasaki et al., 1992; Huang et al., 2004; Ponsá et al., 2009). On the other hand, de Guardia et al. (2010a) reported recently that the initial C/N ratio is irrelevant to the aerobic biodegradability of 5 organic wastes. The bio C/N and bio C/bio N ratios are new alternative indices that have been recently proposed to follow the composting process (Sánchez, 2007; de Guardia et al., 2010a, 2010b).

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Regression analyses and advanced experimental design techniques have been used to study the impact of initial physicochemical parameters on the composting of wastewater sludge (Gea et al., 2003; Mohajer et al., 2009). However, the impact of the contents of individual components contained in a mixture on the degradability of the overall mixture has not been well studied.

The objective of this work was to optimize the co-composting of dewatered sludge with other organic amendments by studying the degradability of the resulting mixtures. The organic amendments were food wastes, mixed paper, sawdust and tree branches that were added in variable percentages to the dewatered sludge. The goal was to locate optimal mixing ratios of the above components to maximize the decomposition process of the mixture during aerobic composting. This was achieved via the application of regression analysis and the adoption of principles of mixture experimental design (MED). A secondary objective was to investigate the effect of initial C/N ratio and moisture content (MC) on the degradation process. The degradability of the mixtures was monitored via several parameters, such as the O_2 uptake rate, CO_2 evolution, organic matter, solid carbon and nitrogen reductions and temperature.

2. Materials and methods

2.1. Substrates

Six (6) components (i.e. substrates) were used to prepare all mixtures in this study. These components were: dewatered sludge (DWSL), office paper (OFP), newsprint (NP), food waste (FW), sawdust (SW) and tree branches (BRC). OFP and NP were mixed at 1:1 ratio to simulate mixed paper waste (MXP). FW was considered as energy (fuel) amendment and MXP, SW, BRC as drying and structural (bulking) amendments (Haug, 1993). Batches of 50 kg of DWSL were obtained as needed from the nearby publicly owned wastewater treatment plant of the city of Komotini (Greece), where the thickened sludge is dewatered via a filter-press. MXP components were collected from faculty offices and student housing. Fifty (50) to 60 kg of FW batches on a wet weight basis (ww) were collected from the university restaurant over a week. Food waste mainly contained cooked meat, bread, vegetables, fruit and cooked pasta. Food waste was thoroughly mixed with a shovel and stored at −20 °C. Sawdust was acquired from a local wood craft facility and the tree branches were collected from nearby trees as needed. The tree branches were cut with scissors at lengths of approximately 5–7.5 cm and were used to increase mixture FAS. Mixtures in this work were prepared in such a manner so that initial C/N ratios and initial MC would vary over widely accepted optimal ranges.

2.2. Experimental design

The experimental design included 8 runs, which were prepared by mixing the 6 aforementioned components in various ratios. Mixing was performed in such a manner, so as to maintain initial moisture contents of the resulting mixtures between 56% and 65% (ww) and initial (total) C/(total) N ratios between 19 and 30. The run that contained dewatered sludge only had an initial C/N ratio of 8.3 and an initial moisture content of 85% ww. Table 1 includes the mixing ratios for all runs.

To check the reproducibility of the experiment, one of the runs (R_{57}, see Table 1) was duplicated using different batches of sludge. The runs lasted up to 40–57 days.

Table 1
Percentages of the 5 organic components used in the mixtures.[a]

	R_{47_sw} (6.2 dry kg) [14.8 wet kg] 40 d		R_{47_nsw} (6.9 dry kg) [17.0 wet kg] 49 d		R_{51} (4.9 dry kg) [12.1 wet kg] 52 d		R_{55} (6.4 dry kg) [14.5 wet kg] 52 d		R_{57}[b] (4.65 dry kg) [12.15 wet kg] 48 d		R_{71} (9.7 dry kg) [28.0 wet kg] 49 d		R_{100} (3.4 dry kg) [23.3 wet kg] 57 d	
	% dw	% ww	% dw	% ww	% dw	% ww	% dw	% ww	% dw	% ww	% dw	% ww	% dw	% ww
Sawdust	29.7	13.4	0.0	0.0	33.0	14.5	0.0	0.0	34.3	14.3	28.7	10.7	0.0	0.0
Branches	30.0	13.5	24.1	11.8	25.3	14.5	21.4	13.8	30.1	14.3	42.9	17.9	0.0	0.0
Mixed paper[c]	4.6	2.0	40.8	17.6	13.5	5.8	59.3	27.6	0.0	0.0	0.0	0.0	0.0	0.0
Sludge	15.5	47.4	15.9	47.1	16.3	50.7	16.8	55.2	22.1	57.1	28.4	71.4	100	100
Food wastes	20.3	23.6	19.2	23.5	12.0	14.5	2.5	3.5	13.6	14.3	0.0	0.0	0.0	0.0

[a] The initial dry weights and initial wet weights of the mixtures are included in parentheses; the duration of the experiments in days is also shown. (dw: dry weight basis; ww: wet weight basis); R subscripts designate the percentage of sludge in the mixture on a wet weight basis (e.g. R_{47_sw} indicates a run with 47% sludge content on a wet weight basis with sawdust).
[b] Two replications were performed at this level.
[c] Office paper and newsprint combined at a 1:1 wet weight ratio.