Composting of brewery sludge mixed with different bulking agents

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Abstract

Purpose. Compost originating exclusively from food industry biosolids can be used as soil amendment according to European legislation. In this study, sludge derived from a Greek brewery was mixed with three bulking agents, namely lignite, sawdust, and shredded dried grass, yielding three different mixtures to be composted. **Methods.** The composting process was assessed through successive measurements of temperature, moisture, pH, electrical conductivity, organic carbon, organic nitrogen, and total phosphorus. Moreover, the total concentration of Cd, Cu, Ni, Pb, Zn, Cr, As, Co, Mn, Na, Fe, K, Ca and Mg was determined in each compost at the end of the process. Additionally, the sanitation degree was evaluated through the detection and quantification of *E. coli*, Enterococci, Salmonella, and Clostridia. **Results.** The highest temperature (39 °C) was observed in the dried grass mixture. In the final composts, pH was near 6.5 and moisture ranged between 23 and 55 %. The ratio of C/N was 10:1 and phosphorus fluctuated around 1 %. Most metals were in compliance with the European legislation while microbiological quality was acceptable. **Conclusions.** The sawdust and dried grass yielded composts of acceptable quality. In contrast, lignite was considered as an inappropriate bulking agent due to the high metals concentrations in the final compost. The end products were categorized as Class B. Characterization of Class A will be feasible, by constructing bigger piles, and thus, achieving sanitation.

Keywords: composting, brewery sludge, bulking agent, soil conditioner, organic matter

1. Introduction

Composting of sewage sludge provides an environmentally sound and energy saving solution to the increasing problem of waste management and disposal. It is also one of the most promising technologies for treating biosolids allowing their recycling. However, according to the European Commission [1, 2], only biosolids derived from food industry can be composted for agricultural use. Brewery sludge originates from the food industry and, as such, is rich in nutrients and organic matter, so it can be used to produce a high-quality end product (compost) that not only reduces the environmental impact but also attracts farmers interest to increase their productivity [3]. Agricultural use of composts can improve soil properties by increasing organic matter, particularly the low one found in Mediterranean soils [4], by suppressing soil borne plant pathogens and thus, reducing pesticide use, and by stimulating the biogeochemical cycles of nutrients thus, enhancing plant growth [5]. However, attention should be paid on potential accumulation of heavy metals and bacteriological contamination that may expose different populations to health hazards [6]. Composts without detectable levels of pathogens are characterized as Class A and can be directly applied to agricultural land [7].

Biological sludges are usually high in moisture content (up to 85 %); therefore mixing with low moisture materials, such as sawdust, dried shredded grass, etc., is needed to optimize the biodegradation. These materials behave as bulking agents, improving porosity and oxygen content of the composting pile and favoring the growth of microbiological communities [8]. Moreover, bulking agents are often required to modify the properties of the sludge to be composted, i.e. pH, conductivity, and concentration of nutrients, and to stabilize the final product [9, 10]. Stability and maturity of compost are the main characteristics of the final product defining its suitability for agricultural purposes [11].

There are two types of composting, aerobic and anaerobic. In anaerobic composting, degradation of organic material is controlled by microorganisms under anaerobic conditions. The final products are partially stabilized sludge and methane-rich biogas [12]. Different types of bioreactors have been employed for anaerobic composting. On the other hand, in aerobic composting, degradation of organic matter is carried out under aerobic conditions, resulting in stabilized final products [12]. Aerobic composting is a widely used technique with low operating and investment costs [13]. Two systems of aerobic composting have been employed, the forced aeration (windrow composting), and the static one. In the windrow composting system, the aeration is achieved by mechanical agitation. The composting pile is stacked in long parallel rows (windrows) [7]. The height, width, and shape of linear stacks are adjusted according to the kind of material to be composted and the equipment used to agitate [12]. In the static aerated composting system, the pile is aerated by internal pipes via inflation and suction. The pile is constructed as that of the windrow composting system. The disadvantage of this method is the slow physical degradation of materials that extends the duration of composting process [12].

Aerobic composting, in relation to anaerobic, is faster, easier, and more economic, while unpleasant odors are produced only in the first few days of the procedure. Moreover, during aeration, the uniformity of the pile is achieved resulting in better quality of the final product [13, 14]. On the other hand, anaerobic composting has some advantages, such as better control of the conditions and smaller needed space, but the final product must undergo further stabilization [12].

In the present study, the windrow composting system was selected because of its low cost and short duration. The aim of the study was to monitor the composting process of a brewery sludge with three different co-composting materials under aerobic conditions.

2. Materials and methods

2.1 Study design

Dewatered brewery sludge was co-composted with different bulking agents. Three piles of approximately conical shape with r ~ 0.80 m and h ~ 0.70 m, were constructed by mixing the sludge with dried shredded grass, sawdust, and lignite respectively, at a volume ratio 1:1.

The composting trials were carried out at a university greenhouse, located in the northern part of the main university campus of the University of Patras, Greece. All piles were aerated manually once per week. Electrical conductivity, pH, moisture content, organic carbon, organic nitrogen, and total phosphorus were measured weekly in samples collected before the turnings. Temperature of the piles was measured three times per week.

2.2 Physicochemical analyses

Temperature was measured *in situ* with a bimetal ground thermometer (TFA, D-wertheim). Samples taken from the composting piles were transferred to the laboratory. Moisture content was determined by oven-drying at 95 °C till constant weight. The dried samples were ground and sieved through 2 mm for determinations of pH, conductivity, and volatile solids and through 0.5 mm for further analyses.

pH and electrical conductivity (EC) were determined in a 1:2.5 compost-distilled water mixture via a digital pH meter (Hach Sension1) and a conductivity electrode (WTW Cond 315i), respectively.

Volatile solids were determined by the loss-on-ignition (LOI) method [15]. Briefly, a known weight of dried sample (approx. 2 g) was placed in a ceramic crucible and was ignited at 550 °C for 2 h in a muffle furnace. The weight loss was measured after cooling in a desiccator. Total organic carbon was assessed by dividing volatile solids by a factor of two [16].

Kjeldahl nitrogen was determined by the APHA method 4500-N_{org} C [17]. Approximately 0.5 g of subsample, accurately weighted, were digested with 30 mL concentrated H_2SO_4, 10 g K_2SO_4, and 0.6 g HgO until solution became transparent. Digestion was continued for an additional 30 min at maximum temperature. After cooling, the mixture was diluted to a final volume of 200 mL with deionized water. The pH of a 10-mL subsample was adjusted to ≥ 9.5 with 12 N NaOH containing 0.25 % sodium thiosulfate, followed by a steam-distillation and ammonia collection into 10 mL of 2 % H_3BO_3. Ammonium nitrogen was determined photometrically at 425 nm according to ASTM D1426-15 [18].

Total phosphorus was determined photometrically in the Kjeldahl digest, according to Taylor [19].

2.3 Metal analyses

Total metal concentrations were determined as follows: Approximately 0.2 g compost subsample, accurately weighted, was digested with 8 mL of mixture 5:2:1 HNO_3-HCl-HF in a microwave-assisted digestion system (Ethos Touch, Milestone) and diluted to a final volume of 25 mL with deionized water. The determination of metals was performed by atomic absorption spectrophotometer (Shimadzu AA-6300) in furnace mode for Cd, Pb, Ni, Cr, As, and Co [17], in flame mode for Cu, Mn, Fe, Zn, Ca, and Mg [17], and in flame emission mode for Na and K. Cold-vapor atomic absorption spectrometry was employed for Hg determination. Precision and accuracy were assessed by analyzing the IAEA 433 reference soil. Reagent blanks, matrix matched calibration curves, and duplicate samples analyses were also employed for the repeatability of the method. The coefficients of variation were below 10 % in all cases.

2.4 Microbiological analyses

To assess the sanitation status of the final composts, the presence of microbial pathogen groups was investigated. *E. coli*, Enterococci, and Clostridia were determined according to ISOs 16649-2:2001 [20], 7899-1:1998 [21], and 6461-1:1986 [22] respectively, while the preparation of the samples was according to ISO 6887-1:1999 [23]. In brief, 20 g of raw sample were mixed with 180 mL Nutrient Broth (Oxoid CM0001) in sterilized bags and were homogenized in a Bag mixer. Depending on the microorganism to be determined, the initial suspensions were inoculated on selective growth media and incubated in appropriate time and temperature conditions.

Salmonella was determined according to ISO 6579:2002 [24]. Briefly, 25 g of sample mixed with 220 mL Buffered Peptone Water (Merck 1.07228.0500) in sterilized bags, were incubated at 37 °C for 24 h. The samples were ten-fold diluted in Selenite-Cystine Broth (Oxoid CM0699) and Rappaport-Vassiliadis Soya Peptone Broth (Oxoid CM866) and incubated according to manufacturer’s instructions. Subsequently, both cultures were inoculated on two selective media, namely XLD agar (Oxoid CM0469) and Salmonella Shigella Agar (Oxoid CM099), and incubated at 37 °C for up to 48 h. Presumptive colonies of Salmonella, with a black centre and a light transparent zone of reddish color, were confirmed via biochemical tests.

3. Results and discussion

3.1 Temperature evolution

The fluctuation of temperature in the piles reflects the progress of the composting process [25, 26]. Three major temperature phases can be identified: the mesophilic (>40 °C), the thermophilic (40-60 °C), and the maturation phase (ambient temperature). Temperature determines the rate of biological processes and affects the evolution and succession of microbiological communities [13, 27, 28]. In this study, the highest temperature was achieved in the mixture with dried grass (39 °C), while in the mixtures with lignite and sawdust the highest temperatures ranged between 26-31 °C (Fig. 1a). None of the three mixtures reached the temperature of 60 °C, in which the hygienization of the final product takes place according to previous studies [29, 30]. A possible explanation for not achieving higher temperature is the small volume of the piles resulting in heat loss.

3.2 Moisture

Moisture content of the composting mixture is an important characteristic, related to oxygen supply, microbial activity, and temperature of the pile [3, 26]. If the mixture to be composted has low moisture content, both the development of microbial populations and the rate of organic material degradation will decrease, resulting in a physically but not biologically stabilized final product [12]. On the other hand, if moisture content is too high, water will occupy the pores of mixture to be composted; in this way, it will prevent the transfer and diffusion of oxygen, resulting in anaerobic conditions and undesirable odors. According to Metcalf and Eddy [31], the optimum initial moisture should not be greater than 60-65 %. In our study, moisture ranged from 70 to 80 %, mainly due to low content of biosolids (10 %) in the initial sludge. However, moisture was reduced by a percentage of 35-66 % in the three mixtures, during the composting process, resulting in final values from 23 to 55 % (Fig. 1b). The results are comparable to those from similar previous studies [13, 28, 32].

3.3 pH

At the beginning of the composting process, pH in the three mixtures was slightly acidic, as a consequence of the degradation of organic acids and polysaccharides and the presence of phenolic compounds [25, 32, 33, 34]. Subsequently, pH is increasing during composting due to consumption of organic acids from fungi resistant to acidic conditions and degradation of organic nitrogen [12]. In the final composts, pH is stabilized between 6.5-6.6 (Fig. 1c). Similar values were also observed by Brito et al., [35]. According to EPA [36] the ideal pH for composts ranges between 5.5 and 9.0.

3.4 Electrical Conductivity

Compost with high EC values may cause phytotoxicity and negative effects on plant growth and seed germination [5, 8, 16]. Additionally, EC, as a measure of salinity, expresses the degree of humification and mineralization during the process [16]. EC in our three piles was increasing during composting, as it was expected due to the degradation of organic matter, production of ions, and release of mineral salts, such as phosphates and ammonium ions [4, 37]. Moreover, in the final composts EC was below 4.0 mS cm^{-1} which has been reported as the upper limit for mature compost [38]. In detail, the final conductivity values were 3.3 mS cm^{-1}, 1.8 mS cm^{-1}, and 1.1 mS cm^{-1} in the grass, lignite, and sawdust composts, respectively.

3.5 Volatile solids

To ensure successful composting, the volatile solids of the initial mixture should be greater than 30 % of the total solids content [31]. In our piles, the initial LOI values were 52 % in lignite, 54 % in sawdust, and 70 % in dried grass mixture. The respective TOC values were assessed to be 29, 27, and 35%. During the composting process, LOI was gradually being reduced in all treatments resulting in final values ranging between 15 and 20 % (Fig 1d). This reduction points out the mineralization and degradation of the organic matter which are occurring during composting process [4, 39].

3.6 Organic nitrogen

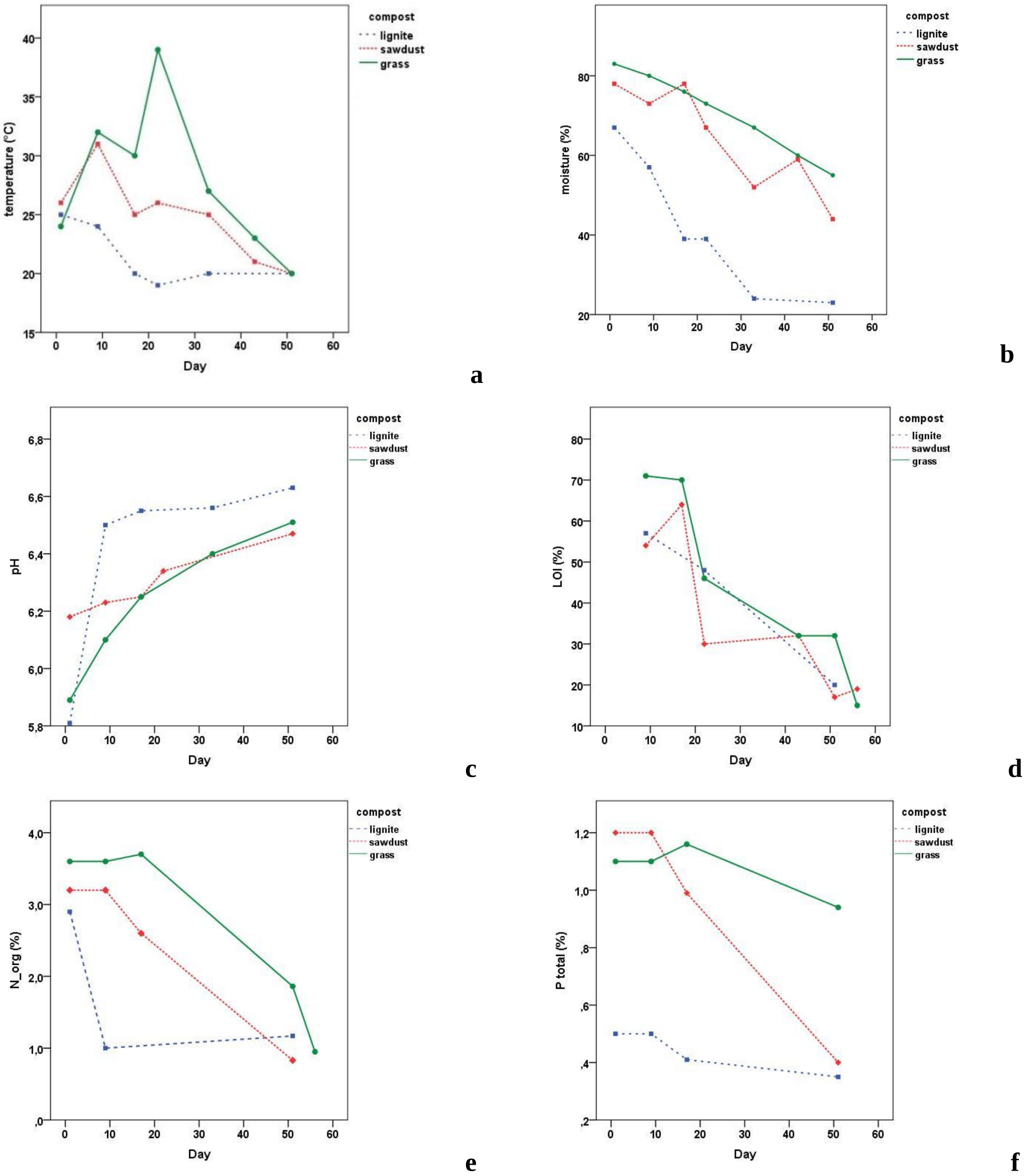
Organic nitrogen was decreasing from the beginning of the composting process in all mixtures to finally reach values around 1 % (Fig. 1e). This decrease was possibly due to volatilization of ammonia, which is related to the type of the co-composting materials [9, 13]. In the present study, the rate of nitrogen loss was similar in the mixtures with grass and sawdust, whereas in the lignite mixture a sharp decrease was observed in the first 10 days and afterwards nitrogen remained almost stable. This could be explained by the fact that this mixture has never been completely homogenized.

3.7 Carbon to nitrogen ratio

Microorganisms use carbon for energy production and nitrogen for cell growth [28]. Consequently, this leads to carbon and nitrogen loss during the thermophilic and mesophilic phases. This ratio can be used to define the degree of maturity of compost [26, 28]. The optimum initial ratio for composting is 25:1 to 30:1. The present study aimed at the composting of the greatest possible amount of sludge with the least addition of bulking agents. So composting was designed to have an initial C/N ratio of 10:1, which remained stable until completion of the process. This means that nitrogen and carbon loss rates were similar. Recent studies have observed similar ratios in their final composts [25, 39] Ratios less than 15:1 indicate that compost can be characterized as mature [25, 40] and may be suitable for agricultural use [39].

3.8 Total phosphorus

Phosphorus is one of the main nutrients used by plants for their growth and root development. In this study, concentration of total phosphorus was about 0.4 % in the mixtures with sawdust and lignite, while in dried grass mixture it was found higher, as expected, at around 1 %, at the end of the process (Fig. 1f). In similar surveys, concentration of phosphorus was also around 1 % in the final composts [13, 33].



a

b

c

d

e

f

Figure 1: Evolution of compost processing: a. temperature (°C), b. moisture (%), c. pH, d. loss-on-ignition (%), e. organic nitrogen (%), f. total phosphorus (%).

3.9 Metals

Table 1 presents the metals content in the three final products along with the values designated by the relative European legislation [1, 2]. It is observed that all metals in the dried grass mixture are within the guideline values. Metals in the sawdust mixture are also in compliance with the European legislation except for Ni, which presents a slight excess. In the lignite mixture, metals concentrations were in accordance to the European legislation, except for Ni and As. Ni concentration was found to be almost eight times higher than the limit, whereas As exceeded the respective guideline value by about four times. Obviously the lignite used in our experiment was an inappropriate bulking agent for composting.

Table 1: Total element concentrations in the final composts compared to the limit values set by the European legislation

Elements	Final compost (mg kg^{-1} DM)			[a] Commission Decisions 2006/799/EC and C(2006) 6962 (mg kg^{-1} DM)
	Lignite	**Sawdust**	**Dried grass**	
Cd	0.14	<0.02	<0.02	1
Pb	7.5	8.9	7.6	100
Cr	110	56.3	52.7	100
Ni	377	60.3	32.5	50
As	43.3	3.1	3.2	10
Cu	56.2	54.0	74.5	100
Zn	93.5	35.6	126	300
Co	23.6	14.3	11.2	-
Mn	672	591	479	-
Fe	23800	19000	14800	-
Na	2980	3520	6710	-
K	6440	7040	8790	-
Ca	11600	17900	19800	-
Mg	11800	6630	5600	-

[a] ECO Label to soil improvers and growing media, respectively

3.10 Microbiological quality of composts

One of the limiting factors for the use of composts in agriculture is the risk posed by pathogens that may contaminate plants and humans. To ensure sanitation of the final product and minimization of health risks, temperatures higher than 55 °C are needed during composting. Temperatures between 45 and 55 °C favor biodegradation, whereas in the range of 35-40 °C microbial diversity is enhanced [8]. In the present study, temperatures higher than 55 °C were not achieved, so the sanitation of the final products could not be guaranteed. The microbiological analyses results of the final composts are presented in Table 2 on a dry weight basis.

Table 2: Microbial groups in the three composts and the corresponding legislation

Pathogen	Lignite	Sawdust	Dried grass	2006/799/EC
E. coli (CFU g^{-1} dw)	483	1291	68	1000
Salmonella (CFU per 25 g dw)	absence	absence	absence	absence
Enterococci (CFU g^{-1} dw)	57	459	2411	-
Clostridia (CFU g^{-1} dw)	352	0	221	-

Salmonella, as ubiquitous bacteria, is considered a good index for the hygienic status of the composts. Salmonella was not detected in any of the three mixtures. Sulphite-reducing clostridia were evident in the lignite and dried grass mixtures, while they were absent in the sawdust mixture. The presence of Clostridia in the two of the three mixtures is not surprising given their resistance to environmental factors, such as temperature or molecules with anti-microbial activity, and the availability of substrate being produced during the degradation of organic matter [4, 41]. Since clostridia are anaerobic microorganisms, their presence indicates anaerobic conditions at least in a micro-environment level. Enterococci were also present in all three final products, but in relatively low concentrations, comparable to those found is soils [42]. Similar values have been reported for enterococci in previous studies, although significantly higher temperatures have been achieved [4, 41]. It can be speculated that if temperatures above 60 °C had been accomplished, the number of enterococci would have been even smaller in the present study. Enterococci are good indicators of fecal contamination and more prevalent and resistant to environmental stress than coliforms [41]. *E. coli* were found within or near the legislation permissible levels (Table 2). Other authors also observed *E. coli* in their composts in the same or higher order of magnitude compared to the present results [4, 27, 41].

In any case, it should be mentioned that the survival of pathogens is not favored since they are allochthonous in the compost and after the complete degradation of organic matter and nutrients, they are expected to be eliminated [6].

4. Conclusions

Brewery sludge co-composted with either dried grass or sawdust yielded composts of acceptable quality for specific uses, such as soil remediation. Lignite was considered as an inappropriate bulking agent due to high metals concentrations measured in the final product. The choice of bulking agent is a matter of availability and economic factors. In the present study, the most promising, suitable and low cost bulking agent was the dried shredded grass.

The production of final composts was completed within a reasonable time (~ 2 months), even though the initial C/N ratio was 10:1, instead of the usually applied 25:1 to 30:1. Therefore, co-composting of brewery sludge with lower initial C/N ratios is feasible and allows the minimization of the required amount of bulking agent, if composting aims at solving the sludge disposal problem.

Final products were categorized as Class B. Characterization of Class A will be feasible, by constructing bigger piles and thus, achieving higher temperatures during composting.

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