Composting as digestate post-treatment: composting behaviour and gaseous emissions of three types of digestate compared to non-digested waste.

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Abstract
In the actual context of French regulation, anaerobic digestion products are still considered as waste and cannot be valorised as product unless being composted. Nevertheless digestates specificities concerning composting treatment have to be thoroughly studied. Thus the present work compared the composting behaviour of digestates with their non-digested waste. Three origins were considered: agricultural waste, source sorted organic fraction of municipal solid waste and mechanically sorted organic fraction of municipal solid waste. Whatever the origin of the waste, biodegradation rate of digestates during composting was lower than the one of the non-digested waste. Temperatures reached during composting were also lower than for non-digested waste even if the produced heat permitted to dry the treated digestates anyway. Composting behaviour mainly differed from one digestate to the others considering biodegradation kinetics and trends of GES and ammonia emissions.

Introduction
In addition to the energy supply it represents, anaerobic digestion treatment allows the recycling of organic matter and nutrients contained in biodegradable waste as the digestion residue can be promoted as organic fertilizer or soil improver. Nevertheless, digestates are known for their high level of ammonia nitrogen and for not being fully stabilized organic matter. In the actual context of French regulation, anaerobic digestion products are still considered as waste and cannot be valorised as product. Composting can be an adequate post-treatment for digestates as it can stabilize their residual organic matter, reducing by the way their phyto-toxicity and improving their humic potential [1-2]. But digestates behaviour through composting treatment has to be studied in order to highlight the specificities of composting management for such substrates. The objective of this work was thus to compare the composting behaviour of three digestates with their non-digested waste in order to assess the feasibility of composting post-treatment for digestates.

Material and Methods
Substrates
Three types of waste were studied (digestate and non-digested raw waste): agricultural waste (Agri1), source sorted organic fraction of municipal solid wastes (SS-OFMSW) and mechanically sorted organic fraction of municipal solid wastes (MS-OFMSW):

- Agri1: fattening bulls manure.
- D-Agri1: solid fraction of the digested fattening bulls manure obtained through a screw press process. Agri1 undergone a mesophilic semi-liquid digestion with a residence time of about 60 days.
- SS-OFMSW: source sorted household biowaste mixed with green waste.
- D-SS-OFMSW: solid fraction of the digested SS-OFMSW obtained after a separation process (screw press + sieving + centrifugation). SS-OFMSW undergone a thermophilic digestion with a residence time around 3 weeks.
- MS-OFMSW: mechanically sorted organic fraction of municipal solid waste
- D-MS-OFMSW: raw digestate of MS-OFMSW. MS-OFMSW undergone a thermophilic dry digestion with a 3-weeks residence time.

To be composted these substrates were mixed with a bulking agent (BA) formed of wood chips in order to establish favourable conditions of aeration (porosity and permeability). The mixture ratios were chosen so as to have comparable amount of waste organic matter in the pilot (between 15 and 20 kg) and comparable moisture content for the mixtures (between 40 and 50 %). After composting

bulking agent was retrieved by sieving (10 mm grid). Waste main initial characteristics and mixture ratio are presented in table 1.

Table 1. Characteristics of waste before composting

	Agri1	D-Agri1	SS-OFMSW	D-SS-OFMSW	MS-OFMSW	D-MS-OFMSW
Dry matter (% WW)	31.4	27.2	45.8	43.7	46.7	30.0
Organic matter (%WW)	27.1	19.4	55.6	22.3	28.6	12.6
Total C (mg C/kg WW)	133.9	96.2	131.6	114.7	137.1	71.2
Total N (mg N/kg WW)	8.1	5.4	6.0	5.1	6.7	5.0
$N\text{-}NH4^+$ (mg N/kg WW)	0.65	1.78	0.80	1.7	0.67	0.76
Mixture ratio (volume of waste/volume of BA)	2/1	2/1	1/1	1/1.5	1/1.5	1/2

Composting pilot and monitoring

Composting trials were performed in a composting pilot reactor, set up to simulate the composting active phase [3]. It consisted in an airtight 300-litre stainless steel cylindrical chamber (Reacting volume: diameter = 0.7 m; height L = 0.8 m). Insulation of the reacting chamber was provided on the sides by a layer of polyurethane. Aeration was supplied via an air blower, from the bottom through the material, and gases were collected at the top in order to analyze them. Parameters monitored during experimental trials were the following: gas flow rate via a volumetric gas meter, temperature of the matter and gas in the reactor with Pt 100 temperature probes, entering gas temperature and humidity, inlet and outlet gas oxygen concentration thanks to a paramagnetic analyzer, carbon dioxide, methane and nitrous oxide concentrations thanks to an infra-red analyzer. Ammonia emissions were monitored thanks to bubbling of exhaust air in acid trap.

Experimental conditions

Standardized experimental conditions were used in order to compare non digested waste and digested waste behaviour. Same ranges of aeration rate were applied for all non digested waste and digested waste respectively: 350 to 500 $l.h^{-1}$ for non-digested waste, and 200 to 300 $l.h^{-1}$ for digestates.
A turning of the composted mixture was performed when the oxygen consumption rate and the temperature became low and constant. The trials were stopped when biological activity remained low after the turning.

Results

Biodegradation behaviour

As expected, digestates (Figure 2) were less biodegradable than non digested waste (Figure 1). This lower biodegradability corresponds to the absence or lower intensity of the first degradation peak. It is generally accepted that this first peak corresponds to the most biodegradable components of the organic matter. Nevertheless, biodegradability of the digested waste can't be considered as negligible as the total oxygen consumption of digestate ranged between 63 and 69 % of the total oxygen consumption of non-digested waste.

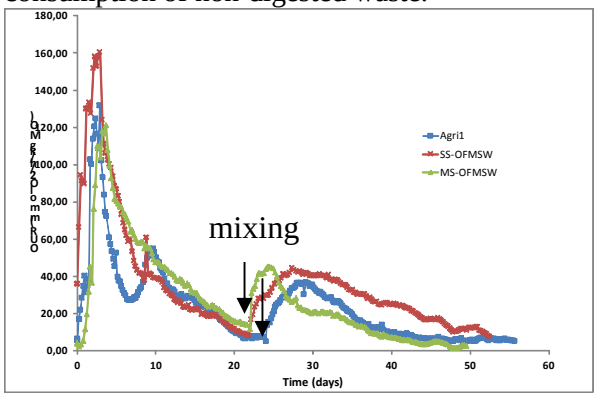

Figure 1. Oxygen uptake rate during composting of non digested waste (MO = organic matter

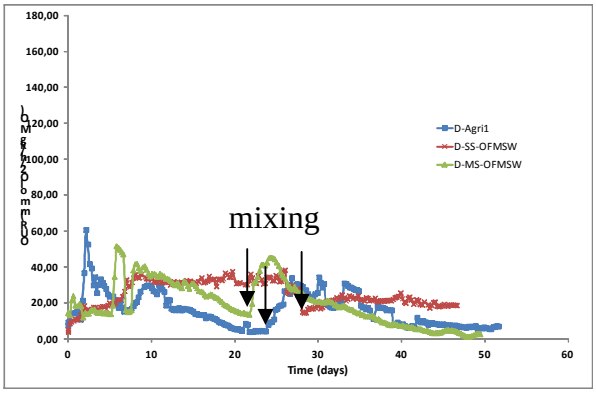

Figure 2. Oxygen uptake rate during composting of digested waste

Kinetic behaviour also differed from non-digested waste to digested waste. Especially for D-SS-OFMSW and D-MS-OFMSW, initial oxygen uptake rate was slower than for non digested waste, reinforcing the hypothesis that the most biodegradable organic components have disappeared during anaerobic digestion.

This lower biodegradability of digestates also induced lower heat release resulting in lower temperature during composting (Figure 3). As a consequence, compost of non-digested waste reached easily temperatures higher than 60°C that were maintained several days and assured hygienisation conditions. But in the case of digestates, even with less aeration, only D-Agri1 maintained a temperature around 55°C during several days.

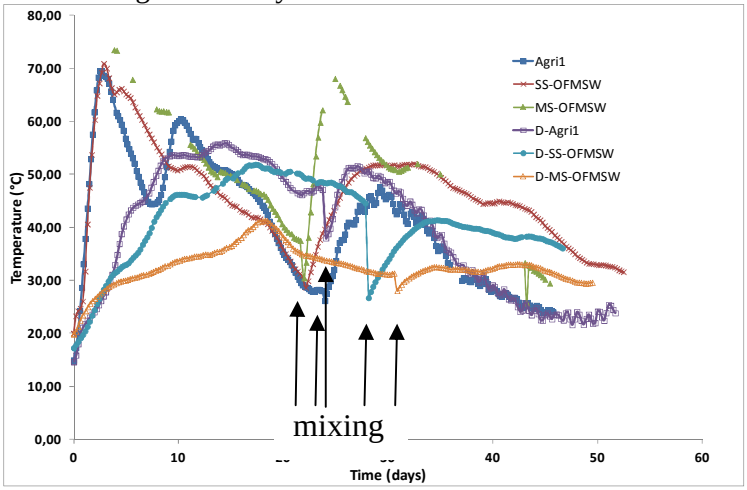

Figure 3. Temperature behaviour during composting

Mass balance

Mass balance is here analysed only in terms of dry matter and water loss. Losses of dry matter and water during the composting of each substrate are presented in table 2.

For non-digested waste, composting resulted in a quasi equivalent loss of dry matter and water, that is to say the effect of stabilisation and drying are comparable. For digested waste the main effect of composting resulted in the drying of the substrate as more than 60 % of the wet mass loss is due to water loss. During pilot experiments, no leachates were collected. Thus all water losses were due to water evaporation and transport through the airflow. Water export increased with temperature, as proved for MS-OFMSW composting which reached the highest temperatures for the longest time.

Table 2. Water and dry matter losses during composting

	Agri1		D-Agri1		SS-OFMSW		D-SS-OFMSW		MS-OFMSW		D-MS-OFMSW	
	kg	% of total wet mass loss	kg	% of total wet mass loss	kg	% of total wet mass loss	kg	% of total wet mass loss	kg	% of total wet mass loss	kg	% of total wet mass loss
Loss of dry matter	15.2	47.1	10.0	38.3	12.7	52.1	NA	NA	17.8	36.3	7.5	29.4
Loss of water	17.0	52.9	16.2	61.7	11.7	47.9	NA	NA	31.3	63.7	17.9	70.6

Gaseous emissions

Composting is an aerobic treatment. As a consequence, the main gas released is carbon dioxide. Nevertheless, green house gases as methane and nitrous oxide can be emitted along the biodegradation process. Moreover, ammonia emissions also represent a non negligible part of the emitted components. When analysing Agri1 and D-Agri1 (Figures 4 and 5), it can be noted that methane emission peaks were observed concomitantly to oxygen consumption peaks. It shows that the rapid consumption of oxygen within the composting pilot led to local anaerobic zones, even when the oxygen concentration in the airflow coming out the composting pilot was still above 10 %.

Concerning nitrogenous emissions it was observed that the first period of the composting process led mainly to ammonia emissions. Nitrous oxide emissions appeared only after the mixing. At this moment no more ammonia emissions were observed. Nitrous oxide emissions could be due to anaerobic conditions in the pilot. But the main hypothesis explaining these emissions is an incomplete nitrification phenomenon, appearing in the second period of composting when temperatures are lower and when oxygen is more available. The emission behaviour was comparable for non-digested and digested waste. Nevertheless, nitrous oxide emissions were higher for D-Agri1.

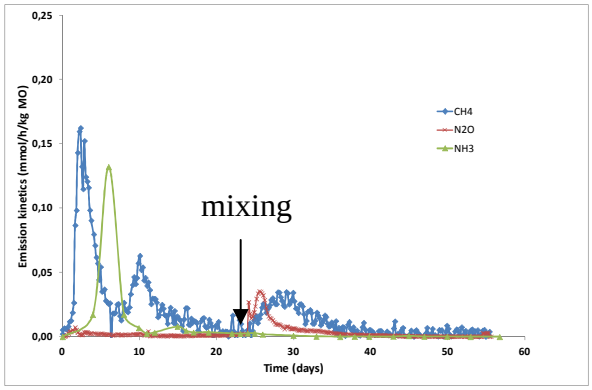

Figure 4. Methane and N-gaseous emissions for Agri1

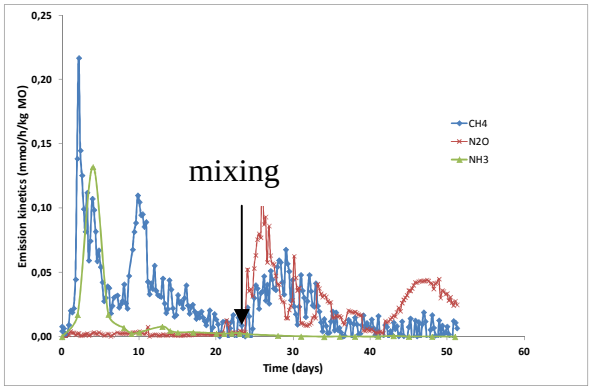

Figure 5. Methane and N-gaseous emissions for D-Agri1

Emitted fluxes (FE) are presented in table 3. Ammonia fluxes ranged between 0.02 and 0.11 gN/kg WW (wet waste). Ammonia fluxes per kg of total nitrogen are 3 to 4 times higher for digestates than for non digested waste and seems to depend on the initial ratio of N-ammonia upon total nitrogen content. N_2O fluxes (0.01 to 0.11 gN/kg WW) were slightly lower than the IPCC [4] figure for composting and increased for digested waste. Methane emissions represented 0.05 to 0.23 % of the initial carbon and no specific different trend was found between digested and non-digested waste.

Table 3. Methane and nitrogenous emissions fluxes during composting experiments

	Agri1	D-Agri1	SS-OFMSW	D -SS-OFMSW	MS-OFMSW	D -MS-OFMSW
FE NH_3 (gN/kg WW ini)	0.04	0.11	0.00	0.00	0.02	0.04
FE N_2O (g N/kg WW ini)	0.10	0.11	0.01	0.02	0.00	0.00
FE CH_4 (g C/kg WW ini)	0.23	0.07	0.12	0.13	0.07	0.05

Conclusion and perspectives

Despite a lower-level of biodegradability, the composting of digestates is possible and enables to dry efficiently these wet substrates. But composting must be carefully conducted. Indeed the environmental impact of the aerobic post-treatment of digestates could be important due to higher nitrogen emissions, and more particularly nitrous oxide emissions. Thus management of composting process must be adapted to minimize these emissions. Composting results have still to be analysed in order to understand composting impacts on the quality of digestates' organic matter and to synthesize all positive and negative effects of composting as digestate post-treatment

Acknowledgement

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