The importance of aeration mode and flowrate in the determination of the biological activity and stability of organic wastes by respiration indices

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Abstract

The aim of this study was to assess the effect of different air flowrates and different aeration modes on the respiration activity of three organic substrates of different stability degree: i) a constant flowrate and ii) a continuously adjusted air flowrate that optimized the oxygen uptake rate (OUR). Above 20 L air kg^{-1} DM h^{-1}, at the constant flow regime, the resulting dynamic respiration index at 24 hours (DRI_{24}) and the cumulative respiration at four days (AT_4) were statistically similar. At the OUR based aeration regime, the DRI_{24} and AT_4 were statistically similar at all initial flowrates tested. Above a minimum threshold, cumulative air flow of around 3000 L air kg^{-1} DM during a 5 day period, the respiration activity was similar, particularly for the two less active substrates. This study highlights the importance of selecting the aeration to obtain reliable measures of biological activity and stability in organic wastes.

Keywords: dynamic respiration index; aeration mode; stability; oxygen uptake rate; biological stability.

1. INTRODUCTION

Several studies have highlighted the importance of knowing reliable measures of the biological activity of an organic waste and the final stability of an end product. For instance, respiration indices can provide a realistic picture about the overall efficiency of a complete waste treatment plant based on biological processes, such as anaerobic digestion or composting (Ponsá et al., 2008; Pognani et al., 2011). In these cases, respiration indices permit the accurate determination of the performance of the plant and to propose actions to improve it (Ponsá et al., 2010a). In other advanced studies, respiration indices have been also used to compare different approaches to organic waste management, such as industrial and home composting. These indices have been demonstrated to be the most suitable parameters to have a fair balance of the pros and cons of both these technologies (Martínez-Blanco et al., 2010).

In some recent advanced works, respiration indices are being proposed in order to determine the full treatment efficiency of an organic waste in all the operation stages of the treatment process and to use this efficiency to assess the environmental impact related to the extent of the organic matter degradation (Colón et al., 2012).

Moreover, respiration indices have been shown to correlate well with anaerobic digestion tests, such as biochemical methane potential (BMP), which are time consuming. In consequence, respiration indices can provide a relatively rapid measurement of the biogas potential of a sample in any stage of the biodegradation process (Cossu and Raga, 2008; Barrena et al., 2009).

For all the above reasons, it is of major importance to have a reliable measure of the biological activity of an organic waste in all its stages of biodegradation (including, but not limited to, final product) and respiration indices are probably the most powerful

tools that are available for researchers (Barrena et al., 2006).

Despite the common use of dynamic respiration tests to evaluate the stability of composts and the biological activity of organic wastes, variable and diverse techniques do exist. Some of the main differences have to do with the adopted sample size (Komilis and Kletsas, 2012) as well as the aeration mode and flowrates used in the experiments. For example, the tests suggested by Scaglia et al. (2000) employ a pilot scale reactor that can accept up to 15 kg of sample size and in which air flow is continuously adjusted so that the oxygen content at the outlet stream is maintained always at 14% v/v. Most tests require a constant air flow throughout the experiment (Barrena et al., 2014), whilst a recent aeration mode designed by Puyuelo et al. (2010) continuously adjusted air flowrate to keep the oxygen uptake rate (OUR) optimized to achieve always the maximum respiration activity, which can result in a more realistic assessment of the respiration activity. Aeration rate is expected to influence the resulting microbial respiration activity indices and, in consequence, both the biological activity and the stability of organic wastes. In Komilis and Kanellos (2012), in which a constant flow regime had been used, a linear increase of the dynamic respiration index (DRI) as the unit air flowrate (UAF) increased was observed.

In this work, 500 mL custom made respirometers were used to measure respiration activity (RA). Two aeration regimes were used and compared, namely: a) a constant aeration rate throughout the experiment so that to achieve a constant unit air flowrate (UAF), and b) a continuously adjusted air flowrate that maximizes the OUR based on a novel control algorithm that has been described in detail in Puyuelo et al. (2010).

Therefore, goal of the study was to assess the effect of different air flowrates and

different aeration regimes on the microbial respiration activity as this was assessed via several dynamic respiration indices. This information will aid in selecting or modifying existing stability limits and to have a reliable picture of the biological activity of any organic waste sample.

2. MATERIALS AND METHODS

2.1. Organic material and sampling

Three representative organic substrates in terms of stability were used in this work: i) a fresh (raw) source-separated organic fraction of municipal solid wastes (OFMSW), ii) a semi-stabilized organic material (SSOM) derived from the aerobic stabilization of mechanically selected organic fraction of the residual (rest) fraction of MSW (after a composting period of 3-4 weeks at a local plant of Barcelona), and iii) a well-stabilized compost (COMPOST) derived from the composting of OFMSW after a prolonged aeration period of 7-8 weeks and one month of curing. All materials were obtained from the same plant. In each case, samples were obtained from large piles of material. 3-4 kg of material were taken from at least six points of this pile to get a final sample of approximately 25 kg. This sample was manually mixed and stored by freezing at -18ºC in aliquots of 1 kg. It has been demonstrated that this procedure does not alter the respiration activity of the samples (Pognani et al., 2012). From those 1 kg aliquots, a random selection was done, and then an additional quartering process was performed on each 1 kg aliquot in order to obtain the 100 g needed for each replicate run.

2.2. Respirometry operation and aeration modes

The dynamic respirometers consist of 15 reactors as described elsewhere (Ponsá et al. 2010b). Briefly, 100 g waste sample was placed in each 500 mL reactor. Each reactor consisted of an Erlenmeyer flask, containing a plastic net to support the organic waste and to provide an air distribution chamber, placed in a water bath at 37ºC. Airflow in the reactors was adjusted by means of an air flow controller (Bronkhorst Hitec, The Netherlands). Air was passed through a humidifier at the same temperature of the reactor to avoid water losses and moisture changes. Exhaust air from the reactors was sent to an oxygen sensor prior dehumidification in a water trap. Both air flow meters and oxygen sensors were connected to a data acquisition system to continuously record these values for OUR on-line calculation.

The calculations to convert O_2 contents and air flowrates to O_2 consumption are based on the ideal gas law (Ponsá et al., 2010b) according to the following equation:

$$OUR = F \cdot (0.209 - y_{O_2}) \cdot \frac{P \cdot 32 \cdot 60}{R \cdot T} \qquad \text{Equation (1)}$$

where: *OUR* is the Oxygen Uptake Rate (g O_2 h^{-1}); *F*, airflow into the reactor (L min^{-1}); y_{O_2}, is the oxygen molar fraction in the exhaust gases (mol O_2 mol^{-1}); *P*, pressure of the system assumed constant at 101325 Pa; 32, oxygen molecular weight (g O_2 mol O_2^{-1}); *60*, conversion factor from minute to hour; *R*, ideal gas constant (8310 Pa L K^{-1} mol^{-1}); *T*, temperature at which F is measured (K). Regarding y_{O_2}, the flow dynamics of the reactors was analysed in previous works (Puyuelo et al., 2010) by the residence time distribution technique resulting in a completely mixed operation. In consequence, a homogenous oxygen distribution can be considered in the entire volume of the reactor.

In the constant air flow regime, air flow was simply adjusted to a constant initial

value so that the UAF was maintained constant throughout the experiment. In the OUR based air flow regime, the air flow was adjusted every 60 min so that to optimize the OUR according to an optimization algorithm mentioned in Puyuelo et al. (2010). It is clarified here that in the OUR based regime, the flow presented in tables and figures refers to the initial air flowrate that, obviously, can continuously change during the process according to the programming algorithm and the biological activity of the material. The principal respiration indices calculated in this work were three, namely: a) a 24h based dynamic respiration index (DRI_{24}), which is the average of the instantaneous oxygen uptake rates during a 24h period of maximum respiration activity, b) the AT_4, which is the total oxygen consumed over a 4 day period beyond the initial lag time, c) the total cumulative flow of air (F_{acum}) introduced into the reactors during a 5 day period. These indices (DRI_{24} and AT_4) are well established and used in the composting research (Adani et al., 2006). It is noted that the experimental period ranged from 5 to 7 days. Some runs were terminated earlier than others since the critical respiration indices (DRI_{24}, AT_4) could be anyway calculated.

Other calculated parameters relevant in respiration activity were: d) the maximum value of the average of instantaneous OUR measurements in one hour (DRI_1) (Barrena et al., 2009), e) the lag time (hours), finishes when the observed respiration activity is, at least, the 25% of the respiration activity observed during the largest increase in the oxygen consumption within the first 4 days (Federal Government of Germany, 2001) and f) the times needed to reach the *first* and *second* (if existed) instantaneous peak in the OUR profile (Berthe et al., 2007).

The initial moisture content in all substrates was 54.3% ± 7.2% while the final moisture contents of all substrates ranged from 20.8% (in only one replicate run) to

68.0% with an average value at 51.1% wb (± 9.7%), indicating that the average moisture content change (decrease) during the experiments was 6.0%.

2.3. Experimental design and statistical analysis

Four to five UAFs were used for each substrate and for each aeration mode. These UAFs ranged from 7.1 to 103 L kg^{-1} DM h^{-1} for the OFMSW and SSOM in both aeration regimes and from 5.6 to 50.1 L kg^{-1} DM h^{-1} for the compost (Table 1). These UAF ranges were selected to cover a wide range of aeration values according to the expected biological activity of the three substrates, especially in the case of source-selected OFMSW, which has a high biodegradability. The experimental period was 5 to 7 days. The number of replications per treatment was three. All statistical analyses were performed with basic ANOVA techniques while pairwise comparisons were based on the Tukey test (at $p<0.05$). Statistics were performed with MINITAB™ v18.

3. RESULTS AND DISCUSSION

3.1. Characterization of materials

The moisture (M) and organic matter (OM) contents of the more active OFMSW were 59.3% wb and 77.2% db, respectively, whilst for SSOM the same parameters were 57.5% wb and 73.1% db, respectively. The compost had an initial moisture content of 46% wb and an OM content of 56.1% db. The pH values of SSOM and OFMSW were 8.16 and 5.58, respectively, whilst compost had a pH of 7.9. The above values appear to be in line with literature references and show that the OM content decreased as the biodegradation proceeded (from OFMSW to compost), as observed in other works (Jurado et al., 2015).

3.2. Typical oxygen uptake profiles

Some typical OUR profiles are shown in Figure 1. According to Figure 1, the OUR of the three substrates followed the typical ascent to a peak value, which is expected to coincide with a temperature rise in the composting process. In these experiments, temperature is constant at 37ºC. It is worth to mention that a second peak was observed only in SSOM. The drop of respiration activity (RA) between the two peaks might be related to a change from two different microbial populations. As the more biodegradable substrates are depleted a second population grew to degrade more recalcitrant organic matter such as fibres present in SSOM. This has been observed by other researchers as well (Berthe et al., 2007). Figure 1a clearly reveals that the OFMSW was the most active material followed by SSOM and finally by compost. The OUR aeration regime seemed to lead to a higher OUR compared to the constant flow mode. This could be due to the much higher UAF supplied by the OUR controller as depicted in Figure 1b. In fact, the ranges of airflow in the OUR controller were: 15-80 L kg^{-1} DM h^{-1} for compost, 40-80 L kg^{-1} DM h^{-1} for SSOM and 40-150 L kg^{-1} DM h^{-1} for OFMSW.

3.3. Effect of aeration regime on respiration indices

Figure 2 depicts the effect of the different aeration modes on the two principal respiration indices (DRI_{24}, AT_4). Table 2 shows the statistical differences between the grand means obtained from all UAFs that were statistically similar (grand mean is defined as the combined mean from all replicates of all different treatments) of some respiration indices and other related parameters (lag time, time to peaks, ΔO_2, F_{acum}) at

the two aeration modes.

Specifically in the case of the constant air flowrate mode and according to Figure 2 (all subfigures), a general observation for all the wastes analysed and the respiration indices can be stated: UAFs above around 20 L air kg^{-1} DM h^{-1} led to constant DRI_{24} and AT_4 values. This practically means that the maximum respiration activity can be reached at the aforementioned threshold UAF and no excess air is necessary. Following with the results of constant air flowrate mode (Figure 2, Table 2), in the case of OFMSW, the maximum DRI_{24} was around 3 g O_2 kg^{-1} DM h^{-1} (average value from all statistically similar DRI_{24}), whilst the constant AT_4 observed after that threshold UAF value was 220 g O_2 kg^{-1} DM. In the case of SSOM, the corresponding constant DRI_{24} and AT_4 achieved were 1.3 g O_2 kg^{-1} DM $h^{-1}$and 100 g O_2 kg^{-1} DM, respectively, apparently lower than those of the OFMSW. In the case of the compost, however, a different respiration activity trend was observed. Actually, although the respiration activity in the lowest UAF was very low as well, a clear increase of the respiration activity was recorded only during the next UAF; as UAF increased later on, the average respiration activity further decreased. Actually, the RA in the highest UAF for the compost was highly variable leading to a coefficient of variation higher than 50%. This is attributed to the fact that, since compost was quite stable and the air flowrate was set at a high value, the O_2 content in the outlet stream was very close to atmospheric contents; thus, the calculation of the RA could not be accurate and repeatable at those high UAFs. Therefore, this fact must be carefully considered when the stability of materials of low respiration activity is measured. The DRI_{24} and AT_4 for the compost were 0.15 g O_2 kg^{-1} DM $h^{-1}$and 10 g O_2 kg^{-1} DM, respectively.

Figure 2 shows that the respiration activity indices recorded by the OUR control

mode were clearly higher than those at the constant flow mode in the case of the OFMSW (fresher material) and the compost. This highlights the importance of selecting a proper aeration mode in the case of very active samples when simple aeration modes, such as constant airflow, can underestimate the actual biological activity (Figure 2). In the case of the SSOM, however, the RA recorded with the OUR based mode was similar (Table 2) to that recorded with the constant air flow rate. In the OUR based aeration mode, no clear differences among the RA indices recorded at the various UAFs existed. This was particularly evident for the compost in which all RAs were statistically similar. Notably, all DRI_1 values (Table 2) were almost identical to the corresponding DRI_{24} values.

The compost was the most stable material at both aeration modes resulting in almost similar DRI_{24} at all UAFs. Komilis and Kanellos (2012), who had used a sample size of around between 300 to 900 g per respirometer and around 7-8 instantaneous measurements of OUR per day, had observed that the DRI_{24} was affected by the UAF and ranged from around 0.11 to 0.22 g O_2 kg^{-1} DM h^{-1}. These are similar values than the ones found here. In addition, Komilis and Kanellos (2012) observed that the DRI_{24} increased as UAF increased too with a rather moderate linear correlation and with some deviations from the regression line for a UAF range from 2.6 to 13 L air kg^{-1} DM h^{-1}. Similarly, the corresponding AT_4 values in Komilis and Kanellos (2012), (termed as $DCRI_4$), ranged from 8 to 15 g O_2 kg^{-1} DM, which were also similar to the values found here. These results are in agreement with the findings of this work, where the range was extended to up to 50 L air kg^{-1} DM h^{-1}. DRI_{24} and AT_4 increase with UAF in the low range below 20 L kg^{-1}DMh^{-1}. Increasing UAF over this threshold does not improve the respiration indices values.

Table 2 shows that there were differences in the lag time, with the constant flow mode resulting in 4.7 and 2.6 hours longer lag times (average) compared to the OUR based mode in the case of OFMSW and SSOM, respectively. No such difference existed for the compost due to the significant lack of readily degradable material. In addition, the lag time was higher in the fresher materials, apparently because no acclimated biomass yet existed in the system (as opposed to the stabilized compost). The effect of UAF on lag time is better illustrated in Figure 3. Actually, the higher lag times of the constant flow system are clearly evident in the case of SSOM, but not in the case of OFMSW, despite the statistical findings of Table 2. In the case of stable compost, no differences between the lag times existed in both modes at all UAFs, as Table 2 also indicated. It, therefore, appears that in most cases the controlled airflow mode can result in an improvement of the composting process by reducing the lag time.

Finally, according to Table 2, a higher delay in the appearance of the first peak existed in the case of the constant flow regime for OFMSW and SSOM compared to the OUR mode. This is probably due to the fact that the OUR based regime eventually manages to optimize the respiration activity, which leads to a faster stabilization of the material (and thereof to a lag time reduction). This optimization effect is also reflected in the shorter lag time and shorter times required to reach the first peak. Interestingly, Table 2 shows that although the total cumulative amount of air was less in the case of the constant flow mode than in the OUR based system, the total O_2 consumed during the process (ΔO_2) in both modes was actually similar for the three substrates. This indicates that there was an excess of air in the OUR based system and that the system is able to eventually utilize the necessary oxygen amounts in both cases.

3.4. Effect of cumulative air flow on respiration activity

In terms of engineering design, the minimum amount of air necessary to maintain the optimum respiration activity for degradation is a useful knowledge. To study that, Figure 4 was drawn with DRI_{24} illustrated as a function of the cumulative air volume (F_{acum}) that passed through the system during the 5-d experimental period. The figure was drawn by including all experiments run at both the constant flow and the OUR based control modes.

According to Figure 4, similar DRI_{24} values seem to be achieved beyond accumulated flows of around 2500 to 3000 L kg^{-1} DM for SSOM and the compost. Beyond that value, respiration activity remains the same and is not affected by the higher amounts of air. This practically means that it is not necessary to aerate more than a minimum threshold value, which is a useful knowledge during the operation of composting facilities. Only in the case of the OFMSW, there seems to appear a slight increasing trend of the DRI_{24} with the accumulated flow. This slight difference of the trend of OFMSW from the other substrates can be explained by the presence of higher amounts of readily degradable material in the former substrate that do require large amounts of oxygen to be decomposed. Probably the advantage of using the OUR controller is the ability to adjust the UAF to the specific degradation period, being this more important than the total cumulative air flow to maximize the respiration activity.

4. CONCLUSIONS

From this study, it can be stated that a constant UAF below 20 L kg^{-1} DM^{-1} h^{-1} limits respiration activity; however, above that value, respiration activity is statistically similar for all substrates. The initial UAF is not important when the aeration system

operates under the OUR based controlled mode. Beyond a threshold accumulated air flow of around 3000 L kg DM^{-1}, the respiration activity remains similar for all three substrates. This highlights the importance of using an adequate flowrate and aeration mode for the composting of the OFMSW and to have a reliable measure of its stability and biological activity.

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Tables

Table 1. Experimental design

Substrate*	Constant UAF throughout the experiment ($L \cdot kg^{-1} DM \cdot h^{-1}$)					Initial UAF in the OUR based aeration mode ($L \cdot kg^{-1} DM \cdot h^{-1}$)			
OFMSW	7.4	22.1	44.2	66.3	103.2	7.4	14.7	22.1	44.2
SSOM	7.1	21.2	42.4	63.6		7.1	14.2	21.2	42.5
Compost	5.6	16.7	33.4	50.1		5.6	11.2	16.7	33.4

*OFMSW: Raw organic fraction of MSW; SSOM: Semi-stabilized organic matter derived from OFMSW; Compost: OFMSW derived well stabilized compost, UAF: Unit air flowrate

Table 2. Statistical differences among several respiration activity indices

Aeration mode	DRI_1 ($gO_2 \cdot kg^{-1}$ DM· h^{-1})	DRI_{24} ($gO_2 \cdot kg^{-1}$ DM· h^{-1})	AT_4 ($gO_2 \cdot kg^{-1}$DM)	Lag time (h)	Time to peak 1 (h)	Time to peak 2 (h)	ΔO_2 ($gO_2 \cdot kg^{-1}$DM)	F_{acum} ($L \cdot kg^{-1}$ DM)
OFMSW								
Constant flow	3.2^A	3.1^A	228.2^A	23.0^A	70.5^A	N/O	306.0^A	9723^A
OUR controlled	4.1^B	3.9^B	287.0^B	18.3^B	30.6^B	N/O	330.5^A	16219^B
SSOM								
Constant flow	1.5^A	1.3^A	103.0^A	4.0^A	7.5^A	38.8^A	132.2^A	4986^A
OUR controlled	1.6^A	1.3^A	98.0^A	1.4^B	3.1^B	45.1^B	131.1^A	8491^B
Compost								
Constant flow	NR	0.14^A	10.2^A	1.4^A	66.2^A	N/O	11.2^A	3856^A
OUR controlled	NR	0.18^B	12.7^B	1.4^A	61.7^B	N/O	13.1^A	5452^B

Similar letters indicate statistically similar means at $p < 0.05$ according to the independent t-test; the grand means shown in the Table were calculated by averaging only the *statistically similar* mean values. N/R: Not recorded; N/O: No peak observed.

DRI_1: Momentary hourly dynamic respiration index; DRI_{24}: Averaged OURs at maximum activity over a 24 hour period; AT_4: Total (cumulative) oxygen consumption over a 4 day period after the point where the 25% of the maximum momentary OUR has been reached; Lag time: time to reach the 25% of the maximum hourly OUR; ΔO_2: total oxygen consumed during the whole experiment; F_{acum}: accumulated flow of during the whole experimental period (7 day).

Figure captions

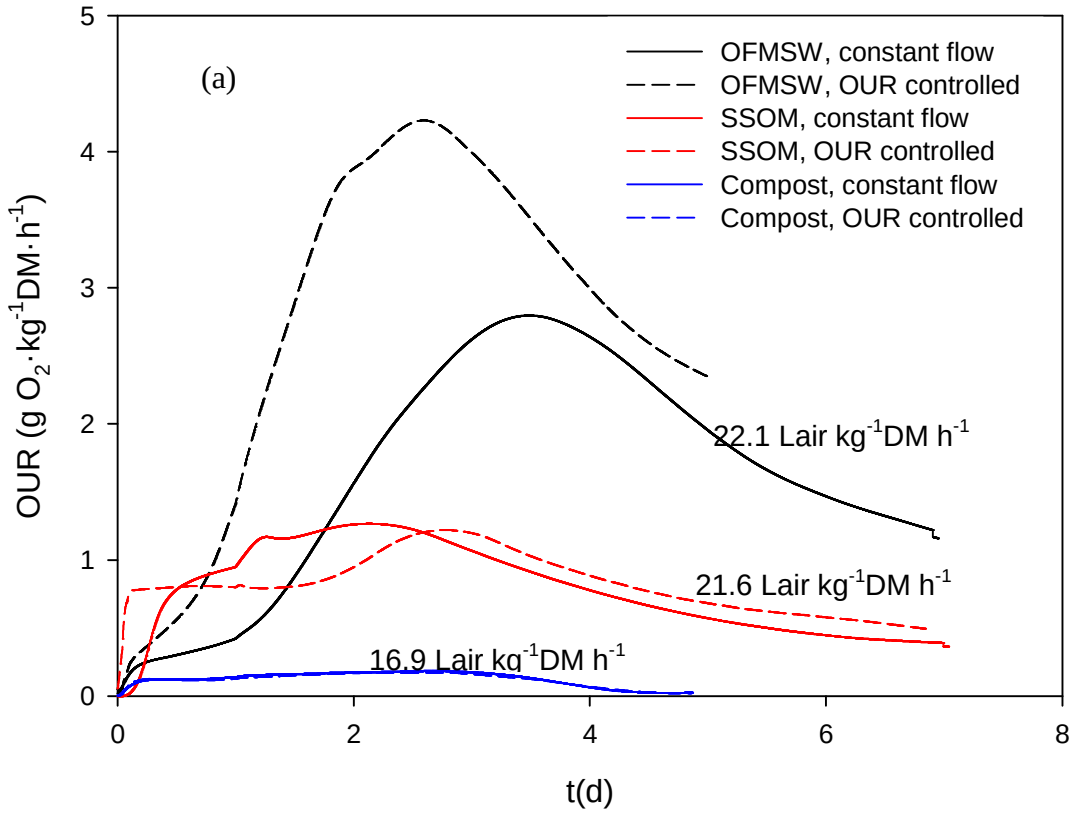
Figure 1. a) Typical OUR profiles (at the UAFs shown within the graph) and b) UAF, for the three substrates at the two aeration modes. Lines represent average values from 3 replications.

Figure 2. DRI_{24} (left) and AT_4 (right) versus UAF (from top to bottom: OFMSW, SSOM, compost); means that share the same letter at the same line indicate statistical similarity at $p < 0.05$.

Figure 3. Lag time versus UAF (from top to bottom: OFMSW, SSOM, compost); means that share the same letter at the same line indicate statistical similarity at $p < 0.05$.

Figure 4. DRI_{24} versus accumulated air flow throughout the experiment; from top to bottom: OFMSW, SSOM, compost.

Figure 1


(a)
OFMSW, constant flow
OFMSW, OUR controlled
SSOM, constant flow
SSOM, OUR controlled
Compost, constant flow
Compost, OUR controlled
22.1 Lair kg-1DM h-1
21.6 Lair kg-1DM h-1
16.9 Lair kg-1DM h-1
OUR (g O2·kg-1DM·h-1)
t(d)

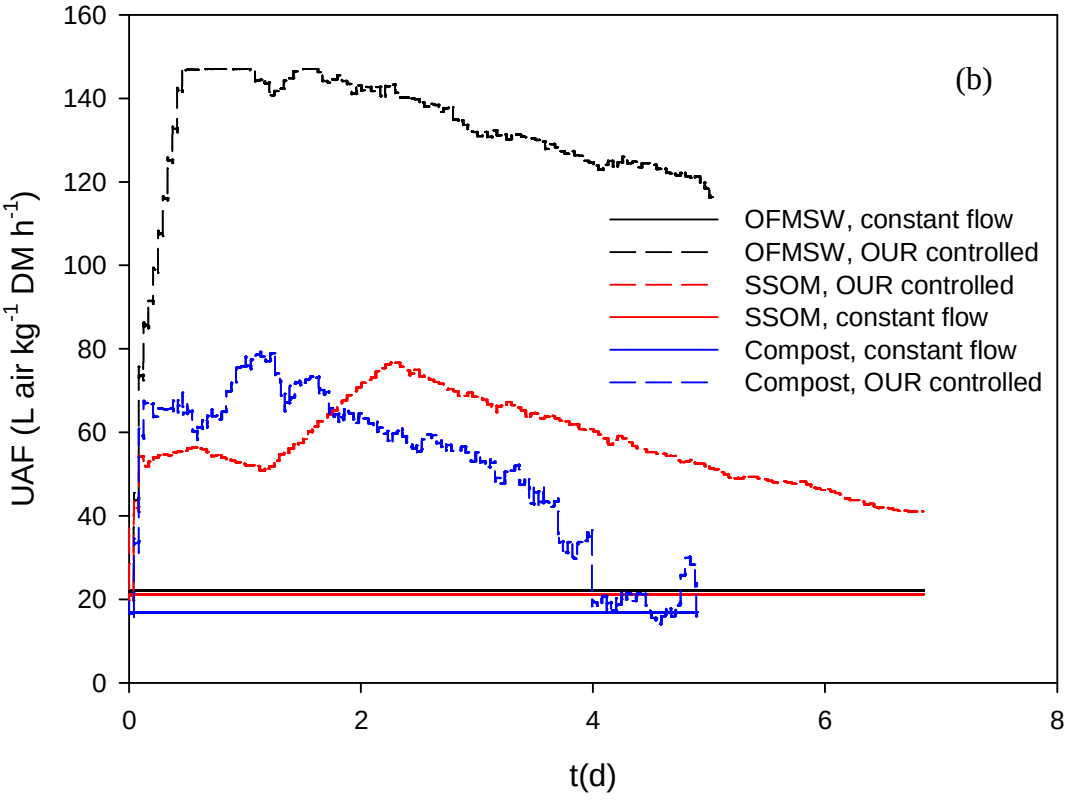

(b)
OFMSW, constant flow
OFMSW, OUR controlled
SSOM, OUR controlled
SSOM, constant flow
Compost, constant flow
Compost, OUR controlled
UAF (L air kg-1 DM h-1)
t(d)

Figure 2

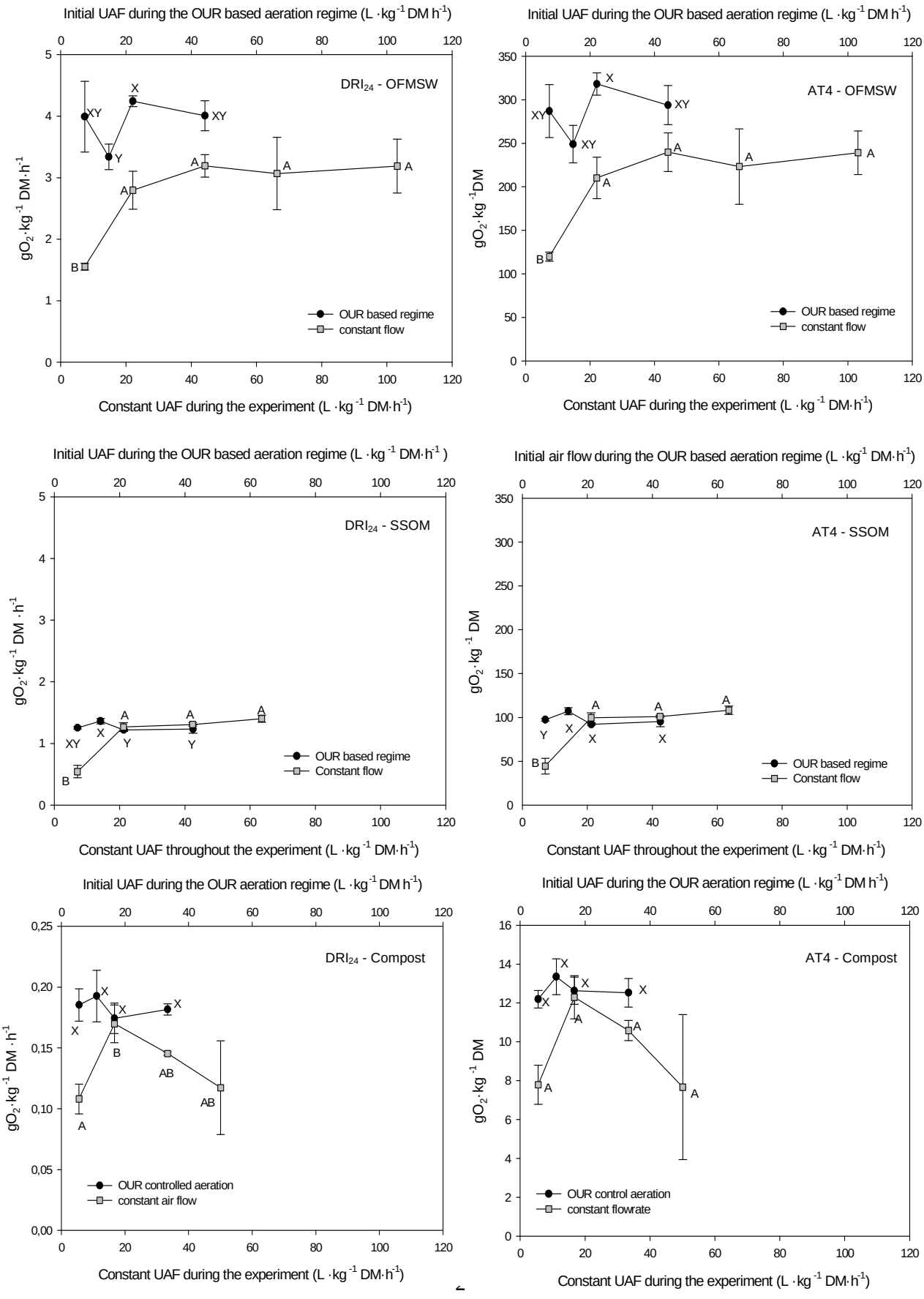
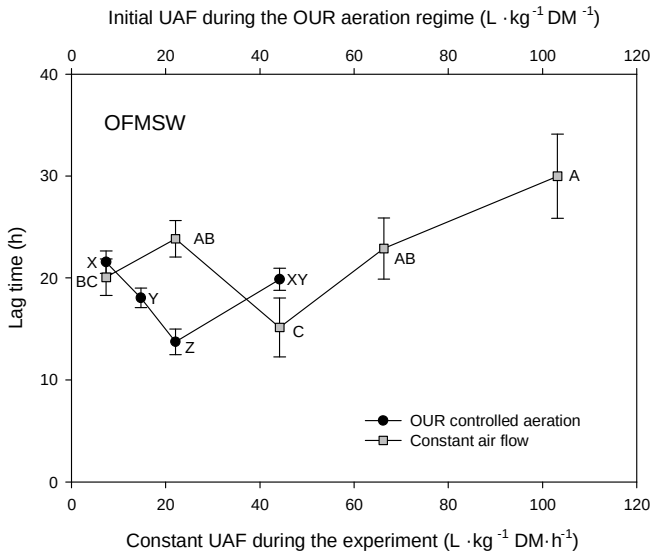
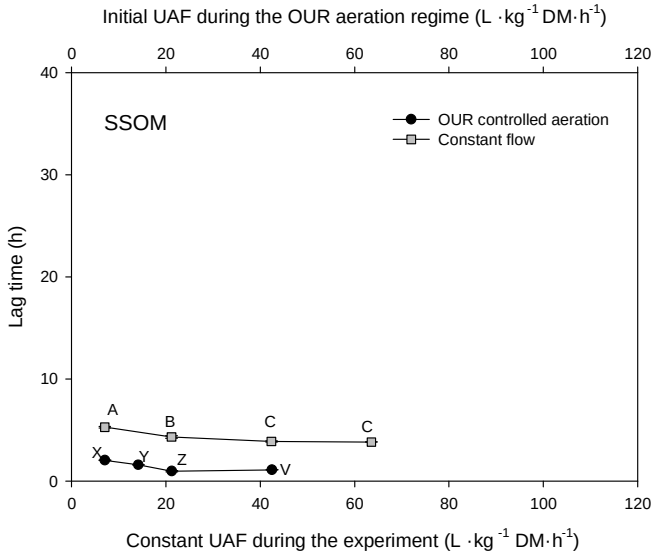

Initial UAF during the OUR based aeration regime (L ·kg -1 DM h-1)
DRI24 - OFMSW
gO2·kg -1 DM·h-1
OUR based regime
constant flow
Constant UAF during the experiment (L ·kg -1 DM·h-1)
Initial UAF during the OUR based aeration regime (L ·kg -1 DM h-1)
AT4 - OFMSW
gO2·kg -1DM
OUR based regime
constant flow
Constant UAF during the experiment (L ·kg -1 DM·h-1)
Initial UAF during the OUR based aeration regime (L ·kg -1 DM·h-1)
DRI24 - SSOM
gO2·kg -1 DM ·h-1
OUR based regime
Constant flow
Constant UAF throughout the experiment (L ·kg -1 DM·h-1)
Initial air flow during the OUR based aeration regime (L ·kg-1 DM·h-1)
AT4 - SSOM
gO2·kg -1 DM
OUR based regime
Constant flow
Constant UAF throughout the experiment (L ·kg -1 DM·h-1)
Initial UAF during the OUR aeration regime (L ·kg -1 DM h-1)
DRI24 - Compost
gO2·kg -1 DM ·h-1
OUR controlled aeration
constant air flow
Constant UAF during the experiment (L ·kg -1 DM·h-1)
Initial UAF during the OUR aeration regime (L ·kg -1 DM h-1)
AT4 - Compost
gO2·kg -1 DM
OUR control aeration
constant flowrate
Constant UAF during the experiment (L ·kg -1 DM·h-1)

Figure 3


Initial UAF during the OUR aeration regime (L ·kg -1 DM -1)
OFMSW
Lag time (h)
Constant UAF during the experiment (L ·kg -1 DM·h-1)
OUR controlled aeration
Constant air flow
A
AB
AB
BC
X
Y
Z
XY
C


Initial UAF during the OUR aeration regime (L ·kg -1 DM·h-1)
SSOM
Lag time (h)
Constant UAF during the experiment (L ·kg -1 DM·h-1)
OUR controlled aeration
Constant flow
A
B
C
C
X
Y
Z
V

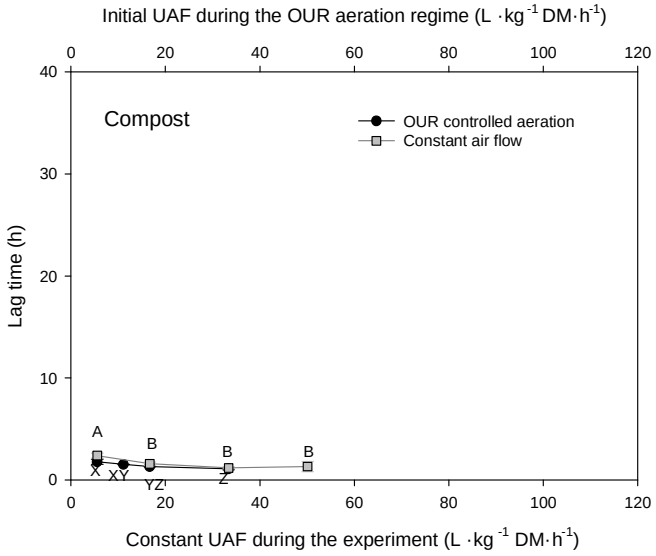
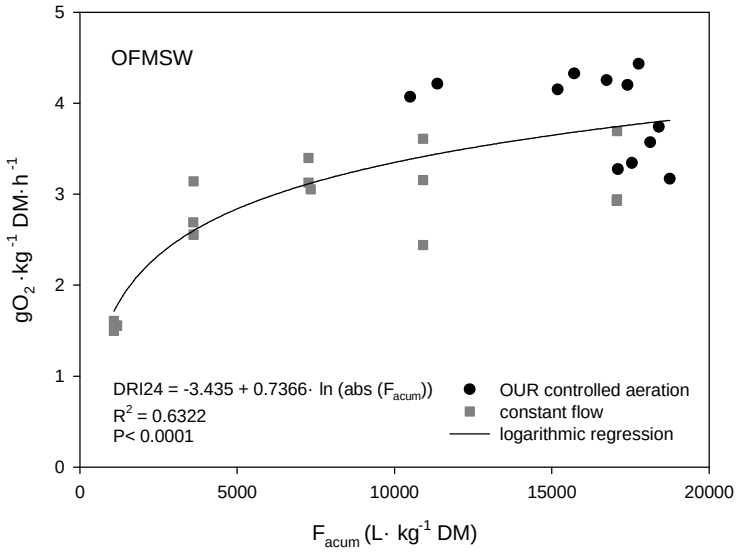
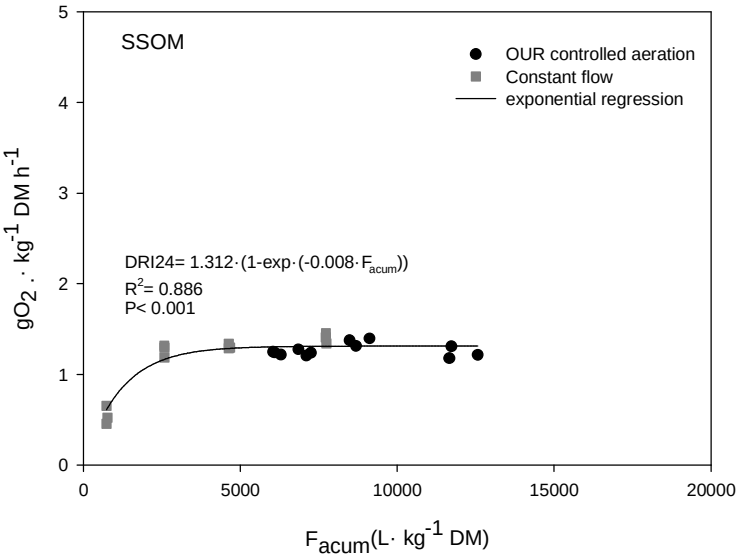
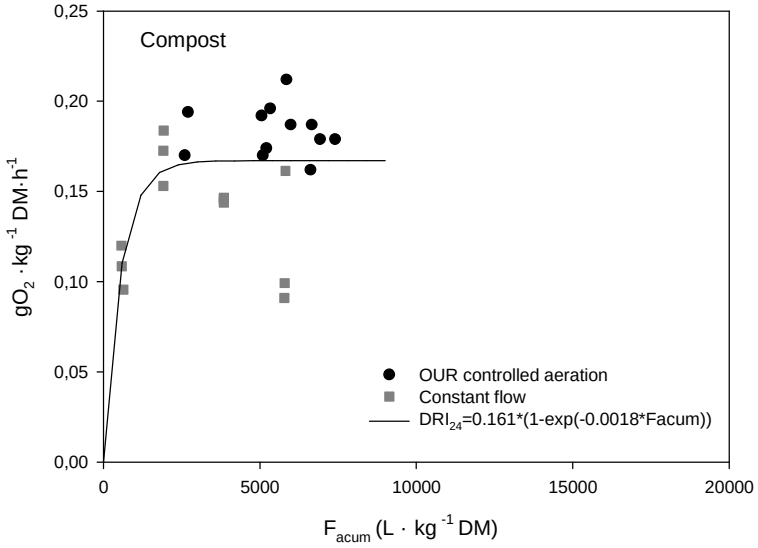

Initial UAF during the OUR aeration regime (L ·kg -1 DM·h-1)
Compost
Lag time (h)
Constant UAF during the experiment (L ·kg -1 DM·h-1)
OUR controlled aeration
Constant air flow
A
B
B
B
X
XY
YZ
Z

Figure 4


OFMSW
DRI24 = -3.435 + 0.7366· ln (abs (F_acum))
R² = 0.6322
P< 0.0001
OUR controlled aeration
constant flow
logarithmic regression
gO2 ·kg -1 DM·h-1
F_acum (L· kg-1 DM)


SSOM
OUR controlled aeration
Constant flow
exponential regression
DRI24= 1.312·(1-exp·(-0.008·F_acum))
R²= 0.886
P< 0.001
gO2 · · kg-1 DM h-1
Facum(L· kg-1 DM)


Compost
OUR controlled aeration
Constant flow
DRI24=0.161*(1-exp(-0.0018*Facum))
gO2 ·kg -1 DM·h-1
F_acum (L · kg -1 DM)