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BIOLOGICAL STABILITY ASSESSMENT OF MSW ORGANIC FRACTIONS BY MEANS OF RESPIROMETRIC AND GERMINATION TESTS

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Abstract

Composting is the mostly applied method for recovering the organic waste producing an organic soil conditioner. Furthermore, the organic fraction of municipal solid waste (OFMSW) of unsorted waste should be treated in mechanical biological treatment (MBT) plants in view of reducing its environmental impacts. In both cases, it's essential the assessment of biological stability as well as the phytotoxicity of the final product. Aim of this work was to evaluate the maturity evolution during the composting process of OFMSW at full scale. Samples were collected from two Sicilian plants and were subjected to the following analytical measures: volatile solids (VS), dynamic respirometric index (DRI), carbon-to-nitrogen (C/N) ratio and germination index (GI). Results showed that some parameters such as pH and water content values can affect the respirometric test response and the proper activity of microorganisms responsible for biodegradation at full scale. For the unsorted waste, the DRI values suggested that depending on the initial values the stabilization duration requires to be increases prior to landfilling. DRI revealed to be effective for the assessment of the matrix stability, even if the simultaneous measurements of the different indices can provide a reliable information of biological stability and maturity of the organic matrices.

Keywords

Biowaste; Composting; Biological Stability; Phytotoxicity; Respirometric analysis

1. Introduction

Landfill is the most widely used strategy worldwide to manage municipal solid waste (MSW) [1].

Nevertheless, landfill disposal causes several environmental hazards due to the presence of organic fraction (30-40% of municipal solid waste - MSW), such as biogas production, emission of volatile organic compounds (VOC), leachate production, vector presence (e.g. insects, rodents and birds), public health hazard, risk of explosions and plant toxicity [2, 3].

The European Commission in view of reducing the aforementioned environmental impacts, imposes to reduce the amount of organic fraction of municipal solid waste (OFMSW) to be disposed in landfill (Directive CE/99/31). The main strategies adopted to reduce the OFMSW amount are source separation and mechanical-biological treatment (MBT). These strategies allow a valorization process aiming to the recovery of material and/or energy.

In particular, composting is the method most commonly applied for the recovery of separately sorted organic waste [4], due to its simple implementation and operation [5, 6]. The composting process provides the biological stabilization of the organic substrate under aerobic conditions and produces a sanitized product, usually referred to as compost, with soil conditioning properties [7, 8] which can be used for improving soil quality [9, 10]. The composting process occurs in two phases: high rate composting (or active composting time - ACT) phase and curing phase. The first phase aims at degradation of organic matter, destruction of pathogens and weed seed, consequently breaking down of the phytotoxic compounds takes place. In the second phase, the compost maturation takes place [11]. The OFMSW sorted not separately is treated in mechanical biological treatment (MBT) plants in order to reduce the biodegradable organic content by subjecting the organic fraction to an aerobic stabilization process, before landfilling, thus decreasing the leachate and biogas production, or to be used for non-agronomic applications [12]. This waste “pre-treatment” is mandatory in Italy in compliance with the European Union sanitary landfill regulation imposing that final disposal must be environmental sustainable and should prevent threats to human health.

Italian Regulations (DM 27/09/2010, updated with DM 24/06/2015) require biological stabilization of waste before landfilling. Biological stability determines the extent to which readily biodegradable organic matter has decomposed [13, 14]. It identifies the actual point reached in the decomposition process and represents a gradation on a recognized scale of values, which thus enable comparison of the process of decomposition [14]. Knowing the degree of biological stability possessed by the organic matter, not only during the aerobic biological processing but also to be found in the final products, is important for the process to be controller effectively, for the products to be used beneficially, and in optimizing the design of the processing plant [15]. In fact, stability affects the potential for odor generation, biomass reheating, residual biogas production, regrowth of pathogens, phytotoxicity, plant disease suppression ability and process parameters such as airflow rate and retention time [16–18]. Stable compost can be considered as that which shows resistance to further decomposition [15, 19]. Unstable composts are of general concern for a number of reasons including their ability to: self-heat, which may lead to fires, generate nuisance odors, attract disease vectors and generate toxic by-products, especially under anaerobic conditions [20, 21].

In both scenarios, the biological stability can be assessed in different ways. In the past, many analytical methods have been proposed for biological stability determination [22–25]. Among them, the respirometric techniques have been recognized as the best one [11, 26–28], to be highly effective [29]and suitable to reflect the process of organic matter biodegradation [30]. The respirometric approach consists of the measurement of O_2 uptake or CO_2 production under standardized conditions by microorganisms degrading the readily degradable organic fraction under standardized aerobic [4, 31] in a short period of time (1-4 days) [17, 31, 32]. Methods based on carbon dioxide evolution are inexpensive, but do not differentiate between anaerobic and aerobic CO_2 [14]; moreover, the degree of oxidation of the organic matter affects the O_2 uptake per mole of the CO_2 produced. Therefore oxygen uptake is preferred for respirometric purposes [33–36].

The dynamic respiration index (DRI) represents a respirometric approach for the evaluation of waste reactivity. One of the advantages of DRI with respect to other methods proposed in the literature is in the use of a large mass (up to 13 kg) to be tested under simulated full-scale conditions [37]. As a consequence, DRI represented one of the more well-studied respirometric methods, and many applications have been proposed. DRI was used to predict potential biogas production [38] and potential odor production [39], and to calculate an index to measure the potential waste reactivity in landfills [40]. Recently, Colón et al. [27] have demonstrated the high potential of the DRI in comparing the effectiveness of different plants treating different matrices [11]. In addition, DRI, measured according to UNI/TS 11184 standard method, was adopted as the main compliance parameter to test the biological stability [41, 42]; only waste having a DRI lower than 1000 $mgO_2/(kg_{VS}h)$ can be landfilled.

In this light, the aim of the present work was to evaluate and compare the maturity evolution and the biological stability during the composting process of organic municipal solid waste at full scale coming from two different Sicilian plants: the first one was a MTB/composting plant (Plant 1),while the second one was a composting plant (Plant 2). Samples were subject to the following analytical measures: volatile solids (VS), moisture content, pH, dynamic respirometric index (DRI), carbon-to-nitrogen (C/N) ratio, seed germination and root elongation tests.

The latters were evaluated to assess the phytotoxicity [4], which is tightly related to biological stability, as the microbial activity of some unstable organic matter can produce phytotoxic compounds [43].

2. Materials and methods

2.1 Plant description

*Plant 1.*The MBT/composting plant is aimed at the treatment of the residual fractions and the unsorted waste (design MTB flow rate: 750 Mg d^{-1}) and of the organic fraction subject to separate collection (design composting flow rate: 90 Mg d^{-1}). The mechanical-biological treatment is performed before waste landfilling, according to Italian Regulation. The process was characterized by two parallel lines, including two units of bag disruption and two waste selection units by sieving (size 130 mm). The upper sieving fraction was subject to metal separation (magnetic and non-magnetic) and could be potentially used as refuse derived fuel (RDF). However, this application was not yet introduced due to lack of facilities and consequently all of the MSW upper sieving is sent to the landfill (excepting metals that are recovered). The under sieve fraction of the two lines was gathered into one line subject to a further sieving facility (size: 70 mm); the fate of the upper sieving was the same of that previously discussed, while the under sieve fraction was subject to biological treatment. The biological treatment is applied by static piles, realized with a maximum height of almost 3 m, inside a bioreactor unit characterized by the following geometrical dimension: length: 30 m, height: 4.4 m, width: 8.7 m. The residence time for the OFMSW is almost 30 days and, after assessed the design stability level, it can be disposed in the municipal landfill, close to the MBT plant.

In the composting line, the organic fraction is fed to a bag disruption unit, then shred and mixed with pruning scraps in order to improve the pile texture and increasing its porosity. The pile features as well as the bioreactors are identical to that above discussed. The residence time of the organic fraction inside the bioreactor is set at 30 days. The material extracted from the bioreactor is then subject to aerated static and windrow maturation, respectively. The residence time for the maturation is set equal to 60 days, for a whole composting time of 90 days. The outlet material is refined by sieving (size: 10 mm), where the under sieve fraction is the mature compost. In Fig.1 the block diagrams for Plant 1 are shown.

[FIG.1]

Plant 2. The plant is sized for the treatment of 19.9 Mg d^{-1} of OFMSW. Also in this case, before treatment, organic fraction is fed to a bag disruption unit, shred and then mixed with ligno-cellulosic materials. The process treatment involves an intensive bioxidation in biocells lasting 14 days, a forced aeration in a confined space for 28 days (post-composting phase) and finally a barnyard maturing on turning piles of 54 days. Biocells volume is equal to 420 m^3, with a useful capacity of 300 m^3; instead, piles from post-composting and maturing phases have the following geometrical dimensions: larger base 4 m, smaller base 2 m, height 3 m and 2.5m, respectively. At the end of the composting process, the raw compost is refined by a two-stage sieving (20 mm and 8 mm, respectively). Fig.2 shows block diagram for Plant 2.

[FIG.2]

2.2 Analytical methods

The composting process was monitored for 184 days (Plant 1) and 120 days (Plant 2); these durations have been established according to the regulatory requirements (process time not less than 90 days) and the measurement frequency of biological stability. During the experimental campaign, for both plants, several samples were collected at different times in order to analyze biological stability parameters. In particular, concerning Plant 1, the experimental campaign was carried out in a winter-spring period while, for Plant 2, two sampling campaigns have been carried out (campaigns 1 and 2). Campaign 1 has been performed in a winter period; while Campaign 2 has been conducted in a summer period. For each sample, analysis for the measurement of volatile solids (VS), dynamic respirometric index (DRI), carbon-to-nitrogen (C/N) ratio and germination index have been carried out.

The respirometric tests on both compost and OFMSW took place in a laboratory reactor; a respirometric equipment produced by Costech International, 3022 model, with a volume equal to 25 L, was used. The analyses were carried out on 10 kg samples collected into the bioreactor and/or static piles and windrows. Before testing, density and moisture of the samples were standardized, if necessary, at values respectively lower than 0.75 kg L^{-1} and 75% maximum water capacity. Samples were analyzed according to the UNI/TS 11184:2016 methodology (UNI/TS, 2016). Each analysis had a 96 hours duration or longer if necessary (120 hours). Temperature (T) and oxygen (O_2) concentration in the air inflow and outflow were automatically measured; in particular, T was also measured within the biomass sample and the highest value reached during the test was annotated to be further correlated with the DRI value.

During the respirometric test, the hourly DRI (DRI_h) was determined by measuring the difference in the O_2 concentration (mL L^{-1}) between the respirometer inlet and the outlet airflow, and was calculated as reported by Scaglia et al. [38]:

$$DRI_h = \frac{Q \cdot \Delta O_2}{V_g \cdot VS(DM)} \cdot 31.98 \quad [mgO_2/kg_{VS}\,h]$$

where DRI_h is the hourly DRI, Q (L h^{-1}) is the airflow rate, ΔO_2 (mL L^{-1}) is the difference in the O_2 concentration in the inlet and the outlet air flows of the reactor, V_g (L mol^{-1}) is the volume of 1 mol of gas at the inlet air temperature, 31.98 (g mol^{-1}) is the molecular weight of O_2, and VS and DM (kg) represent, respectively, the initial volatile solids and dry matter content. According to Adani et al. [31] a typical DRI_h (respirogram chart) consists of a lag phase, increasing phase and peak, decreasing peak. However, depending on the nature of the matrix and involved processes, the respirogram profiles may be strongly different.

Phytotoxicity tests employing seed germination and root elongation were used following the APAT method (APAT, 2003). *Lepidium sativum,* seeds were used for germination and growth assays on compost aqueous solutions and placed in Petri dishes (90 mm diameter) with one sheet of filter paper as support, in five replicate experiments. After the addition of 10 seeds and 1 mL of test solutions, the Petri dishes were sealed with parafilm to ensure closed-system models. The seeds were placed in a growth chamber at 27°C for 24 h. After this period, the number of seeds germinated was counted and the radical length was measured. The Index of growth (IG) was calculated by multiplying the germinated seed number (G) and length of roots (L). The Germination Index results were used to calculate the effect, expressed as percentage (GI%) with respect to the control using the following equation:

$$GI = \frac{G_S \cdot L_S}{G_C \cdot L_C} \cdot 100 \quad [\%]$$

where S and C stands for the samples and the control, respectively. For the evaluation of the C/N ratio, the content of both total organic carbon (TOC) and nitrogen (N) were measured through a TOC-V and TNM-1 Shimadzu Analyser. VS were determined according as specified in Manual ANPA 03/2001.

3. Results and discussion

3.1 Results achieved for Plant 1.

Fig.3 shows the pattern of the DRI and T_{max}values (a) and VS and GI values (b) measured during the composting time. For sake of completeness in Tab.1 are summarized all the other variables measured. Data reported in Fig.3a reveal an initial increasing of the DRI value from 4729 to 7032 $mgO_2/(kg_{VS}$ h) between sample at process start-up and after 33 days of composting time. This result seems to be contrasting with the expected increase of the sample stability during the composting process.

[FIG.3]

Nevertheless, the low pH value (5.3) of the initial sample (composting time equal to zero) (Tab.1) could have likely inhibited the proper development of the biological process during the respirometric test thus reducing the microorganisms oxygen consumption. This low pH value could be related to the seasonal composition of the matrix subject to composting, which was rich in citrus waste. Moreover, the long storage times (almost one week) before starting the composting process could have favored the beginning of hydrolysis, thus affecting the proper development of the aerobic biological process. However, starting from composting time of 33 days, a progressive reduction of the DRI was obtained from 7032 $mgO_2/(kg_{VS}$ h) (at day 33) to 303 $mgO_2/(kg_{VS}$ h) (at day 184) (Fig.3a).

[FIG.4]

This behavior could be confirmed by the pattern of the observed respirogram charts reported in Fig.4. Indeed, the shape of respirogram chart at t=0 (raw matrix) which showed a very fast increase of instantaneous respiration index, followed by a rapid decrease and, again, a subsequent slow increase before the final decrease, highlighting that the aerobic process did not developed properly. In contrast, the shape of the subsequent respirogram charts was different, with a clear and regular increase of DRI during the test, followed by a net decreasing portion, suggesting in this case the proper development of the aerobic biological process. Moreover, in sample 2 it was observed a prolonged lag phase in the first part of respirometric test, likely related to the still low pH value (5.5). In sample 3, the lag phase was significantly reduced compared to sample 2, whilst it completely disappeared in sample 4. Therefore, excepting sample 1, the last three samples (2, 3 and 4) were characterized by decreasing DRI values. The reduction of the maximum value of hourly DRI confirmed the reduction of the biodegradable organic matter contained inside the sample and the increasing stability reached by the composted matrix, in good agreement with previous results [11].

The maximum temperature values (T_{max}) measured during the respirometric tests reduced from 68°C (at day 33) to 19°C (at day 184) showing a similar trend of DRI associated to the decrease of biological degradation reactions,thus confirming the progressive matrix stability (Fig.3a). Moreover, reaching high temperatures ensured the matrix sanitation. In terms of VS, a reduction from 85% to 48% was observed during the composting time (Figure 3b). Conversely, a progressive increase of the GI value was obtained from 3.15% to 92% thus revealing a very quality of the mature compost, with a final value significantly higher compared to the threshold limit value of 60% imposed by the Italian Regulation (Legislative Decree n. 75/2010). The very low GI values at the beginning of the process are likely related to the production of germination inhibiting compounds such as alcohols, phenolic compound and organic acids, as highlighted by previous studies [44]. This results were well in line with what achieved by Cesaro et al. [45] (Fig.3b). Moreover, the carbon-to-nitrogen ratio decreased over time with a faster reduction in the first phase, due to the carbon mineralization. This reduction slowed down during the curing stage, according to previous results [45]. Moreover, the mineralization of organic nitrogen to ammonia contributed to the pH increase observed during experiments.

[TAB.1]

Fig.5 shows the correlation between the main monitored parameters during the experimental campaign: T_{max} and DRI (Fig.5a), GI and VS (Fig.5b), respectively. Higher temperature reflect higher degradation reactions and lower matrix stability, corresponding consequently to higher DRI values (Fig.5a); this result is in accordance with the study reported by Adani et al. [46]: more stable substrates reach lower temperatures than fresh substrates, as they are characterized by lower microbial activity. GI and VS showed a good correlation too (Fig.5b); indeed, as phytotoxicity decreases (increase of GI), since matrix is stable, the organic matter content of the biomass (expressed in terms of VS) decreases.

[FIG.5]

Tab.2 summarizes the results of the two samples analyzed for the MBT. In particular, data refer to the samples analyzed at the beginning of stabilization time (t) zero (t = 0) and 34 days (t = 34), at the end of the established stabilization time. Data reported in Tab.2 show that the initial sample (t = 0) has a very high DRI value, equal to 12277 $mgO_2/(kg_{VS}h)$, and an acid pH value (5.7). The biological reactors of the MBT plant have in charge the treatment of the under sieve of both residual fraction of separate collection and unsorted waste stream. Due to the very poor percentage of separate collection (close to 20%) in the considered urban case study, the flow stream subject to biological process was characterized by considerable amount of organic matter, thus justifying the very high value of DRI. Moreover, the low pH value has likely influenced the biological process within the MBT. Indeed, at the end of the stabilization time, which duration was set by the plant operator, the achieved DRI value of 5966 $mgO_2/(kg_{VS}h)$ was still significantly higher than the value imposed by the Italian Regulation equal to 1000 $mgO_2/(kg_{VS}h)$ for the waste acceptability in a landfill (Legislative Decree 3 settembre 2020 no. 121). The poor sample stability at t = 34 days was also corroborated by the very low GI value (5.13 %) and the high VS (50%) value compared to the initial sample, thus confirming that the considered sample was not acceptable for landfilling. Consequently, a longer stabilization duration should be required. The very low GI values suggested that the matrix maturity was quite low, also due to the high heterogeneity of the raw matrix (unsorted waste and residual fraction) which could promote germination inhibition. However, the observed results highlighted that a stabilization process was occurring, also confirmed by the halved value of C/N ratio, following the degradation of the organic matter content, according to what reported by Cesaro et al. [43]. From this experimental study, it could be proposed that the stabilization time of 21 days imposed by local authorities in Sicily for unsorted waste and/or residual fraction from separate collection prior to landfill disposal is quite unrealistic and a prolonged duration should be proposed.

[TAB.2]

3.2 Results achieved for Plant 2.

Fig.6 shows respectively the trend profile of DRI and T_{max} values (Fig.6a) and VS and GI values (Fig.6b) measured during the composting time for experimental Campaign 1.

[FIG.6]

Referring to experimental results achieved in Campaign 1, the maximum temperature (T_{max}) measured during the respirometric tests decreased from 52°C (at day 0) to 22°C (at day 120) following the same pattern of DRI, thus confirming the progressive matrix stability (Fig.6a) [46]. Data reported in Fig.6a reveal a decrease of the DRI value from 4940 to 200 $mgO_2/(kg_{VS}\ h)$ between sample at the beginning and after 120 days of composting time, respectively. Moreover, the experimental DRI values can be well expressed by a depletion model, the latter supported by a high correlation index ($R^2 = 0.95$). In general, the DRI values observed for Plant 2 during the experimental campaign 1 were slightly lower compared to what observed for Plant 1, thus suggesting an unlike behavior, probably due to the different composition of the matrix subject to the biological process. This result is confirmed by the lower T_{max} values shown in Plant 2, compared to what observed in Plant 1; indeed, the temperature increase, as above discusses, is usually associated with to the development of biological degradation reactions; therefore, the higher the amount of organic available to biodegradation, the higher will be the temperature during process. Nevertheless, the temperature values during composting are also affected by aeration mode and airflow rates and aeration excess can promote a significant water losses, thus hampering the proper development if biological process [47]. Concerning the VS and GI values (Fig.6b), also in this case it was observed a different behavior compared to what achieved in Plant 1. Indeed, for Plant 2 the VS showed only a limited variation during experiments, while the GI index remained very low throughout experiments, highlighting that the organic matrix was far behind compared to the required Regulation limit, suggesting the presence of germination inhibiting compounds that hinder the maturation of the organic matrix.

Referring to Campaign 2, Fig.7 shows respectively the trend profile of DRI and T_{max} values (Fig.7a) and the trend profile of VS and GI values (Fig.7b). As notable from Fig.7a, both T_{max} and DRI maintained high values during experiments, indicating that at the end of the process, the organic matrix wasn't yet stable. In particular, after an initial increasing of the DRI value from 3851 to 9866 $mgO_2/(kg_{VS}\ h)$ between sample at zero and 14 days of composting time, the latter began to decrease reaching at the end of the composting process a value equal to 5070 $mgO_2/(kg_{VS}\ h)$, which is higher than the biological stability limit. The significant difference between the values obtained from the two campaigns can be attributed to their different seasonality (Campaign 1 in winter, Campaign 2 in summer). On one hand, this aspect could affect the composition of the matrix to be subject to biological process while, on the other hand, the water content of the samples analyzed was significantly different between the two campaigns (Tab.3). Indeed, the moisture values of samples collected in winter were significantly higher compared to what observed in summer; therefore, these lower moisture contents in the full scale plant during Campaign 2 could have slowed down the biological process, thus producing a dried matrix rather than a stable and mature compost. In contrast, the moisture values in Campaign 1 (winter) were more suitable for the development of microorganisms responsible for biodegradation. Indeed, moisture is essential for the microbial metabolic processes can take place. Particularly, biological activity finds optimal conditions in an environment with a water content between 55% and 65%; while, as the humidity of the organic matrix approaches 40%, the composting process begins to be inhibited [43].

[FIG.7]

[TAB.3]

Considering the whole composting process, it was observed a general slight decrease in the solids content (Fig.7b). The GI values also in Campaign 2 remained very low over time, in contrast with the results achieved in previous experiences [48]. A possible explanation could be found in the scarce separation of the OFMSW at the source; indeed, the latter showed poor quality due to the high presence of plastics and other non-compostable materials; therefore, these impurities might have negatively affected the phytotoxic features of the composting matrix.

Fig.8 shows the correlation between T_{max} and DRI for Campaign 1 (a) and Campaign 2 (b), respectively.

[FIG.8]

Referring to Campaign 1 (Fig.8a), the values of biomass maximum temperature (T_{max}), reached during the respirometric tests, and the DRI showed a good correlation (correlation index $R^2 = 0.99$), this result was expected and it was in good agreement with Adani et al. [46]. Conversely, data reported in Fig.8b reveal that, although the high correlation index, DRI proved to be ineffective in describing the biological stability of organic matter.

4. Conclusions

The key findings of this study are summarized as follows. For Plant 1 the results obtained for the composting plant revealed that the initial pH value may exert a relevant role for the proper evaluation of the DRI by means of respirometric tests; low initial pH value could negatively affect the real respirometric test response. Therefore, in order to avoid decrease of pH value during the matrix storage the reduction of the storage time before starting the composting process as much as possible is suggested. Moreover, the DRI revealed to be a useful index to monitor the matrix stability, in order to properly design the composting time. The results obtained for the MBT samples suggested to adopt some pH correction of the inlet sample and to establish a total stabilization time according to the initial DRI value in order to achieve the regulation limits. Finally, for MBT samples, the imposed standard for unsorted matrices is hardly achievable, especially with the suggested processing time of 21 days.

Concerning Plant 2,DRI for Campaign 1 revealed to be an excellent indicator for the evaluation of the biological stability degree, reaching a final value at the end of the composting process equal to 200 $mgO_2/(kg_{VS}\ h)$; while, DRI for Campaign 2 showed weaknesses in the description of the process revealing an increasing trend during the first days of composting treatment. The poor sample stability was also supported by the low GI (5.4%) and the high VS (53%) values. The different DRI values obtained during the two campaigns may be due to the different seasonality in which they were performed, as this influenced the water content of the analyzed samples, and therefore on the development of microorganisms responsible for biodegradation. Lastly, in both campaigns, GI and VS alone proved to be ineffective in describing the degradation of organic matter.

To conclude, the achieved results showed that both initial pH and water content values can affect the real respirometric test response and the development of microorganisms responsible for biodegradation; in addition, DRI proved to be the a reliable parameter in the evaluation of biological stability. As final remark, the simultaneous measurements of the different indices can provide a complete and reliable information about the biological stability and maturity of the organic matrices.

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Figure captions

Figure 1. Schematic layout for Plant 1: MBT (a) and composting (b) line.

Figure 2. Schematic layout for Plant 2.

Figure 3. DRI and T_{max} during the composting time (a); VS and IG pattern during the composting time (b).

Figure 4. Respirogram charts achieved for the different samples, in terms of instantaneous and cumulated DRI values.

Figure 5. Correlation between T_{max} and DRI (a) and GI and VS (b).

Figure 6. DRI and T_{max}(a) and VS and IG (b) trend profile during the composting time for Experimental Campaign 1.

Figure 7. DRI and T_{max} (a) and VS and IG (b) trend profile during the composting time for Experimental Campaign 2.

Figure 8. Correlation between T_{max} and DRI for campaign 1 (a) and campaign 2 (b), respectively.

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Table 3. Water content for the samples analyzed during Campaign 1 and 2.

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Articles other than as stated below are accepted for exclusive publication in the *Journal of Material Cycles and Waste Management*. By submitting a paper, authors guarantee that they have not submitted and will not submit a similar paper for publication elsewhere in any language. If part or all of a paper has been presented at any scientific meeting, this must be declared in a footnote to the title page.

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Journal of Material Cycles and Waste Management

Manuscript title: BIOLOGICAL STABILITY ASSESSMENT OF MSW ORGANIC FRACTIONS BY MEANS OF RESPIROMETRIC AND GERMINATION TESTS

Authors' names: Daniele Di Trapani, Alida Cosenza, Federica De Marines*, Gaspare Viviani

I hereby certify that the authors of the above manuscript have all:
1. Conceived, planned, and performed the work leading to the manuscript, or interpreted the evidence presented, or both;
2. Written the report or reviewed successive versions and shared in their revisions; and
3. Approved the final version.

Further, I certify that:
1. This work has neither been published in whole or in part elsewhere nor is under consideration elsewhere; and
2. This paper has been carefully read by a native English speaker who is familiar with the field of the work. (This applies to authors who are not fluent in English.)

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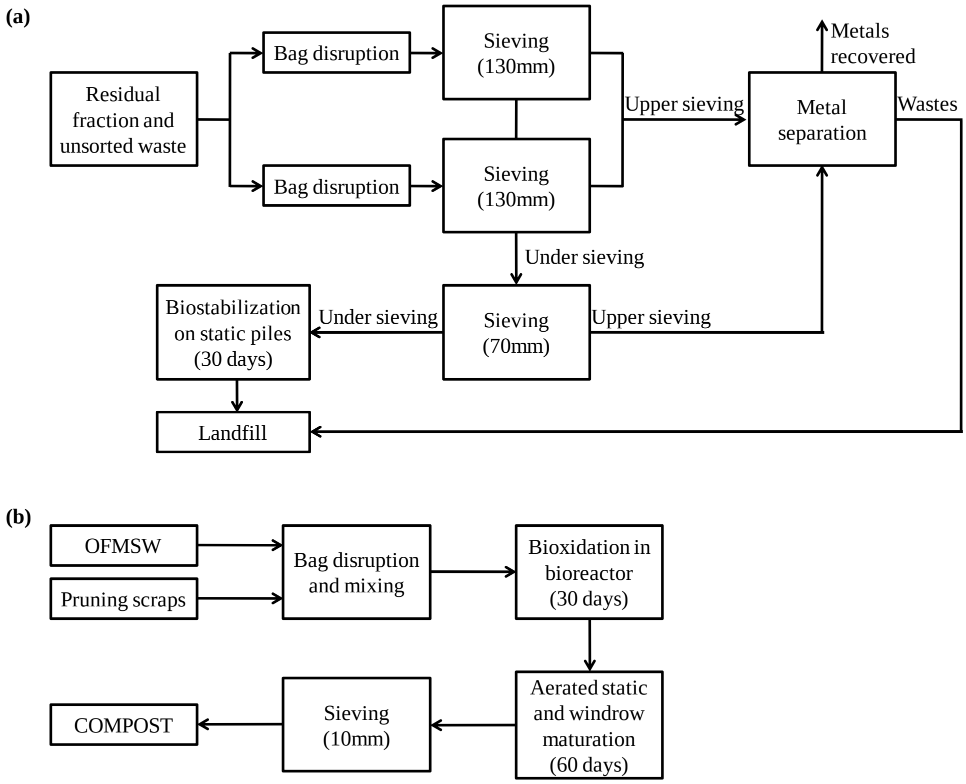
Figure 1



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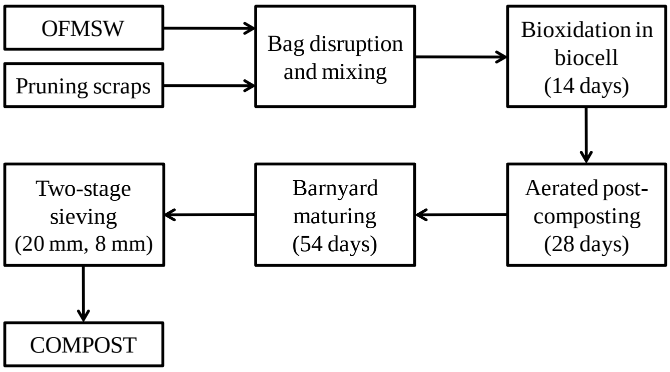
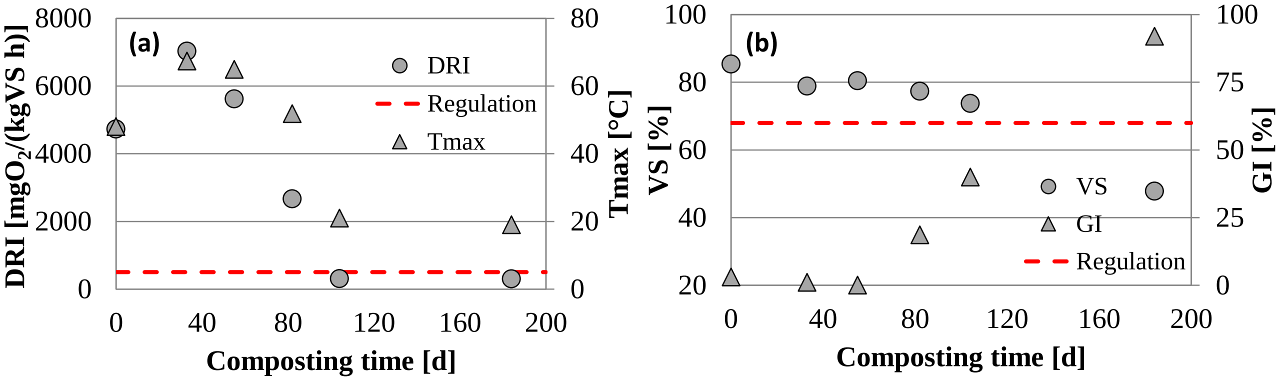


Figure 2. Schematic layout for Plant 2.

Figure 3



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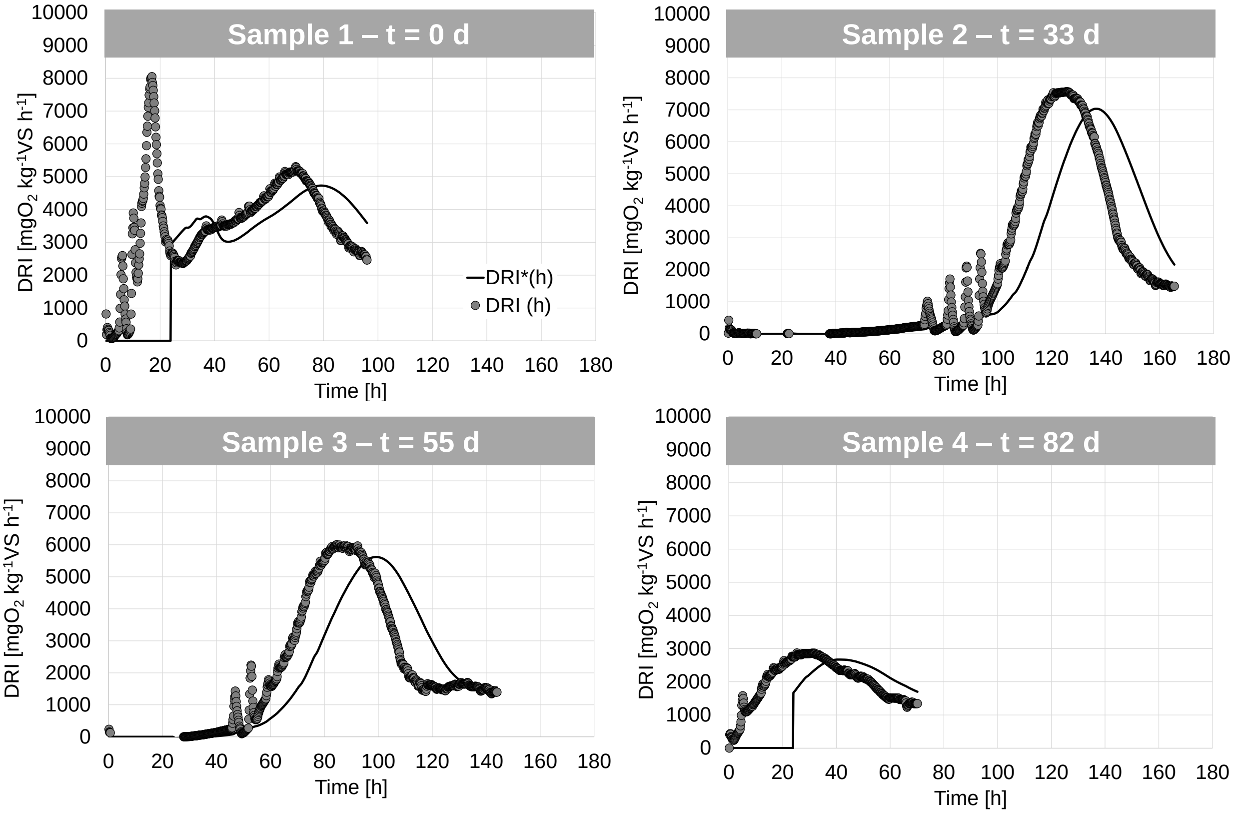

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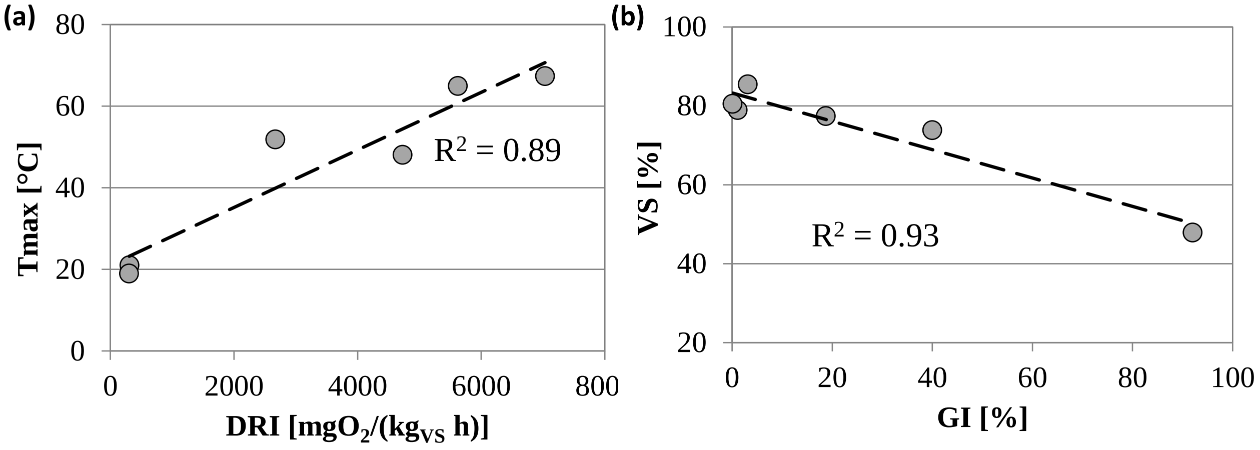

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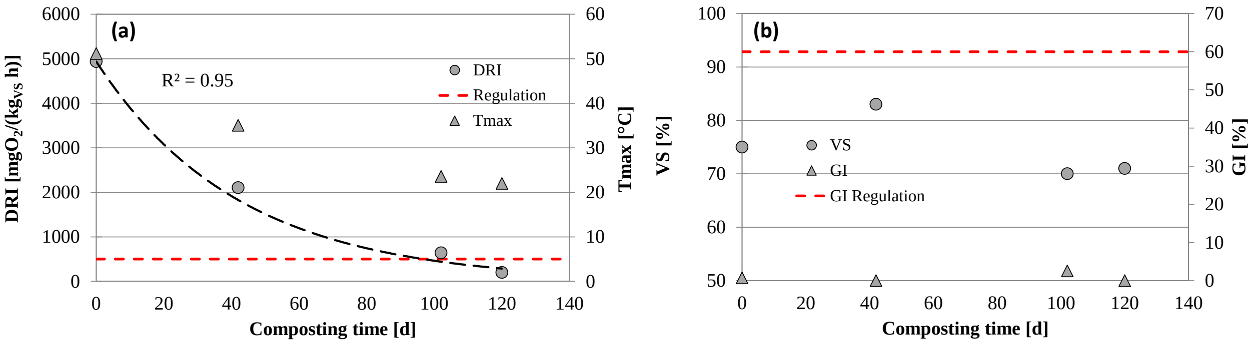

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Figure 7

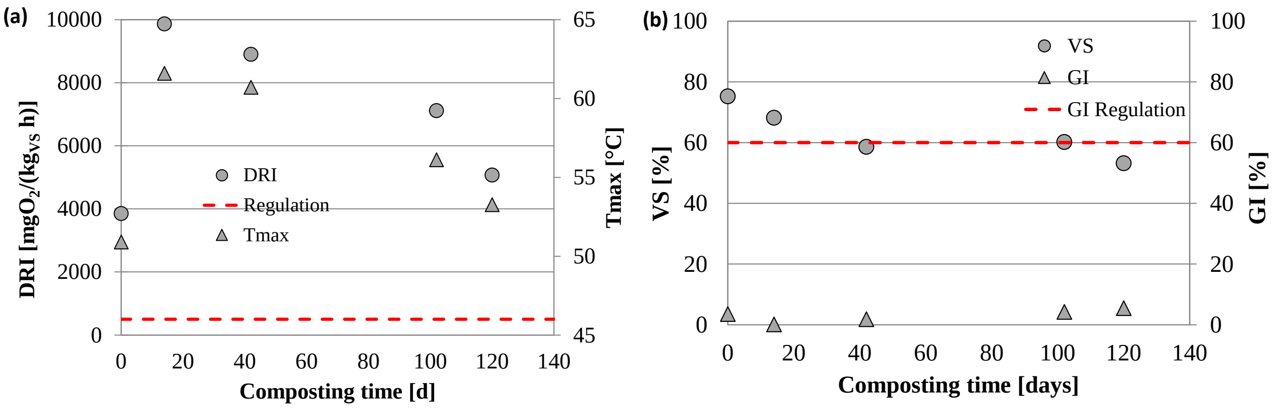

Figure 7. DRI and T_{max} (a) and VS and IG (b) trend profile during the composting time for Experimental Campaign 2.

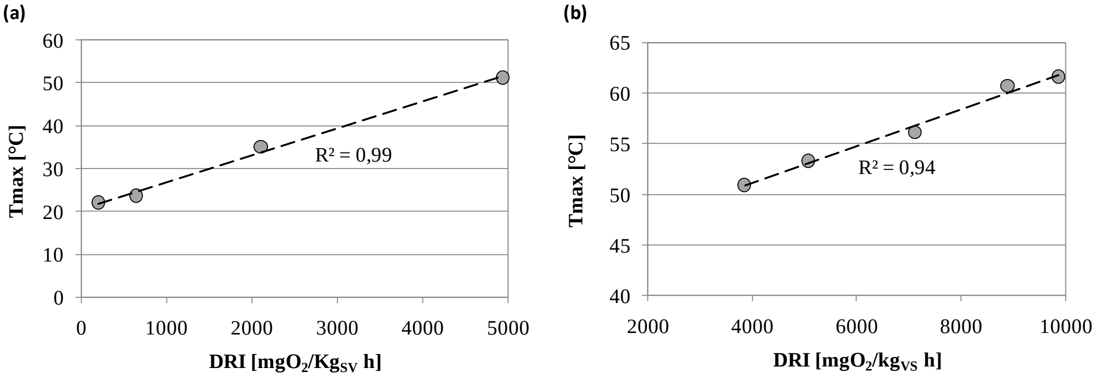

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Table 1

Table 1. pH, moisture, TS and C/N measured for the sample collected in the composting plant.

Parameter	**Symbol**	**Unit**	**Value**					
		d	**t = 0**	**t = 33**	**t = 55**	**t = 82**	**t = 104**	**t = 184**
pH	-	-	5.3	5.5	6.4	7.7	7.7	8.2
Umidity	U	%	66.2	57.5	51.8	33,8	32	25
Total solids	TS	%	33.8	42.5	48.2	66.2	41.06	75.25
Carbon-to-nitrogen ratio	C/N	mgTOC/ mgTN	-	8.75	6.62	6.53	6	5

Table 2. Measured data for the samples analyzed at the stabilization time (t) zero (t = 0) and 34 days (t = 34 days) in the MBT.

Variable	**Symbol**	**Unit**	**Value**	
Duration	**d**	**days**	**t = 0**	**t = 34**
pH	-	-	5.7	7.4
Umidity	U	%	49.5	35.4
Total solids	TS	%	50.5	64.6
Total volatile solids	TVS	%	65	50
Index of growth	IG	%	0.04	5.13
Dynamic respirometric index	DRI	mgO_2/kg TVS*h	12277	5966
Maximum temperature	Tmax	°C	47	48
Carbon-to-nitrogen ratio	C/N	mgTOC/mgTN	13.05	6.35

Table 3. Water content for the samples analyzed during Campaign 1 and 2.

Moisture content [%]					
	t = 0days	**t = 14 days**	**t = 42 days**	**t = 102 days**	**t = 120 days**
Campaign 1	60	-	49	65	55
Campaign 2	52	49.6	22	25	31