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Compost from organic solid waste: Quality assessment and European regulations for its sustainable use

A. Cesaro [a] , V.Belgiorno[a], M.Guida[b]

[a] SEED – Sanitary Environmental Engineering Division, Department of Civil Engineering, University of Salerno, via Giovanni Paolo II, 84084 Fisciano, SA, Italy

[b] Federico II Naples University, Department of Structural and Functional Biology, Ecotoxicology Research Laboratory, I-80126 Naples, Italy
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Highlights

•OFMSW compost is increasingly used in agriculture as a soil conditioner or fertilizer.
•Regulations on compost quality show heterogeneity and blind spots in its characterization.
•The need for standardized procedures to assess compost quality is highlighted.
•The reliability of Italian regulation phytotoxicity parameter is evaluated.

Abstract

Composting represents the most common option to recover material from the organic fraction of municipal solid waste, due to the possibility to use compost as a fertilizer. To this end the assessment of compost quality needs to be adequately enforced in national regulations. This work aims at reviewing European regulations regarding compost quality, in order to identify the most common parameters used to define compost characteristics as fertilizer. It was found that the majority of European States requires the fulfilment of specific criteria, but a lack of uniformity in regulations and guidelines can be observed. In particular the approach to the evaluation of stability and maturity, which account for compost safe use on soils, shows great heterogeneity throughout Europe. As stability and maturity go hand in hand, the proper characterization of compost toxicity should rely on the determination of both parameters. The results of an annual monitoring of compost under the Italian regulation highlighted, indeed, that the evaluation of the

germination index can provide only partial information on the product maturity but not reliable operating indication on compost inhibitory properties.

Keywords

Biological stability
Compost related risk
Maturity
Solid waste compost
Standard procedure
Toxicity

1. Introduction

Composting is the biological degradation process of organic matter under controlled aerobic conditions, with the production of a biologically stabilized material, which is not oxygen consuming nor able to generate phytotoxic metabolites.
The microbial community in composting process converts degradable organic matter into more stable, humified forms as well as water, carbon dioxide and ammonia, releasing heat as a metabolic waste product (Ciavatta et al., 1993). The aerobic conversion process occurs through different steps: degradation extent depends on the input material as well as on the process operating conditions.
Compost originating from the organic fraction of municipal solid waste (OFMSW) is increasingly used in agriculture as a soil conditioneras well as a fertilizer, in order to meet both crop nitrogen and organic matter addition (Hargreaves et al., 2008, Iqbal et al., 2010). In Europe the use of compost is regarded as a way forward to address both security of nutrients and organic matter supply thus improving soil conditions (European Union, 2012). It has been estimated that 32% of the produced compost originates from biowaste and 9% from mixed waste, whereas the remaining part mainly comes from green waste and sewage sludge. Almost 50% of the whole amount of compost produced in Europe is used in agriculture (Sayen and Eder, 2014).
The application of OFMSW compost on soil may entail both health and environmental risks that are often neglected. Solid waste may contain a number of chemical or biological contaminants that may expose different populations to health hazards (Déportes et al., 1995). The removal of these pollutants from waste improves compost quality and, to this end, collection systems play a fundamental role.

Mechanical selection of residual waste and source sorting represent the two main pathways to obtain OFMSW. Cecchi et al. (2003) highlighted that OFMSW coming from mechanical sorting has a higher total solid (TS) content, due to the greater presence of materials, such as plastic and glass, which are not biodegradable and affect compost inert content. Gomez (1998) also proved that heavy metal concentration is significantly higher for compost originated from the treatment of MSW without separation than from source separated waste. Conversely, Zdanevitch and Bour (2011) highlighted that there are not significant differences, both in terms of organic and inorganic pollutants, between compost originated from mechanical sorted OFMSW and the one from source sorted organic waste. The same authors stated that compost is better stabilized when composting process follows an anaerobic stabilization phase, pointing out the importance of the biological process efficiency. A proper composting extent allows the degradation of some contaminants along with the substrate: differently from metals, organic contaminants may be metabolized by microorganismsduring a composting process (Oleszczuk, 2007); only the very stable ones may persist in compost because their complex molecular structure is not easy to biodegrade during a conventional biostabilization process.
Scientific studies have been mainly focused on the detection of contaminants in compost, where harmful contents can be found due to the concentration effect originating from the curing phase (Paré et al., 1999). This approach takes into account that the concern related to the presence of persistent organic compound is mainly due to their resistance to degradation and tendency to bioaccumulation (Macgregor et al., 2010). If potentially toxic compounds that are ubiquitous in the environment can also be present in waste going to composting, it is necessary to quantify the potential for uptake of toxins and/or pathogens into the food chain, resulting from the use of waste produced composts within the supply chain (Hough et al., 2012).
Therefore compost characterization, both in terms of stability and maturity, represents the main requirement in order to safely use compost for agricultural purposes.

Compost stability is related to the level of activity of the microbial biomass. Several approaches have been proposed to assess biological stability of organic matter. Some of them consider both chemical methods (López et al., 2010), which are not expensive, and physical ones (Fernández et al., 2012), recognized as less time consuming. Biological tests have been largely investigated, whereas enzymatic methods have been proposed recently (Komilis et al., 2011).
Baffi et al. (2007) compared three techniques to assess the stability of 15 different composts and found that, differently from the biological one, chemical and thermo-

analytical methods do not reflect directly the content of easily degradable organic material in composts and, as they are also affected by the composition of the input material, they do not substantially describe biological stability correctly. Biological tests are, therefore, suitable to realistically assess the achievement of the biological stability after a composting process. Such tests can be performed in either aerobic (Scaglia et al., 2007, Scaglia et al., 2011) or anaerobic (Barrena et al., 2009) environment as well as under static or dynamic conditions (Scaglia et al., 2000). Respiration techniques, in particular, have been reported to provide the more detailed compost stability characterization (Barrena et al., 2014).

On the other hand compost maturity refers to the degree of humification and implies the absence of both phytotoxic compounds and pathogens (Bernal et al., 1997). Maturity is partially affected by the relative stability of the material, since phytotoxic compounds are produced by the microorganisms in unstable composts (Bernal et al., 2009). Nevertheless Komilis and Tziouvaras (2009) demonstrated that stable compost, characterized by a low microbial activity, cannot be mature and, hence, phytotoxic. This outcome suggests that maturity also describes the impact of other compost chemical properties on plant development.

Even though different procedures are often used to describe compost maturity degree (Bernal et al., 2009), it is usually assessed by phytotoxicity tests.

Plant tests used in both research studies and quality standards can be divided into four broad categories: germination tests (including root assessments), growth tests (assessment of top-growth and sometimes root mass), combinations of germination and growth and other biological methods such as enzyme activities. Germination tests provide an instant picture of phytotoxicity, whereas growing tests will be affected by continuing changes in the stability or maturity of the compost tested: there may be damaging effects on growth in the earlier stages, but beneficial effects later on, with different conclusions depending on the time of assessment (Bernal et al., 2009). Komilis and Tziouvaras (2009) stated that germination indices are highly dependent on the types of seeds used.

Therefore the evaluation of compost maturity can properly rely on germination tests, which are not time-consuming, on condition that the seed to be used must be clearly identified in order to ensure result reproducibility.

Even though many attempts have been made in order to define the most suitable methods, further research is required for the definition of a reliable procedure to evaluate compost stability and maturity and to assess the effective risks associated with its agricultural use.

In Europe regulations dealing with compost quality assessment are differently established at national level.

This evidence states a risk for human health associated to both the use of toxic compost on soils and to the cross-border commerce of agricultural products. The lacks in quality assessment regulations imply the use of potentially harmful compost for agricultural purposes, including the cultivation of food products. This risk reasonably exists also in countries where strict limit values are established for compost quality evaluation, as any specific restriction is set for agricultural product market in Europe.

This work aims at reviewing European regulations dealing with compost quality, in order to identify the most common parameters used to define its characteristics as a fertilizer. In particular, stability and maturity tests adopted in different European States are discussed. Following the analysis of enforced legislation and guidelines, compost samples collected in a full-scale plant treating source sorted OFMSW were analyzed under the Italian regulation, in order to identify limits and capabilities of the proposed characterization procedure.

2. The assessment of compost quality in Europe

Across European Member States standards that compost must meet in order to be qualified as product differ considerably (Table 1). In some countries, including Austria, France, Germany, Italy, there are explicit and detailed rules set by legislation under waste law. In other countries, such as the United Kingdom, the classification of compost as waste is left to case by case decisions of the regulatory authorities. In the remaining Member States, there is an implicit assumption that compost ceases to be waste when registered as a product (Sayen and Eder, 2014). Similarly regulations and standards on compost quality are not equally established at European level, with the exception of the limits set by the Decision 2006/799/Ce as well as by the Animal By-Products Regulation. The former act specifies the criteria for a compost to be awarded of the community eco-label for soil improvers; the latter provides detailed hygienization rules for composting and biogas plants which treat animal by-products. A further reference is provided by the Regulation 834/2007/EC that lays down conditions for the use of compost in organic farming.

Table 1. Compost criteria for its qualification as product/waste in different European Member States.

Country	Compost status	Criteria for the definition of compost status and its use on soil
Austria	Product	– Production in a registered plant; – Origin from specific input materials; – Documented life cycle (from waste reception to product selling); – Certification of the product by acknowledged institutes.
Flanders (Belgium)	Product	Requirements on: – Input materials; – Process conditions; – Product characteristics and use.
Wallonia (Belgium)	Waste	Among the four classes (A-D) defined by the Government Decree, compost belong to class B and can be used on/in agricultural soil. Within class B, subclasses B1 and B2 are distinguished. The main difference lays in the acceptable metal content.
Czech Republic	Product	Need for registration as “One Compost Class” on the basis of the inspection/control of samples performed by the Control and Testing Institute for Agriculture.
Denmark	Waste	Possibility of using for agricultural purposes, with strict limit on heavy metal content applied to soil.
Finland	Waste/product	Defined as waste under the Waste Act, compost turns into product if the requirements of the fertilizer regulations are fulfilled.
France	Waste/product	Requirements of the NF U 44-051 Standard must be fulfilled. If not, compost is considered as waste.
Germany	Waste	Requirements established by the bio-waste Ordinance. On a voluntary basis, if certified under the QAS of the RALGZ 251, compost can be put on the market and used as a *PRODUCT*.
Greece	Product	Requirements of the Specifications and General Programmes for Solid Waste Management need to be fulfilled for the compost to be sold.
Hungary	Waste/product	Requirements of the Statutory Rule 36/2006 (V.18) must be fulfilled. If not, compost is considered as waste.
Ireland	Product	On site specific waste licence or waste permit must be fulfilled.
Italy	Waste/product	Requirements of the Legislative Decree 75/2010 must be fulfilled for compost use as fertilizer. If not, environmental restoration applications can be considered, when limit values of Inter-ministerial Decree 27/7/84 are fulfilled. Otherwise compost is considered as waste.
Latvia	Product	Requirements on hygienic properties and pollutant potential must be certified by acknowledged laboratories.
Lithuania	Product	Certificate on compost quality provided by the producer, without external approval and/or inspection.

Country	Compost status	Criteria for the definition of compost status and its use on soil
Luxembourg	Product	Fulfilment of quality assurance system based on: –input materials characteristics; – process operating conditions; – product properties (pathogens, heavy metals,) and labelling.
The Netherlands	Product	– Process and its documentation; – Product properties, including stability (no limit value!); – Declaration and labelling.
Poland	Waste/product	According to the Waste Law/Fertiliser Law
Portugal	Product	Considered as a soil amendment under the Fertiliser Law
Slovakia	Product	– Process operating conditions; – Product qualitative characterization; – Certification by acknowledged laboratories/institutes
Slovenia	Waste/product	Requirements of the Decree on the treatment of biodegradable waste must be fulfilled. If not, compost is considered as waste.
Spain	Product	– Origin from specific input materials; – Documented life cycle (from waste reception to product selling); – Requirements for compost qualitative characterization.
Sweden	Waste	Standard defined by the Swedish Standardisation Institute.
UK	Waste/product	Depending on case by case decision, on the basis of the possible agricultural benefit. When considered product, standard certification protocols are followed.

Adapted from Sayden and Eder (2014).

However within Member States, standards on the use and quality of compost differ substantially, partly due to differences in soil policies.

The lack of harmonisation creates legal uncertainty for waste management decisions and for the promotion of quality assurance. A high level of environmental protection can be achieved only if there is reliable and comparable information on the relevant product properties, whose variability should be within known limits.
While the agronomic value (C/N ratio, minimum carbon content, …)
and contaminant presence in terms of heavy metals and inerts are usually well established in compost quality regulations, a lack in uniformity can be recognized for direct methods used to assess pathogen presence and phytotoxicity, as shown in Table 2, where regulation or guidelines established in different countries are listed.

Table 2. Compost quality assessment in terms of pathogen concentration and phytotoxicity in different European Member States.

Country	**Regulation**	**Application**	**Parameter**	**Limit value**
Austria	Statutory Guideline	Land reclam.	*Salmonella*	Absent
		Agriculture	*Salmonella*	Absent
			E. coli	If positive result, recommendation for safe use
		Sacked, sport/playground	*Salmonella*	Absent
			E. coli	Absent
			Camylobacter	Absent
			Listeria	Absent
		Technical use	No requirements	
		Horticulture/substrate	Weeds/propagules	Germination ≤3 plants/L
Belgium	VLACO		Process control	Time, temp relation
			Weeds	Absent
Czech Republic	Biowaste Ordinance		*Salmonella*	Absent
			E. coli	$<10^3$ CFU/g
			Enterococcae	$<10^3$ CFU/g
Denmark	Biowaste Ordinance	Controlled sanitized compost	*Salmonella*	Absent
			E. coli	<100 CFU/g FM
			Enterococcae	<100 CFU/g FM
Finland			*Salmonella*	Absent in 25 g
			E. coli	1000 CFU/g
			Root rot fungus	Not ascertainable in substrates used in seedling production
			Quarantine pests causing plant diseases	Not ascertainable in fertiliser from plant waste or substrates in greenhouse production
France		Gardening/retailer	*Salmonella sp.*	Absent in 1 g
			Helminth ova	Absent in 1 g
		Other use	*Salmonella sp.*	Absent in 25 g
			Helminth ova	Absent in 1.5 g
Germany	Biowaste Ordinance		*Salmonella senft.*[a]	Absent
			Plasmodoph. Brass[a]	Infection index: ≤0.5

Country	**Regulation**	**Application**	**Parameter**	**Limit value**
			Tobacco mosaic virus 1	Guide value biotest: ≤8/plant
			Tomato seeds[a]	Germination rate/sample: ≤2%
			Salmonella senft.[b]	Absent in 50 g sample
			Weeds/propagules	Germination ≤2 plants/L
Italy	Fertilizer law		*Salmonella*	Absent in 25 g
			E. coli	≤1000 CFU/g
				≤5000 CFU/g (max value)
			Weeds	Germination index ≥60%
Latvia	Cabinet Regulation no. 530 – 25.06.06	Fertilizers	*Salmonella*	Absent in 25 g
			E. coli	≤2500 CFU/g
Netherlands	Beoordeli ngsrichtlijn keurcompost		Eelworms	Absent
			Plasmodoph. Brass.	Absent
			Weeds	Germination ≤2 plants/L
Poland		All application	Ascaris	Absent
			Trichuris	Absent
			Toxocara	Absent
			Salmonella sp.	Absent
Slovenia	Decree on the treatment of biodegradable waste		*Salmonella sp.*	Absent in 25 g
Spain			*Salmonella sp.*	Absent in 25 g
			E. coli	<1000 MPN/g
United Kingdom	PAS 100 voluntary standard	All application	*Salmonella*	Absent in 25 g
			E. coli	≤1000 CFU/g
			Weeds/propagules	Germination weed plant: 0/L

[a] Process validation.

[b] Compost production.

Adapted from Sayden and Eder (2014).

The most common criteria are *Salmonella* and *E. coli* detection with reference to pathogen presence and germination index for phytotoxicity. In many European countries regulations also provide indirect methods to prevent pathogens and phytotoxicity in compost through the requirement of a specific temperature profile during the stabilization process.
The detection of pathogens by means of *Salmonella* determination is required by twelve states out of the fourteen ones listed in the table; additionally, eight out of those twelve countries consider the estimation of *Salmonella* along with *E. coli* to verify the presence of pathogens in compost. Differently, Belgium VLACO relies on process control while the Netherlands consider different species.
The evaluation of phytotoxicity by means of the germination index is applied in Austria, Italy, Germany, the Netherlands and the United Kingdom: in Italy and Germany, it is a parameter enforced by law whereas, in the other countries, an indicative limit value is provided in existing guidelines.

The assessment of compost stability by specific tests is not as spread as the one of phytotoxicity throughout Europe and it is mainly carried out on voluntary basis. In Germany, the voluntary quality assurance RAL GZ identifies different compost classes according to the biological stability evaluated by a self-heating test. The same method has been borrowed from both Luxembourg and the Netherlands (Sayen and Eder, 2014). The inclusion of stability criteria for compost quality evaluation is a relevant issue, as a stability requirement can help prevent the introduction into the soil of materials that have hardly undergone any treatment.
It seems interesting to highlight that regulations enforced in some Member States, such as Austria, Belgium, France, Germania, Denmark, Luxemburg also consider persistent organic compounds (i.e. dioxins, PAHs, AOX, …). Their presence in compost is mainly related to the characteristics of the input material, which is not usually the focus point of regulations. Currently most European States define the kind of waste that are allowed to be treated for compost production, but only few of them, such as Luxemburg, the Netherlands and Sweden, clearly specify the kind of material to be excluded.
Although the control of the input substrate is important, composting products should be always evaluated, as both stability and maturity result not only from the qualitative characteristics of the substrate but also from the proper development of the process.

The analysis of compost quality assessment regulations in Europe proved that it is affected by high variability, both in terms of parameters and limit values and suggested that further efforts must be provided for the standardization of a common evaluation

method and for the definition of reliable threshold limits. Regulations should provide, for each class of contaminant, limit concentrations able to ensure that the risk associated with compost use for agricultural purposes is acceptable for both public health and environment. To this end, risk analysis represents the most suitable tool, as it allows the evaluation of the maximum concentration of toxic compounds that can be found in compost so that its use involves a tolerable risk. At the same time, for limit values that are already legally established, risk analysis can support the quantification of hazard to health and environment in order to verify its acceptability.
As an example of the importance of reliable procedures for compost quality assessment, a case study is presented in the following paragraphs.

3. Reliability of Italian regulation indicators: a case study

In Italy compost quality assessment is disciplined by Legislative Decree no. 75/2010, which regulates characteristics of fertilizers originated from different substrates. The achievement of adequate stability and maturity is ensured by indirect methods based on both temperature profile and minimum process duration, which are established by the Ministerial Decree enforced since 05/02/1998.
The monthly monitoring of compost quality under Italian regulation is presented in the following paragraphs, along with the experimental activity carried out in order to identify any relation between composting curing phase duration and *Lepidum sativum* germination index, which had been recently enforced within Italian regulation for fertilizer commercialization. Moreover, since germination index evaluation proved to be highly dependent on the kind of seed, it was also performed with *Lactuca sativa* (Charles et al., 2011), *Cucumis sativus* (An et al., 2004) and *Sorghum saccharathum* (Oleszczuk and Hollert, 2011).

3.1. Materials and methods

The compost under investigation originated from an integrated anaerobic/aerobic treatment of source sorted organic fraction of municipal solid waste (SS-OFMSW): the two stage anaerobic step produces a digestate entering a further stabilization step, under aerobic conditions. The retention time in the digesters is approximately 76 days, whereas the aerobic step lasts 95 days, five days more than Italian regulation requirement.
The produced compost is stored into an opened windrow, on a shield-covered area, with neither turning nor forced ventilation. Storage period can vary according to the product

demand that regulates its selling. During this period, uncontrolled biological processes can occur depending on the adequacy of environmental conditions as well as on the bioavailability of organic matter. In order to verify the effect of the storage period on the maturity of compost, phytotoxicity tests were carried out on the following kind of samples:

- freshly produced compost, which underwent the full characterization under Italian regulation for fertilizer commercialization (sample A);
- compost produced five months before the sampling, which was the oldest product still stored at the plant when the sampling campaign started (sample B);
- composite material, obtained by mixing compost samples produced in the previous five months (sample C).

The compost was monthly sampled and analyzed according to the UNI 10780: 1998 procedure. This monitoring campaign was performed over one year.
In order to perform phytotoxicity tests, the sample (200 g) was mixed with water to reach 85% moisture content, stored for 2 h and centrifuged at 6000 rpm for 15 min. The sample supernatant was then filtered at 3.5 atm with sterilizing membrane and the aqueous extract was diluted to a 30% concentration.

For *L. sativum*, *S. saccharatum*, *C. sativus* assays, bottoms of Petri dishes(90 mm diameter) were lined with filter paper and moisturized with 3 mL of test solution or deionized water, used as control. Each plate was seeded with 10 seeds of *L. sativum*, *C. sativus* and *S. saccharathum*(Ingegnoli s.p.a) and incubated in the dark at 25 ± 1 °C for 72 h. Afterward the number of germinated seeds was counted and the total length of the seedlings, including both root and shoot, was evaluated. According to UNICHIM (2003), the seed was considered to be germinated when radicle was over 0.5 mm long.
For *L. sativa* tests, bioassays used Petri dishes (50 mm diameter) with one sheet of Whatman no. 1 filter paper as support. After the addition of 25 seeds (Ingegnoli s.p.a.) and 2.5 mL of test solutions, the Petri dishes were sealed with Parafilm to ensure closed-system models and placed in a growth chamber at 25 °C. Bioassays took 5 days and after growth, plants were frozen at 10 °C for 24 h to avoid subsequent growth during the measurement process (Macìas et al., 2000).
The germination index (GI) was calculated according to the following equation:

$$GI(\%) = \frac{G_1 L_1}{G_2 L_2} x100$$

where G_1 is the number of seeds germinated in contact with test solution; L_1 is the average radicle length originated in contact with test solution; G_2 is the number of seeds germinated in contact with control solution; L_2 is the average radicle length originated in contact with control solution.

All tests were performed in duplicates and repeated three times.

3.2. Results and discussion

During the annual monitoring compost was found to be characterized by pH values ranging between 6 and 8.5 (Fig. 1) and C/N ratio lower than 25 (Fig. 2). These outcomes suggested that composting processdeveloped properly thus reducing the amount of organic carbon to be converted by microorganisms. Similarly, results showed that metal concentrations were always below limit values (Fig. 3).

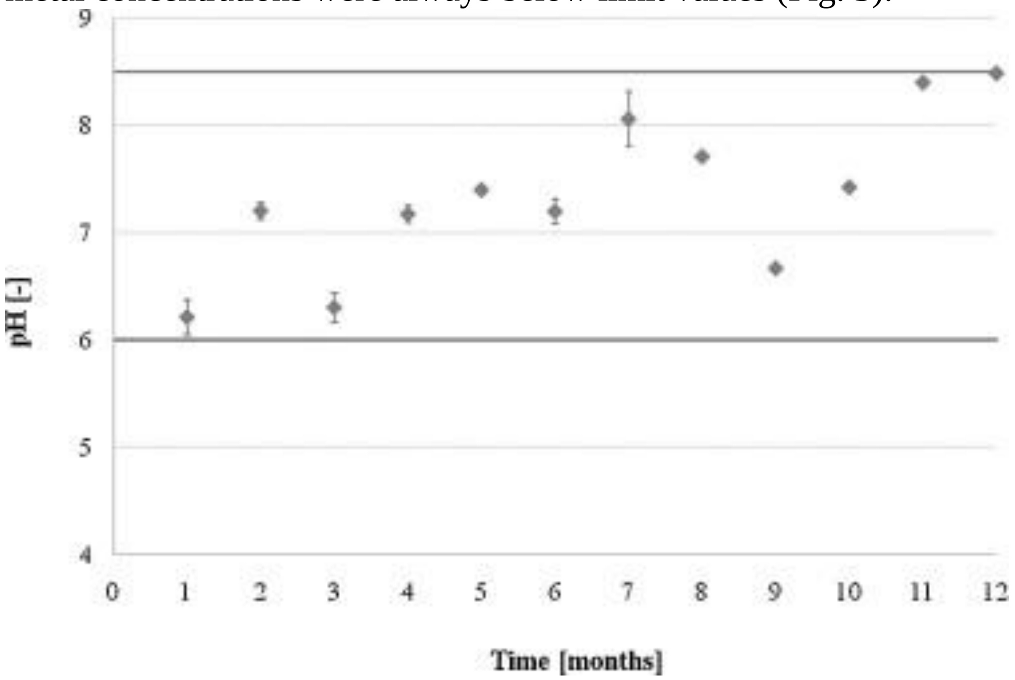

Fig. 1. Compost pH values during the monitoring campaign (pH = 6–8.5).

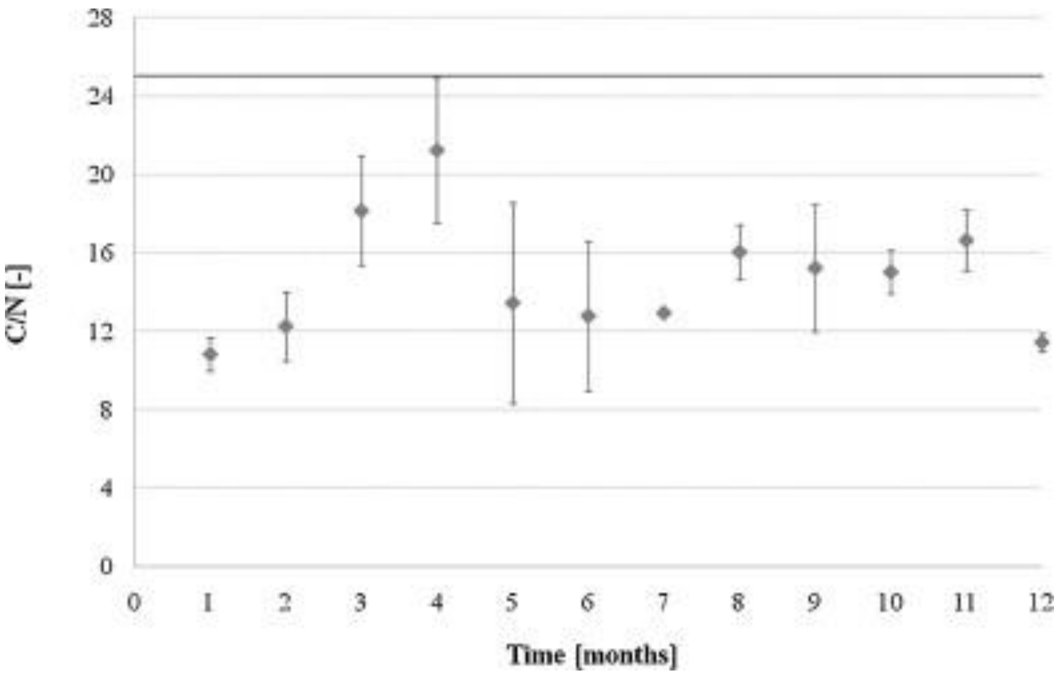

Fig. 2. Compost C/N ratios during the monitoring campaign (C/N ≤ 25).

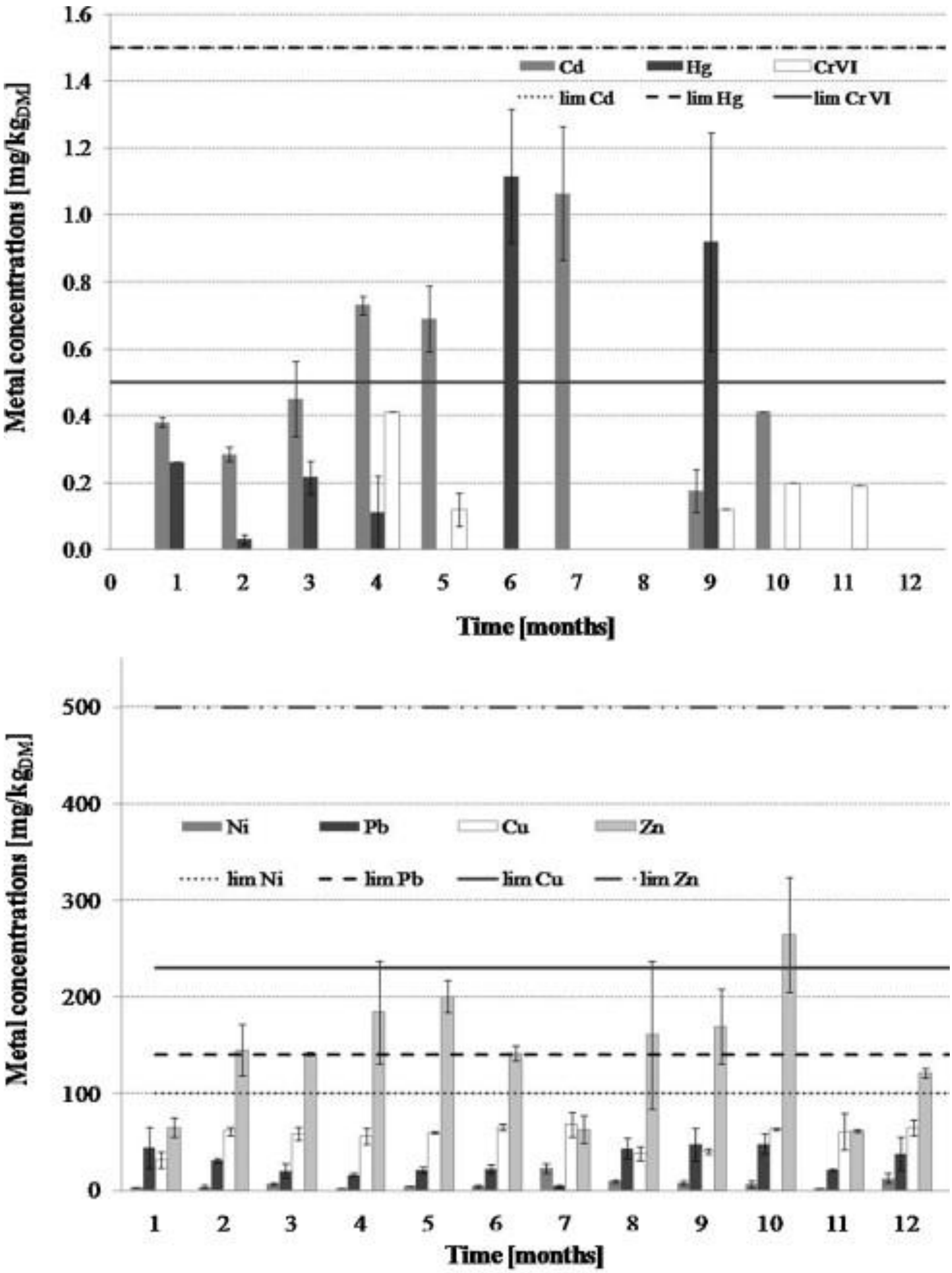

Fig. 3. Heavy metal concentrations in compost during the monitoring campaign.

Metal content in compost was found to be far below the one found by Zorpas et al. (2008), likely due to the different materials destined to the composting process. However the concentrations of metals were observed to be also lower than the ones reported by Hamidpour et al. (2012) for composted municipal waste; only zinc content was found of the same order of magnitude. Bearing in mind the results of this study referring to compost incorporation for the correction of metal deficiency in soils, it can be concluded that the compost under investigation can be valuably applied in Zn-poor soils, as the concentration of other heavy metals was found to be not enough high to bring concern about toxic metal accumulation.

The presence of impurities, mainly plastic materials, was also observed. Italian regulation establishes that the content of plastic, glass and metals with a size greater than 2 mm has to be lower than 0.5% on a dry basis. As the organic waste going to composting was mainly collected in plastic bags, the content of impurities was frequently found to be higher than the limit values; in these cases, experimental results slightly exceeded the required limit values. The size of the particle analytically detected in compost was always lower than 10 mm, as composting curing phase ends in a sieving step realized by a trommel screen with 10 mm wide holes. Therefore the presence of impurities was not considered of great concern as it could be easily reduced by promoting the use of biodegradable bags for organic waste collectionas well as by providing an efficient sieving of the waste destined to composting.

Similar consideration arises for the concentration of *E. coli*. On the eighth month of monitoring it was observed to exceed limit value, but such an isolated case was related to incorrect sample handling.

Fig. 4 plots germination index values obtained during the monitoring campaign: for the first seven months it was found to be lower than 10%, which is very far from the set limit value of 60%.

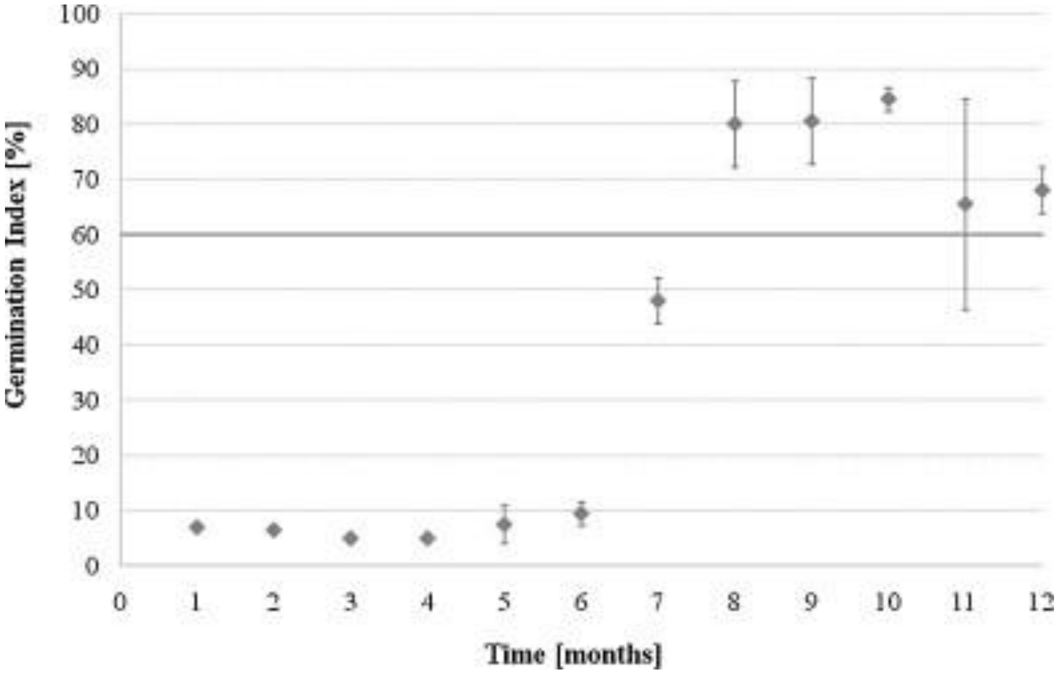

Fig. 4. Germination index in compost during the monitoring campaign (GI ≥ 60%).

The germination index is representative of compost phytotoxicity: the lower is the plant growth, the higher is the inhibitory effect of the tested substrate. Therefore monitoring results indicated a serious inhibition potential of the compost under investigation.
This evidence could be related to both the quality of the input material and the composting operating conditions. As process duration lays in the range reported in literature to obtain a ripe product (Sidelko et al., 2010), scarce aeration could have negatively affected the process.
A recent study pointed out that aeration rate is the main factor influencing compost stability: when aeration rates do not provide oxygen content above 10%, the product is not adequately biologically stabilized (Guo et al., 2012). It has been widely documented that incomplete composting limits the degradation of phytotoxic intermediates and synthetic compounds (Getahun et al., 2012).
Since any inhibition phenomenon was observed during the biological process, phytotoxicity could be most reasonably related to the low level of compost stability.

In order to verify this hypothesis, the germination index test was repeated on three samples of composts, which had been stored for different period of time after production.

L. sativum tests show that the freshly produced compost (sample A) was characterized by a germination index lower than 40%, which is representative of a material inducing sensible inhibition on plant growth. According to the Italian legislation, this compost could not be utilized as a fertilizer. However, the storage of the compost into an opened windrow, even without an aeration system, changed its characteristics, reducing its inhibition power, as given in Fig. 5.

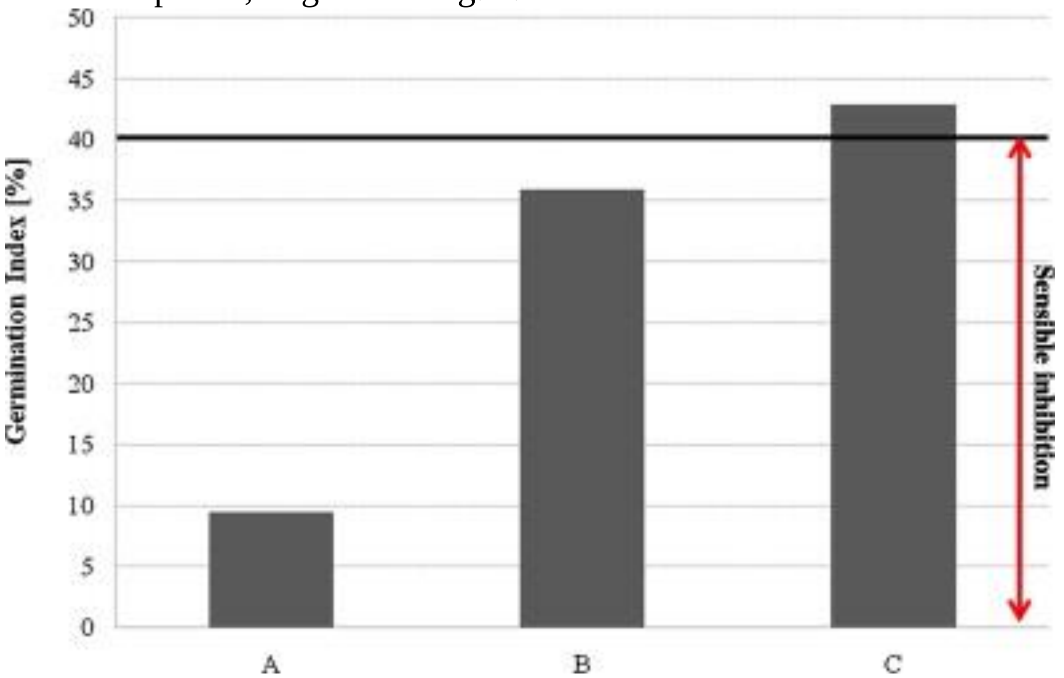

Fig. 5. Results of germination tests with *L. sativum* on different compost samples.

Compost phytotoxicity changes proved that the germination index, in combination with the other parameters fixed by Italian regulation, does not allow a reliable assessment of the material quality: the increase in germination index after storage can be reasonably related to the occurrence of a further material stabilization, which is not directly considered by Italian regulation.

Therefore the evaluation of compost stability is fundamental not only to reach the complete and reliable characterization of compost quality for its safe use in agriculture but also for the definition of the composting process efficiency.

Moreover sensible differences in maturity evaluation can be obtained by using different plant seeds, as plotted in Fig. 6.

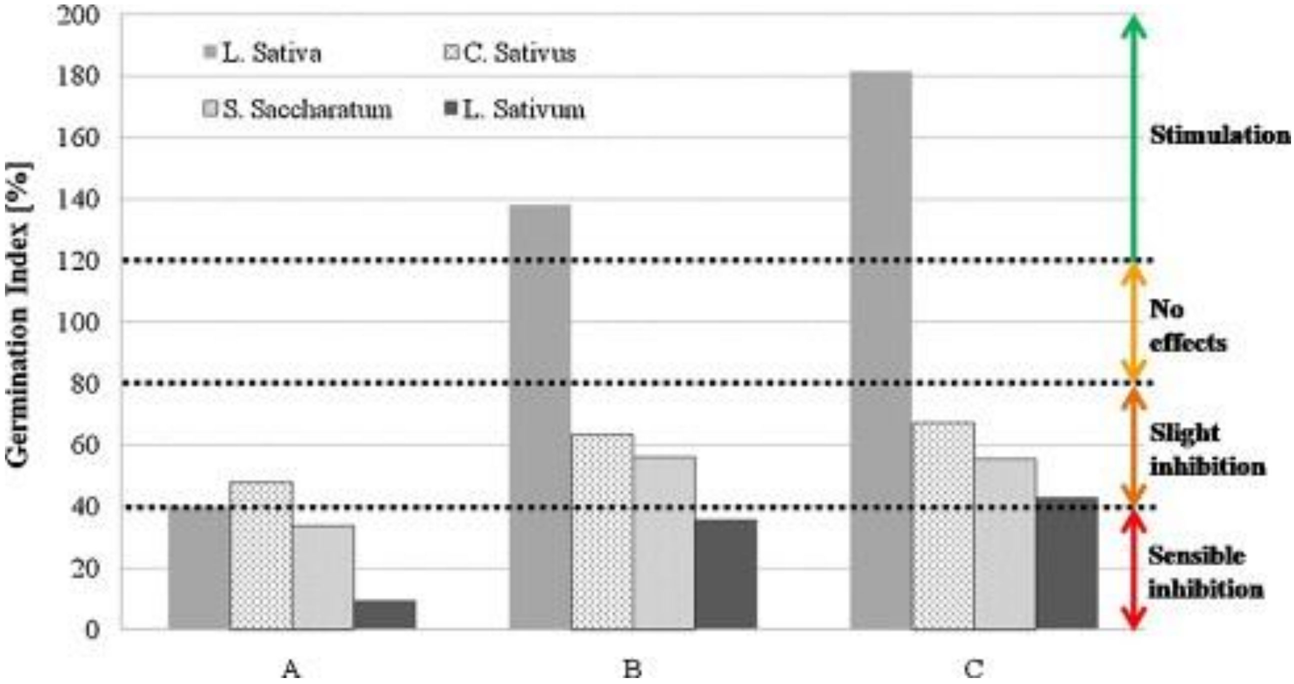

Fig. 6. Germination index evaluation with different seed species.

Results show that the inhibitory effect of compost was affected not only by the stabilization degree, but also by the kind of plant seed used. Although low differences can be observed for sample A, it is evident, for samples B and C, that the tested material could significantly inhibit *L. sativum*, but could stimulate *L. sativa* growth.
These outcomes suggested that the evaluation of maturity should be carried out along with the stability assessment and should be based on standardized procedure, in order to ensure the reproducibility of the test results.

4. Conclusion

The spread of OFMSW compost use in agriculture as a soil conditioneras well as a fertilizer raises the issue of its characterization.
The analysis of literature pointed out that compost quality is affected by different elements and several parameters can be used in order to assess the final product quality to ensure its safe use, especially in agriculture.

Across European Member States regulations enforced for compost handling follow different approaches and a great lack in uniformity can be found, both in terms of parameters and limit values: in Italy, parameters assessing compost quality for its safe use as fertilizer proved to be not adequate in providing a complete compost characterization.

Experimental results showed that compost quality assessment cannot be limited to conventional parameters, describing main chemical–physical and agronomic properties; nor the evaluation of both germination index and pathogens can adequately identify compost maturity. The germination index can provide only information about compost phytotoxicity, which can be related to the presence of compounds toxic to plants. Such compounds are typically present in unstable compost, so that the assessment of compost biological stability could be a suitable option to adequately integrate compost characterization for its safe use on soil.

Further efforts must thus be provided for the standardization of common evaluation methods as well as for the definition of reliable limit values, associated with acceptable risk for both public health and environment. To this end risk analysis should be performed not only for the evaluation of the maximum concentration of toxic compounds that are not legally regulated, but also to quantify hazard to health and environment associated to compost use in agriculture, for those contaminants that are already established in regulations.
The assessment and quantification of risks associated with compost application to land will promote the uniformity in regulations and arise stakeholder and consumer confidence, thus promoting the trade of agricultural products as well as compost market. After the identification of reliable parameters to assess compost quality, it seems reasonable that the specific conditions and rules for its application on soils (such as how much compost and of what quality may be used on certain types of soil) are regulated at the level of Member States. Diversity in soil properties, climates, land use practices throughout Europe is very high so that specific conditions need to be considered.

References

Y.J. An, Y.M. Kim, T.I. Kwon, S.W. Jeong SW. Combined effect of copper, cadmium, and lead upon *Cucumis sativus*growth and bioaccumulation Sci Total Environ, 326 (2004), pp. 85-93

C. Baffi, M.T. Dell’Abate, A. Nassisi, S. Silva, A. Benedetti, P.L.Genevini, *et al.* Determination of biological stability in compost: a comparison of methodologies Soil Biol Biochem, 39 (2007), pp. 1284-1293

R. Barrena, G. d’Imporzano, S. Ponsá, T. Gea, A. Artola, F.Vázquez, *et al.* In search of a reliable technique for the determination of the biological stability of the organic matter in the mechanical–biological treated waste J Hazard Mater, 162 (2009), pp. 1065-1072

R. Barrena, X. Font, X. Gabarrell, A. Sánchez Home composting versus industrial composting: influence of composting system on compost quality with focus on compost stability Waste Manage, 34 (2014), pp. 1109-1116

M.P. Bernal, C. Paredes, M.A. Sánchez-Monedero, J. Cegarra. Maturity and stability of composts prepared with a wide range of organic wastes. Bioresour Technol, 63 (1997), pp. 91-99

M.P. Bernal, J.A. Alburquerque, R. Moral. Composting of animal manures and chemical criteria for compost maturity. Bioresour Technol, 100 (2009), pp. 5444-5453

F. Cecchi, P. Traverso, P. Pavan, D. Bolzonella, L. Innocenti.Characteristics of OFMSW and behaviour of anaerobic digestion process. J. Mata-Alvarez (Ed.), Biomethanization of the organic fraction of municipal solid wastes, IWA Publishing, London (2003), pp. 141-179

J. Charles, B. Sancey, N. Morin-Crini, P.M. Badot, F.Degiorgi, G. Trunfio, *et al.* Evaluation of the phytotoxicity of polycontaminated industrial effluents using the lettuce plant (*Lactuca sativa*) as a bioindicator Ecotoxicol Environ Saf, 74 (2011), pp. 2057-2064

C. Ciavatta, M. Govi, L. Pasotti. Changes in organic matter during stabilization of compost from municipal solid wastes.Bioresour Technol, 43 (1993), pp. 141-145

I. Déportes, J.L. Benoit-Guyed, D. Zmiroub. Hazard to man and the environment posed by the use of urban waste compost: a review. Sci Total Environ, 172 (1995), pp. 197-222

European Union. Report on the implementation of the soil thematic strategy and ongoing activities. European Union, Bruxelles (2012)

J.M. Fernández, C. Plaza, A. Polo, A.F. Plante. Use of thermal analysis techniques (TG-DSC) for the characterization of diverse organic municipal waste streams to predict biological stability prior to land application. Waste Manage, 32 (2012), pp. 158-164

T. Getahun, A. Nigusie, T. Entele, T. Van Gerven, B. Van der Bruggen. effect of turning frequencies on composting biodegradable municipal solid waste quality. Resour Recycl Conserv, 65 (2012), pp. 79-84

A. Gomez. The evaluation of compost quality. Trends Anal Chem, 17 (1998), pp. 310-314

R. Guo, G. Li, T. Jiang, F. Schuchardt, T. Chen, Y. Zhao, *et al.* Effect of aeration rate, C/N ratio and moisture content on the stability and maturity of compost Bioresour Technol, 112 (2012), pp. 171-178

M. Hamidpour, M. Afyuni, E. Khadivi, A. Zorpas, V.Inglezakis. Composted municipal waste effect on chosen properties of calcareous soil. Int Agrophys, 26 (2012), pp. 365-374

J.C. Hargreaves, M.S. Adl, P.R. Warman. A review of the use of composted municipal solid waste in agriculture. Agric Ecosyst Environ, 123 (1–3) (2008), pp. 1-14012

R.L. Hough, P. Booth, L.M. Avery, S. Rhind, C. Crews, J.Bacon, *et al.* Risk assessment of the use of PAS100 green composts in sheep and cattle production in Scotland Waste Manage, 32 (2012), pp. 117-130
0
M.K. Iqbal, T. Shafiq, A. Hussain, K. Ahmed. Effect of enrichment on chemical properties of MSW compost. Bioresour Technol, 101 (2010), pp. 5969-5977

D.P. Komilis, I.S. Tziouvaras.A statistical analysis to assess the maturity and stability of six composts. Waste Manage, 29 (2009), pp. 1504-1513

D. Komilis, I. Kontou, S. Ntougias. A modified static respiration assay and its relationship with an enzymatic test to assess compost stability and maturity. Bioresour Technol, 102 (2011), pp. 5863-5872

M. López, O. Huerta-Pujol, F.X. Martínez-Farré, M. Soliva. Approaching compost stability from Klason lignin modified method: chemical stability degree for OM and N quality assessment. Resour Recycl Conserv, 55 (2010), pp. 171-181

K. Macgregor, I.W. Oliver, L. Harris, I.M. Ridgway. Persistent organic pollutants (PCB, DDT, HCH, HCB & BDE) in eels (*Anguilla anguilla*) in Scotland: current levels and temporal trends Environ Pollut, 158 (2010), pp. 2402-2411

F.A. Macìas, D. Castellano, J.M.G. Molinillo.Search for a standard phytotoxic bioassay for allelochemicals. Selection for standard target species. J Agric Food Chem, 48 (2000), pp. 2512-2521

P. Oleszczuk. Changes of polycyclic aromatic hydrocarbons during composting of sewage sludges with chosen physic-chemical properties and PAHs content Chemosphere, 67 (2007), pp. 582-591

P. Oleszczuk, H. Hollert. Comparison of sewage sludge toxicity to plants and invertebrates in three different soils. Chemosphere, 83 (2011), pp. 502-509

T. Paré, H. Dinel, M. Schnitzer. Extractability of trace metals during co-composting of biosolids and municipal solid wastes. Biol Fertil Soils, 29 (1999), pp. 31-37

H. Sayen, P. Eder. End-of-waste criteria for biodegradable waste subjected to biological treatment (compost & digestate): technical proposals. Brussels (2014)

B. Scaglia, F. Tambone, P.L. Genevini, F. Adani. Respiration index determination: a dynamic and static approach. Compost Sci Util, 8 (2000), pp. 90-98

B. Scaglia, F.G. Erriquens, G. Gigliotti, M. Taccari, M. Ciani, P.L. Genevini, *et al.* Precision determination for the specific oxygen uptake rate (SOUR) method used for biological stability evaluation of compost and biostabilized products Bioresour Technol, 98 (2007), pp. 706-713

B. Scaglia, M. Acutis, F. Adani Precision determination for the dynamic respirometric index (DRI) method used for biological stability evaluation on municipal solid waste and derived products Waste Manage, 31 (2011), pp. 2-9

R. Sidelko, B. Janowska, B. Walendzik, I. Siebielska. Two composting phases running in different process conditions timing relationship. Bioresour Technol, 101 (2010), pp. 6692-6698

UNI 10780:1998. Compost – Classificazione, requisiti e modalità di impiego.

UNICHIM Metodo 1651 – Saggio di germinazione ed allungamento radicale (2003)

I. Zdanevitch, O. Bour. Quality of composts from municipal biodegradable waste of different origins. Proceedings Sardinia 2011, thirteenth international waste management and landfill symposium, CISA Publisher (2011)

A.A. Zorpas, V.J. Inglezakis, M. Loizidou Heavy metals fractioning before, during and after composting of sewage sludge with natural zeolite Waste Manage, 28 (2008), pp. 2054-2060

Web references

Animal By-Products Regulation (last access 22/09/2014). http://ec.europa.eu/food/food/biosafety/animalbyproducts/index_en.htm.
Commission Decision, 2006/799/Ce (last access 22/09/2014). http://eur-lex.europa.eu/legal-content/ES/TXT/?uri=CELEX:32006D0799.
Council Regulation 834/2007/Ce (last access 22/09/2014) http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2007:189:0001:0023:EN:PDF.