Assessment of The Composting Process and Compost’s Utilizations

Radhouani Afrâa1*, Singh Sushant2, Ferchichi Ali3

Abstract
Recently, several studies have affirmed the deleterious effects of conventional agriculture on environmental safety and quality of products. Organic farming was selected as the most promising alternative. This agricultural system is based on the adoption of biological techniques as composting. This process can be taking either in aerobic and anaerobic conditions added to the use of earthworms or vermicomposting. The process is realizing in mesophilic, thermophilic, cooling and maturation phases. It finishes by the production of compost having enhancements on the physical, chemical and biological properties of soil. Moreover, it stimulates the plant’s growth and enhances the quality of products when used as amendment or substrate. However, these advantageous are impeded unless it presents some criteria related to its maturity and stability.

Keywords
Organic agriculture; Composting; Compost; Quality’s standards

Introduction

The green revolution, based on the use of agrochemicals, has induced a prominent increment of the agricultural production [1] but at expense of environment [2] by inducing pollution and altering the ecological symmetry [3,4]. This detrimental effect in conjunction with the high concerning of consumers about the food safety has rekindled ecological symmetry [3,4]. This detrimental effect in conjunction with the high concerning of consumers about the food safety has rekindled ecological symmetry [3,4]. This detrimental effect in conjunction with the high concerning of consumers about the food safety has rekindled ecological symmetry [3,4]. This detrimental effect in conjunction with the high concerning of consumers about the food safety has rekindled ecological symmetry [3,4]. This detrimental effect in conjunction with the high concerning of consumers about the food safety has rekindled ecological symmetry [3,4]. This detrimental effect in conjunction with the high concerning of consumers about the food safety has rekindled ecological symmetry [3,4]. This detrimental effect in conjunction with the high concerning of consumers about the food safety has rekindled ecological symmetry [3,4]. This detrimental effect in conjunction with the high concerning of consumers about the food safety has rekindled ecological symmetry [3,4].

Composting’s Definition

Traditionally, composting is an agricultural practice adopting long process open methods as heap and pit structures [8,11]. In modern era, composting was firstly developed by Albert Howard who settled the Indore method [12] used further for developing small scale aerobic composting techniques [8] (Table 1). Recently, faster and more developed methods were investigated [13]: windrow system, vessel and boxes.

Chemical definition of composting

Chemically, composting is a self-heating, aerobic and natural process of organic matter’s degradation [14,15,16,17]. These compounds are, predominantly, in nature of carbohydrates (e.g. cellulose), proteins, lipids and lignin. It is discriminated from natural rotting or putrefaction through the aerated conditions [17] and the human involvement [16]. It can be impeded in anaerobic conditions and produces intermediate compounds (methane, organic acids, hydrogen sulphide) with lesser weed seeds and pathogens’ damaging than aerobic one [8]. Furthermore, it can be of vermicomposting type using earthworms in organic wastes’ conversion [11].

Aerobic composting: Aerobic composting produces well-stabilized, hygienic, rich on humic-like substances and free of pathogens and viable weed seeds compost [9,18,19] indicated four mechanisms of humification:

Mechanism 1: It is strictly chemical and well known as the Maillard reaction. The products of the microbiological metabolism (namely the carbohydrates) are condensed, without enzymatic degradation, and combined with amino compounds leading to the production of melanoid substances. These substances are easily polymerized into humus.

Mechanism 2: It is characterized by the production of polyphenols from the non-lignin substances. The polyphenols undergo enzymatic oxidation inducing the production of quinons which are transferred to humic substances by polymerization.

Mechanism 3: With this procedure, microbial degradation of lignin’s products (acids and phenolic aldehyds) is converted into quinons by enzymatic reactions. Further, quinons are polymerized into humic substances.

Mechanism 4: It is recognized as the ligno-proteic theory developed by Waksman (1936). The process consists in the combination of modified lignin with proteic substances (amino compounds) produced by microorganisms following the further reaction:

(Modified ligning)-CHO + RNH2 (modified lignin)-CH=NR + H2O

The modified lignin is obtained by loss of the methoxyl groups (OCH3), production of ortho-hydroxyphenols and oxidation of lateral aliphatic groups leading to the formation of free carboxylic groupments (-COOH) [20].

Stevenson (1982) distinguished that the ligno-proteic mechanism is dominated in humid soils and the marsh while the polyphenolic mechanism characterizes the forest soils.

Vermicomposting: It is an enzymatic degradation through the digestive system of earthworms into vermicast [8]. These invertebrates are classified into burrowing (Pertima elongata and Pertima asiatica)
and non-burrowing (Eisenia fetida and Eudrilus eugeniae) known, respectively, as surface and deep dwelling [21]. Thus, referring to their habitat, they are classified into epigeics (mineral soil surface), anecics (burrows in mineral soil layers) and endogeics (mineral soil horizons). The advocated species for vermicomposting are of epigeic class well known by a great potential of waste decomposition. The common used epigeic species are E. eugeniae, Eisenia fetida, Perionyx excavatus and Eisenia Andrei [5,13]. However, it is recommended to combine these microorganisms with anecic ones as Lampito mauritii [22].

Vermicomposting can be impeded in pits, concrete tanks, rings, wooden and plastic crates [13]. In addition to its superiority on accomplishment’s rate [21], vermicomposting has better performance in terms of nutrients recovery, microbial richness and phytotoxicity [5].

A combination of aerobic and anaerobic decomposition and vermicomposting may be useful for more effective production of high-quality compost: While high temperature ensures better quality through the destruction of pathogens and weed seeds, worms permit turning and maintaining an aerobic condition, thereby reducing the need for investment and labor [24].

**Microbial composting:** Composting is an exothermic reaction [20,17], $\Delta G$ = -667 Kcal/mol, of organic matter’s decomposition by successive microbial populations [7,4,12,22] that the interfered type depended on mass’s temperature [14]. Referring to these last authors, in view of the optimal temperature ranges of their growth activities, microbial groups can be classified in psychrophilic (optimum growth temperature below 20$^\circ$C), mesophilic (prefer temperatures oscillating between 20 - 40$^\circ$C; presented by fungi in particular molds and bacteria), thermotolerant and moderately thermophilic (favor temperatures comprising between 40 - 60$^\circ$C; represented specially by actinomycetes) and thermophilic microorganisms represented solely by thermophilic bacteria that wish temperatures between 60$^\circ$C and 80$^\circ$C (Figure 1).

The mass of compost is characterized by microbial diversity which enables it to overcome both environmental and nutritional conditions [14]. The microorganisms occupying a compost pile are classified, predominantly, into bacteria, fungi and actinomycetes which may be facultative or strict aerobic and have individual preferential substrates and environmental conditions for growth [12].

Bacteria: They are typically unicellular with a size of 0.5 to 3 µm conferring them, in addition to their short generations, a prevalence regarding with micro-organisms of greater dimensions such as fungi [17]. This predominance is mainly perceived during the first stage of composting owing to their high capacity to promptly transfer soluble substrates inside their cells [22]. They include a wide range of organisms able to withstand unfavorable environmental conditions in form of spores [14].

Fungi: They form networks of individual cells in strands called filaments. They favor mesophilic temperature (5-37$^\circ$C) excepting some thermophile ones. They have a lignocellulosic degrading capacity like Phanerochaete chrysosporium, higher rate of nitrogen and an acid pH. They tend to be present overridingly in the later stages of composting seeing the decay-resistant nature of the materials they decompose (woody substances, waxes, proteins, hemicelluloses, lignin, and pectin) which are not accessible for bacteria.

Actinomycetes: They are lesser effective nutrient competitors than bacteria and fungi [17]. Their growth is stimulated by the derived humic acids [3]. They are pervasive, namely, in the later stages of composting for attacking the remaining non decomposed compounds and improving hygienisation [17]. 90% of actinomycetes biomass is represented by Streptomyces and Nocardia. They are, putatively, responsible of the characteristic earthy smell of the compost given their production of sesquiterpenoid compounds such geosmine. Under drastic conditions, actinomycetes strive and survive as spores [23].

**Physical composting:** Physically, composting is a biodegradation process that depends mainly on temperature, humidity, oxygen content and porosity of the compost’s mass. The control of temperature is ultimate for monitoring the composting efficiency [9,18] seeing that it, affects the growth rate, metabolic activity and type of interfering microorganisms’ community [4] and influences the physicochemical characteristics of the final product [9]. It was affirmed that a small size of the pile and excessive exposure to cold weather can spike the

**Table 1:** Salient features of selected small-scale aerobic composting techniques [8].

<table>
<thead>
<tr>
<th>Method</th>
<th>Salient features</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indore pit</td>
<td>Substrate size reduction</td>
<td>+15, +30, +60</td>
</tr>
<tr>
<td>Indore heap</td>
<td>Mass added</td>
<td>+42, +84</td>
</tr>
<tr>
<td>Chinese pit</td>
<td>Shredded</td>
<td>+30, +60, +75</td>
</tr>
<tr>
<td>Chinese high temperature compost</td>
<td>Shredded</td>
<td>+15</td>
</tr>
<tr>
<td>Educator on-farm composting</td>
<td>阳光透过</td>
<td>+21</td>
</tr>
<tr>
<td>Berkeley rapid composting</td>
<td>Shredded to small size</td>
<td>Daily or alternate day turning</td>
</tr>
<tr>
<td>North Dakota State University hot composting</td>
<td>Shredded</td>
<td>+3 or +4</td>
</tr>
<tr>
<td>IBS rapid composting</td>
<td>Shredded</td>
<td>+7, +14, the every 2 weeks</td>
</tr>
</tbody>
</table>

than 50% induces a temperature's reduction (energy loss exceeds materials. Bernal et al. [17] considered that a porosity greater of composting process is affected significantly by porosity of the particular mixture [20]. In conjunction to these factors, performance requirement for the microbial population, a compromise should be favor anaerobic metabolism inducing nuisance odors and polluting ventilation [25]. Low levels of oxygen slow composting rate and in oxygen can be realized by regular turnings or injection by forced too. It depended on its porosity and the microbial activity. The supply of composting operation [12].

In addition to temperature, moisture affects considerably the composting process especially that most of the decomposition is impeded in thin liquid films on the surface of particles [12] . The advisable moisture during the composting process depends on the wastes to be composted, but generally the initial mixture should be at 50 - 60 % [18,24] and the final output should have a value of 30% [8]). Broadly, pertinent moisture content should enable the achievement of a balance between organic matter decomposition and air renovation in the feedstock mass [12]. In practice, a lack of humidity slows the process by disrupting the microbial activity and produces fungal pathogens such as Aspergillus fumigates and white, a resistant form of pathogens such as Bacillus [22]. A big diversity of bacterial ones originating from surviving spores [22]. Microorganisms are dominated by mesophilic actinomycetes, whilst a too wet pile induces anaerobic conditions and entails, thus, additional turnings [14,16,25]. Moisture adjustment can be fulfilled by aeration and water addition occurred during turning operation [12].

The content on oxygen is a requisite factor in composting process too. It depended on its porosity and the microbial activity. The supply in oxygen can be realized by regular turnings or injection by forced ventilation [25]. Low levels of oxygen slow composting rate and favor anaerobic metabolism inducing nuisance odors and polluting gases. Aerobic metabolism requires 5-10% of oxygen (v/v) in the free air space of the pile. In order to accomplish the oxygen and water requirement for the microbial population, a compromise should be achieved between the free air space and the moisture content for each particular mixture [20]. In conjunction to these factors, performance of composting process is affected significantly by porosity of the materials. Bernal et al. [17] considered that a porosity greater than 50% induces a temperature's reduction (energy loss exceeds heat produced) whilst a value lesser than 35% leads to anaerobic conditions and odor generation. Broadly, porosity is improved by a more uniform mix of material.

It is noteworthy that these physical parameters depend on the type of composting system [20]. Indeed, it was affirmed that porosity is low in heaps and pits [24,26], moisture is lower in windrow shape than in concave, high porosity and appropriate temperature are impeded with turning windrows [14] while vessel system permits keeping of oxygen out of the system and capture of the released biogas [12].

### Phases of Compost

The composting process can be devised into four successive phases:

#### Mesophilic phase

This phase lasts 1 to 3 days (Figure 1). Initial fresh materials with a low molecular weight, simple chemical structure and water solubility pass straightforwardly through the cells walls of the mesophilic bacteria and / or thermotolerant fungi and bacteria [18] inducing a prompt increase of the temperature owing to energy of the organic combinations. The pH typically decreases as organic acids are produced [22].

#### Thermophilic phase

This phase is characterized by a noticeable increment of temperature in the center of the pile (Figure 1) consequently to vigorous degradation of organic matter's complex (fats, cellulose, hemicelluloses and some lignin) by thermophilic microorganisms represented namely by fungi and numerous thermophile bacteria, especially the genre Bacillus [22].

In addition to temperature increment, alkalinity of the medium, release of CO₂ in significant quantity and an obvious dryness of the compost pile subsequent to enormous water evaporation are often noted [22]. Moreover, pathogens were destroyed, actinomycetes in particular streptomycetes strive, larvae were killed and most weed seeds were cracked: it is the sanitation of the compost [17].

These two phases can be assimilated in one phase known as active or degradation phase [9,22].

#### Cooling phase

It is recognized as the curing phase too. It starts when turning no longer reheats the pile [8]. This phase is characterized by a conspicuous decline of the temperature to this of ambient air (Figure 1) due to the reduction of microbial activity concomitantly with the depletion of degradable organic matter: sugars, cellulose and hemicelluloses [9,18]. Microorganisms are dominated by mesophilic ones originating from surviving spores [22]. A big diversity of bacterial taxonomy and metabolism was enunciated and several mesophilic and thermotolerant actinomycetes, yeasts and fungi reappear (Figure 1). Commonly, curing period lasts 30 days and insures enduring against the risks of immature compost’s application [8,16,17,23].

The final stage of this phase marks the stability of compost [9]. These three phases can be combined in the biooxidative one [18].

#### Maturation phase

The needed period for maturation of the compost depends on initial materials: lignocellulosic wastes (manure) can be swiftly composted (above 6 weeks) whereas lignic wastes (green wastes)
require, at least, six months being ready for use after their composting. Furthermore, external factors like oxygen supply, moisture content, active turning and outside temperature affect strikingly the taken time for the maturation phase [17]. During this phase, macroorganisms such as lombrics, several insects, mites, gastropods and myriapods interfere. Microorganisms namely fungi ensure the humification process [17,23,22].

### Advantages of Composting

The use of compost has assumed significant relevance in agriculture owing to its numerous advantages [27]. Indeed, it ensures:

- The waste management: Composting permits the wastes’ reinsertion into economic and environmental innovation [6,8]. It is considered as a promising alternative to sanitary landfill input, dumping and incineration [7,4,12,22,28,29]. Likewise, it constitutes an appropriate solution for shrinking biodegradable residues' volumes [9,16,30] and a safe option for sustainable solid waste management [5] combining the recovery of valuable resources with environmental protection [18].

- Enhancement of the soil’s fertility: Application of compost is considered as a common provider of organic matter in soil given its both amendment and fertilizer roles [8,11,13,21]. Indeed, it replenishes this content in a cheap cost [29] and permits more sustainable building of the soil fertility and tilth [16,26,31] than the chemical fertilizers. This effect was noted, too, with the compost tea [32].

- Improvement of the physical properties: Ozores-Hampton [14] indicated that compost’s application improves soil’s physical properties such as porosity and CEC, fights against degradation of the soil surface [22] by mitigating runoff and erosion’s processes [1,14,26,28], reduces intensity of sand flux whereby increases the soil’s strength and roughness, enhances water retention [29] and reduces the density affording opportunity for deeper root penetration [16]. Protection against soil-borne diseases [1,7,13] specified that the main plant diseases suppressed by composts are ‘wilt’ caused by Fusarium spp.; ‘damping off’ caused by Fusarium, Pythium, Rhizoctonia and Sclerotium spp.; ‘stem and root rot’ caused by Fusarium, Rhizoctonia, Pythium, Phytophthora, Sclerotium and Aphanomyces spp. This suppression varies considerably with the compost inclusion’s rate, feedstock materials [11], the degree of organic matter’s decomposition [16,32] and population size [33]. Martin and Brathwaite [11] reported that the suppressive effect of compost is, in nature, biological rather than chemical or physical seeing that the water extracts of several composts are suppressive of soil-borne pathogens while they don’t contain antibiotics or siderophores. These authors have identified four mechanisms of the attack:

  - Antibiosis: It corresponds to an association between two organisms where the production of antibiotics (specific and/or non-toxic specific metabolites) by one organism has a direct effect on the other one. It is the case of bacteria and fungi against P. oxysporum, Enterobacter which produces chitinolytic enzymes against Rhizoctonia solani and Gliocladium virens which affects P. ultimum by glucotinin.

  - Competition: It occurs when a non-pathogen enters in competence with a plant pathogen for a resource lending to disease control. The attack of Pythium spp by lessening of the availability of iron via the production of low molecular weight ferric-specific ligands remarked in iron limiting conditions exemplifies this process;

  - Parasitism: This attacking mechanism is impeded in four successive stages: chemotrophic growth, recognition, attachment and degradation of the host cell walls through the production of lytic enzymes. These steps, namely the last one, are influenced by the presence of glucose and other soluble nutrients that repress the production of lytic enzymes used to kill pathogens. This mechanism is prominent with propagules of 200 mm diameter;

  - Induced systemic resistance impeded by numerous beneficial microorganisms namely Trichoderma spp.

- Sanitation of toxic substances [1] and remediation of contaminated soils via heat’s production, the long term treatment duration and the development of a saprophyte flora competing with pathogen population [22].

- Substitution of peat: Compost is suggested to be a feasible substitution for peat based on its better performances regarding the plant morphology, biomass, and yield [11,35].

- Stimulation of the plant’s growth by dint of humic substances that can affect it directly (stimulation of proteins’ synthesis, hormonal effect such as this of gibberellins, auxins and cytokinins, increment of photosynthetic activity) or indirectly (solubilization of oligoelements, reduction of compounds’ toxicity, stimulation of microbial activity) [1,8,13,19,21]. Sinha et al. [1] indicated that the promotion of growth by vermicompost is of 5 - 7 times over other bulky organic
fertilizers and 20 - 40 % higher than chemical fertilizers. Moreover, it was proved that the foliar application of humic and fulvic acids in combination with others nutrients enhances the vegetative growth of plants.

**Standardization of the Compost’s use**

Feedstock, composting system and management have been reported to affect significantly the compost’s quality [11]. The aforementioned advantageous of compost’s application depend on its quality which is closely correlated to both stability and maturity [36]. Seeing diversity of compost’s feedstock and composting technology, it may be advisable to adopt a combination of methods evaluating compost’s maturity and stability that differ in simplicity, duration and approaches [16,30]. These methods are broadly classified into physical, chemical and biological groups [18]. Although these wide approach, there is still a controversy to the reliable parameters that can be used for defining maturity and/or stability of the compost [16,30].

**Evaluation of compost’s stability**

Compost’s stability is defined as the level of organic matter’s decomposition [4]. Francou [19] estimated this in relation to the content on organic carbon (Table 2). Ozores-Hampton et al. [15] considered that it represents the degree of nitrogen and CO₂ consumption to support biological activity [18,19,22]. This activity generates anaerobic conditions [23]. Leads to the production of harmful compounds such as hydrogen sulfide and nitrite [17] and permits the release of water vapor which induces the plant stunting and leaves’ yellowing. This activity can be assessed by determining the microorganisms’ respiration (measurement of O₂ consumption, CO₂ production, self-heating capacity) that is inversely correlated to the content on organic carbon in relation to the total one 108 days after composting at 28°C [19]. Besides, it produces ammonia, ethylene oxide and lower molecular weight fatty acids [16,22] acetic, propionic, isobutyric, butyric and isovaleric acids [15] which inhibit seeds’ germination [36].

Furthermore, compost’s stability can be forecasted via malodors, the nutrient availability, the available carbon or other energy sources, color, heavy metal dissolution, the environmental health risks [37] and the content on organic volatile acids such as acetic and butyric ones [14]. Indeed, these acids are mainly produced subsequently to incomplete oxidation due to low O₂ diffusion rate relative to respiration one. These last authors affirmed that presence of these acids is indicative of anaerobic fermentation thus instability and are inducers of odors. However, their absence does not necessarily indicate stable compost. USDA (2000) noted the relationship volatile acids/ stability (Table 4). The C/N ratio is commonly adopted as an indicator of compost’s stability: Dayegamiy et al. [25] enunciated that stabilization of compost is reflected by a C/N ratio less than 30 whereas Zbytniewski and Buszewski [38] reported that it is achieved with a ratio of 15. Albrecht [22] reported that stable compost is characterized by a C/N ratio limited between 10 and 15.

The redox potential is putatively an indicator of compost’s stability: during incubation’s period, stable material shows stable redox potential’s value whereas lesser stable one displayed a reduction of this parameter [15]. Khiyami et al. [20] indicated that stable composts are characterized by alkaline pH. Albrecht [1] thank that conversion of lignin to humic acid is in “the heart” of the compost’s stabilization. Thus, humification indices such as humification index, humification ratio and humification percentage, are considered as reliable parameters in evaluating compost’s stability [6] even their absolute values vary greatly among feedstock of composts.

**Evaluation of compost’s maturity**

Compost’s maturity estimates the degree of completeness of composting [7,9] and its readiness for employment [39] seeing that immature compost induces problems during storage (establishing anaerobic conditions), marketing and use [7]. Thus, it ascertains its phytotoxic behavior [14,40,18,19] which is strongly related to the composting method: indeed, phytotoxins disappeared faster in piles than in windrows [41].

Maturity can be estimated via intensity of the microbial activity using the Dewar self-heating test based on the concept that this activity induces a significant heat’ production. USDA (2000) indicated the level of compost’s maturity accordingly to this test (Table 3). Brinton et al. [23] considered that the Dewar test is limited seeing that it mostly distinguishes only very mature from very immature. Brinton et al. [23] specified the use of compost regarding it maturity’s level (Table 5). The continual microorganisms’ activity after compost’s application immobilizes native and added nitrogen [40] and induces anaerobic conditions in the root system where recorded an increment of temperature [15]. Besides, it produces ammonia, ethylene oxide and lower molecular weight fatty acids [16,22] acetic, propionic, isobutyric, butyric and isovaleric acids [15] which inhibit seeds’ germination [36].

In addition to this test, microbial activity can be estimated using the Solvita test based on carbon mineralization (respiration) and ammonia gas emission [23]. Francou [19] indicated that an index of 1 to 8 characterized mature compost.

### Table 2: Evaluation of stability/ maturity of compost referring to the content of organic carbon in relation to the total one 108 days after composting at 28°C [19].

<table>
<thead>
<tr>
<th>Degree of stability of compost</th>
<th>C-CO₂ 108 days after composting (%)</th>
<th>Degree of maturity of compost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very stable</td>
<td>[0; 19]</td>
<td>Very high</td>
</tr>
<tr>
<td>Stable</td>
<td>[10; 15]</td>
<td>High</td>
</tr>
<tr>
<td>Relatively stable</td>
<td>[15; 20]</td>
<td>Average</td>
</tr>
<tr>
<td>Unstable</td>
<td>[20;30]</td>
<td>Slight</td>
</tr>
<tr>
<td>Very unstable</td>
<td>&gt;30</td>
<td>Very slight</td>
</tr>
</tbody>
</table>

### Table 3: Dewar self-heating test and CO₂ loss for determining the compost stability/maturity (USDA 2000).

<table>
<thead>
<tr>
<th>Eating rise over ambient</th>
<th>CO₂ loss (mg C g⁻¹ C d⁻¹)</th>
<th>Rating</th>
<th>Description of stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>0-2</td>
<td>V</td>
<td>Completely stable, can be stored</td>
</tr>
<tr>
<td>10-20</td>
<td>2-8</td>
<td>IV</td>
<td>Maturing compost, can be stored</td>
</tr>
<tr>
<td>20-30</td>
<td>8-15</td>
<td>III</td>
<td>Material still composting, don’t store</td>
</tr>
<tr>
<td>30-40</td>
<td>15-25</td>
<td>II</td>
<td>Immature, active composting</td>
</tr>
<tr>
<td>40-50</td>
<td>&gt;25</td>
<td>I</td>
<td>Fresh, very active composting</td>
</tr>
</tbody>
</table>

### Table 4: Volatile organic acids as indicator of stability (USDA 2000).

<table>
<thead>
<tr>
<th>Volatil organic rating</th>
<th>Level of volatile organic acids dry basis (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very low</td>
<td>&lt;200</td>
</tr>
<tr>
<td>Medium-low</td>
<td>200-400</td>
</tr>
<tr>
<td>Medium</td>
<td>1,000-4,000</td>
</tr>
<tr>
<td>High</td>
<td>4,000-10,000</td>
</tr>
<tr>
<td>Very high</td>
<td>&gt;10,000</td>
</tr>
</tbody>
</table>
Commonly, mature compost is distinguished by a pH of 8 [18,22] while acid pH characterizes immature one. The C/N ratio is largely used as an indicator of compost’s maturity even there is no general consensus about a specific value [2]; indeed, the interval indicating compost’s maturity ranges between 25 and 35 for Ryckeboer et al. [35] yet it oscillates between 25 and 40 for Baldwin and Greenfield [15] and Naidu et al. [3] Raj and Antil [36] have reported that a C/N ratio lesser than 20 and even 15 characterizes mature compost whilst Zbytniewski and Buszewski [38] have reported that maturity is achieved with a ratio lower than 12. Conversely, Komilis and Tziouvaras [18] adopted that a C/N ratio of 10 classified comports as mature. However, this parameter can be misleading particularly when the compost contains higher level NH₂ - N.

Mature compost is characterized by total nitrogen content of 1 to 4 % of dry mass [20]. A low degree of released carbon dioxide reflects advanced humification [15]. Indeed, Francou [19] indicated that the proportion of organic carbon in mineralized compost for 108 days is of 0 to 10 % for very mature compost hence of 10 to 15 % for mature one (Table 2).

The increasing level of humic acid, HA, produced by polymerization and/or degradation of fulvic acid, FA, is strictly concomitant with the compost’s maturity [17,41,42]. Indeed, H₂ /FA ratio inferior to 1 characterizes immature compost yet values higher than 1.9 specify mature one [33] without exceeding the limit of 3 [1]. Besides, it was suggested that a Cu/Cu_ratio limited between 1.7 and 3 pertains mature compost [12]. Spectroscopic analyzes of humic substances indicate that mature comports are characterized by a low A₆₅₀/A₄₅₀ ratio recognized by Q₈ /Q₄, [1,43]. Higher index of decomposition of chlorophyllous compounds, predictable by the absorbance in 667 nm, implicates that decomposition of these compounds is incomplete thereof a lack of maturity [44].

### Biological parameters

In addition to chemical and physical analyzes, biological tests are adopted to complement them [45,46] seeing that toxic substances don’t present a permanent state [45]. Moreover, toxins are produced solely in certain stages of decomposition and tend to be swiftly inactivated and plants’ sensitivity to toxins tends to be transient [25]. Plant tests used in quality standards are categorized into: germination tests; growth tests (assessment of both top and root growth), combination of germination/ growth and other biological methods like enzyme activities [18]. The most adopted germination test is this of Zucconi et al. [43]. It is, commonly, carried out on garden cress seeds incubated on various concentrations of compost’s extracts. Many species including cabbage, lettuce, carrot, cucumber, tomato and oats are recommended for this test too. However, due to the selective toxicity of different composting materials towards species, it will be necessary to select species that are sensitive to the specific composting materials before this test can be used for the evaluation of compost’s stability [44].

It is noteworthy that the germination index, GI, has been proven to be the most adequate parameter in estimation of the phytotoxic risks [44]. Referring to this parameter, compost presents higher phytotoxicity when GI is lower than 50 %, the phytotoxic potential is moderate in case of GI values limited between 50 and 80 % whereas values over 80 % reflect that the material does not show phytotoxic risks [41]. Brinton [23] specified the level of toxicity referring to the inhibition of germination (Table 6). Exceptions can be found by values of GI over 100 which indicate the presence of nutrients or germination promoters [43]. Nonetheless, a widely accepted threshold germination index, above which maturity can be ascertained, does not appear to exist in the literature [19].

### References
