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Advances in assessing soil maturity and stability of compost

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Abstract: Composting is the transformation of organic material through decomposition into a biologically humus rich substance suitable for growing plants. A properly managed composting process can destroy weed seeds, plant pathogens, and human pathogens. Compost quality is closely related to its stability and maturity. Stability is the resistance of compost to further biological decomposition. Maturity is the suitability of compost for a particular use. The parameters for finding maturity and stability are basically classified into physical and sensory parameters, chemical parameters, biological parameters. Use of multiple parameters help to assess the maturity and stability. Advances in these ensure the compost is mature and safe to use.

Introduction

Due to a significant intensification of agricultural production systems brought on by global economic expansion and rising food consumption, there is now a greater generation of organic waste. The macro elements (nitrogen [N], phosphorous [P], and potassium [K]) in organic wastes have been analysed, and the results show that the intensification of the agricultural system has resulted in a large economic loss. The proper treatment of such wastes would be a successful method of restoring organic matter to the deficient soils by carbon restitution through organic additions. Over time, composting has become a method of waste processing that is increasingly popular. The procedure typically involves a variety of microorganism species decomposing organic waste components naturally and biologically. Those organic waste products could rebuild soils and serve as a vital fertiliser reserve. The quality and stability of composts made from various organic wastes vary, and this is also dependent on the makeup of the raw materials used to make the compost. The stability and maturity of the compost have a direct impact on its quality. It has been challenging to come to consensus on techniques for the practical assessment of maturity due to the large range of chemical and biological alterations that occur during composting and the diversity of approaches offered in literature.

Composting is the process of turning organic matter into a humus-rich, biologically viable substance that is ideal for plant growth. It is a controlled procedure for stabilising organic material that has the potential to transform organic waste into a useful soil additive. The bioconversion of agricultural leftovers into a nutrient-rich product that can increase soil fertility and microbial diversity and consequently boost agricultural output is thus an environmentally viable alternative.

It is a biological decomposition process where solid organic materials are broken down under aerobic circumstances by the action of diverse microbial consortia, producing a stable, mineral-rich, and humic product that may be applied to soil without risk (Lashermes *et al*., 2012)

Weed seeds, plant infections, and human pathogens can all be eliminated by a composting process that is correctly controlled. Compost analysis enables bulk compost purchasers to feel certain that they are getting good value for their money.

The compost's stability and maturity are key indicators of how safely to apply nutrient additives to the soil. Because immature and unstable composts can be phytotoxic and may have a negative impact on plant growth, also they can lead to imbalance in mineral contents of the soil due to the presence of high amounts of organic acids and salts characterized by low (< 6) or high pH (< 8) and high EC (> 1). For its safe application, composts must be evaluated for quality in terms of maturity and stability. Therefore, stability and maturity are two of the most significant elements that may have an impact on how compost is used in agriculture. (Paradelo *et al*., 2010)

Maturity and Stability

Compost's stability is its ability to withstand additional biological deterioration. Composts used in greenhouse potting mixes and bagged composts must have sufficient stability (Sullivan *et al*., 2018)

The degree of stabilisation of the organic components in compost is referred to as compost stability. It is adversely correlated with microbial activity and organic matter bioavailability (Paradelo *et al*., 2010).

While maturity is an agronomic parameter that is clearly linked to the effect of compost on plant growth, stability is the resistance of the organic matter in compost against further microbial decomposition as long as there is no inhibition on the microbes by other factors not relevant to the organic matter (Komilis, 2015).

The potential of compost to be used for a certain purpose is categorised by maturity, which is a broad, arbitrary category. Very young composts can harm or kill plants because they contain ammonia and/or volatile organic acids. The term "maturity" refers to the extent of phytotoxic compounds that are broken down throughout the decomposition process, such as NH3 or short-chain organic acids, as well as the suitability of compost for plant growth. Since compost maturity is defined in terms of consumption, appropriate maturity varies depending on the compost's intended purpose (Paradelo *et al*., 2010).

The level of maturity is a crucial factor to consider when assessing the stability and safety of a compost product. Compost is deemed "mature" when microbial activity and plant toxins levels reach an acceptable level and there are no longer any visible material changes. However, great variation exists in our comprehension of the indices used to assess compost product maturity due to the diversity and heterogeneity of raw materials (USSC, 2001)

The US Composting Council defines compost maturity as the compost's acceptability for a certain function. Three levels of compost maturity are identified by the Composting Council's rating system: very mature, mature, and immature.

- **Very mature** composts are well cured. They are highly stable due to their extremely low rate of breakdown. They don't emit smells, and there is no obvious plant toxicity.

The general marketing standards for compost are met by **mature composts**. They are cured, have a low rate of decomposition, and have a high degree of stability. Mature composts have a low potential for toxicity to plants and are unlikely to emit unpleasant aromas when kept.

- **Immature** composts have a high rate of breakdown and limited stability. Such composts have a significant potential for plant toxicity and are prone to develop odours when kept.

Composts that are very mature are said to be suitable for all applications. There are less applications for mature and immature compost.

Bernal *et al*., 2009 and Nolan *et al*., 2011 noted that No one quality or parameter was able to adequately represent the maturity of the compost. To measure compost maturity, many research have employed a variety of physical, chemical (such as pH, temperature, and total organic carbon), and biological (such as germination index (GI), seedling development quality) characteristics. Before applying compost to the ground, its quality, including its stability and maturity, should be assessed. Due to the reduced oxygen and/or nitrogen availability, or the presence of phytotoxic substances, the unstable and/or immature compost may have negative impacts on seed germination, plant growth, and soil environment (Bernal *et al*., 2009).

1. Classification Of Parameters Used for Evaluation Compost Maturity and Stability

Physical and sensory, chemical, and biological characteristics are the different categories of parameters (Sullivan and Miller, 2001)

2. Physical And Sensory Parameters

a) Temperature

Since temperature fluctuates in a way that is related to the decomposition of organic matter and the development of microorganisms, it is one of the main parameters used to monitor the composting process (meng *et al*., 2018).

A quick, low-cost, and precise evaluation of the growth of compost to a stable and mature state might be possible by keeping track of temperature rises and falls along with oxygen profiles (which are a sign of microbial activity) (Boulter-Bitzer *et al*., 2006).

1. **Mesophilic phase:** This is the first stage, and during the first two days the temperature rises to 45 ^{o}C.
2. **Thermophilic phase:** This phase, which lasts for around 42 weeks, sees temperatures rise to 72 ^{o}C. Further temperature increases are avoided by adding compost to the area once every week.
3. After two months, the temperature levels start to drop and eventually reach ambient levels. The compost at this level is presumed to be of steady nature. Temperature monitoring is attractive as a potential stability–maturity evaluation method because it is simple, fast, and inexpensive (Boulter-Bitzer *et al*., 2006)

Temperature profile is the key marker of microbial activity in a composting heap (Cáceres *et al*., 2015). The four main stages of the composting process are as follows: (1) a mesophilic phase that occurred in the initial days 0–1; (2) a high temperature, thermophilic phase that took place during days 2–10; (3) a drop in temperature days from day 8 to day 10 and (4) a maturation phase which occurred after days 30–45 depending on the type and complexity of the composting substrate (Villar *et al*., 2016)

High temperatures (> 50 °C) over the first 10 days in every composting reactor show a successful start to the hydrolytic/fermentation phase of the composting process and suggest a very active decomposition activity in the reactors. According to published research, the ideal temperature range needed for effective breakdown of ligno-cellulosic materials is between 50 and 60 °C (Wong *et al*., 2001). High temperatures are seen and a lot of heat is produced due to the microbial respiration because the easily available soluble organic and nitrogenous chemicals degrade quickly (Bernal *et al*., 2009). The composting materials are essentially disinfected by the high temperatures (50 °C) in the reactors (pathogenic organisms arising from cow dung used in the composting process). Soon after the weekly rotation (aeration) of the composting materials, temperatures in all the reactors decreased as a result of the removal of heat generated by microbial respiration and oxygen passage through the compost (Himanen and Hanninen 2011). In all of the composting reactors, high temperatures (40–60 °C) were also noted at a depth of 15 cm, indicating considerable microbial activity during the first 10 days. 15 days after the composting process started, temperatures in all of the reactors approached nearly ambient levels, indicating the cessation of thermophilic microbe activity (Nolan *et al*., 2011). The dynamics of temperature were seen to follow a normal pattern for composting, which aided in the effective microbial breakdown process (Guo *et al*., 2012). The breakdown process slowed down as temperatures began to drop to ambient levels, which was also demonstrated by a decline in microbial activity.

Odour And Colour

The compost starts maturing and stabilizing, changes in its color and odor start appearing. When compost reaches maturity, its colour typically darkens and its odour changes from rotting and ammonia-like to plush and earthy. For evaluating four color tendency of compost, a moderately novel process. CIELAB colour space also known as “Lab” color space, has shown promising results as a parameter of stability and compost stability is designated by steadying of the color variables (Khan *et al*., 2009).

Since it is well known that the material gradually darkens during the process, colour has been utilised to monitor the degree of degradation during composting (Iglesias *et al*., 2008)

5. Chemical Parameters

1) Carbon to nitrogen proportion
2) pH
3) Humification
4) Spectrophotometric test

a) Carbon: Nitrogen Proportion

During the composting process, microbes utilise carbon and nitrogen for cell growth and energy production. This causes significant variations in the C/N ratio, which can be used to determine the compost's maturity. The raw material's initial C/N ratio was close to the ideal range (25-20), which provided the ideal balance for the process to run smoothly. The C/N ratio generally trended downward, with the exception of the upward trend from day 5 to day 10, primarily because the rate of carbon breakdown was slower than the rate of ammonia stripping. The drop in the C/N ratio over the course of the composting process was very similar to that observed in a prior study (Zhang *et al*., 2016), and it was most likely brought on by the mineralization of the substrate or an increase in total nitrogen as a result of carbon degradation (Zhang and Sun, 2014). Typically, a C/N ratio of 12 indicates a satisfactory level of composting maturity (Fourti, 2013).

According to the California Integrated Waste Management Board (2007), it is crucial to correlate preliminary and final data in order to apply the C: N proportion of no more than 25:1 when determining the compost maturity. If combined with other limitations, such as the release of carbon dioxide, water dissolving carbon, humic materials, or pile temperature, the carbon-to-nitrogen ratio would produce superior outcomes (Goyal *et al*., 2005).

Composting substrates' C/N ratios are excellent measures of maturity since they have a big impact on microbiological proliferation and, consequently, decomposition rates (Chauhan and Singh, 2013). While a lower C/N ratio (< 25:1) suggests an effective breakdown process, a high C/N ratio shows the presence of unutilized complex carbon material (Pan *et al*., 2012). Higher carbon and nitrogen content substrates typically need more time to complete the maturation step.

Compost maturity was said to be best indicated by a C/N ratio of less than 20, with 15 or less being optimum (Goyal *et al*., 2005). The C/N ratio of mature compost should ideally be about 10, but this is difficult to attain since there are complex and resistant organic molecules present that resist decomposition because of their physical or chemical properties (Goyal *et al*., 2005). According to several studies, a C/N ratio of less than 20 indicates a maturity that is acceptable, with a ratio of 15 or even less being preferred (Rashad *et al*., 2010). When low C/N ratio materials are composted, more N is lost than when high C/N ratio wastes are composted (Wei *et al*., 2015).

b) pH

Acidity and alkalinity are measured by the pH of compost. The majority of plant-based composts have a pH range of 6.6 to 7.0. (pH 7.5). Composts made with manure typically have a pH of 7 to 8.

One of the key elements influencing the development and procreation of microorganisms is the pH. Composting is hampered by pH levels that are either too high or too low, which can limit microbial activity. The pH drops as a result of the release of organic acids as a result of the destruction of easily accessible/soluble organic compounds that occurs throughout the fermentation process. After 10 days, when both temperature and thermophilic microbe activity started to decline, the pH gradually increased to 8 and above. By the end of the first month, the pH ranged from 7.5-8, indicating that the process of decomposing easily degradable compounds had been completed and that the composted materials were maturing. The elevated pH also signals that the composted materials contain more ammonium (Sundberg, 2005).

c) Humification

The composting process produces humic compounds, which are essential for improving soil, promoting plant growth and development, and increasing agricultural productivity.

Tiquia (2005) showed that as manure compost matured, humic acid increased and the oxygen consumption % decreased, whereas fulvic acid decreased and the ratio of humic acid to fulvic acid increased, reaching over 1.6:1 for fully mature composts (Ko et al., 2008). The two humification limitations are humification degree and humification index. These two markers attained stable values at the composting process's end, demonstrating the stable nature of the compost material (Mondini *et al*., 2003).

Humic acid content has been shown to be highly correlated with the maturity of compost (Tiquia, 2005). Because the amount of humic acid in the compost increases dramatically after composting, strengthening the stability of the soil's organic matter and signalling that the compost is ready for subsequent land application (Zhou *et al*., 2014). There are two ways that humic compounds are produced during microbial breakdown or activity (Lopez *et al*., 2002) (1) lignin derivatives are oxidized from side chains of lignin which form the core structure of humic substances, and (2) during the polymerization of monomers. A normal humification process is taking place when the CHA/CFA ratio is greater than 1, and a product is mature when the ratio is larger than 1.6 (Iglesias-Jiménez *et al*., 2008)

D) Spectrophotometric Test

Spectrophotometric methods make it easier to identify different organic compounds, allowing an accurate evaluation of the state of decomposition of composted materials; relative levels of chemical compounds vary as compost matures, and this is reflected in the spectral patterns produced by a sample. The classification of various biological composites is made possible by spectrophotometric processes, providing a precise evaluation of the state of compost degradation, Comparative stages of chemical components change as compost ages, and this is visible in the spectrum patterns that a sample produces (Smidt and Meissl, 2007).

6. Biological Parameters

1)Respiration
2)Dewar self- heating test
3)Solvita method
4)plant bioassay
5)Seed germination
6)Plant growth
7)Enzyme activity

Respiration

Respiration is directly related to the metabolic activity of a microbial population. Microorganisms respire more quickly when there is a plentiful supply of bioavailable organic matter, while their respiration rate slows down when there is a shortage of this type of material.

Since bacteria consume oxygen and exhale carbon dioxide during aerobic decay, the amount of respiration was calculated by the production of carbon dioxide and the usage of oxygen.

Based on CO2 production, O2 intake, or heat release, a variety of Respiro metric methods have been recorded. The techniques that rely on O2 uptake are the most popular.

No matter the operating circumstances, raw materials, or initial state of the resources, the respiration % for steady composts remains largely consistent and indicates the current level of degradation of the waste matter (Diana *et al*., 2017).

Dewar Self-Heating Test

This test is based on an ancient German technique for assessing "compost ripeness" through the measurement of reheating in a dedicated 1-liter laboratory Dewar flask. The method provides information that is distinct from other stability tests because it permits self-heating to have a positive impact on the test result. To put it another way, compost produces heat through respiration, and the heat may lead to an increase in microbial activity until a plateau is reached, known as the Tmax. Maintaining stable ambient conditions, using the right flasks, and using the appropriate moisture are necessary for the test to be accurate.

Dewar self-heating increments, rating and description of stability classification based on European system

Temperature Rise Above Ambient in C	**Official Class of Stability**	**Descriptors of Class or Group**	**Major Group**
0 --10°	V	Very stable, well-aged compost	Finished Compost
10 --20°	IV	Moderately stable;curing compost	
20-30°	III	Material still decomposing; active compost	Active Compost
30-40°	II	Immature, young or very active compost	
40->50°	I	Fresh, raw compost, just mixed ingredients	Fresh Compost

Solvita Method

For routine testing of composts for stability and maturity, Woods End Laboratories, Maine, USA, developed the SolvitaTM test kit. The test measures the evolution of ammonia and carbon dioxide in a compost sample's headspace. To identify the degree of activity from which a Maturity Index is generated, use the Solvita colour chart. Things in the kit:

- Incubation jars, lids and gas-tight gaskets
- 6 High-CO2 detector probes
- 6 Ammonia detector probes
- Colour Chart for reading CO2 and NH3 results

kept at 20–25 °C for 4 hours. before opening the jar, check the detector probe against a colour chart. then take a look at the probe outside of the jar. Using a digital colour reader, this probe can also read. It shows the colour grade number, CO2% (which denotes aeration need), and ammonia volatized.

Plant Bioassay

In plant bioassays, plant growth in extracts or compost mixtures is assessed together with seed germination.

Test findings are reported as a percentage of germination or growth compared to a control after being conducted under controlled settings (Sullivan and Miller, 2001).

Seed Germination Index

The seed germination index (GI) has been defined as a factor of relative seed germination and relative root elongation (Moharana and Biswas, 2016). According to a study, unstable and immature composts can produce phytotoxicity, which can hinder seed germination and root development and lower seed GIs (Awasthi *et al*., 2014).

Chinese cabbage seed could be utilised as a model organism to study the toxicity of compost because of its benefits in terms of the reaction to toxic compounds (sensitive), the germination cycle (48 h), and the seed size (medium) (Luo *et al*., 2017).

An efficient and affordable bioassay to determine the possible toxicity of compost before to use is the seed germination test. If the compost or substrate's GI value is less than 65%, it is classified as phytotoxic; if it is between 66% and 100%, it is stable and non-toxic and may be used in agriculture; and if it is greater than 101%, it is classified as a phytonutrient and a phytostimulant and can be used as fertiliser (Jagadabhi *et al*., 2019).

The Germination Index (GI), based on relatively simple phytotoxicity testing Tests for phytotoxicity are really germination bioassays that measure seed growth after applying compost liquid extracts to the seeds; GI is determined by the root length and the percentage of germination of chosen test plant seeds in comparison to a control (control is commonly tested using deionized water). Any compost's GI can be used to determine its level of toxicity; for example, toxicity at low levels primarily affects root growth, but toxicity at high levels impairs seed germination. Consequently, GIs below 100% suggest probable phytotoxicity, but values above 100% show a favourable impact on seed growth and, as a result, denote a developed compost. A phytotoxicity test merely quantifies the toxicity for seed growth in an indirect manner; it does not address the underlying causes of the compost's toxicity. The presence of partially degraded organic acids, fermentation intermediates, ammonia, salts, and heavy metals in the compost extract can all contribute to phytotoxicity (Jagadabhi *et al*., 2019).

Plant Growth

Since there are numerous compost materials that can be used to produce plants, it makes sense to use a plant growth test as a technique for determining the compost's maturity.

The most direct and efficient way to assess the compost's maturity is through plant growth, and the physicochemical maturity indices based on plant growth have greater adaptability and believability (Meng *et al*., 2018). Plant height, stem diameter, number of leaves, leaf area, crop size, and fresh and dry weights of the root, stem, leaves, and crop are some of the parameters that are frequently compared (Niamat *et al*., 2019).

Enzyme Activity

Enzymes have the catalytic role in the respiratory chain of all microorganisms. Different types of enzymes, including peroxidases, proteases, cellulases, and dehydrogenases, are involved in a variety of processes. For example, peroxidases play a role in catalysing the disintegration of benzyl alcohols and lignins. Cellulases hydrolyze polysaccharides like cellulose. Proteases break down proteins. And dehydrogenases aid in the fermentation of glucose (TMECC 2002a).

It is possible to determine the degree of microbial activity in a compost sample using enzyme activity. Depending on the enzyme under consideration, the trend in enzyme activity will vary. For instance, a high level of DH-ase activity may indicate that there are still significant amounts of readily biodegradable material (such as glucose) present. As this material is consumed and compost stabilises, it is expected that DH-ase activity will decline. Peroxidase activity, on the other hand, should increase as composting progresses, when the proportion of less degradable matter such as lignin increases (TMECC 2002*a*; Benito et al. 2003). Analyzing enzyme activity is a reasonably quick, easy, and inexpensive process (Go´mez-Brando´n *et al*., 2007).

The amount of organic matter that decomposes during the composting process is a typical factor in determining compost stability (Benito *et al*., 2003). The presence of organic components in the early and middle phases of decomposition is certainly indicated by high rates of biological activity, therefore the decline in microbial respiration is viewed as a reliable sign of increasing stability (Barrena *et al*., 2006). The simplicity of the determination of the DHA and its relationship with microbial respiration leads us to support the conclusion of Tiquia (2005), as this enzymatic activity being a suitable predictor of compost stability.

Conclusion

Compost is a valuable tool for returning the nutrients to soil. Thus, it helps to maintain nutrient content and soil texture. Safe compost protects the soil from harmful effects. The maturity and stability are two important factors that helps to determine the safety of compost to use in land. These two factors cannot be determined by a single factor. Monitoring of these parameters ensures the quality of compost.

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