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Review

Microhabitat drive microbial anabolism to promote carbon sequestration during composting

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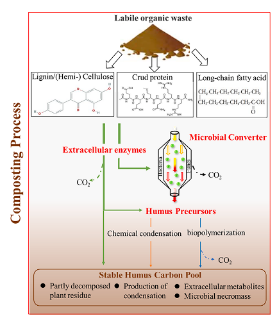
HIGHLIGHTS

- Microbial metabolism drives the transformation of organic matter in composting.
- Microhabitat factors directly affect microbial metabolism.
- Regulating composting parameters may realize carbon fixation with high efficiency.
- Utilize functional materials could stabilize formed humus components.

GRAPHICAL ABSTRACT



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ABSTRACT

Transforming organic waste into stable carbon by composting is an eco-friendly way. However, the complex environment, huge microbial community and complicated metabolic of composting have limited the directional transformation of organic carbon, which is also not conducive to the fixation of organic carbon. Therefore, this review is based on the formation of humus, a stable by-product of composting, to expound how to promote carbon fixation by increasing the yield of humus. Firstly, we have clarified the transformation regularity of organic matter during composting. Meanwhile, the microhabitat factors affecting microbial catabolism and anabolism were deeply analyzed, in order to provide a theoretical basis for the micro habitat regulation of directional transformation of organic matter during composting. Given that, a method to adjust the directional humification and stabilization of organic carbon has been proposed. Hoping the rapid reduction and efficient stabilization of organic waste can be realized according to this method.

1. Introduction:

Organic solid waste (OSW) transformation has become an important topic in recent years owing to its mass discarding and improper disposal, including developing and developed countries (Angulo-Mosquera et al., 2021; Liu et al., 2017). Generally, compost is one of the best ways to management organic waste C, for it avoids secondary pollution caused by arbitrarily discard and incinerate (Neri et al., 2018). Compost can also rapidly and efficiently transform OSW into positive end-product which is beneficial to improve soil fertility, repair environmental

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pollution, and even be widely utilized in pharmaceutical and cosmetic fields (Awasthi et al., 2021; Chen et al., 2022). Because organic carbon (C) transformation in composting is ultimately the consequence of microbial growth and activity(Witzgall et al., 2021), understanding C release and fixation in compost demands improved knowledge of how microbial physiology regulates the process controlling organic C degrading, transforming, CO_2 releasing and humification.

Microorganisms perform two contrary roles in transforming organic C during composting: promoting release of CO_2 into the atmosphere by catabolism or fixing C into compounds that with high humification degree and not easy to be degraded by metabolism (Kallenbach et al., 2016; Liang et al., 2017). To date, researches has focused on the role of microhabitat in regulating humification with less attention paid to anabolism to generate products that can be sequestered(Cotrufo et al., 2015; Liang et al., 2017). This has stimulated research considering the direct incorporation of microbial residues (cellular components from both living and senesced biomass) into the stable organic C pool (Benner, 2011; Ludwig et al., 2015; Miltner et al., 2012; Schaeffer et al., 2015). Recent studies with the main purpose of research on humification is to promote compost maturity by improving microbial activities through regulating microhabitats (aeration, charcoal); while for the purpose of C sequestration, research needs to control carbon emissions based on promoting compost maturity (Awasthi et al., 2020a). High microbial activities are contributed to C transformation and sequestration, but it also leads to huge amount of C be transformed into CO_2, causing organic C loss (Kone & Yao, 2021). During composting, microbe with high active state will promote CO_2 emission accounts for 1.81% of the organic matter (Lu et al., 2018). Calculated according to the composting plant with an annual treatment capacity of 100,000 tons, the cumulative emission of CO_2 is as high as 1810 tons, which causing a huge waste of organic matter. Nevertheless, the less release of CO_2 may reflect low microorganism activities, which might delay the humification process. Therefore, any attempt to manage compost for promoting C sequestration will require an understanding of how to manage microbial-derived C in compost by reducing CO_2 emission. Actually, reducing the release of CO_2 is to reduce the utilization of formed small molecular organic matter by microorganisms. To regulate microbial metabolism to decompose macromolecular organic matter and provide precursor compounds for the formation of stable organic matter such as hums during composting.

To this end, we cite microbial carbon pump (MCP, it was first proposed in marine system and used for reference by soil science(Jiao et al., 2010; Liang et al., 2017) as a conceptual framework for understanding the role of microbial processes in regulating organic waste C dynamics. This framework breaks the balance between organic carbon decomposition and formation (Liang et al., 2017). It highlights the effect of microenvironment on microbial assimilation in the production of stable organic compounds. Here, we focus on the role of microbial metabolism in compost C dynamics, particularly the contributions of microbial anabolism to stable C storage. We first discuss evolving views on metabolic controls of compost microorganism in organic waste C turnover. We then discuss the influencing factors that control microbial metabolism relating to C sequestration during composting. Finally, we propose a way to regulate the parameters to advance C storage by reducing C release during composting.

2. Transformation of organic carbon during composting

Composting is a process of transforming organic waste into mature products by microbial hydrolysis, microbial synthesis and chemical synthesis (Rebollido et al., 2008; Chen et al., 2020; Zhou et al., 2021). Among them, the microbial metabolism is the basis in driving organic C transformation during composting. Conversions in organic C mainly process three stages: degradation, release of CO_2 and C sequestration.

2.1. *Degradation of organic waste*

OSW, including garden waste, such as agricultural straw, lawn waste, fruit and vegetable waste, municipal solid waste, livestock manure, kitchen waste, can be classified into lignin-like, cellulose-like, protein-like and fat-like materials (Zhao et al., 2019). During composting, the non-structural compounds derived from OSW will be incorporated into microbial biomass firstly (Cotrufo et al., 2015). The protein, fat, lignin and cellulose will be degraded in order afterwards (Liu et al., 2015). Actually, there are no clear boundaries among the degradation of protein, fat compounds, lignin and cellulose. In the initial stage of composting, microorganisms will degrade the non-structural compounds like labile protein-like or fat-like compounds in disorder for adapting the environment by releasing protease and lipase with the production such as ammonia, hydrogen sulfide and organic acids (Shao et al., 2014; Voberkova et al., 2017). With the composting proceed, microbial biomass and activity are gradually stabilizing, the degradation is also gradually taking cellulose, hemicellulose, lignin, and any other refractory organic C as the main objective (Zhao et al., 2017). These refractory organic carbons will be degraded by extracellular enzymes, including endoglucanases, cellobiohydrolases, β-glucosaccharase, lignin peroxidase and manganese peroxidase (Feng et al., 2011; Payne et al., 2015), into polysaccharide, polyphenols or some monomer molecule which provide substrates for microbial activity and organic C transformation. Of course, partly undecomposed residues will deposit in the compost pile and not readily assimilate by microorganism (Liang et al., 2017). The degradation of organic matter will continue throughout the composting process, which will be detrimental to the retention of organic C in compost. Researches showed that the microbial metabolite and necromass are difficult to be reused by microorganisms(Cotrufo et al., 2015; Jiao et al., 2010). Therefore, increasing microbial biomass and metabolites are the main ways to promote organic C sequestration during composting. Significant knowledge gaps regarding microorganism mediated C preservation in composts include our comprehensive understanding of C loss, C conversation pathways and C retention forms hinders our ability to promote C sequestration during composting.

2.2. *Release of carbon dioxide*

Reducing CO_2 emission is one of the main ways to enhance organic C sequestration by regulating microbial metabolism (Hu et al., 2019). It is necessary to clearly understand pathways of CO_2 release at first. It can be categorized two major pathways by which microorganisms influence CO_2 emission: *ex vivo* (extracellular) degradation, in which extracellular enzymes attack and transform organic waste to labile organic C that can readily assimilated by microorganisms; and *in vivo* turnover of organic C via dauntingly complicated metabolism pathway. In the *ex vivo* degradation, CO_2 release is the result of extracellular hydrolysis of organic matter, which is the key steps for deposition of microbial-derived C and should not be restricted by any external force. Therefore, regulating microbial metabolism to limit CO_2 release maybe an effective way to promote C fixation. Decarboxylation reactions are the basic pathway for producing CO_2, which can be regulated by the feedback of NADH, ATP and other inhibitors (Jones et al., 2016; Weusthuis et al., 2011). *In vivo* turnover, fatty acid α-oxidation, amino acids decarboxylation, conversion of pyruvate to acetyl-CoA and tricarboxylic acid cycle (TCA) are the main ways of CO_2 production during composting. Among them, TCA is the core path for receiving end products of these pathways and providing intermediates for other anabolisms. Theoretically, inhibition of TCA can reduce CO_2 released by microbe. However, TCA as the basic pathway of cellular respiration, it is bound to inhibit microbial activity if its metabolism is blocked. Therefore, can we find a way to reduce CO_2 emission by improving the microbial anabolism?

2.3. Microbial carbon pump in composting

MCP is a comprehensive concept involving environment, nutrient source, physiology, molecule and gene interactions for refractory C synthesis and storage of related C in composting systems(Jiao et al., 2010). Factors affecting microorganisms to *in situ* synthesize refractory C are generally referred to microhabitats here. Therefore, the MCP is used as the theoretical support to discuss how to promote the transformation of degradable substances into refractory C by adjusting the microhabitats. During composting, anabolism of aromatic compounds can contribute to improve C stability and promote organic C sequestration. In the microbial anabolism, shikimic acid and acetic acid-malonic acid pathway are the main ways to synthesize lignin-like compounds (Stevenson, 1994; Tan, 2014). On the other hand, increasing microbial biomass is another way to promote organic C sequestration, because of the refractory property of microbial structure substances, such as chitin, amino sugar, lipopolysaccharide, are different to be degraded by microorganism again(Cheng et al., 2017). During composting, readily alkane compounds will be transformed into aromatic substances through the above pathways, and the productions are mainly stored as humus (Stevenson, 1994). Humus as one of the most important by-products of composting, improving its yield and aromatic structure has been focus of current studies about organic waste composting (Piccolo et al., 2019; Rodriguez et al., 2016). Therefore, this study aims to promote the contribution of microbial anabolism to carbon fixation by regulating composting microenvironment based on a thorough understanding of microbial anabolism and its influencing factors (Fig. 1).

3. The influencing factors of carbon metabolism

Microorganisms are the main drivers of C flow in composting and play critical roles in the C balance through the decomposition and anabolism of organic waste of different origin. Here, we review the main factors affecting mineralization and assimilation of organic matter. It appears to be an important step to understand both the C flow and the mechanism controlling the sequestration of C during composting (Fig. 1).

3.1. Factors affecting CO_2 release

In vivo, many factors including substrate patterns, microhabitat and the existence of minerals can drive CO_2 release. Commonly, readily assimilated substrates of glucose, hemicellulose and even the fungal biomass can promote CO_2 release significantly (Lopez-Mondejar et al., 2018). On the other hand, the existence of clay, mineral or metallic oxide can protect organic C from microbial mineralization to CO_2 (Johnson et al., 2015; Lalonde et al., 2012; Ma et al., 2018). However, during composting, the most important factor affecting CO_2 release is the microhabitat in which microorganisms live, including aeration rate, moisture, pH, temperature and any others environmental factors. During aerobic composting, appropriate aeration rate is the key to ensure oxygen concentration and maintain the high activity of microorganisms (Gao et al., 2010). Moreover, suitable moisture (commonly 60–65%) combines with good dissolved oxygen can reduce the waste of organic C in the form of CO_2 (Chen et al., 2020). Because even under adverse conditions, microorganisms still maintain basic breathing, released CO_2 is almost equal to the desirable microhabitat and the microbial activity and diversity are also limited under water shortage conditions (Whitman et al., 2016). In addition, tricarboxylic acid cycle as a major source to produce CO_2 *in vivo*, which can be regulated by some regulatory factors during composting (Wang et al., 2019). Adenosine triphosphate and nicotinamide adenine dinucleotide as the direct energy and reducing power are like "two sides of a coin". They may not only enhance the C flux, but their high concentration may also slow the metabolism rate by the feedback inhibition (Causey et al., 2004; Shima et al., 2008; Zhou et al., 2009). However, the adenosine triphosphate and nicotinamide adenine dinucleotide can only promote CO_2 production, while the malonic acid, a succinic acid substrate analogue, is effective in inhibiting the release of CO_2.

3.2. Factors related to microbial anabolism

Microbial anabolism including "vegetative growth" and "reproductive growth", both contribute to C sequestration, but they are also affected by environmental factors at the same time (Glassman et al., 2018). The fixed factor is composting period which promoting microbial transformation between two metabolic modes with other factors remain unchanged. At the initial period of composting, the easily degradable plant materials are firstly utilized for microbial cell growth, that is vegetative growth (Palaniveloo et al., 2020). Driven by the time turnover, they will use sufficient nutrition to enter the reproductive growth stage. Microorganisms thus promote the C fixation into microbial biomass in an iterative process of cell generation, growth and death. In addition, the microhabitat factors (pH, temperature, moisture, physicochemical property, types of substrates and so on) as the variable factors can regulate the anabolism of microorganism in the whole composting process (Wang et al., 2019). Especially the composting temperature which is not conducive to microbial survival in its highest

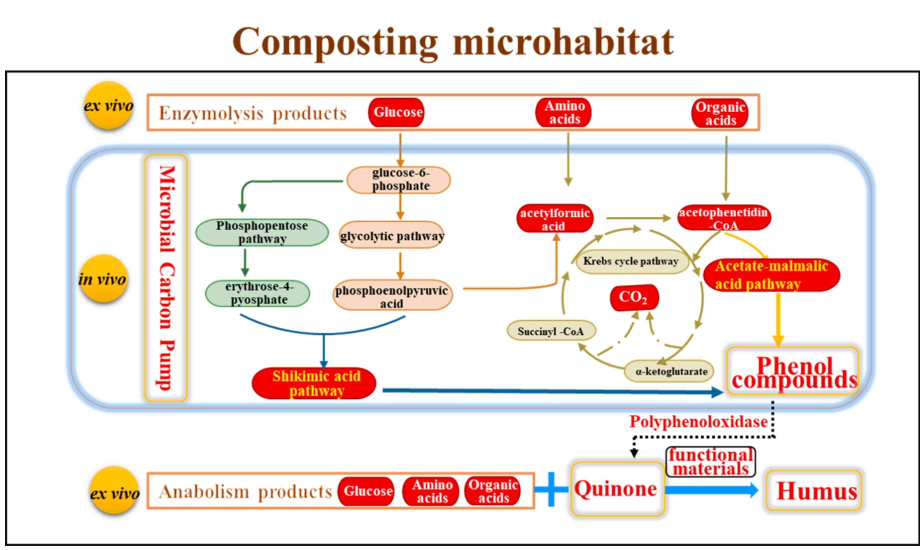

Fig. 1. Microbial metabolism affected by micro habitat during organic wastes composting.

level (∼70 ℃) (Zhang et al., 2016). However, thermotolerant microorganisms remain active, providing sustainable energy by driving C conversion, even though this period is in the extreme water shortage environment. In order to survive in harsh environment, microorganisms will slow down anabolism for maintain basic respiration (Wang et al., 2019). Moreover, the change of pH from low to high caused by the production of organic acid and humus formation in compost also pushes the microbial metabolism from synthesis to decomposition (Malik et al., 2018). Comprehensively speaking, long term and stable microenvironment is conducive to the anabolism of microorganisms. Nevertheless, in view of the high temperature is the essential factor to kill the pathogens derived from the organic waste, which have limited the above process. Therefore, in the changing composting environment, microorganisms with prominent anabolism may become an important research object for the purpose of carbon sequestration. It can highlight their dominant role in composting through micro environment regulation.

4. Regulating the process parameters of carbon transformation

4.1. Physicochemical regulator

Physicochemical regulators including temperature, pH, C/N, aeration rate, moisture, ammoniacal nitrogen and nitrate nitrogen can not only adjust C transformation, but also the basic parameters to maintain composting process. Commonly, regulating the initial C/N is about 25 ∼ 30 and maintaining the moisture at 60–70% in composting process is beneficial to ensure the success of composting (Proietti et al., 2016; Silva et al., 2014). In addition, regulating the aeration rate is contribute to accelerate the maturity of composting products (Gao et al., 2010; Yuan et al., 2016). It is meaningful for reducing organic solid waste pollution. Moreover, reasonable control of aeration can also affect the structure of humus during composting (Gao et al., 2010; Wu et al., 2019). The structure of humus may directly affect its utilization: humus with high aromatic components can be applied in contaminated soil as a soil remediation agent, while the humus with more alkanes fraction may make a stronger contribution in improving soil fertility (Wu et al., 2019). Applying the humus to environment according to the structure and composition will effectively improve the utilization efficiency of compost products and environmental governance. This kind of classified application is called the resource utilization of humus by different components. When compost products are used as organic fertilizers, C/N, ammoniacal nitrogen and ammonia reflux can promote the available nitrogen and phosphorus content in compost products (Wang et al., 2020b). However, the composting process regulated by microhabitat factors is realized by changing microbial metabolism, whether it is to shape the structure of humus or to improve the nutrient content of compost products. The activity of culturable and unculturable microorganisms in compost can be fully mobilized by regulating composting microhabitat factors (Wei et al., 2021). This provides the possibility for the regulation of microbial anabolism by microenvironment factors. In addition to environmental factors, microbial activity is also affected by other microorganisms or its related regulators.

4.2. Biological regulators

During composting, microbial inoculation involved in promoting recalcitrant components degradation (Wu et al., 2022), limiting carbon emission (Awasthi et al., 2020a), enhancing nitrogen fixation (Zhang et al., 2016), boosting compost start-up in low temperature (Xie et al., 2021), controlling pollution of organic waste by composting (Chen et al., 2019), and so on. In the study of organic carbon fixation, the effects of microbial inoculation on organic matter transformation are mainly considered. The research on promoting recalcitrant components hydrolysis by microbial inoculation has still attracted much attention, especially for the degradation of lignocellulose (Cortes-Tolalpa et al., 2016; Fernandez-Bayo et al., 2019). Even that, the mosaic structure of lignin and cellulose still limits the metabolic intensity and enzyme activity of microorganisms (Sitarz et al., 2016). Additionally, the complexity and drastic changes of composting environment also affect the effect of inoculant. Therefore, both the functional and environmental tolerance should be considered when inoculating microorganisms for the purpose of promoting lignocellulose degradation. Recently, preliminary progress has been made in microbially promoting lignin cellulose hydrolysis in composting. Meanwhile, the small molecular products after hydrolysis have also attracted attention, because the active inoculation may mineralize them as energy, which will cause organic carbon loss (Razanamalala et al., 2018). Accordingly, microbial assimilation of small molecular organic matter is also very important during composting with inoculation. But unfortunately, little studies focused on the microbial anabolism. Stable composting system is conducive to microbial anabolism which synthesis of metabolites through primary and secondary metabolism and even the necromass (Liang et al., 2017; Ni et al., 2021). During the period of drastic changes in the composting environment, no matter the exogenous or indigenous microbe, high microbial activity and diversity promote the formation of a large number of small molecules compounds that are both energy and humus precursors (Tan, 2014). Thereafter, limiting microbial activity and promoting the polymerization of precursor compounds may be conducive to the immobilization of organic carbon in the form of humus. On the other hand, during composting with the purpose of nitrogen fixation, it was unexpectedly found that the effect of exogenous nitrogen fixing bacteria on carbon fixation was also significant (Wang et al., 2020a). Because ammonia is fixed in the composting system in the form of ammonia nitrogen which can polymerize with reducing sugars, polyphenols, and any other precursors (Stevenson, 1994; Tan, 2014). Similarly, phosphorus regulating bacteria are also beneficial to humus formation. Accordingly, functional bacterial agents that enhance the content of nutrients may indirectly promote carbon fixation. Inoculation of microorganisms related to carbon transformation has also achieved certain progress in promoting organic carbon fixation (Wu et al., 2020). However, the research is still at the level of enzyme activity, microbial community or organic matter concentration (Ni et al., 2021), few studies focus on microbial anabolism. While, there are abundant studies on microbial agents combined with functional materials to promote organic carbon immobilization.

4.3. Functional material adjustment

In this review, the functional materials mainly point to the exogenous materials which were added to promote the composting process. The most common functional material is biochar, which has been studied in regulating composting system, accelerating composting maturity, controlling heavy metal pollution in waste and improving humification of composting products (Chen et al., 2020; Godlewska et al., 2017). In the respect of carbon sequestration, the effect of common biochar (without modification and not used in combination with other materials) on composting mainly promoted the humification, while the organic carbon fixation needs to be further detected (Guo et al., 2020). Because the ordinary biochar mainly be regarded as bulking agent to increase the porosity of composting (Yin et al., 2021). However, modified biochar, high biochar concentration or biochar combined with other functional materials can efficiently promote carbon fixation (Awasthi et al., 2020b; Li et al., 2020; Qu et al., 2020). Before the beginning of composting, addition of regulator to promote composting humification is the most common application of functional materials, include the metallic oxide, mineral, humus precursors, modified biochar or others, which have been studied for decades years (Li et al., 2020; Qi et al., 2012; Wu et al., 2022). While the research reports on promoting the directional transformation of organic components to form stable humus are increasing in recent years. During the single material composting, the formation efficiency of humus is often limited due to the haploid type of humus precursor. Therefore, researches that added amino acids or reducing sugars as functional precursors into straw or chicken manure composting have been conducted to promote humus formation (Wu et al., 2022; Zheng et al., 2021). Additionally, benzoic acid has also been utilized as aromatic skeleton of humus to improve carbon stabilization (Zhang et al., 2018). On the other hand, metallic oxide (e.g., manganese (IV), iron (III), aluminum and silicon oxide) can catalyze humus precursors polymerization by abiotic process to for humus (Jokic et al., 2004; Qi et al., 2012; Zhang et al., 2017). In earlier years, this chemical catalysis was mainly achieved under sterile conditions (Hardie et al., 2009; Jokic et al., 2004; Song et al., 2021). In recent years, it has been proved in composting practice that their promoting effects on humus formation depends on the material source, especially for manganese bioxide (MnO_2) (Wu et al., 2020). If there are abundant reducing sugars, MnO_2 will effectively exert its chemical catalytic properties and promote the formation of humus (Wu et al., 2020). Otherwise, MnO_2 will act as bioactive activator to drive OC degradation (Qi et al., 2021; Wu et al., 2020). Overall, the application of multi-functional materials should be targeted according to the material type in order to obtain high-efficiency carbon sequestration.

5. Future perspectives of the retention of organic matter

At the later stage of composting, the humus, plant residue, and some unpolymerized microbial necromass (for the broken cytoplasma membrane, structural protein and any other metabolic intermediates) and extracellular metabolites are composed of the stable carbon of composting products. However, the persistence of microbial activity must degrade the stable organic carbon of compost, including macromolecular humus. Therefore, while preventing carbon loss, it is also necessary to prevent the formed stable carbon from being further degraded by microbe.

5.1. Reduce organic carbon loss by regulating microbial anabolism

Microbial anabolism can be predicted by the results of 16S rRNA gene (Qi et al., 2020). While the most common way is through multi omics to conduct comprehensive research (Hultman et al., 2015; Shahab et al., 2020; Chen et al., 2021). The locally anaerobic of composting will lead to denitrification, which can hydrolyze aromatic compounds by carboxylation (Shi et al., 2020b; Xu et al., 2015). Given humus is a complex macromolecule with aromatic compounds as the core structure, it has great potential to be hydrolyzed by denitrification (Stevenson, 1994). Moreover, study have confirmed that denitrification does reduce the content of humus during composting (Shi et al., 2020a). For solving this issue, the process of dissimilatory nitrate reduction to ammonium (DNRA) is attracting widespread concern, which utilized the same substrates and enzymes with denitrification (Caceres et al., 2018; Kraft et al., 2014; Ribeiro et al., 2018). In view of the ammonium is also the precursors of humus, regulating denitrification turn to DNRA is a win–win way to promote carbon stabilization. On the other hand, microbial anabolism and catabolism reached a balance at the stably later stage of composting, which also presents the balance between priming effect and entombing effect (Liang et al., 2017). Breaking this balance may also achieve the promotion of carbon fixation (Fig. 2), because microbial anabolism contributes greatly to the formation of soil organic carbon(Kallenbach et al., 2016). But the related studies are insufficient, especially in the composting system. The complex composting environment and microbial communities result in metabolic diversity, which limit the in-depth study of metabolic direction adjustment (Qi et al., 2021), including to confirm the boundary between “reproductive” growth and “vegetative” growth. Reproductive and vegetative growth is a couple concept cited from botany. The vigorous reproductive growth of microorganisms in the early stage of composting provides the possibility for the hydrolysis of organic matter and the increase of composting temperature. But the persistence of this growth state is not conducive to the sequestration of organic matter. At the later stage of composting, vegetative growth is dominant and contributes to organic carbon fixation. However, vegetative growth is the basis of reproductive growth, and reproductive growth is a necessary condition for vegetative growth. They restrict and compete with each other. No research has revealed the two metabolic transformation conditions and their effects on organic carbon fixation during composting. Therefore, it is It is necessary to explore the influencing factors of microbial metabolism in the composting process in order to better adjust the metabolic direction according to different composting purposes.

5.2. Preservation by functional materials

Metal oxides and minerals can act as functional materials to interact with organic components to form protection and prevent them from being degraded by microorganisms (Johnson et al., 2015; Wiesmeier et al., 2019). For metal oxides, they can combine with organic matter by ion adsorption or chemical interactions, and then form a metal layer on the surface of organic matter (Cloy et al., 2014). The structure of composted products is rich in oxygen-containing functional groups, for example the carboxyl group, phenolic hydroxyl group, alcohol hydroxyl group, benzoquinonyl and any others (Stevenson, 1994). These groups will ionize into negative status, which easy to combine with positively charged metal ions. And it has been confirmed that the metal layer has a significantly protective effect on protecting organic matter (Johnson et al., 2015). However, metal oxides applied must be controlled under

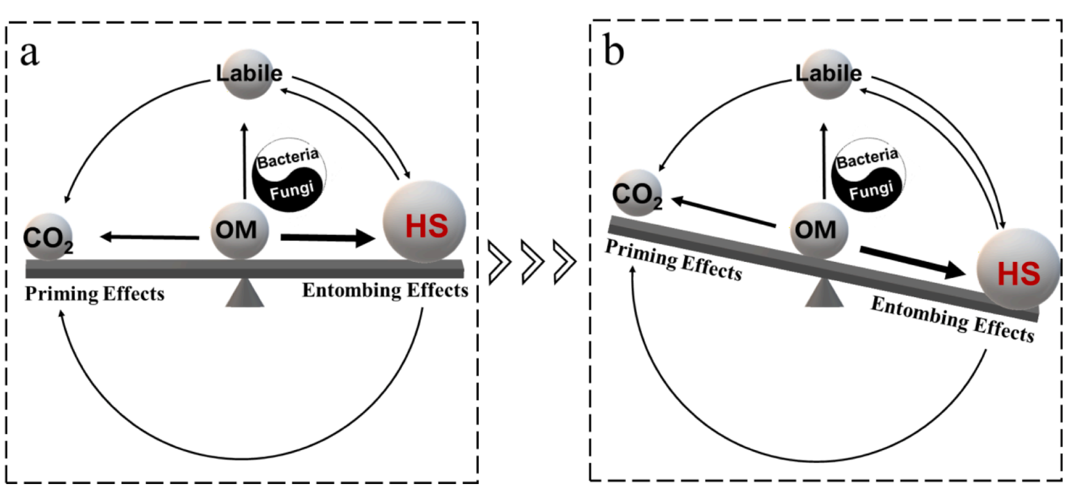

Fig. 2. Promoting humic substance formation by breaking the balance of priming effects and entombing effects (OM: organic matter; HS: humic substance).

pollutant concentration to avoid secondary pollution. Given the threaten of heavy metal pollution, minerals may be the eco–friendly materials for organic carbon stabilization. For minerals, the principle of its combination with organic matter is similar to that of metal oxide (Barre et al., 2014). But the adsorption mechanism between minerals and organic matter is more diversity, including Van der Waals force and ion adsorption (Araujo et al., 2017). But the adsorption efficiency between them has not been compared. Illite, montmorillonite, clay minerals, chitosan and their modified materials are the stabilizers which attract more attention at present. Heat-pretreatment, acid-base treatment, cation replacement and organic reagent washing are the common pretreatment ways for modifying these functional materials (Pan et al., 2021). They can effectively increase the specific surface area or activate the surface adsorption center. Recently, research has primarily tested and verified the addition of illite and montmorillonite can positively promote carbon sequestration (Pan et al., 2021).

6. Conclusion

How to achieve efficient fixation of organic C while rapid transformation is always a restrictive problem for OSW composting. This review focus on how to increase C sequestration by promoting humus formation and stabilization. During composting, organic C will be hydrolyzed into humus precursors, with the mineralization of organic matter by microorganisms, which leads to organic C loss. Therefore, we cited the concept of MCP to decrease CO_2 release and enhance microbial anabolism to promote C fixation, including regulation of the microhabitat of composting and immobilization of organic C with functional materials.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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