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Composting and microbiological additive effects on composting

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ABSTRACT

Nowadays, composting is the method of choice to reduce and recycle the ever increasing organic wastes generated from human activities. The four phases of composting and the factors affecting each phase, particularly carbon to nitrogen ratio, temperature, aeration, moisture content and pH are critically reviewed. The process of composting is believed dependent on the microbial activities such as bacteria, fungi and actinomycetes under the stipulated conditions. The inoculation of beneficial microbes in the compost would further enhance the soil fertility and crop productivity. However, the interaction between the species of microorganisms is still unknown. Organic matters are composted into humid substances which can be used for the promotion of sustainable agriculture. In addition to plant growth promotion, microbiological additives inoculated compost is also likely to increase plant stress tolerance and disease suppression capacity. The completion of decomposition is usually measured based on the physical appearance of compost, the chemical property of compost substances, as well as the absence of toxins, noxious odor and pathogenic microbes. The application of mature compost is of great importance because direct application of organic matters into the soil may produce toxins and threaten the ecosystem.

KEYWORDS

Composting;
Microbiological additives;
Compost maturity,
Organic wastes;
Sustainable agriculture.

INTRODUCTION TO COMPOSTING

The increases of human population and human activities have generated a lot of organic wastes from agricultural, industrial and municipal sectors across the globe annually. Till to date, landfill and incineration are the most commonly used methods for the disposal of ever increasing organic wastes. However, these disposal methods are seriously threatening the health of our ecosystem. The incineration of organic wastes releases green house gases such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O)[1]. On the other hand, landfill of organic wastes is not a cost effective approach which might cause pollution to the soil quality. Furthermore, the land available for the development of residential, industrial, infrastructural and agricultural projects is getting limited nowadays. Thus, recycling these biodegradable organic wastes into humid substances that highly useful for agriculture have become the method of choice as it is considered as eco-friendly and sustainable approach.

Organic matter plays an important role for sustainable agriculture since it possesses many desirable properties such as high water holding capacity, cation exchange capacity, sequestering contaminants (both organic and inorganic) and other beneficial effects on the physical, chemical and biological characteristics of soil[2,3]. Somehow, direct application of raw organic matter to the soil is not appropriate due to the presence of unknown substances, particularly pathogens, toxic compounds, weed seeds, heavy metals and foul odor[1]. These substances might change the ecosystem for plantation. Other metabolites such as ammonia could also be produced by microflora which is not suitable for plant growth[4]. Therefore, composting is considered as the most appropriate way to obtain stable organic composition. Composting is a bio-conversion process which converts organic wastes such as manure, sludge, fruits, vegetables and other food wastes into an amorphous dark brown to black colloidal humus-like product under the optimal condition of temperature, moisture and aeration. The black colloidal product is known as compost which is widely used as a soil conditioner or organic fertilizer in agriculture.

FOUR PHASES IN COMPOSTING

The process of composting can be categorized into four phases in a bell shaped curve. The temperature profile of the four phases composting: first mesophilic phase (20 – 40 °C), thermophilic phase (> 40 °C), second mesophilic phase and maturity phase are illustrated in Figure 1. Initially, organic wastes are breakdown by microorganisms into stable organic matters with the production of carbon dioxide. The organic matters are then decomposed into humid substances. Heat is generated during this phase because of the extensive microbial metabolism and water is being vaporized. Figure 2 describes the process of composting in schematic diagram. The characteristics and factors affecting the composting for each phase are reviewed critically in the following section.

First mesophilic phase

The first mesophilic phase is also known as the preparatory stage. It initiates the decomposition process and the temperature is between 20 and 40 °C. During this phase, the compost pile is predominately colonized by mesophilic bacteria, fungi and actinomycetes due to the suitability of growing condition such as the ambient temperature, as well as the abundance of easily accessible nutrients. These mesophiles, especially mesophilic bacteria will initiate the decomposition process and raise the inner temperature of compost into thermophilic phase (40 – 65 °C)[5,6]. Those readily available and easily decomposing organic compounds such as sugar and starch are rapidly decomposed with the production of carbon dioxide and other volatile compounds, humus, organic acids and other incompletely oxidized compounds[7].

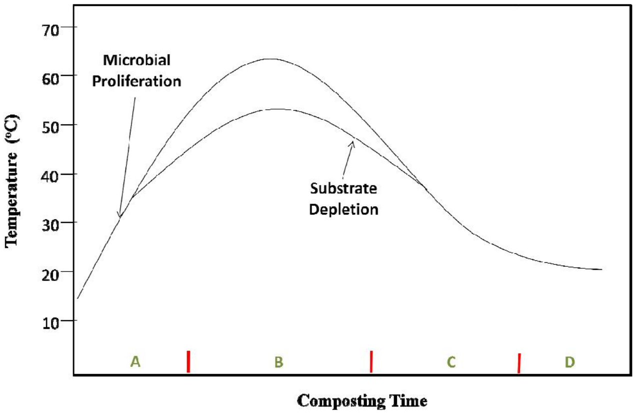

Figure 1 : Temperature profile of four phases composting. A is first mesophilic phase; B is thermophilic phase; C is second mesophilic phase and D is maturity phase

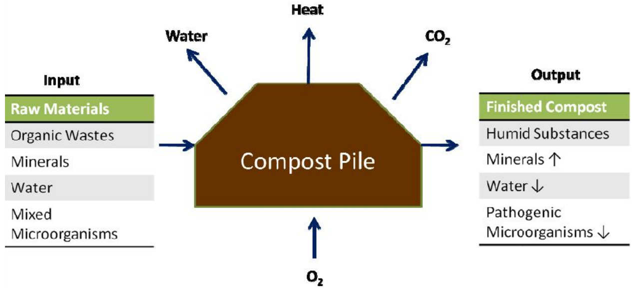

Figure 2 : Schematic diagram of organic waste decomposition to compost

Approximately, more than 20 fold increment of microbial population can be achieved during this phase, in particular mesophilic bacteria because they grow faster compared to mesophilic fungi and actinomycetes. A population up to 10^{10}-10^{12} cfu/g of compost had always been reported by previous investigators[5,6,8-10]. A small number of thermophilic bacteria and thermophilic fungi could also be detected during this phase[8,12]. This phase normally could last for 5 - 14 days, and then the temperature of the compost pile could rise higher than 40 °C, due to the high metabolic activity and exothermic processes. The increase of temperature would bring the compost pile entering into the thermophilic phase.

Thermophilic phase

During thermophilic phase, most of the heat-sensible microorganisms are either killed or entered into the dormant state. The noticeable decrease in mesophilic bacterial and fungal population were observed, while the population of actinomycetes were either maintained or having slight decrease in population[6]. As reported by Rebellido *et al.* (2008), the population of actinomycetes was 10^{10} cfu/g of compost during this phase[10].

Thermophiles will overtake the decomposition process during this phase. The high temperature (40 - 65 °C) would ensure the stabilization and pasteurization of compost. Therefore, the increase of temperature not only accelerates the decomposition of organic wastes, but also stabilizes and pasteurizes the compost pile from pathogenic microorganisms. Besides, the high temperature also promotes the degradation of recalcitrant organic compounds such as lignocelluloses[11]. As shown by Tomati *et al.* (1995), about 70% of lignin was degraded at the end of the thermophilic phase if the temperature was maintained around 50 °C[13]. Some microorganisms could also increase the availability of organic elements such as carbon (C), nitrogen (N) and phosphate (P), as well as inorganic minerals such as magnesium (Mg), zinc (Zn), cuprum (Cu) and Manganese (Mn)[2,3]. Thermophilic phase shall be maintained for more than three days for efficient composting[14]. However, the temperature higher than 70 °C might slow down the decomposition process, since only a few species of thermophiles are metabolically active in this range[15]. Hence, adequate aeration is necessary during thermophilic phase in order to control the temperature between 55 and 65 °C, which is also the desirable temperature range for eliminating most of the thermo-sensible plant and human pathogens[16].

It is important to note that both thermophilic bacterial and fungal populations are observed to have steep increase during thermophilic phase[6]. The thermophilic bacteria were found to be in the population ranging from 10^8 to 10^9 cfu/g of compost. However, the population of fungi never reach 10^6 cfu/g of compost throughout this phase[17].

Second mesophilic phase

After the thermophilic phase, the temperature of compost pile is dropped to the mesophilic stage, where the re-establishment of heat resistant mesophiles such as bacillus species, fungi, yeast and actinomycetes will be observed. The increase of bacterial and fungal population was detected, but only to the limited number of population. Davis *et al.* (1992), Goyal *et al.* (2005) and Rebellido *et al.* (2008) reported that approximately up to 40 % of bacteria and fungi were survived after thermophilic phase. The finding explains that most of the heat-sensible microorganisms are destroyed during thermophilic phase[8,10,17]. Probably, actinomycetes are able to withstand the adverse condition during thermophilic phase, therefore their population are either maintained or slightly dropped after thermophilic phase[5,10].

In this second mesophilic phase, which is also known as the cooling phase, both actinomycetes and fungi play important role in the degradation of the remaining recalcitrant organic matters. They degrade macromolecules such as cellulose, hemicellulose, lignin and chitin and re-colonize the compost pile, particularly at the latter stage of the phase. The degradation is crucial for the release of inorganic nutrients and humus formation[6,10,18]. This explains the major population of actinomycetes in the compost pile after the second mesophilic phase. Therefore, it could be an indicator for compost maturity[18]. In contradiction to the actinomycetes population, the population of bacteria remains constant until compost maturity is reached.

The second mesophilic phase might be prolonged with the formation of newly synthesized, more stable products and humid substances. This phase is also known as maturity phase with the significant reduction of heat in compost pile (ambient temperature). The composted materials are usually lacking of toxic substances such as phenols and ammonia, detrimental microbes and noxious odor.

FACTORS AFFECTING COMPOSTING

A successful composting process is dependent upon various factors, namely carbon to nitrogen (C:N) ratio, temperature, oxygenation, microbial activities, particle size, moisture content and pH. A C:N ratio describes the nutritional balance of a composting process. Since composting is highly dependent upon the activity of microorganisms, it is necessary to supply the microorganisms with adequate carbon and nitrogen sources. Besides as an essential energy source, carbon is also the main building block of cellular material. While nitrogen is the major constituent of amino acids, nucleic acids, cell proteins, enzymes and co-enzymes which is required for proper cell functions[7]. It is noteworthy to maintain the initial C:N ratio in the range of 25 and 35 for high quality compost[14,19]. The C:N ratio of common organic materials that usually employed for composting such as 34-85 for leaves, 80-145 for wood materials, 5-25 for manure and 12 for organic municipal wastes has been reported by Shilev *et al.* (2007)[7].

The higher C:N ratio (> 40) is likely to immobilize the availability of nitrogen in compost and directly slow down the decomposition rate[20]. Microorganisms need to go through many life-cycles in order to oxidize off the excessive carbon until reach the desirable C:N ratio for metabolism. Thus, high C:N ratio would increase the composting time[19]. However, the low C:N ratio (< 25) might lead to the nitrogen loss in the compost pile through ammonia volatilization, which could also slow down the composting process[1,19]. This phenomenon usually occurs in compost pile with high temperature and pH value. It is also a common practice to add sludge for the compost with high C:N ratio. The addition of sludge is to increase the nitrogen availability for composting.

As highlighted, the temperature of compost is an essential parameter for the determination of compost quality. The increase of temperature in the thermophilic phase is due to the exothermic process and the high metabolic activity of microorganisms. Therefore, the temperature profile of compost strongly affects the rate of composting. High composting rate in conjunction with satisfactory microbial number and microbial activities, as well as adequate aeration and moisture content are likely to be getting high quality of compost. Figure 3 indicates the temperature profile during composting with the application of aeration at interval time.

Composting can be performed either in aerobic or in anaerobic system. In an aerobic decomposition (18 - 30% oxygen level), the process of composting is faster and does not produce foul odor[1]. This is because oxygen is used by microorganisms as a terminal electron acceptor for aerobic respiration and decomposition. An oxygen level below 18 % might delay the process of decomposition and cause foul odor in compost pile[14,19]. However, the excess of oxygen content was reported to have no significant effect on the composting.

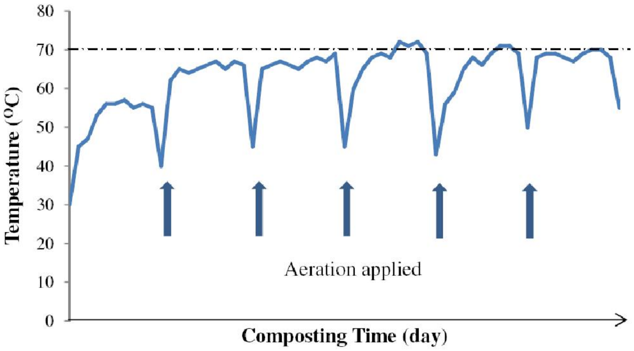

Figure 3 : Temperature profile of compost by aeration at interval day

The rate of oxygen consumption is highly related to the temperature of compost pile. The temperature of compost in the range of 30 and 55 °C would enhance the microbial metabolism, and thus increasing the oxygen consumption rate[21]. The aerobic decomposition is preferable because of its efficiency to achieve high temperature in short period of time (less than a week). An anaerobic decomposition is mostly conducted only if under the minimal manpower operation[1].

The oxygen content in the compost pile could be maintained by periodic aeration such as continuous turning or forced ventilation[19]. The continuous turning of compost pile was reported to be cost ineffective and might also interfere with the growth of some microorganisms such as filamentous fungi[16]. Therefore, continuous forced ventilation by blowing or vacuum induction is always conducted for an aerobic decomposition.

Particle size of the compost starting materials also affects the movement of oxygen into the pile. A smaller particle size of starting materials increases the surface area available for microbial attack which accelerates the composting process and *vice versa*[14]. However, small particles tend to pack tightly together and prevent the movement of air into the pile and the movement of carbon dioxide out from the pile[14]. Therefore, larger starting materials are usually chopped or shredded into smaller size, while smaller starting materials are used together with other bulking agents such as wood chips or tree bark with the particle size around 10 - 50 mm for better aeration.

Indeed, moisture content and aeration are correlated during composting. The excess of water interferes the oxygen accessibility, while too little of water can cause early dehydration, in which the diffusion of substrate and biological process are hindered. Subsequently, the decomposition process is slowing down and giving a physically stable but biologically unstable compost[14,22]. A moisture content of 40 - 60 % was suggested at the beginning of composting[22]. Somehow, the compost needs to be dried for storage purpose, but only after the maturity phase of compost is achieved.

There is no specific pH requirement for composting since those organic wastes that suitable for composting are having a wide range of pH from 5 to 12[22]. However, the pH range between 5 to 8 was proposed by Bertoldi *et al*. (1983) as the optimum pH for composting. It was reported that bacteria prefer in nearly neutral pH, while fungi developed better in a fairly acidic environment. The change of pH during composting is dependent on the microbial metabolism[19]. A decrease in pH will be noticed when organic acids are produced from the decomposition of carbohydrates and lipids, whereas the pH value will increase when the production of ammonia is observed because of protein deamination.

MICROBIAL PROFILE OF COMPOSTING

Composting is known as a microbial process, particularly involving the activities of bacteria, actinomycetes, yeasts and fungi[1,19,23]. These microorganisms are widespread in nature and indigenous to soil, dust, fruits and vegetables. The microbial diversity and the succession of microbial populations is a prerequisite to ensure the complete biodegradation of organic wastes, especially the first three stages of composting. This is because of the complexity of substrates and the production of many intermediate products during composting. The growth of microorganisms are always restricted by the environmental and nutritional conditions[24]. For instance, temperature was found to be the major parameter influencing the microbial population, diversity and metabolism rate throughout this process[10,25]. The microbial profile can be used not only for monitoring the progress of composting, but also reflecting the compost maturity with the detection of specific microorganism, namely *Arthrobacter* sp.[26].

Bacteria

Bacteria have smaller physical size (0.5 - 3.0 μm) and thus producing higher surface to volume ratio compared to fungi and actinomycetes. They have advantages in the colonization of compost pile by allowing rapid transfer of soluble substrates into the cells[27]. The rapid growth rate of bacteria on soluble proteins and other readily available substrates also allowed them to dominate the colonization of compost pile in the early stage of composting[28]. Moreover, the capacity of bacteria produces extracellular hydrolytic enzymes to breakdown the complex polymers such as polysaccharides, nucleic acids and lipids also making *Bacillus* to be dominant throughout the composting process. Some bacteria such as *Bacillus* spp. are able to produce endospores which allow them to be dormant under the harsh environment of high temperature, radiation and chemical disinfection[29].

A wide range of bacteria species has been isolated from different compost environments including *Pseudomonas, Cohnella, Cellulomonas, Paenibacillus* and *Bacillus*[30,31]. Among them, *Bacillus* dominates the colonization of compost pile, especially during the thermophilic phase[32]. It was found that 87 % of randomly colony samples was belong to the genus of *Bacillus* under the species of *B. licheniformis, B. subtilis, B. coagulans type B, B. stearothermophilus*, and *B. sphaericus*. Besides *Bacillus*, the other species such as *Cohnella, Thermotogae* and *Thermus* species were also found likely to be sustained at high temperature for more than 70°C[27,30].

Fungi

Fungi are aerobic chemoorganotrophs that secreting extracellular enzymes to digest complex organic materials such as polysaccharides and proteins into their monomeric constituents[29]. The major ecological activity of fungi is to decompose woods, papers, cloths and other recalcitrant organic matters such as hemicellulose, cellulose and lignin[27]. The degradation is usually performed by fungi such as *Aspergillus fumigatus*, *Malbranchea cinnamomea*, *Ganoderma colossum* and *Heterobasidion annosum* in the compost.

As bacteria, the growth of fungi in composting is affected by the factors of temperature, moisture content and pH. Fungi requires acidic environment (pH 4.5 – 5.0) to grow, although most of them can tolerate to a wide range of pH; less than pH 7.5[27,31,33]. Since most of the fungi are mesophiles, they can grow at the temperature of 5 to 37 °C, with an optimal range of 25 and 30 °C[27,34]. The detected mesophilic fungi population within the first mesophilic phase is always low. The low population of mesophilic fungi, 10^5 to 10^7 cfu/g of compost is due to the high water content at the beginning of composting. Even after the microbial proliferation phase, a population of greater than 10^8 cfu/g of compost was not observed[5,8,17,35]. The microbial number of mesophilic fungi is always reestablished at the end of cooling phase and the maturity phase[6,9,12].

For thermophilic fungi, they are able to sustain at high temperature during the thermophilic phase. The growth of thermophilic fungi is optimum between 40 and 50 °C with the upper temperature limit of 55 – 62 °C[27-29]. The decline in the fungi population has always been observed when the compost reaches the upper limit of temperature.

Actinomycetes

Actinomycetes are considered as a higher form of bacteria that consisted of multicellular filaments. They are common in many environments and able to utilize a wider range of carbon sources in order to sporulate prolifically due to their ubiquity[35]. In contradiction to fungi and bacteria, the relatively low rate of colonization has restricted the growth of actinomycetes during composting. The low colonization rate is significantly observed at the beginning of composting and are usually colonized up to 15 cm in diameter on the surface of an adequately ventilated material[36].

Similarly, actinomycetes also secrete a wide range of extracellular enzymes to degrade cellulose and lignin. Their degradation capacity for lignocellulose was found to be lower than fungi. However, actinomycetes are considered as the main group of microorganisms responsible for organic matter conversion during thermophilic phase, as well as the latter phase of composting. This is because actinomycetes are able to sustain in the harsh environment[37,38]. Although the ideal growth temperature of actinomycetes is within the mesophilic range, some species of actinomycetes can withstand at high temperature during thermophilic phase, and even become more active when the temeperature is approaching to 60 °C[18,37]. This observation could also be happened during the condition of nutrient depletion.

Microbiological additive and its application

In order to speed up the composting rate, the addition of beneficial microbial inoculants and/or earthworms is always proposed. The chemical additives such as nitrogen and phosphorus, and plant growth regulators such as kinetin, indole-3-acetic acid and glibberellin acid were also found to be beneficial to the compost[1].

The microbial inoculants which are also known as microbiological additives are likely to accelerate the composting process by increasing the decomposition rate, especially with the inoculation of cellulolytic and lignoolytic microorganisms[39]. As reported by Medina *et al.* (2004), the decomposition of agrowastes was improved when some selected beneficial microbial inoculants (arbuscular mycorrhiza fungi, *Y. lipolytical*, *Rhizobium* sp.) are inoculated together with the originally presented fungal species of *A. niger* in sugar beet and dry olive cake waste materials[40]. The availability of both organic and inorganic plant nutrients were reported to be increased, in addition to the enhancement of soil fertility in term of biochemical and biological characteristics.

Sasaki *et al.* (2006) also highlighted the successive effects of commercial microbiological additive on the composting of beef manure[41]. The beef manure was likely to have higher microbial population and faster temperature increment rate at the beginning of composting. Besides, the reduction in ammonia emission and nitrate production were also reported in the microbiological additive inoculated compost. The reduction was contributed by the constructive metabolism of microorganisms through the process of ammonia assimilation, instead of nitrification.

The positive effect of compost was likely to be further improved if beneficial microorganisms were inoculated together with the compost. Meunchang *et al.* (2006) reported the enhancement of plant growth for tomato (*Lycopersicon esculentum* L.) when sugar mill by-products compost was inoculated with the nitrogen fixing bacteria[42]. Hameeda *et al.* (2006) showed the growth of pearl millet (*Pennisetum glaucum* L.) for 88%, 83% and 82% when *Serratia marcescens* EB67 inoculated rice straw compost, *Gliricidia* vermicompost and *Pseudomonas sp.* CDB 35 inoculated *Gliricidia* vermicompost were applied, respectively[43]. Perner *et al.* (2007) also highlighted the increase in buds and flower numbers of pelargonium (*Pelargonium peltatum* L'Her.) when three mycorrhizal inocula (Terra Vital Hortimix, Endorize-Mix and AMYkor) were inoculated into compost separately[44].

At present, there are approximately 100 types of commercial microbiological additives widely used for deodorization and acceleration of composting in Japan[41]. However, the lack of scientific research and investigation, their performance on plant growth at different locations remains as a major challenge, in terms of efficacy and consistency. The performance could vary due to the variance in soil fertility, microbe composition, plant type, and climate change. Effective microorganisms (EM) is a commercial microbial inocula firstly proposed by Professor Teruo Higa from University of Ryukyus, Okinawa, Japan in 1991[45]. It is a mixed culture of beneficial and naturally occurring microorganisms which more than 80 microorganisms is living in synchronization including predominant populations of lactic acid bacteria and yeasts, small numbers of actinomycetes, photosynthetic bacteria and other minor group of organisms[46,47]. Recently, EM has become one of the most well known microorganism additives in Japan because of its effectiveness as a microbial booster for organic waste degradation in composting. It has been widely used for soil and crop management practices such as crop rotation, use of organic amendment, conservation tillage, crop residue recycling and bio-control of pests.

The commercial EM is needed to be activated before used. Activation can be performed by the addition of molasses and incubated at ambient temperature until the pH of EM solution reaches around pH 3 to 4[46]. Kengo and Xu (2001) reported that the lower pH value would produce higher microbial activity to increase microbial persistence in EM inoculated compost[47].

It is initially prepared for agricultural industry to enhance the productivity of organic or nature farming. For instance, the production of papaya in Vietnam[48], peanut in China[49], vegetables in New Zealand[50] and apples in Japan[51]. Nowadays, its potential applications in other sectors are being discovered. The application of EM has been expanded and showed successful effects on animal husbandry, gardening and landscaping, waste treatment or composting, bioremediation, algal control, aquaculture and household uses. EM has been proven to effectively control or suppress pests, pathogens and diseases on plants. Pham and Nguyen (2010) reported that the reduction of disease infection in papaya by Anthracnose, powdery mildew, papaya mosaic and ringspot diseases with the use of EM[48]. Zimmermann and Kamukuenjandje (2008) showed the control of red spider mite attack in tomato[52].

Besides the promoting effect of EM on crop production and being as a bio-control agent, the use of EM as an inoculants in compost is also likely to increase the decomposition rate of organic materials, as well as to reduce the unpleasant odors during waste water treatment. The reduction of biological oxygen demand, chemical oxygen demand and ammonia content were also reported in the swine waste management in Korea[53] and wastes management in Egypt[54]. Moreover, Kengo and Xu (2001) also highlighted the increase in electrical conductivity, humid substances and metabolites such as antioxidants, organic acids, nucleic acids, enzymes and minerals in EM-treated soil and compost[47].

COMPOST AS BIO-FERTILIZER

Besides organic waste recycling or bio-remediation, composting has become an attractive way to produce bio-fertilizer. The introduction of compost as bio-fertilizer offers advantages for the promotion of sustainable soil health and crop production. The promotion is mainly due to the increase of elemental nutrients in soil[55]. The nutrients might be plant hormones or phytoharmones which are usually present in small quantity. The phytoharmones such as indole-3-acetic acid, cytokinin, gibberellin and 5-aminolevulinic acid are well known as plant growth promoting metabolites. Indole-3-acetic acid and cytokinin had been reported to be extracted from the leachate of compost in many investigations[56,57]. It is believed that these metabolites are produced by the microorganisms via the process of composting[58-60]. These metabolites are also of great importance for the other physiological processes including stomatal movement, plant cell differentiation and development.

The beneficial effect of compost on the growth of cucumber, and the germination and the early growth of four switch grass population had been observed after the introduction of composted humid substances[61]. The significant increase in plant height, biomass, chlorophyll content and photosynthetic rate and nitrogen content in plant leaves was also reported with the application of sewage sludge compost[62]. The growth of lettuce (*Lactuca sativa* L.) had also been noticed with the application of sugarcane bagasses sewage sludge based compost[63]. Recently, the advantages of compost is being recognized since the application of chemical fertilizer often leads to high cost, environmental pollution and depletion of soil organic matter.

Unlike chemical fertilizer and pesticides, compost causes no harm to the environment. It replenishes the soil nutrient content and improves the soil fertility. Besides, compost also increases the buffering capacity of soil, particularly increasing the plant resistance towards acidic pH environment[64]. As reported by Marosz (2012), the growth of plants (*Acer platanoides*, *Fraxinus excelsior*, *Robinia pseudoacacia*, *Cornus alba*, *Spiraea vanhouttei*) could be better if green waste compost were applied even under saline stress, especially with arbuscular mycorrhiza inoculation[65]. It is noteworthy that the use of green waste compost would also increase the potassium and sodium uptake by the plants.

Indeed, the mature compost is carrying millions of microorganisms, which forms a tightly knitted soil food web and creates natural immune system for the plants. The system is likely to be natural predator against most of the plant diseases[64]. Significantly, the use of sludge compost had suppressed *Fusarium* wilt of cucumber due to the presence of fungus, *Fusarium oxysporum*[66]. The growth inhibition of oomycete plant pathogens by the chitin waste based compost from two-phase composting was due to the increase in total Gram-positive bacteria population[67]. The reduction of black mold disease in onion was observed when the onion seeds were treated with sunflower compost[68].

The stress tolerance and disease suppression of plants are of great importance for high productivity of crop, since world population is in the increasing trend. Besides plant growth promotion, compost could increase plant resistance towards stresses and diseases due to the infection. Plant stress is a highly unpredictable fluctuation which can be categorized into abiotic and biotic stresses. Abiotic stress includes extreme temperature, drought, flood, poor edaphic conditions such as rock content, pH, high radiation, compaction and contamination, whereas biotic stress includes those damage because of the presence of other living organisms such as bacteria, viruses, fungi, parasites, harmful insects and weeds. Plant stress might disrupt the equilibrium and regular metabolic pattern of plant that resulted in injury, disease or aberrant physiology[64].

DETERMINATION OF COMPOST MATURITY

The application of immature compost can be a problem to the ecosystem. This is because further decomposition in soil can induce anaerobic condition, which the available oxygen in soil pores is utilized by microorganisms. This phenomenon might deprive plant roots of oxygen, and leading to the generation of H_2S and NO_2^-[69]. Therefore, the completeness of composting is crucial to ensure the stability and maturity of compost for agricultural application.

The maturity of compost can be determined by the resistance of compost to further biologically breakdown into smaller metabolites. This can be measured based on the rate of microbial activities in the compost. The microbial activity is usually evaluated by using respirometric measurement or by studying the transformation of chemical properties of compost substances[70]. On the other hand, the maturity of compost can also be determined by the degree of phytotoxic organic compound decomposition during the active composting phase. The absence of pathogens and viable weed seeds is always referred to the completeness in decomposition. Some biological methods such as seed germination tests and plant growth bioassays are also used for the compost maturity evaluation.

There is no single parameter can be used to determine the stability and maturity of compost. It is always referred to compost that lacking of toxins and detrimental bacteria, fungi and noxious odor. Mature compost also has stable nutrient composition, more homogenous and uniformly dark brown or black in color. The maturity phase of compost is always accompanied with noticeable reduction in heat[4,71]. Currently, there were numerous methods being developed to assess the compost maturity such as C:N ratio, moisture, formation of humid substance, production of odor and stability of organic matters. TABLE 1 shows the list of parameters commonly used to evaluate the maturity of compost.

TABLE 1 : Common parameters and their optimum values for mature compost

Parameter	Optimum range for mature compost	References
C:N ratio	10 – 15	Bary *et al.* (2002)
pH	6.5 - 7.5	Bary *et al.* (2002)
Organic substance	40 – 60 %	Bary *et al.* (2002)
Odor	Odorless (slight 'earthy' and inoffensive smell)	Bary *et al.* (2002)
Electrical conductivity	0 - 4 dSm^{-1}	Bary *et al.* (2002)
Moisture	15 – 25 %	Bary *et al.* (2002) Ahmad *et al.* (2007)
Color	Dark brown to black (Humid substances)	Ahmad *et al.* (2007)
Texture	Crumby (Particles is decomposed into smaller size)	Ahmad *et al.* (2007)
Nitrogen	1 – 3 %	Ahmad *et al.* (2007)
Phosphorus	0.5 – 1 %	Ahmad *et al.* (2007)
Potassium	1 - 1.5 %	Ahmad *et al.* (2007)

CONCLUSION

The limited natural resources all over the world have increased the awareness for wastes recycling for sustainable agriculture. Composting is the effective way of degrading organic wastes and transforming them into humid substances as bio-fertilizer. The application of mature compost not only increases soil nutrient and beneficial microbial population, but also promotes plant growth and diseases suppression. The application of microbiological additive inoculated compost is likely to exhibit persuasive results compared to the direct use of organic wastes. The microorganism in mature compost could persist in soil for longer period of time and colonize more aggressive in the rhizosphere.

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