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# Feedstock Amendment for the Production of Quality Compost for Soil Amendment and Heavy Metal Immobilisation

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Composting is a waste management technology for recycling organic waste. A compost without detectable of pathogens and heavy metals can act as a soil conditioner or organic fertilizer to promote plant growth. It provides the soil with organic matter and nutrients, improving soil texture and water holding capacity and suppressing plant diseases with the presence of beneficial microorganisms. Many researchers aim to improve the quality of compost at a reduced process cost and composting duration. Preferably the composting process also offers the co-benefits of reduced environmental impact. The quality of the compost is closely related to the feedstock used for the composting. The feedstock ranges from bio-waste, plant- and animal-based agricultural waste and sometimes the organic fraction in the municipal solid waste. This paper reviews a range of feedstock amendment methods including the addition of bulking agent or chemical additive, inoculation with earthworm or microbial inoculants, and the addition of the mature compost, that could influence the composting process and the end product quality. The potential of immobilisation of the heavy metals in the waste material through composting was also discussed.

## 1. Introduction

As the backbone of many developing countries, agricultural sectors face various global challenges, including climate change, urbanization, and some environmental issues such as leaching and accumulation of pesticides and fertilizers. The performance of the conventional farming associated with the overconsumption of chemical fertilizers has led to some severe environmental problems. To cope with the natural leaching caused by the loss of around 2/3 of the applied fertilizers, high amount of fertilizers has been applied and resulted in the contamination of ground water (especially by nitrate, or some other pollutants such as pesticides) (Devassine et al., 2002). World fertiliser consumption rate had increased from 98.7 to 120 kg per hectare of arable land from year 2002 to 2013 (Food and Agriculture Organisation, 2016). According to the Department of Statistics (2016), Malaysia's population reaches 31.7 million in 2016 with an annual growth rate of 1.5 % where 71 % of the total population has resided in the urban area in tandem with the rapid development of Malaysia. Rapid population growth and urbanisation have increased the generation of the solid waste. In many fast developing countries such as Malaysia, landfilling remained the main disposal method, i.e about 94.5 % of the collected wastes is disposed in the landfills, with a recycling and composting rate of 5.5 and 1 % (Periathamby et al., 2009). About 57 % of the waste is made out of organic solid waste (Saeed et al., 2009).

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Composting can be an alternative to overcome these challenges. Composting is a biological process which converts organic wastes into a stable organic product with high humic substances that last longer in soil. It involves a relatively low processing cost and less complicated technology. Composting has been widely practised in many developing countries however the replacement ratio of compost for chemical fertilizer is still low due to the inconsistency in the end quality of compost (Fan et al., 2016). Composting transforms the organic wastes into compost that can be used to improve soil quality, minimise soil erosion, and promote plant growth. Table 1 lists general requirements for organic fertiliser according to Malaysia Standard MS1517:2012. This paper reviews the feedstock amendment strategies during composting to enhance the end compost quality and the immobilisation of bioavailable heavy metal in compost and soil.

*Table 1: General requirements for organic fertiliser*

| Characteristic | Recommendation Range |
|---|---|
| Moisture Content | ≤ 30 % (wet weight basis) |
| Organic Matter Content | ≥ 50 % |
| Nitrogen Content | ≥ 1.5 % |
| C/N Ratio | ≤ 25 : 1 |
| Maximum Permissible Value for Heavy Metals | Cr ≤ 200 mg/kg; Pb ≤ 300 mg/kg; Ni ≤ 150 mg/kg; Cd ≤ 5 mg/kg; Hg ≤ 2 mg/kg; As ≤ 50 mg/kg |
| Pathogenic Evaluation | E. coli < 10 cfu/g; Pseudomonas aeruginosa < 10 cfu/g; Salmonella: Absent; Staphylococcus aureus < 10 cfu/g |

## 2. Feedstock amendments during composting

Several amendments can be made during the composting process to improve the efficiency of the process as well as the quality of the final compost. A range of amendment strategies during composting has been reported to mitigate the emission of greenhouse gases (GHG) (Bong et al., 2016). Common amendment strategies include the control of the aeration rate, addition of bulking agent or chemical additive, inoculation with earthworm or microbial inoculants, and covered or mixed the compost with the mature compost. Table 2 shows the positive effect of different amendments in the final compost quality. Most of the amendments gave more than 50 % of increment in the final nutrient concentrations with lower carbon-to-nitrogen (C/N) ratios indicating a better degree of waste degradation. For instance, a two-stage composting technology, amended with earthworm and chemical (Zhang and Sun, 2015) or matured compost (Zhang and Sun, 2016), has enhanced the decomposition of the recalcitrant green waste. It was likely that the beneficiary microbes in the mature compost improved the biochemical transformation of the organic materials, while earthworms enhanced the substrate availability to microbes (Lim et al., 2014). This innovative composting system has shortened the traditional composting period (90 - 270 d) to 30 d.

The addition of microbial inoculant (MI) improves the degradation of the organic waste and humic substance formation. It is a common practice when interact with those recalcitrant organic wastes, i.e. lignocellulosic- and cellulosic- based wastes such as oil palm empty fruit bunches and wood bark. Previous studies indicated that the effect of MI for composting is more significant on the recalcitrant organic wastes than the easily degradable waste such as the food waste. MI enhances the initial microbial population in the waste by providing higher concentration of enzymes for the degradation of substrates. Single MI tends to offer a more specific and reproducible effect when degrading specific substrates. A similar quality of final compost was obtained when the sugar-cane waste by-products were inoculated with either *Pleurotus sajorcaju* alone or the mixed culture of *Pleurotus sajorcaju*, *Trichoderma viridae*, *Aspergillus niger*, and *Pseudomonas striatum* (Kumar et al., 2010). The effect of single or mixed MI is complicated and specific to the characteristics of the feedstock and operating conditions.The addition of chemical or mineral additive, such as zeolite and biochar, are able to increase the water and nutrient retention, reduce N volatilisation, improve aeration, enhance microbial activities, mitigate GHG emission, and immobilise the heavy metal in compost and soil following compost application (Zhang and Sun, 2015). According to Zhang and Sun (2015), zeolite have the unique structure that is efficient in adsorbing gases, water, nutrients, and heavy metals and stabilising the final compost. Covering or mixing the compost pile with the mature compost was report to reduce the GHG emission, the mature compost can also serve as the microbial inoculant for the next cycle of composting (Fukumoto et al., 2011). Although aeration rate is the main factor that influences the compost stability and GHG emission, it has little impact in the final compost quality (Yuan et al., 2016).

*Table 2: Type of amendment made during composting and their respective effect in improving the final compost quality*

| Reference | Study Area | Composting System | Waste | Duration (d) | Amendment | Nutrient content (%) C/N | N | P | K |
|---|---|---|---|---|---|---|---|---|---|
| Zhang and Sun (2015) | Beijing, China | Two-stage composting process:<br>• Primary Fermentation (PF): cement containers (6 L × 2 W × 1.5 H m) with automated turning and watering system<br>• Second Fermentation (SF): windrow with trapezoidal cross-section (2 L × 1.5 W × 1 H m) | Green waste | PF: 6<br>SF: 24 | a) No amendment | 17.22 | 2.27 | 0.12 | 0.30 |
| | | | | | b) 0.3 % earthworm casts + 25 % clinoptilolite | 5.02 | 4.23 | 0.58 | 0.91 |
| Zhang and Sun (2016) | Beijing, China | Two-stage composting process:<br>• PF: cement containers (6 L × 2 W × 1.5 H m) with automated turning and watering system<br>• SF: windrow with trapezoidal cross-section (2 L × 1.5 W × 1 H m) | Green waste | PF: 6<br>SF: 24 | a) No amendment | -- | 2.07 | 0.08 | 0.26 |
| | | | | | b) 15 % woodchip + 35 % composted green waste | -- | 4.90 | 0.72 | 1.01 |
| Lim et al. (2014) | Selangor, Malaysia | Rectangular plastic containers (17 cm × 14 cm × 12 cm) Compost was periodically turned for 2 weeks followed by a 6-weeks vermicomposting | POME | 56 | a) 1 part rice straw : 3 parts POME (without earthworms) | 20.36 | -- | 0.36 | 1.01 |
| | | | | | b) 1 part rice straw : 3 parts POME (with earthworms) | 9.64 | -- | 0.63 | 2.14 |
| Kumar et al. (2010) | India | 60 kg pre-decomposed substrates (6 d) were subjected to compost (30 d) with microbial inoculation followed by vermicomposting (another 40 d) | Press-mud: bagasse: sugarcane trash = 1: 1: 1 | 70 | a) Without microbial inoculant | -- | 0.96 | 0.88 | 0.60 |
| | | | | | b) With microbial inoculant (*P. sajorcaju*) | -- | 1.40 | 1.44 | 1.82 |
| Awasthi et al. (2016) | Shanxi, China | 130 L bench-scale PVC composter air was pumped from the bottom into the composter with a constant air flow about 0.35 L $h^{-1}$ $kg^{-1}$ dry weight during thermophilic phase | dewatered fresh sewage sludge: wheat straw = 1: 1 (C/N ~25) | 56 | a) No amendment | 25.7 | 1.63 | 0.93 | 2.85 |
| | | | | | b) Amended with 1 % lime and 12% biochar | 11.8 | 2.41 | 1.24 | 2.70 |

According to Yuan et al. (2016), higher AR (≥ 0.3 $L \cdot kg^{-1}$ dry matter·$min^{-1}$) might lead to the insufficient in compost sanitation, especially when running a laboratory scale composting. The insufficient heat during the process caused by high AR also decreased the degree of compost maturity and humification. Low (0.4 $L \cdot kg^{-1} \cdot min^{-1}$) to medium (0.6 $L \cdot kg^{-1} \cdot min^{-1}$) AR were suggested by Rasapoor et al. (2009) when running a larger scale (3 m wide × 6 m long × 1.6 m high) composting process when considering from the aspect of energy consumption and overall compost maturity.

*Table 3: Effect of composting or compost for the immobilisation of heavy metal and compost quality*

| Reference | Study Area | Type of Compost | Nutrient content (%) C/N | HA | pH | Experimental Design | Composting Effect |
|---|---|---|---|---|---|---|---|
| Al Mamun et al. (2016) | New Zealand | Municipal compost | 9.10 | -- | 7.40 | Addition of 2.5% compost to soil (Pukekohe and Levin soil) | Application of compost decreased the Cd uptake by 20 – 60 % (plant type: onion, spinach, lettuce) |
| Tapia et al. (2010) | Madrid, Spain | Pruning waste + biosolids (1 : 3 w/w) compost | 15.20 | 8.40 | 6.90 | Sequential extraction of Cd from compost after 4-week incubation with 80 or 200 mg/kg Cd | Only 0.2 % of Cd leached out from the compost |
| Lv et al. (2016) | Shang-hai, China | Vermicomposted cattle dung (CD) | 13.60 | 6.23 | 7.90 | Using sequential extraction to evaluate the effects of vermicomposting on the Speciation and mobility of heavy metals (Zn, Pb, Cr, and Cu) in CD and PM | The total heavy metals in the final CD and PM were higher than the initial values and also the control without the worms (due to the concentrated of substrates), however vermicomposting decreased the migration and availability of heavy metals |
| | | Vermicomposted pig manure (PM) | 13.30 | 5.70 | 7.10 | | |
| Song et al. (2014) | Su-zhou, China | Vermicomposted cow manure/ mushroom residues | 11.32 | 5.62 | 7.57 | Investigating the effects of vermicomposting on the mobility and availability of heavy metal | Composting increased the total heavy metal concentration irrespective of the presence of earthworm in both cases; but the availability of heavy metal significantly decreased especially in vermicomposting |
| | | Vermicomposted pig manure/ mushroom residues | 10.43 | 6.70 | 7.35 | | |
| Awasthi et al. (2016) | Shaanxi, China | Dewatered fresh sewage sludge : wheat straw | 11.80 | 17.23 | 7.72 | Evaluating the effect of lime and biochar amendment on bio-availability of heavy metals | Amended compost showed higher humic acid (17.23 %) concentration which reduced the bio-availability of heavy metals (34.81 % Cu, 56.74 % Zn, 87.96 % Pb and 86.65 % Ni) and improved compost maturity |
| Singh and Kalamdhad (2013) | India | Water hyacinth: cattle manure: sawdust = 6 : 3 : 1 | -- | -- | 7.3-7.7 | Determining the bioavailability and leachability of heavy metals (Zn, Cu, Mn, Fe, Ni, Pb, Cd and Cr) in compost mixed with lime | Addition of lime (≤2 %) can enhance the composting temperature (to >57 °C), organic matter degradation (up to 38.5 %) and reduce the bioavailability and leachability of heavy metals (>61 %) |

## 3. Immobilisation of heavy metal by compost

Intensification of industrialisation and urbanisation, and the intensive use of chemical fertiliser, herbicide, pesticide, and fungicide, have caused the contamination of many agricultural soils with heavy metals (Khairiah et al., 2012). These heavy metals can lead to severe health issue if they enter the food chain via the vegetables and animal feedstock. Composting can be a potential solution to overcome this issue. Composting has been reported to immobilise the heavy metals in the waste. Table 3 shows the effect of composting on the immobilisation of heavy metal in the contaminated waste and soil. With the formation of humic substances (HS), composting can reduce the bioavailability of heavy metals. HS are physically and chemically homogeneous mixture with relatively high molecular mass and stability. The present of carboxyl and hydroxyl groups in HS allowed their strong interaction with heavy metals. The concentration of heavy metals increased during the composting process due to the concentrated effect of substrates, however the bio-availability of the heavy metal was significantly decreased. Reduced bio-availability of the heavy metal is crucial to avoid the uptake by the plants. All reviews on the immobilisation of heavy metal by the amendment methods are summarised in Table 3.

Apart of the presence of HS, pH is another key factor that affects the mobility of heavy metal. The higher the pH of the compost (pH 6 and above), the more stable the insoluble complexes formed between heavy metals and the organic matters (Tapia et al., 2010). According to Al Mamun et al. (2016), the uptake of Cd by plants has been reduced by 30 – 60 % at a higher pH of the soil (at pH 6.2) following the application of compost. The application of amendments, such as earthworm inoculation and alkaline materials and mineral additives, into compost also improved the immobilisation of heavy metal.  The mineral additives can improve the heavy metals binding by the stable organic matter while the addition of alkaline material, such as lime, can increase the compost pH and these further lead to the decrease in the bioavailability of heavy metals (Singh and Kalamdhad, 2013).

Vermicomposting combined the positive effects by the earthworms and microorganisms. Vermicomposting could offer a higher degree of humification (Lv et al., 2016), as it could directly or indirectly accelerate the humification process through their digestion, burrowing or simulating (Song et al., 2014). Earthworms can also bio-accumulate the heavy metal in their bodies. Vermicomposting seems to be more efficient in decomposing the waste with heavy metals contamination and to produce better quality compost with higher humus content and less phytotoxicity, and within a shorter period of composting.

## 4. Conclusions

Composting can be a viable and effective treatment for organic waste management. With the application of feedstock amendments for composting, higher rates of composting, assimilation of nutrient contents and the immobilisation of heavy metals could be achieved. Future study should intensify the potential of microbial and earthworms to achieve high efficiency for the immobilisation of heavy metals content for the composting of organic waste followed by the plant uptake study on the bio-available of heavy metals.

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