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Evaluation of composting process using rice straw as a bulking agent for municipal sewage sludge stabilization

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ملخص:
كان الهدف من هذا العمل هو دراسة أداء عملية الكمر باستخدام قش الأرز لمعالجة الحمأة الناتجة من مياه الصرف الصحى. تم عمل عدة خلطات من الحمأة وقش الأرز بنسب مختلفة وكانت نسب الخلط كالتالى (1:1و 2:1و 3:1و4:1) قش : حمأة بالوزن. واستمرت عملية الكمر لمدة 90 يوم . أثناء هذه الفترة تم عمل التحاليل اللازمة لقياس محتوى المواد الصلبة و البكتريا المسببة للأمراض (السالمونيلا وبكتريا القولون) والأمونيا والأس الهيدروجينى ودرجة الحرارة. وبدراسة وتحليل النتائج كانت أفض نسبة خلط (2:1) قش : حمأة بالوزن وقد حققت هذه النسبة بعد 90 يوم من حملية الكمر تخفيض فى محتوى المواد الصلبة مقداره 92.34% ومقدار تخفيض فى محتوى السالمونيلا وبكتريا القولون يحقق مواصفة الولايات المتحدة لاعادة استخدام الحمأة بدون قيود.

Abstract

The objective of this work is to study the performance of using rice straw (RS) as a bulking agent for the sewage sludge composting process. Sewage sludge (SS) was mixing with rice straw in mixing ratios of 1:1, 2:1, 3:1 and 4:1 (w/w). The process continued for 90 days. During the composting period, volatile solids (VS), salmonella content, fecal coliform content, ammonia nitrogen, temperature and pH were monitored. The best mixing ratio was 2:1 w/w (SS: RS). Under the best mixing ratio, VS reduction was 34.92%, Salmonella content was less than 3 MPN /1g DS and Fecal coliform content was less than 1000 MPN /1g DS which complying with USEPA, class (A) sludge.

Keywords: Sewage sludge, Composting, Municipal solid waste, VS reduction, Pathogenic

1. Introduction

Sewage sludge is the most important byproduct of wastewater treatment (Zhaang, et al., 2018). It is considered a source of pollution in the environment and linked with health problems. It also contains large amounts of nutrients, such as N, P, K, and organic material, which could be reused in beneficial purposes such as land applications and land reclamation (Feng et al., 2015). However, this sludge should be stabilized to be safe for reuse applications (Gea et al., 2007).there are different methods for sludge stabilization process such as aerobic digestion, anaerobic digestion, lime stabilization, sludge dewatering and composting (U.S. Environmental Protection Agency 1978). Sludge composting is reported as a successful method for sludge stabilization (Yañez et al., 2009). Composting is a generally accepted and highly beneficial method of stabilizing the organic matter in these wastes. (Yañez et al., 2009). It could remove the majority of pathogenic microorganism content (Gea et al., 2007). The high temperature reached due to the metabolic heat generated during the thermophilic phase of the composting process is effective in killing the pathogens (Gea et al., 2007). additional benefits from sludge composting is that the compost made from bio solids returns useful resources to the environment and has a number of beneficial effects, such as, accelerating plant growth, increasing organic matter in the soil, improving moisture retention in the soil, and improving erosion control. There are many factors affecting composting process such as, temperature, moisture content, oxygen and aeration, pH and bulking agent (Li, et al.2013; Strauss, et al., 2003; Kutzner 2000). Bulking agent type and its mixing ratio are important factors affecting the process Tengman et al. 1995; Knight, 1997). Due to its high moisture content, dewatered sewage sludge cannot be composted alone (MC, about 80%) and poor air permeability (Zhou et al., 2014). Excessive moisture content inhibits aerobic metabolism, failure of self-heating, GILLETT and poor processing. Many researchers have reported the effectiveness of adding bulking agents such as municipal solid waste, rice straw, wood chips, and sawdust in improving the composting process (Zhang, et al., 2018 ; Iranzo et al., 2004 ; R. Yañez et al., 2009 ; Eftoda et al., 2004; Antonis A. Zorpas et al., 2008; Roca et al., 2009; Cofi et al., 2009 ; Doublet et al., 2011). Every year, huge amounts of Rice straw in Egypt are disposed of, traditionally by burning in situ, causing real environmental problems. This practice produces huge clouds of smoke which affect all the adjacent municipalities' health. In some countries, for example Japan, Spain the emissions from burning of rice residuals have been related to the appearance of respiratory diseases such as bronchial asthma, cardio-respiratory and allergic disorders (Iranzo et al., 2004). From the other hand, In many low income countries, a large amounts of municipal wastes are not properly disposed (Cofi Olufunke et al., 2009) and attempting to reduce the amount of biodegradable solid waste that is sent to landfill (Litterick & Wood, 2009). Most of these wastes are biodegradable and can be converted into valuable resources that reduces their negative impacts (Gillett, 1992). These materials, including rice straw and municipal solid waste, were selected as a bulking agent due to potential efficiency and low cost as well as it's available in Egypt.

Recent studies have been conducted to investigate the feasibility to co-compost sludge and other organic wastes, such as MSW and rice straw as the following. (Roca et al.2009), reported that rice straw and sewage sludge to be used in a composting process are highly compatible. Static piles with mixing ratios 2.6:1 (w/w fresh weight) sewage sludge with rice straw for 90 day periods achieved the compost maturity indicators. (Iranzo et al., 2004), reported that composting can be useful for minimizing the rice straw and sewage sludge environmental impact and suggested that these materials could be used in the composting process. The C/N ratios suitable for a rapid increased in microbial activity were in the range of (17–24). (Cofi et al., 2009), reported that municipal solid waste and sewage sludge Composting allows recycling of nutrients into agriculture. The two materials complement each other. Solid waste: FS mixing ratio 2:1 is better than 3:1. The final co-compost was well sanitized as a result of the high temperatures achieved during the thermophilic phase in the composting duration of 90 days. (Zhang, et al., 2018), reported that composting of SS and OFMSW could be achieved with cornstalk at 15% (of total wet weight) as bulking agent. Increasing OFMSW proportion enhanced organic content to improve composting. OFMSW > 55% of total weight wet; produced poor quality compost over 15 days of rapid composting

2. Material and methods

2.1 The Municipal Sewage Sludge

The source of the raw sludge was the dried sludge from Al Berka secondary wastewater treatment plant. The raw sludge was collected and transported to Al Berka composting plant where the study was conducted.

2.2 Bulking agent

Rice Straw is selected as the bulking agent. Bulking agent is important for sludge composting to adjust moisture content and balance C/N ratio.it was collected from local farm located nearby the plant. The rice straw characteristics and the raw sludge are given (Table 1).

Parameter	Sewage sludge	Rice Straw
PH	7.90	6.37
Electrical conductivity (dS m^-1)	1.78	2.63
Moisture content (%)	69	8.35
Total organic carbon (% of D.W)	38.7	47.81
Total Phosphorus (% of D.W)	0.15	0.34
Volatile solid (%)	57	81.19
Ammonia nitrogen (mg/kg)	490	76
Nitrate nitrogen (mg/kg)	190	24
Salmonella content (MPN /1g DS)	60,000	Absent
Fecal coliform content (MPN /1g DS)	80,000	Absent

Table (1), physicochemical properties of the municipal sewage sludge and rice straw

2.3 Experimental design for windrow composting.

The sewage sludge was mixed with the rice straw (RS) and composted for 90 days in a window system. Four composting windrows were carried out by homogeneously mixed of the bulking agent (RS) with the dewatered sewage sludge (SS) with Machine and manual turning. The length, width and height of the windrows are 1.5m, 1.25 m and 1.25meespectively. The windrows were turned weekly to ensure the supply of oxygen and allow materials to be exposed to the inner high temperature. Moisture losses were adjusted by the addition of water, maintaining the moisture level at 40-60%. Mixtures for different composting windrows were mixed as described in Table (2):

No. of Run	Mixture name	SS ratio (weight)	RS ratio (weight)
Run 01	M1	1	1
Run 02	M2	2	1
Run 03	M3	3	1
Run 04	M4	4	1

Table (2), Mixtures for different composting windrows

2.4 Sampling procedures: -

Compost mixtures were turned and samples were taken on days 10, 20, 30, 40, 50, 60, 70, 80 and 90 for pH, OM, NH4 and NO3, and microorganisms, and daily for (T) and at days 1, 90, for TN and TP.

2.5 Analytical methods

Temperature was measured by digital thermometer with a probe 100 cm length. pH was measured with a calibrated pH meter combined glass electrode. Electrical conductivity (EC)(ds/m) was measured instrumentally by Self-contained. Conductivity instruments. Total organic fraction determination was measured according to Nelson and Sommers, 1996 method. Total nitrogen (TN) was measured according to APHA (2012). Ammonia Nitrogen (NH4-N) was measured according to APHA (2012). Nitrate Nitrogen (NO3-N) was measured according to (APHA, 2005). Total Phosphorus was measured according by Applying the DR 2800 Spectrophotometer Phosphorus, Reactive (Orthophosphate) recorded method (8048, Ascorbic Acid Powder Pillows Method), (0.02 to 2.50 mg PO4/L) (September 2005 Edition 1).

3. Results and discussion

3.1 Sewage sludge composting with RS as a bulking agent.

Rice straw was mixed to the sewage sludge with a variable ratio 1:1, 2:1, 3:1and 4:1 (w/w). Composting process was monitored as follows:

3.1.1 Temperature

Temperature is an important indicator for both microbial activity and decomposition rates in composting (Li, et al.2013). The temperature was measured throughout the composting process. Fig. 1, shows the temperature of windrow piles throughout the composting process. The temperature raised to 50 °C in the first (10) days which indicate that the composting process changed from mesophilic to thermophilic phase. This could be ascribed to the microbial activity in the biodegradation of organic matter (Zhang, et al., 2018; Awasthi et al., 2016; Wang et al., 2013). From day (10) to day (45) the temperature remained in the thermophilic phase with temperature range of (50-65 °C). This agreed well with other reported studies in the literature (Hu et al., 2015; Cofi et al., 2009; Cukjati et al., 2012). After (45) days of composting, the temperature decreased to (27 °C) this could be ascribed to the limited microbial activities at lower content of biodegradable material. There is no significant difference in the temperature change pattern due to the change of bulking agent mixing ratio. Bernal, et al.2009 suggested that the temperature above 55 °C are required to eliminate pathogenic microorganisms. Indeed, all of M1, M2, M3 and M4 temperature can meet the aforementioned condition.

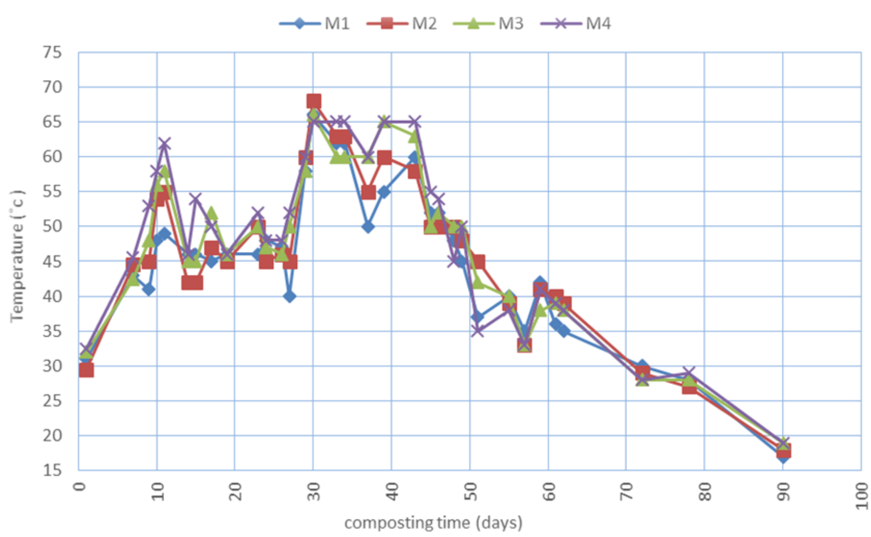

Fig.1. Temperature evolution during composting process

3.1.2 Changes of pH

The microbial growth is sensitive to the pH value (Khalil et al., 2011). The pH of 6.7–9.0 is the suitable range of microbial activity during composting process (Bernal, et al.2009). Changes of pH were measured throughout the composting process. Fig. 2, shows the pH of windrow piles throughout the composting process. The pH of the compost increased during the first 10 days. The maximum pH of 8.30 was occurred in windrow (M2). This increase in the pH could be ascribed to the biodegradation of acidic substance and production of inorganic nitrogen ($NH4+$ and $NH3$) from organic nitrogen (Zhang et al., 2018; Roca et al., 2009; Mahimairaja et al., 1994). After (10) days, the pH decreased. This decrease in the pH could be ascribed to ammonia volatilization (Hu et al., 2015; Pérez et al., 2009). This agreed well with other reported studies in the literature (Roca et al., 2009; Yanez et al., 2009; Cofi et al., 2009; Hu et al., 2015). There is no significant difference in the pH change pattern due to the change in bulking agent.

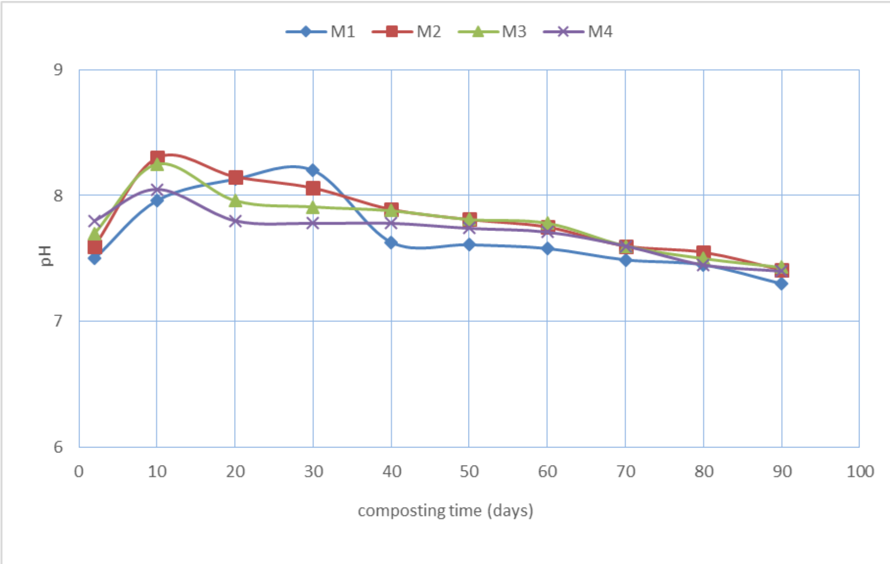

Fig.2. pH evolution during composting process

3.1.3 Volatile Solid Reduction (VS reduction)

VS reduction was monitored throughout the composting period of 90 days. As shown in Fig. 3, the VS reduction increases during the process for all mixtures. This reduction could be ascribed to the mineralization of biodegradable substances by microbial activity into carbon dioxide and ammonia (Zhang, et al., 2018; Cofi et al., 2009; Chang and Hsu, 2008) . Most of the reduction occurred during the first 50 days of composting, VS reduction was 27.51%, 28.73%, 27.30%, 24.72% for M1, M2, M3 and M4 respectively. After 90 days of composting the VS reduction increased to reach values of 32.71%, 34.92%, 30.54%, and 28.23 % for M1, M2, M3 and M4 respectively. Analysis of the variance (one –way Annova) was conducted in the results to find out if the increase of composting time is significantly increase the VS reduction or not. Differences between means were compared and a post-hoc analysis of variance was performed using LSD significant difference test ($P < 0.05$). the analysis showed that the increase of composting time from 50 to 90 days did not significantly improve the VS reduction. Based on the results and analysis of variance, the optimum composting time were 50 days. Under the optimum operating conditions, Higher VS reduction were 34.92% at mixing ratio of 2:1 (w/w).

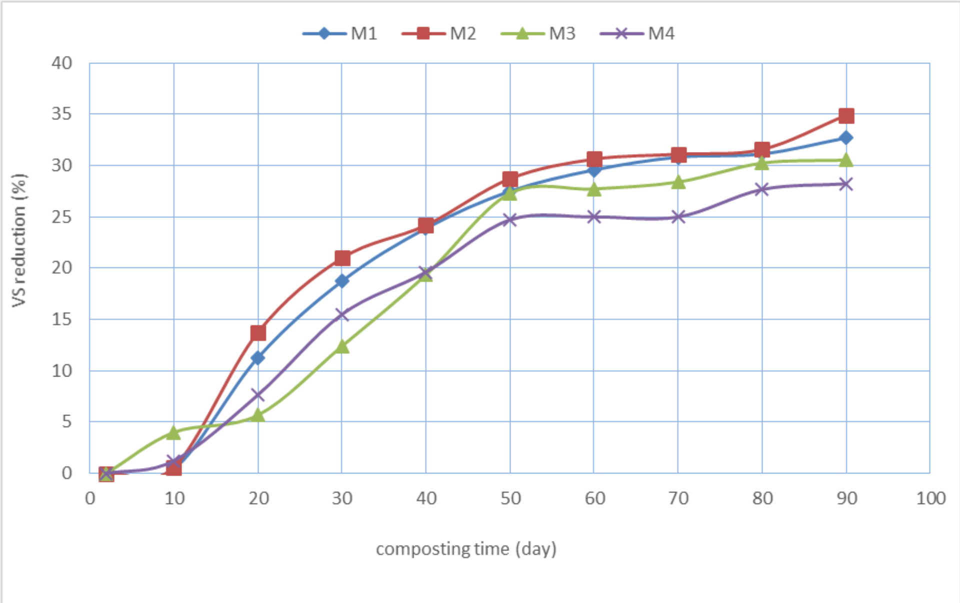

Fig.3. Effect of time on VS reduction during composting process

3.1.4 Changes of NH4-N

Change in the ammonia is an important indicator for the evaluation of composting process performance (Guo et al., 2012).it present the microbial activity due to mineralization of organic nitrogen (Zhang, et al.,2018; Sánchez et al.2001). the NH4-N concentration was monitored throughout the composting period for windrow M1,M2,M3 and M4. Fig. 4, shows the evolution of NH4-N for windrow piles throughout the composting process. The NH4-N concentration for M1, M2, M3 and M4 increased rapidly during the first (30) days of composting process. This could be ascribed to the intense microbial activity and organic matter degradation during this period which led to the formation of ammonium through the mineralization of Norg. (Sánchez et al.2001; Zhang, et al., 2018). For M1, M2, M3 and M4 respectively, the maximum NH4-N concentration was 2107, 2413, 2651, and 2315 (mg/kg). After composting period of (30) days NH4-N concentration for all mixtures sharply declined and reached similar levels of about 268, 284, 235, 288 (mg/kg) at the end of composting (day 90). The decrease of NH4-N concentration at the end of composting period might result from nitrification, ammonia emission, and immobilization by microorganisms. (Zhang, et al., 2018; Awasthi et al., 2015). (Guo et al., 2012) reported that the maximum NH4-N content in mature compost should be less than 400 mg/kg at the end of composting period (90 day).

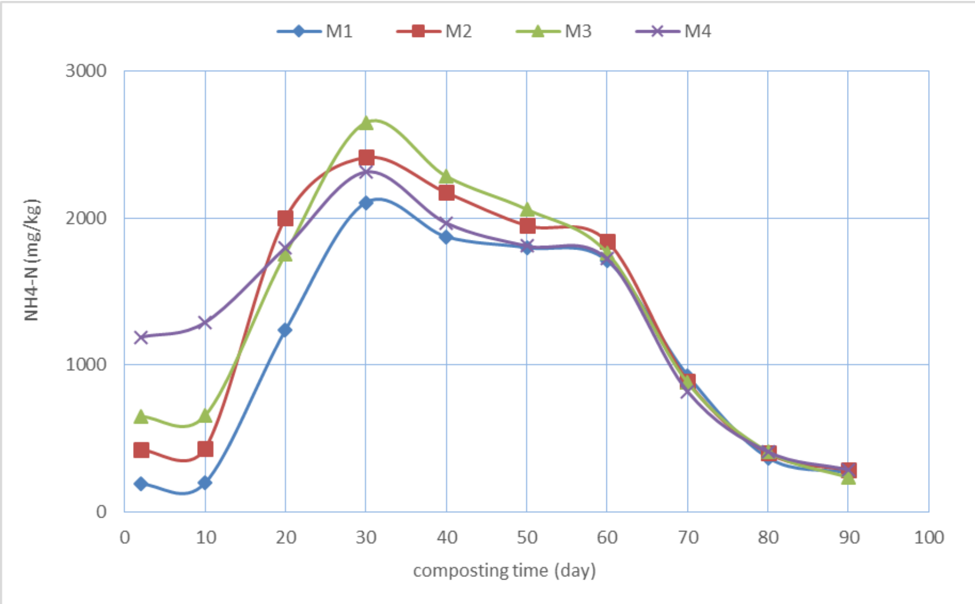

Fig.4. NH4-N evolution during composting process

3.1.5 Microorganism reduction

The direct use of sewage sludge without treatment in agriculture represent a real risk to humans due to the high pathogenic microorganism content. The high temperature reached due to the metabolic heat generated during the thermophilic phase of the composting process is effective in killing the pathogens (Gea et al., 2007).as reported in the international standard, class (A) sludge, the Salmonella and Fecal coliforms shall be less than 3 MPN /1g DS and 1000 MPN /1g DS respectively (USEPA, 1994). As shown in Fig.5a,5b after 50 days of composting process, the windrow M2 and M4 achieved Salmonella content of less than 3 MPN /1g DS. However, this limit was achieved after (60) days for M1 and M3. Regardeng the Fecal coliform, after 60 days of composting process, the windrow M2 and M4 achieved Fecal coliform content of less than 1000 MPN /1g DS. However, this limit was achieved after (70) days for M1 and M3.

(a) (b)

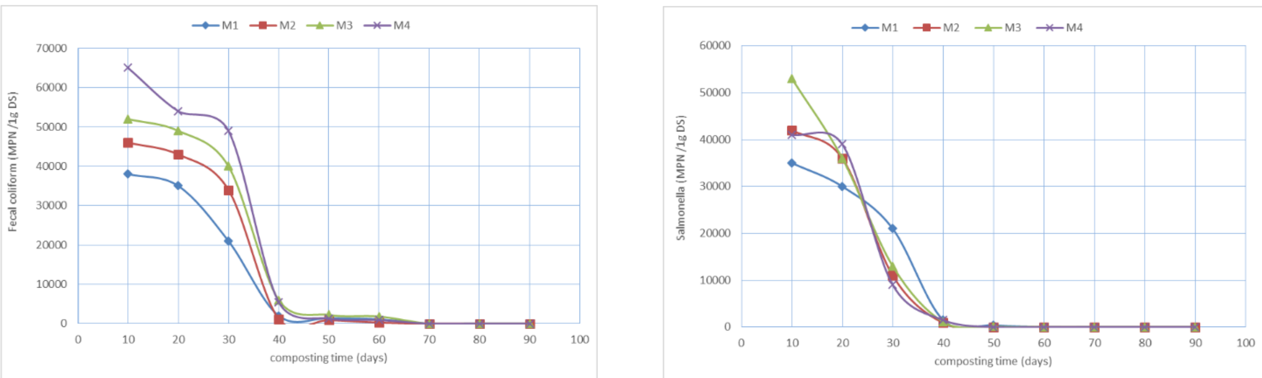

Fig.5. Effect of composting process on Microorganisms redaction during composting process

4. Conclusions

I. The best sewage sludge to rice straw mixing ratio is 2:1 (w/w).
II. at mixing ratio of 2:1 (w/w), at (90) days of composting period, the VS reduction is 34.92%, Salmonella content is less than 3 MPN /1g DS and Fecal coliform content is less than 1000 MPN /1g DS.
III. Composting sewage sludge with rice straw could effectively achieve USEPA class A sludge

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