Technical Report on Organic Fertilizer & Pellet Production

International Water Management Institute

Contents

List of Abbreviations

A	Ampere
AIT	Asian Institute for Technology
AS	Ammonium Sulphate
BA	Binding Agent
CEA	Central Environment Institute
CMC	Colombo Municipal Council
DFS	Dry Fecal Sludge
FS	Fecal Sludge
ft.	Feet
HP	Horse Power
Hr.	Hour
IWMI	International Water Management Institute
Kg	Kilogram
L	Liter
LA	Local Authority
m	meter
m^3	Cubic Meter
MCK	Kurunegala Municipal Council
MENR	Ministry of Energy and Natural Resources
Min	Minutes
mL	milliliter
mm	millimeter
MSW	Municipal Solid Waste
MT	metric ton
N	Nitrogen
OC	Organic Carbon
RF	Rice Flour
SL	Sri Lanka
SW	Solid Waste
SWM	Solid Waste Management
V	Volt
W	Watt

Definitions

Composting	Biotransformation of organic substrates under controlled conditions with the presence of oxygen. It allows the recovery of nutrients and organic matter for use in agriculture by mineralization and humification of organic compound which is safe in use. Composting process includes development of thermophilic temperature to produce a final product that is stable, free of pathogens and seeds and that can be beneficially applied to land
Co-composting	Composting can include a wide variety of bio-solids and organic wastes. Incorporation of crop residues with livestock manure is a kind of co-composting. Integrating of dried human fecal sludge with organic solid waste, mainly MSW is discussed in this report as co-composting.
Pelletization	Usage of mechanical pressure to increase the density of the material while converting it into pellets as cylindrical or granular shape. Pelletization is a process that includes the compaction of the treated bio mass.
Pradeshiya Sabha	The ruling body of the rural areas like council for urban and semi urban areas.

Summary

Co-composting of Municipal Solid Waste (MSW) together with one or more feed stocks has been proven to be addressing common drawbacks such as low nutrient density, nutrient imbalance, elemental deficiency etc. when it is compared with compost that has been produced solely by MSW. Meantime the disposal of septage from onsite sanitation systems (such as pit latrines, septic tanks, etc.) has emerged as one of the major problems for local authorities because of rapid urbanization and land scarcity. The co-composting of the dried faecal sludge (DFS) and organic fraction of MSW seems to be a credible solution.

Co-compost trials were conducted using turning windrow composting method where one windrow was made solely with MSW as a control and other was made with 90% MSW and 10% FS by mass. Each windrow was allowed to undergo a 10 weeks active composting period and a two-week curing period. Results show that addition of faecal sludge maintained pH of co-compost pile within the favorable range during the overall time span enhancing the microbial activity. Further, improved Nitrogen retain condition has enhanced Total Nitrogen (TN) content within the compost together with high and favorable improvement of electrical conductivity. Meanwhile, Total and Water Soluble Phosphorous content observed to be uplifted during satisfactory maintenance of pathogen species.

Composting of organic Municipal Waste (MW) is one of the dynamic answers for the management of MW and confirms the sustain agriculture. The bulky nature of the powdered compost is one of the main drawbacks in use in agriculture due to various practical and economic reasons based on the low density of the compost. Pelletization of compost into compost pellets could be a solution to address such drawbacks. Here, co-compost (Municipal solid waste (MSW): Dried faecal sludge (DFS) co-compost) was pelletized using die and roller pelletizer which is economical compared to other common pelletizers. This test identified the changes to pellet properties with altered three mesh sizes (2.5 mm, 3.5 mm, and 5 mm sieves) and five moisture contents (25%, 30%, 35%, 40%, and 45%). The pellets made of-0-5mm particles displayed approximately 50% strength than other particle sizes. Bulk density increase of the compost was 30% in pelletized form. It evidenced that 25% moisture contents produces the highest strength pellets than other moisture contents. Longer pellets were produced 0-5 mm particle size and 25% moisture content compared to others. As the pellets are intended to use in agriculture, pellet strength should withstand handling, transportation, and application. The pellets survived a 50 km distance transportation and remained unharmed until application to the field. This study confirmed the high influence of moisture content and particle size on physical properties of co-composted pellets.

1. Introduction

Background

Solid Waste Management (SWM) is a challenge for almost all municipalities in developing countries, without any exception to Sri Lanka. This challenge is greater and escalating in big cities where high population densities bursting due to urbanization. For an example, Figure 1 shows the increasing waste issue in Colombo, Sri Lanka. Uncontrolled open dumping is the common disposal method in developing world and Sri Lanka with a huge cost to the environment and human health. Although open dumping sees as a low cost method in the sense of capital need at a first glance, it involves huge social and environmental aftercare costs. Unsustainably managed organic waste could produce leachate and landfill gas emissions that trigger water pollution, climate change and risks for human health. Sri Lanka is divided into 335 local councils and out of them, only one council owns an engineered landfill site.

On the other hand, Municipal Solid Waste (MSW) in low and middle income countries consists of high organic and high moist waste (AIT, 2004). MENR (2005) states that MSW consist in average of 69% biodegradable organic waste and the composition can be found in Figure 2. The moisture content of MSW in Sri Lanka is 60-70%, where high organic and moist waste is ideal for composting.

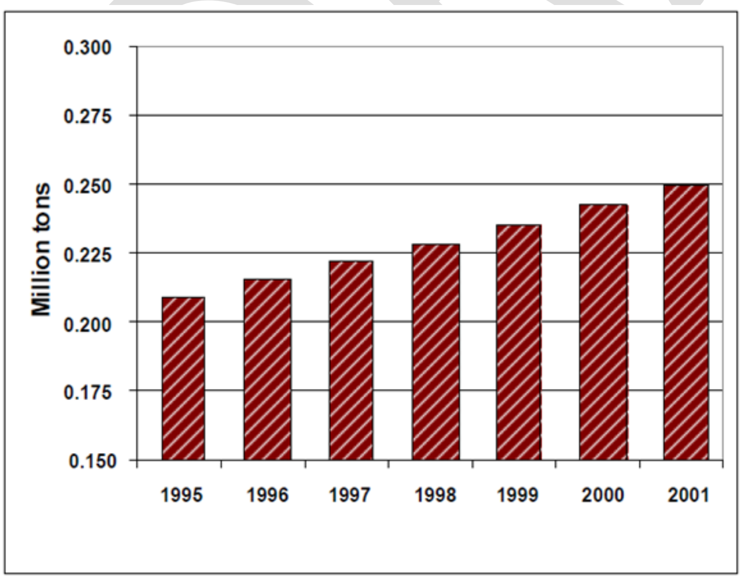

Figure 1 – Annual waste generation in Colombo from 1995 – 2001 (Source: AIT, 2004)

Only less than 3% of the Sri Lanka is covered by a sewerage network and this facility is mainly limited to the city of Colombo. Rest of the country is served by on site sanitation systems such as septic tanks. When the on-site sanitation systems get filled, the general practice is collect septage by the septic truck and discharge to the environment without any treatment. This practice continuously produces huge environmental and health problems.

Thus, co-composting of municipal solid waste and FS are identified as a solution for both urban waste streams, whereas the joint treatment offers many advantages compare to sole composting of municipal waste. Cofie et al., (2003) states that FS and MSW are two materials that complement each other in view of composting, because human waste is relatively high in nutrient content whereas MSW is relatively high in organic carbon (OC) with 33 % (Seema Jilani, 2007). Therefore co-composting of both waste materials can provide solution to two polluting urban waste streams and produce a sanitized high nutrient agricultural input (compare to the soil conditioner derived from organic fraction of the municipal solid waste).

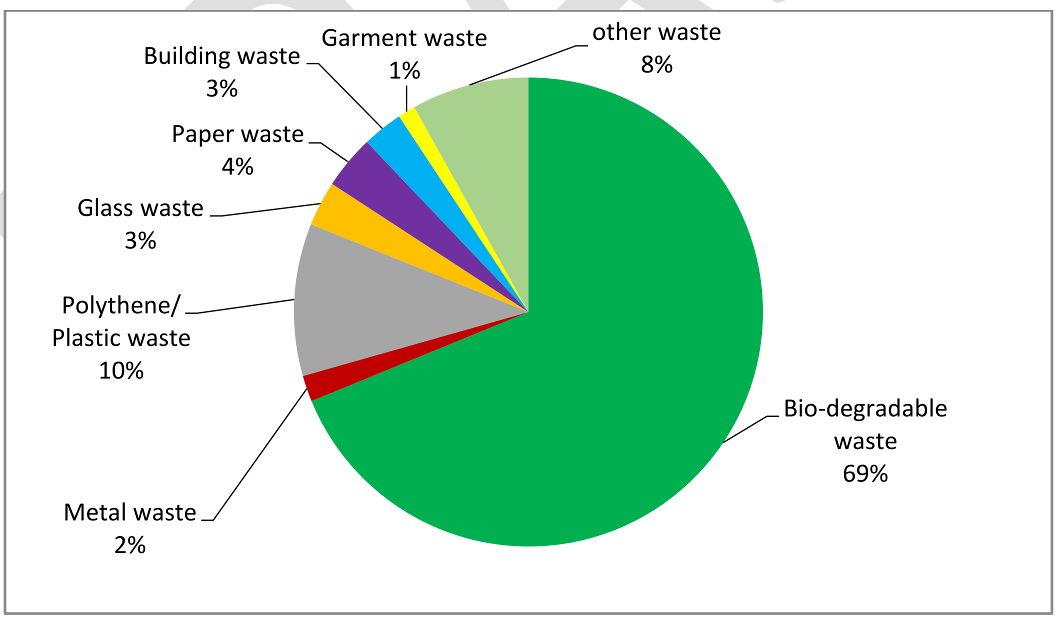

Figure 2 – MSW composition Sri Lanka (Source: CEA, 2012)

Main Problems

MSW compost is rich with organic matters but low in nutrients. Most of MSW compost qualifies as a soil conditioner (instead of fertilizer) and less attractive to farmers due to low nutrient density.

Compost is bulky in nature and has an average bulk density of 550 kg/m^3. In many cases compost producers market their compost in loose form. The low specific gravity of compost is responsible for most of the difficulties related to packaging, storing, transporting, handling and application of compost due to volume requirement and labour intensive processes. Besides, compost handling often generates dust at the point of application and, thus can cause health & sanitation risks for farmers (Hara 2011), (Zafari and Kianmehr 2012).

Solutions

Fecal sludge is one of the neglected urban waste stream in Sri Lanka, which is high in nutrients. MSW and DFS co-composting can create high nutrient agricultural input while reducing the environmental pollution and impact on health from both waste streams.

As one option to enhance compost quality through valued adding processes “pelletization” can be applied to increase product density and to enhance other features of compost (Alemi et al., 2010). Pelletization is the use of mechanical pressure to increase the density of the material while converting it into pellets and typically compost pellets are in cylindrical shape, 5–10 mm in diameter, 25– 30 mm in length. Pellets require 20 – 50 % less packaging volume than powdered composts with a final specific gravity over 1000 kg/m^3 (Carter, 2010). In addition to benefits related to volume reduction, pelletization also contributes to easy handling, increase market demand and value, reduction of dust generation (production, handling and application) (Mavaddati et al., 2010; Hara, 2001).

2. Co-composting

Methodology

Drying and filtration bed for FS was prepared by applying medium size stone gravel particle screened by 20 mm and 10 mm mesh. A metal net with appropriate mesh size was laid on top of all four layers in order to avoid mixing of gravel particles with faecal sludge. Black water from septic tanks was fed onto the drying bed directly through gully trucks that are currently being utilized by municipal council. The filtered effluent was directed to the wastewater treatment plant. DFS was obtained after 21 days of drying of faecal sludge in the drying bed.

Compost piles were constructed using control and different mixtures. First pile was constructed solely with sorted market waste sourced from MSW in order to keep as the control. The other piles were constructed with the addition of dried faecal sludge (DFS) as a fortifying agent.

DFS was added to a pile in order to keep FS composition at 10% by mass so that initial C/N ratio is maintained around 30 (Cooperband, 2002) based on available values of carbon and nitrogen content of market waste. Addition of DFS with MSW was done by consecutive constituent layering method. Sorted MSW was spread at the beginning to cover the base and DFS was then distributed on top of MSW layer and hand rake was used to mix the content so that maximum possible homogeneousness can be expected. Once raked, the mixture is spread. This process was followed until all the constituent quantities were introduced to the pile.

Each pile was first turned after the temperature exceeded 55^0C from the day of piling (usually 2 to 3 days after piling). Piles were turned weekly after the initial turning until 10 weeks Moisture level of each pile was maintained in the range of 45 - 60% with the addition of water based on squeeze test (David & Gamble, 2013) performed on site. The squeeze test is a simple field methodology where it is believed that water can be squeezed out in droplets if compost has a moisture content about 60% (which is within the optimum moisture content range) and neither water is released nor remained when compacted. Each pile was allowed to cure for two weeks after 10^{th} turning. Any obstruction or water addition were not performed during this curing phase.

Samples collected at each turning were subjected for testing in order to determine Electrical Conductivity (SLS 1219 / 1:6 V/V), P^H Value (ISO – 10390:2005) and C/N Ratio (ISO – 11261/14235) which were pre-decided as characterization parameters. Sample drawn after two weeks of curing (i.e. 12 weeks after first turning) were subjected for full parameter lab testing in order to determine Electrical Conductivity (SLS 1219 / 1:6 V/V), P^H Value (ISO – 10390:2005) and C/N Ratio (ISO – 11261/14235), together with Total Nitrogen (as N) (ISO – 11261: 1995), Total Phosphorous (ISO 11263: 1994) and Water Soluble Phosphorous (SLS 645).

Results

Co-composting of FS and MSW is expected to be beneficial since they complement with each other. Nitrogen and moisture content in human waste is relatively high whereas organic carbon content in MSW is relatively high. Meantime, high temperatures generated in composting can effectively inactivate pathogens present in both FS and MSW, eventually generate hygienically safe soil conditioner and a fertilizer.

Electrical Conductivity

Electrical conductivity is an indicator of soluble salts and ions prevailing in compost. From the results presented in Figure 3 it is clearly visible that MSW only sample has very low conductivity when compared with MSW: FS co-compost pile. This may be due to the fact that organic components are the prime element in MSW and it lacks inorganic ions and salts. Free ion availability would increase if more inorganic ions are added to the compost.

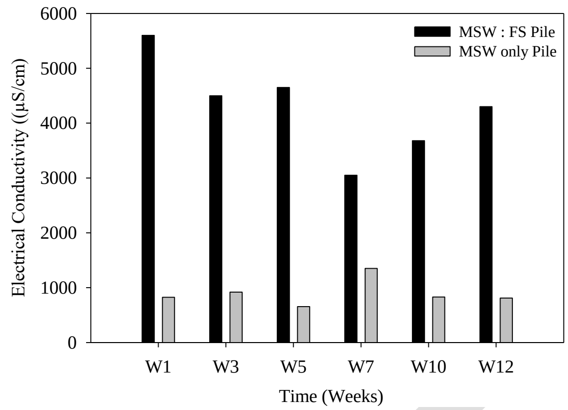

Figure 3 - Electrical Conductivity Variation with composting time

Increased electrical conductivity in DFS added samples indicate the presence of inorganic matter in sludge. Salts and other water soluble inorganic ions that have been consumed by humans may have been transferred to the FS. FS added MSW pile shows gradual decrease in conductivity with time. This could be due to the irregularities in decomposing of constituent components available in feedstock. It is reported that unnecessarily high conductivity dissolve sodium chloride in soil and is not beneficial to plants. Further, soil salinity greater than 4000 µS/cm could lead to inhibition of plant growth and germination (Cofie, et al., 2009). Conductivity of final compost obtained in 12 weeks from this study has an acceptable conductivity value of 4300 µS/cm.

Throughout the time span of 12 weeks the electrical conductivity does not show a significant improvement in MSW only sample; it remained constant around 1000 µS/cm throughout the monitoring period. According to reported work, less EC value tends to cause adverse effects compared to higher EC values in compost since composts are used as a soil conditioner in agriculture, which will be incorporated into the soil and thus diluted. (Dimambro, et al., 2006). Therefore, addition of DFS as a co-composting agent has positively affected the quality of compost.

pH

With the addition of faecal sludge, a significant increase in pH value of the contents in the pile can be seen from the week 1 onwards to week 3 and remained around 8.0 (7.5 – 8.5). The pH increase from week 1in DFS added pile should be due to the electron accepting ability of ions released with the process of decomposition as reflected in high electrical conductivity in Figure 3.

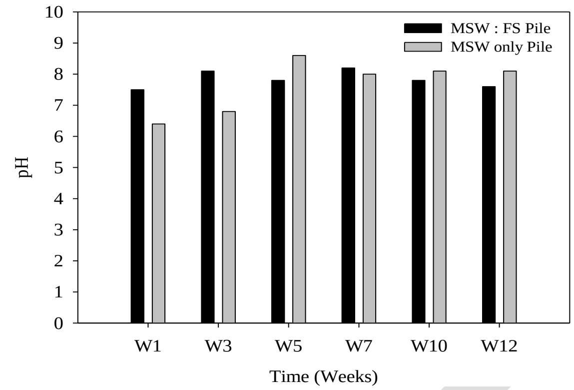

Figure 4 - pH Variation with Composting Time

At this pH it could expect to enhance the kinetics of composting process due to prevalence of favourable condition for microbial existence as reported by (Chen, et al., 2011), Further, this favourable pH environment will improve the nutrient value of co-compost by reducing nitrogen loss as ammonia which happens under alkaline pH conditions (Kokhila, 2015). MSW piles demonstrated less alkaline conditions compare to the MSW:FS piles.

During the period from W7 to W12 a drop in pH could be observed in faecal sludge added pile when compared with the control (Figure 4) and this could be due to the neutralization of alkaline constituents by acidic waste generated during decomposition.

Carbon Nitrogen (C/N) Ratio

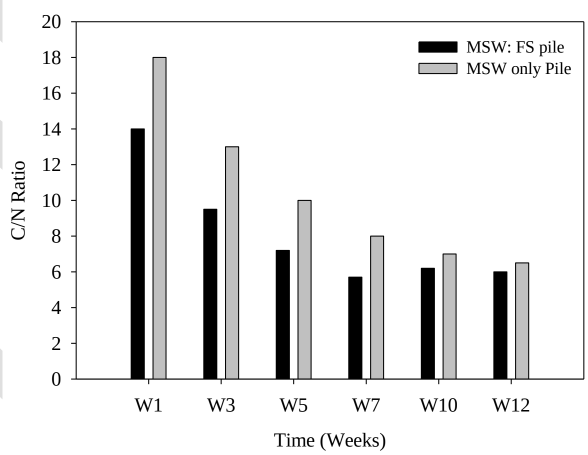

Figure 5 - C/N Ratio Variation with Composting Time

When analyzing results, it can be clearly seen that addition of faecal sludge has decreased the C/N ratio initially compare to the MSW. This is a clear indication that is rich in Nitrogen components when compared with constituents of MSW. Higher water soluble nitrate concentrations lead to faster discharging of nutrients enhancing the fertility value of compost since all nitrates are highly water soluble. These results showcase the correlation of PH variation plot in Figure 4, since significantly high pH conditions supposed to release Nitrogen in the form of ammonia and result in high C/N ratio. When it comes to end use, co-composting has added a considerable value in terms of Carbon to Nitrogen ratio. But it is better to have the proper C/N ratio so as it'll maintain a favourable environment for microbes to proceed with degradation. It is accepted to have a C/N ratio in the spec 20% to 30% for proper microbial action (Kutzner, 2008). Results has shown acceptable C/N ratio below 20 at the maturity according to (Wong, et al., 2001) and even recommended level at maturation below 16 suggested by (Bernal , et al., 1996) and achived.

Nutrient Content Parameters

Figure 6 show the total Nitrogen (TN), total Phosphorus and water soluble Phosphorus content in both compost samples after 12 weeks. According to Figure 6, MSW based control pile has low TN content when compared with MSW: DFS co-compost pile. This is a reflection of Figure 5 i.e. end of the line acidic condition is generated through introduction of FS has enhanced nitrogen availability in nitrite and nitrate forms by demoting nitrogen loss in the form of ammonia tendency in alkaline conditions.

The presence of acidic constituents which maintains pH within favourable range increases nitrogen availability in the forms of nitrites and nitrates where alkaline constituents decrease the nitrogen availability in the forms of nitrites and nitrates. (Ameen & Ahmad, 2016)

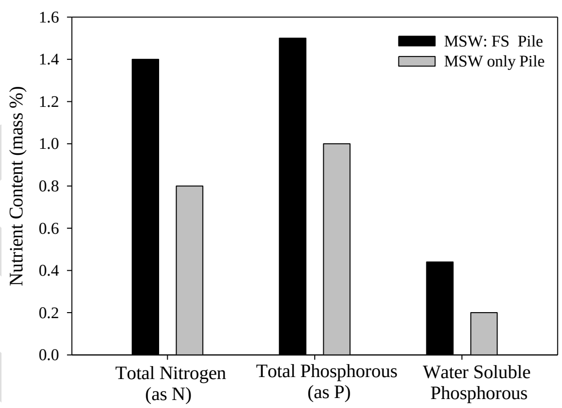

Figure 6 - Total Nitrogen, Total Phosphorus and Water Soluble Phosphorus content in finished compost

Variations observed in total phosphorous and water soluble phosphorous content follow characteristic low proportional relationship between total phosphorous and water soluble phosphorous in both pile configurations. If the ratio between water soluble phosphorous and total phosphorous is taken as characterization parameter, it could be seen that MSW based control pile has got about 20% of its total phosphorous in water soluble forms while the ratio is about 30% in MSW: FS co-composting pile. This is due to low level of alkalinity maintained with the addition of faecal sludge as reflected in P^H variation curve i.e. figure 2. According to (Kauwenbergh, 2010) acidic nature of faecal sludge has assisted the task of acidic constituent formation during decomposition process and hence has been promoted, phosphorous dissolution and ultimately shown the higher total and water soluble phosphorus content. This would enhance further investigations for evaluate the effectiveness of addition of faecal sludge as a phosphorous enhancement agent.

Biological Parameters

Faecal coliform availability is believed to be one of the parameters of concern in evaluating FS application due to hygienic aspects and has been subjected for discussion in the recent times. It is reported that if faecal Coliform is below 1000 MPN/g then that particular FS mixed compost is suitable for ground application (Miller, 2015).

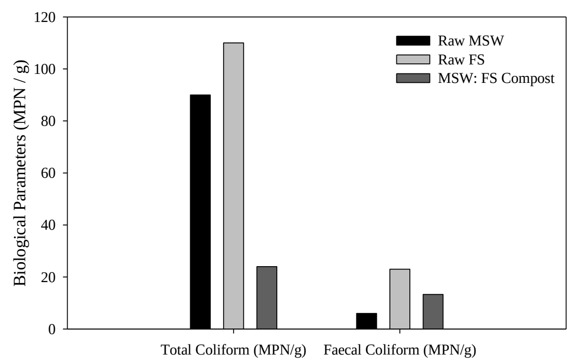

Figure 7 - Total and Faecal Coliform Availability in raw materials and finished compost

MSW: FS co-compost produced in this study has satisfactory level of biologically available pathogens with 13.3 MPN/g of faecal coliform. Therefore, addition of 10% by weight DFS to MSW has not affected the hygienic parameters of the co-compost.

3. Pelletizing

Co-compost used in palletization work was produced using raw material MSW and dried FS (DFS) at 9:1 weight ratio. Commonly employed die and roller method was used to produce compost pellets in this study and the pelletization machine has the following specifications; input voltage 415 V, 30 HP motor, a die consisting of 6 mm diameter holes.

The improved pelletization process adopted in this work is shown as a block diagram in Figure 8. First, co-compost was sieved to get favorable sized particles using three different mesh sizes: 2.5, 3.5 and 5 mm sieves and the oversized particles remained on the sieve were discarded. Then, water was added to sieved compost particles of up to 2.5 mm (particle category 1 - **PC1**), up to 3.5 mm (particle category 2 - **PC2**) and up to 5 mm (particle category 3 - **PC3**) to adjust the moisture to the required level. Co-compost having up to 5 mm (PC3) particles and the moisture adjusted to 25 % (close to the as received moisture content) was used in preparation of pellets combined with different binding agents. Three locally available binding agents were used namely;

(1) Rice flour - RF

(2) Lime

(3) Eppawala Rock Phosphate (local rock phosphate) – ERP

Binding agents were mixed with compost at 1, 2 and 3% weight basis, moisture content was adjusted and fed to the pelletization machine to produce pellets. If needed the produced pellets were sun/air dried before packing.

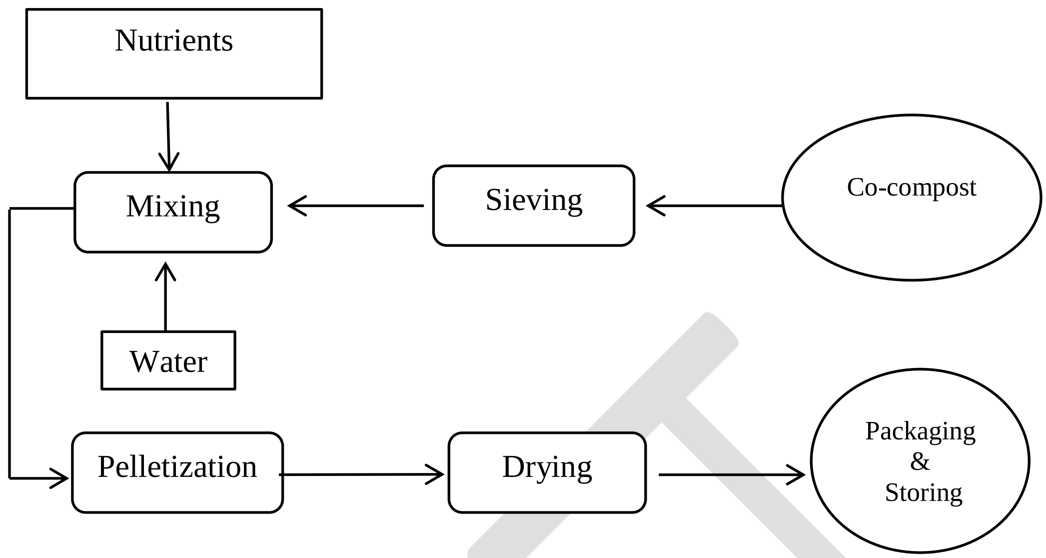

Figure 8 –Schematic block diagram of improved pelletization process adopted

Study was carried out in two phased manner. During the initial stage it was targeted in identifying; (a) the effect of particle size and (b) moisture content of co-compost on pellet properties. During the second phase it was focused on type of binding agents and it's concentration on the following parameters length, strength of co-compost pellets, the bulk density (packing density) and disintegration properties with the presence of water. During the second phase of the study the moisture content of co-compost was maintained at 25% for the investigation of particle size (3 size categories above) while pellets made with PC3 (0-5 mm) were used to investigate the effect of moisture content from 25-45% with 5% increment on pellets' qualities.

Initial moisture content of co-compost was measured using an analog portable moisture meter (Vktech-54433). In order to adjust moisture, the method adopted by the British Standards Institute (BSI, 1990) for moisture alteration in clay soils was used. According to the method a measured volume of water was added to compost, thoroughly mixed (manually), placed in a polythene bag or in an airtight container to avoid moisture loss by evaporation and then allowed 24 hours to settle. After that the moisture level was measured before feed into the pelletizer. Bulk density (packing density) refers to the mass of pellets per unit volume and was determined by following the method given in ASAE Standards S269.5.

Compressive resistance of compost pellets was determined by diametrical compression test (Tabil 1996). Cylindrical pellets were placed horizontally between two plates, a bottom plate and a disc shape metal plate and then two equal and opposite forces were applied in the radial direction of the pellets as shown in Figure 9.

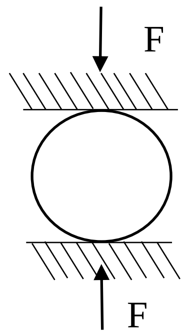

Figure 9 - Application of equal and opposite forces along the radial direction of the pellet

Compost used in 3 particle size categories was subjected to sieve analysis to obtain the size distribution of particle within each particle size category. Wet sieve analysis (Anon, 2005) was carried out to determine the particle size distribution in pellets made out of PC3. To determine the pellet length distribution, random samples were taken from each treatment and each sample was segregated according to lengths of pellets; > 5 mm, 5-10 mm, 10-15 mm, 15-20 mm, and 20mm < and weight of pellets in each length category was recorded.

A representative pellet sample from each test with different particle sizes, moisture contents and binding agents were tested for the disintegration in the presence of water. The pellets were placed into a transparent cup filled with 200 ml distilled water. After that, the cups with distilled water and pellets were kept static for one month to disintegrate the pellets.

Machine efficiency was considered as the weight percentage of pellets produced in a unit time and the production efficiency of the machine was calculated as the weight percentage of marketable pellets produced from a given compost sample.

Results

Initial (received) moisture content of loose compost (bulk compost) was found to be 25% and this value was taken as the lowest level of moisture that can be presented in loose compost. Co-compost pellets made with 0-2.5 mm particles (PC1) is shown in Figure 10.

Figure 10 - Compost Pellets made with co-compost (MSW+ DFS) using die and roll pelletizer with 0-2.5 mm (PC1) particles and 25% moisture

Figure 11 shows particle size distribution in loose compost after sieving into 3 particle categories. Compost of PC1 and PC2 has higher percentage of small (<2 mm) particles (99 & 94% respectively) while PC3 sample had only 63% of small size (<2mm) particles. PC3 compost sample shows a good distribution of particles of different sizes. In PC3 about 10% particles by weight is above 3.5 mm in size.

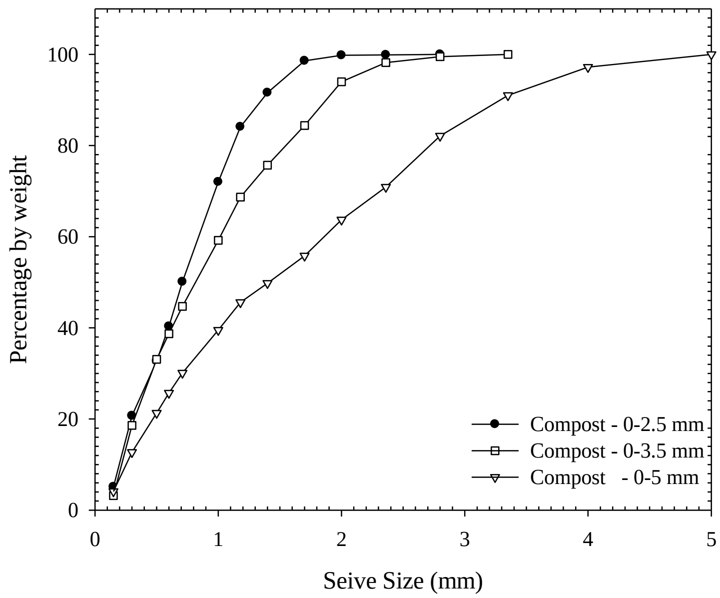

Figure 11 –Particle size distribution of loose compost from all 3 particle size categories

Effects of Particle Size

Pellet Length Distribution

Length distribution (by weight) of compost pellets made with all three particle categories at 25% moisture resulted higher percentage of 5-10 mm long pellets (Figure 12) and that was 35, 36 and 34% for pellets made with PC1, PC2 and PC3 respectively. Pellets made with PC1 has 32% (by weight) pellets shorter than 5 mm when pellets consisting of PC2 and PC3 particles gave 22 and 21% respectively.

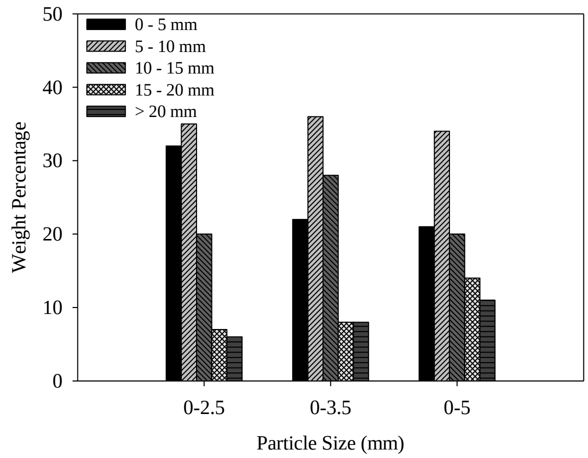

Figure 12 - Weight percentage of compost pellets of different lengths (moisture content – 25%)

It can be seen that pellets made with PC1 and PC2 particles have high percentage (> 85%) of pellets that are less than 15 mm in length. Pellets of PC3 resulted higher percentage (25%) of long pellets (15< mm) while pellets made with PC1 particles resulted the lowest percentage (13 %) of longer pellets (15mm<).

According to the results obtained, the best particle size to achieve longer pellets with the selected die (6mm in diameter) in this work is PC3 which is closer in size to the die diameter. When the die diameter is closer in size to the particles, good compaction happens in the die in pelletizing. Further, presence of particles with wide range of particle sizes (in PC3) allows good compaction giving a good strength invariably resulting long pellets. Compost pellets with small particles; PC1 and PC2 resulted more pellets that are shorter than 10mm in length due to the easy movement of particles through the die without proper compaction giving rise to weaker pellets which are susceptible to break easily. Thus weak pellets break easily giving rise to short pellets. Zafari and Kianmehr (2012) concluded similar results for composted MSW pellets in a hydraulic pelletizer.

Compressive Strength

Figure 13 shows the variation of pellet strength (given as the load required to rupture 1 cm long pellet) with compost particle sizes (3 particle categories considered). According to results obtained, pellet strength has increased when the particle size was increased. Pellets made with PC1 could withstand only 43.0 N/1cm but pellets made with PC3 could withstand 64.3 N/1cm.

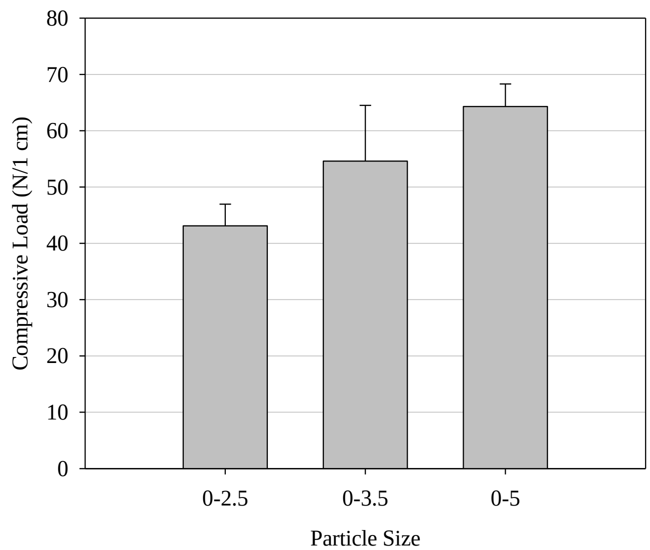

Figure 13 – Variation of compressive strength with compost particle size

A mixture of different particle sizes and a wide particle size distribution support compaction of material. Smaller particles fill gaps facilitating interlocking of particles and minimizing the voids present. In addition short range forces such as hydrogen bonds and van der Waals forces are present in closely packed particles and these too contribute to the increase of strength of pellets. These forces are strong when the particles are close to each other and the forces decrease when the particles are loosely packed. As seen from Figure 4, PC3 has a wide distribution of particles compared to PC1 & PC2. Therefore, pellets made with PC3 shows high compressive strength (Figure13) due to better compaction that has resulted because of the presence of well distributed particles of different sizes. When the particles are closely packed, inter-particle bonding is high making the pellets stronger so that pellets can withstand high compressive forces. Similar finding for extruder briquetting of agro biomass has been reported by Mishra and Grover (1999) and for corn waste, rice husk and livestock diet briquettes by Kaliyan and Morey (2009).

Bulk Density

It can be seen from Figure 14 that the bulk density of loose compost does not appreciably change when composed of different particle sizes. The density of bulk compost was 557.0 kg/m^3, 551.0 kg/m^3 and 567.0 kg/m^3 for the 3 different particle categories; PC1, PC2 and PC3. Moreover, there is no distinct difference in bulk density of compost pellets made from PC1 & PC2 particles (730.3kg/m^3 and 730.7 kg/m^3) however, there is a noticeable drop in the bulk density of pellets made from PC3 (687.5kg/m^3).

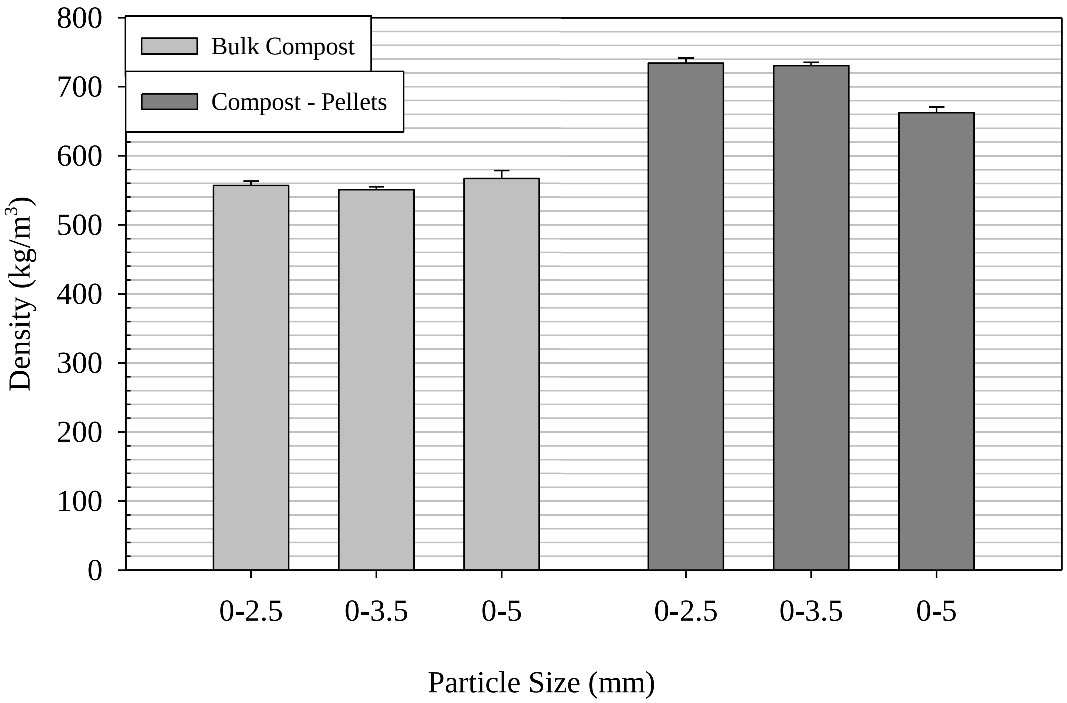

Figure 14 – Bulk Density of loose compost of 3 particle size categories and bulk density of pellets made with same size category compost at 25% moisture

The bulk density of compost pellets made with all 3 particle sizes has increased due to compaction of compost in pellets increasing the total mass in a unit volume. The bulk density of pellets made with PC1 and PC2 does not show a noticeable difference and that may be due to similar distribution of pellet lengths in both categories. In both these categories, there is high percentage of short pellets allowing better packing, filling the voids. With PC3 there is a fairly large amount of long pellets resulting a lower bulk density due to less well distributed pellets sizes.

Effect of moisture content

Pellets Length Distribution

Distribution of pellet length with moisture for PC3 is shown in Figure 15. For all moisture contents considered, the highest weight was recorded for 5-10 mm length class and pellets longer than 20 mm showed the lowest percentage. With the increase of the moisture level of the compost mixture, the strength of the pellets decreases resulting short pellets as clearly seen in Figure 15. This is an indication that higher the moisture level in compost, lower the strength of pellets. Moreover, moisture may help to increase the lubricity and the fluidity of compost and therefore easily pass through the die without proper compaction resulting shorter and low strength pellets. It can be seen that when the moisture content was increased, the percentage of longer pellets decreased and that of shorter pellets increased.

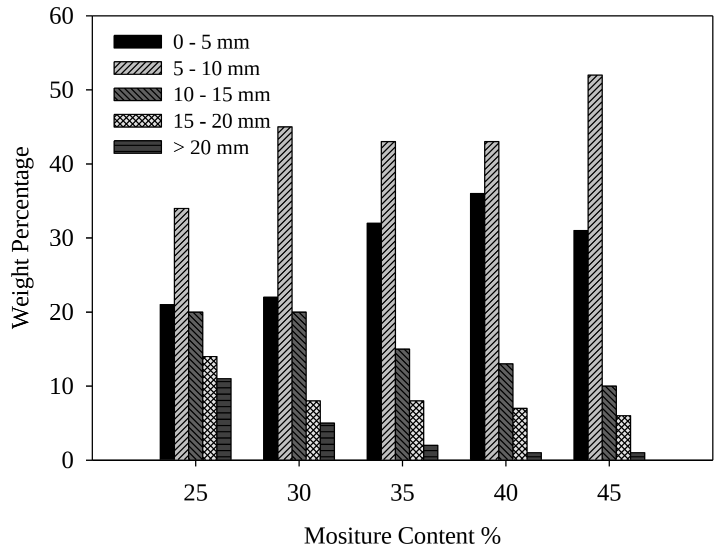

Figure 15 - Weight percentage of compost pellets of different length with different moisture levels (pellets made out of PC3)

Compressive Strength

Pellet strength with increased moisture for five different moisture contents (25-45% in 5% increments) is shown in Figure 16. In all the samples tested, the highest strength was observed in pellets made with 25%, moisture compost where the compressive load was 64.3 N/1 cm. The lowest strength was shown in pellets made with compost having the highest moisture content of 45% and the load required to break the pellets was 18 N/1 cm.

According to the previously published work moisture in the feedstock acts as an important factor in the pelletizing process. Moisture has an ability to serve as a binding as well as lubricating agent (Kaliyan and Morey, 2009). It has been reported that the right amount of moisture develops self-bonding properties in densification. Interfacial forces between solid compost and moisture create strong bonds adding strength to pellets. However, with the increase of moisture, the distance between particles increases trapping water in voids creating a biphasic mixture (liquid phase and solid phase). In such a situation intermolecular forces such as Hydrogen bonds and van der Waals forces disappear weakening the forces between particles and tends to rupture easily resulting low compressive strength as can be seen from Figure 16. Similar observations have been observed by Mani et al. (2003), Zafari and Kianmahr (2012) and Romano et al. (2014). It has been seen that the best moisture content is about 25% for the Die and Roller disk pelletizer used in this work. At 25% the fluidity of compost falls while increasing the frictional resistance as the compost passes through the holes of the die resulting enhanced strength in pellets as described by Hara (2001).

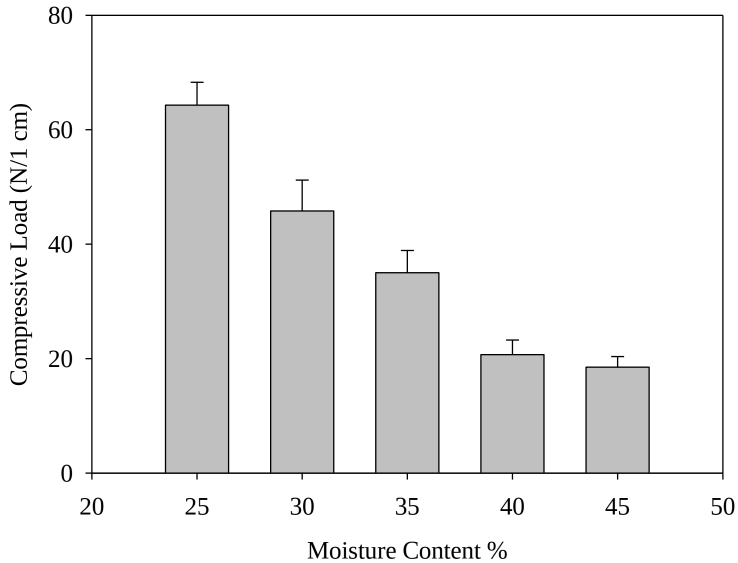

Figure 16 – Effect of moisture content on compressive load of the compost pellets

Bulk Density

Bulk densities of pelleted compost at various moisture contents are shown in Figure 17. Bulk density increase with increased moisture in compost pellets and this could be due to two reasons. One reason could be that with the increase of moisture pellets are short pellets and hence those can pack while minimizing voids. The other reason could be due to voids in compost filled with excess water while increasing the density or the both reasons.

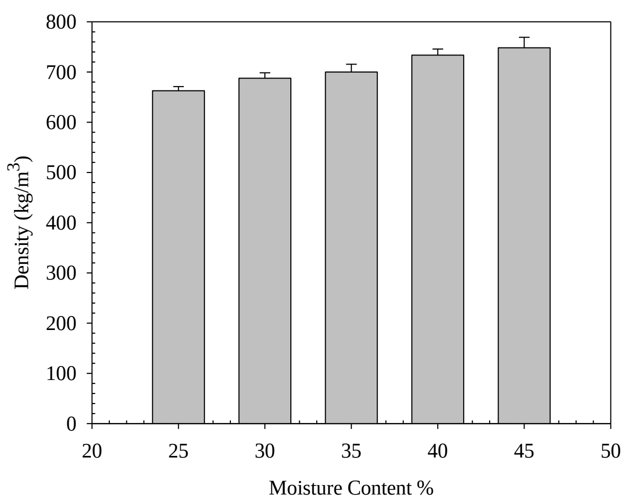

Figure 17 – Effect of Moisture Content on Bulk Density of compost pellets

Production and Machine Efficiency

As can be seen from Table 1, machine efficiency and the production efficiency increased with compost particle size. When the particle size of the compost (with 25% moisture) was increased from 0-2.5 mm to 0-5 mm, the production and machine efficiencies increased. Further, both production and machine efficiencies decreased with increasing moisture content for PC3.

This can be explained; the pellet strength decreases with the moisture resulting weaker pellets which break easily giving short pellets and reduced amounts of sellable pellets. In addition it was encountered that handling of moist compost was difficult in the pelletizer; clogging of the die reduced both production and machine efficiencies. These results are in agreement with Hara (2011) for livestock manure compost, Zafari and Kianmahr (2012) for cattle manure, Romano et al. (2014) for swine manure.

Pellets produced from PC 3 compost particles with 25% moisture content were transported a 50 km distance to observe the resistance against shocks and impacts. It was assumed that the compost would be marketed within maximum 50 km in urban context in Sri Lanka. Transport trial confirmed the pellets were in good condition after 50 km transportation and pellets can endure shocks and impacts both in packaging and transportation.

Particle Size and Moisture Content			
Particle Size (mm)	**Moisture Content (%)**	**Production Efficiency (%)**	**Machine Efficiency (Pellet kg/h)**
2.5	25	55	30
3.5	25	75	41
5	25	85	64
5	30	83	54
5	35	78	50
5	40	70	40
5	45	64	25

Effect of Binding Agents

Pellets Length Distribution

Length distribution (Percentage by weight) of compost pellets with three different binding agents, three different weight percentages and pellets with no binding agents is shown in Figure 18. It is clear that the percentage of short pellets have decreased and that of long pellets have increased when binding agents (all 3 types) were used compared with pellets with no binging agents. Therefore, it can be considered that all three binding agents were able to enhance the binding ability resulting long pellets.

Out of the three binding agents, the highest percentage of long pellets (> 20mm) was obtained when lime was used and the lowest percentage of long pellets were obtained when RF was used as the binding agents. ERP added pellets showed weight percentage of different pellets length in between lime and RF which is closed to lime. The highest percentage of short (< 5mm) pellets resulted from RF added compost and the lowest percentage of short pellets resulted from lime added compost and ERP resulted long pellets than RF. The percentage of the long pellets in ERP is very much closed to lime added pellets (but in less percentage).

ERP is a less soluble binding material used in this experiment. The major element in ERP is Ca which was presented in the range of 21.5-24.5% and the main constituent is apatite (Ca5(PO4)3 (OH, F,Cl)) (Rathnayake and Navarathne, 2014). Although, Ca2+ ions are present in ERP, their interactions with compost are weaker than Ca2+ in lime produces because of the presence of OH-, F- and Cl-. These weak interactions give low strength to pellets and in turn produce short pellets.

RF has no effective chemical compound and free ions identified to produce stronger pellets and RF added pellets gave the lowest percentage of pellets of length < 15mm since RF is a potential binder at adequate moisture and heat. Though heat is generated during pelletization by friction, the moisture is not sufficient as it requires 30-50% moisture (Tabil, 1996) to produce durable pellets. Due to the dry nature of added RF and compost at moisture (at 25%), material does not move easily through the dies of the pelletizer to form long pellets. However, when RF percentage was increased there is a possibility of enhancing the interlocking and adhesion of particles, which may results in sufficient strength in pellets and to resist the disruptive forces as explained by Tabil (1996) and Grover and Mishra (1996) for biomass densification.

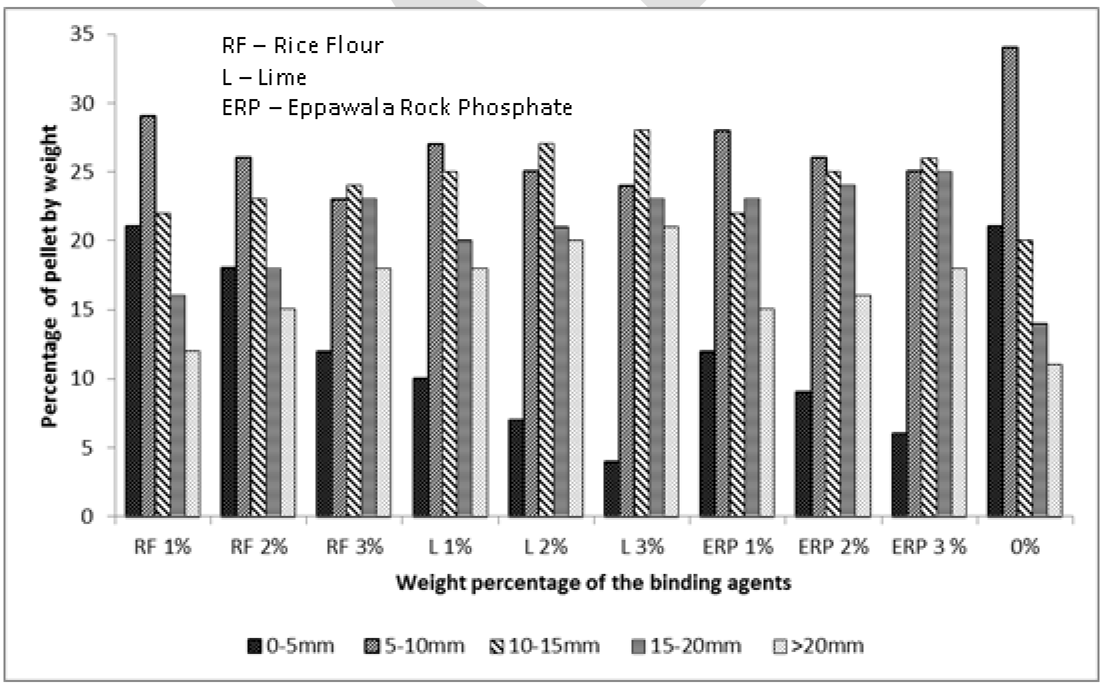

Figure 18 - Weight percentage of compost pellets of different lengths when different types and weight percentages of binding agents were used

Compressive Strength

Figure 19 shows the change of compressive strength of compost pellets made with different types and weight percentages of binding agents. Pellets with no binding agents (25% moisture and 0-5mm particle size) have compressive strength of 64 N/cm. Pellets with 1% RF gave the highest compressive strength of 107 N/cm. However, when the percentage of RF was increased to 2% and 3%, the strength gradually decreased to 70 N/cm and 63 N/cm respectively. Pellets with 1% (by weight) lime showed a decrease in compressive strength than that of pellets with no binding agents and then increased from 43N/cm to 80N/cm when the amount of lime increased from 1-3%. ERP added compost pellets also showed a compressive strength change similar to lime added compost pellets from 30N/cm to 80N/cm when the binder percentage increased from 1-3%.

RF in dry form has limited binding ability than in gelatinized form; gelatinized RF shows good binding ability due to stickiness and bind compost particles together to make stronger pellets; (Tabil, 1996; Nikiema et al, 2014). When the percentage of RF increased up to 3%, the moisture available may be not sufficient to gelatinize and remains further in dry form reducing the binding ability, which in turn results weak pellets. Tabil, (1996) reported that 30-50% moisture is needed for RF to produce strong pellets.

The reason for the decrease in strength of 1% Lime and 1% ERP added pellets compared to pellets with no binding agent may be due to the moisture level. Water (moisture) in the compost with no binding agent acts as a self –bonding agent and support higher densification by promoting Van Der Walls forces, capillary pressure and interfacial forces for binding of particles (Tabil, 1996; Grover and Mishra, 1996). When addition of external binding agents, the ability of water to bind with compost gets limited and therefore showed low strength. However, when addition of lime and ERP at 2 and 3 %, it bind compost particles together and produce stronger pellets since strong Ca2+ ions in lime tends to attract molecules present in the mixture to form ion dipole interaction with the molecules available in the mixture to form strong pellets. In addition, formation of solid bridges among the particles during pelletization at high temperature and pressure by melting of compost particles also results strong pellets. Same reason seems apply for the ERP.

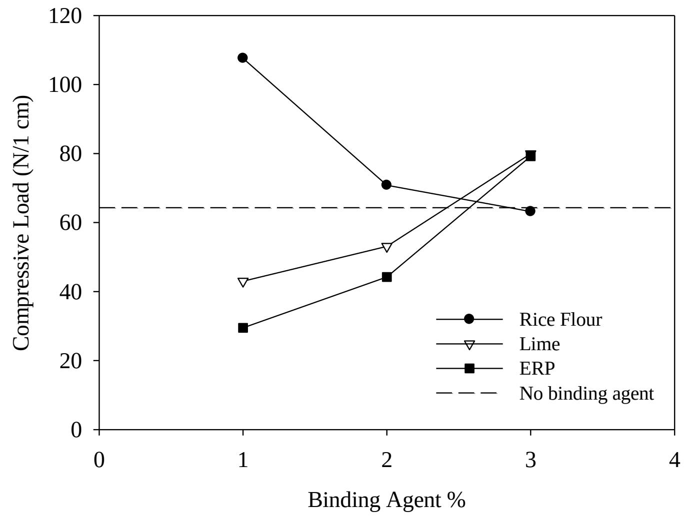

Figure 19 - Variation of compressive strength with different binding agents and their weight percentage

Disintegration Test

Percentage of pellet disintegration with different percentages of three binding agents in the presence of water is shown in Figure 20. Pellets with no binding agents did not show any disintegration during the one month testing period in water. However, incorporation of binding agents show promising results for pellet disintegration. Pellets made with RF as the binding agent showed the highest disintegration ability than pellets made with other two binding agents. With increased percentage of RF, the disintegration also increased from 60% to 90% and within 3 days 100% disintegration occurred. With the increase of the amount of ERP, pellet disintegration decreased while lime added compost pellets did not show a change in percentage of disintegration with increased amounts of lime remained around 10% during the one month period considered for experiment. Reasons for changes that happened in pellets are due to interaction of pH, temperature, and movement of ions and diffusion of molecules (Nikiema et al, 2013a). As a result, molecules induce, swell, may trigger to disintegrate. In addition growth of microorganisms helps disintegration, especially in RF added compost where nutrients and moisture are present for microbial growth. A layer of foamy material has been observed as fungi developed on top of the pellets in the work conducted by Nikiema et al, (2013a) on co-compost pellets where the pellets with cassava starch have disintegrated in 46 hours in water. Reason for low disintegration of pellets with ERP is low solubility of ERP and hence it does not release ions and diffusion of molecules for easy disintegration. Further, ERP absorbs moisture, becomes sticky and bind particles together avoiding the disintegration. In the case of lime, CaO reacts with water and form calcium hydroxide ($Ca(OH)_2$). Long period (one month) of $Ca(OH)_2$ in water, with the presence of atmospheric CO_2 may form Calcium Carbonate ($CaCO_3$) and it will bind compost particles strongly and produce strong pellets. The solubility of $CaCO_3$ is poor in water and therefore remains without disintegrating the pellet.

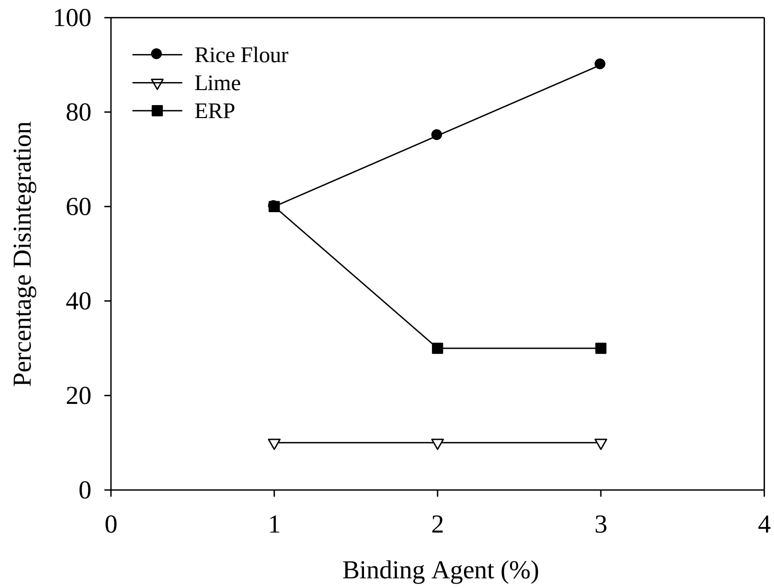

Figure 20 - Disintegration of the pellets made with 1-3% binding agents of RF, lime and ERP in water.

Conclusions

The following conclusions can be drawn from the study.

- Addition of FS as the co-composting agent has improved Electrical Conductivity within derived co-compost by increasing free ion availability and hence favorably maintains soil characteristics.
- Addition of FS leads to favorable pH maintenance within derived co-compost and hence avoid Nitrogen loss in the form of ammonia and increases Total Nitrogen content ultimately. This phenomenon leads to generate nutrient enhanced co-compost.
- FS act as compatible co-composting agent for Municipal Solid Waste and improves Total Nitrogen (TN), Total Phosphorous (TP) and Water Soluble Phosphorous (WSP) content availability within derived co-compost.
- Addition of 10% by mass FS has not induced a severe safety consideration due to availability of permissible concentrations of Heavy metals and Faecal coliform.
- This research on co-compost pelletization was conducted using Die and Roller method which was proved to be less complex and economical compared to the extruder method.
- Pelletization increased the bulk density of compost pellets due to compaction that occurs in the process along with good pellet length distribution giving rise to good compaction.

- Compressive strength increased when compost particles have a good size distribution (PC 3) but the compressive strength decreased with the increase of moisture.
- The amount of short pellets increased and both production efficiency and machine efficiency decreased with moisture.
- According to results obtained, appropriate particle size distribution and correct level of moisture is required to produce compost pellets with a good strength, length and durability.

References

AIT, Asian Institute for Technology. 2004. *Minicipal Solid Waste Management in Asia.* Thailand: Asian Institute of Technology.

Alemi, H., Kianmehr,M.H., & Borghaee,A.M. 2010. "Effect of Pellet Processing of Fertilizer on Slow-Release Nitrogen in Soil." *Asian Journal of Plant Sciences* 9: 74-80.

Ameen, A. & Ahmad, J., 2016. Effect of pH and moisture content on composting of. International Journal of Scientific and Research Publications, Volume 6(Issue 5), pp. 35-37. [24] Kauwenbergh , . V. S., 2010. World Phosphate rock reserves and resources, Alabhama-USA: IFDC.

Bernal , M., Navarro , . A., Roig , . A. & Cegarra, J., 1996. Cabon and Nitrogen transformation during composting of sweet sourghm bagasse.

Brinton, F. W., 2000. Compost Quality Standards and Guidelines, New York: New York State Association of Recyclers. [26] Cofie, O. et al., 2016. Co-composting of Solid Waste and Faecal Sludge for Nutrient and Organic matter recovery. s.l.:CGIAR Research Program on Water, Land and Ecosystems (WLE).

Carter, JM. 2010. "North Carolina Biomass Availability and Pellet Production from Mixed Forest Understory for Bioenergy Industry,." M.Sc. thesis, North Carolina State University.

CEA, Central Environment Authority. 2012. *Data Base of Solid Waste in Sri Lanka.* Battaramulla, Sri Lanka: Central Environment Authority.

Chen, L., Morti , M. d. H., Moore , A. & Falen, 2011. The Composting Process. [20] Kutzner, H. J., 2008. Microbiology of Composting.

Cofie, O.,Strauses, M., Dresher, S., Zurbruegg, C., Montangero, A. and Drechsel, P. 2003. *Co-composting of Faecal Sludge and Municipal Organic Waste: A Literature and State-of-Knowledge Review*. Swiss Federal Institute of Environmental Science & Technology (EAWAG), Dept. of Water & Sanitation in Developing Countries (SANDEC), International Water Management Institute (IWMI).

Cofie, O. 2003. *Co-composting of Faecal Sludge and Solid Waste for Urban and Peri-urban Agriculture in Kumasi, Ghana, Final Report.* International Water Management Institute.

Cofie, O., Nikiema, J., Imprain, R., Noah A., Paul, J. and Kone, D. 2016. *Co-composting of Solid Waste and Fecal Sludge for Nutrient and Organic Matter Recovery.* Resource Recovery & Reuse Series. 3, International Water Management Institute.

Cofie, O., Kone, D. & Rothenberger, S., 2009. Co-composting of faecal sludge and organic solid waste for agriculture: Process Dynamics. Water research.

Cooperband, L., 2002. The Art and Science of Composting, s.l.: University of WisconsinMadison, Center of Integrated agriculture systems.

Davidson, G., 2011. Waste management practices, Halifax, Norva Scotia: Dalhousie university.

Dinis, M., 2009. Co-composting: A Brief Review, University Fernando Pessoa-PortoPortugal.

David, A. & Gamble, S., 2013. Municipal Solid waste Organics Processing. s.l.:ISBN: 978-1-10021707-9.

Dimambro, . M., Lillywhite , R. & Rahn , C., 2006. Biodegradable municipal waste composts: analysis and application to agriculture, United Kingdom: the university of Warwick.

Ferreira, N. L. & Oliveira, R., 2013. Cocomposting cow manure with food waste: The influence of lipids content. s.l., World Academy of Science, Engineering and Technology . [13] Hasanimehr, M., Rad, H. A., Babaee , V. & baei, M. S., 2011. Use of Municipal Solid Waste Compost and Waste Water Biosolids with CoComposting Process. World Applied Sciences Journal, 11(Special Issue of Food and Environment), pp. 60-66.

Hara, Masayuki. 2011. *Fertilizer Pellets Made from Composted Livestock Manure.* FFTC Publication Database - Extension Bulletins. 11 01. Accessed 10 20, 2015. http://www.agnet.org/library.php?func=view&style=type&id=20110801154610.

Hirrel, S. s. & Riley, T., 2005. Understanding the Composting process, University of rkansas.

Jilani., Seema. 2007. "Municipal Solid Waste Composting and its Assessment for Reuse in Plant Production." *Pakistan Journal of Botany* 39 (1): 271-277.

Kathryn, P., 2003. Chemistry and Compost. In: Chemists celebrate earthday, pp. 2-7. [9] Kokhila, M. S., 2015. Composting: Advantages and Disadvantages, Ilia state university.

Liyanage, B. C., Gurusinghe, R., Herat, S. & Tateda, M., 2015. 2015. "Case Study:Finding better solution for municipal solid waste management in a semi local authority in Sri Lanka." *Open Journal of Civil Engineering* 5: 63-73.

MENR, Ministry of Environment and Natural Resources. 2005. *Database of Municipal Solid Waste in Sri Lanka.* Battaramulla: Ministry of Environment and Natural Resources.

Mollazadeh, N., 2014. Composting: a new method for reduction of solid waste and waste water. International Research Journal of Applied and Basic Sciences, 8(3), pp. 311-317.

Miller, C. M., 2015. Microbiological Safety of Organic Fertilizers Used to Produce Production.

Nikiema, J., Cofie, O. & Impraim, R. 2014. *Technological Option for Safe Resource recovery from Fecal Sludge.* Vol. Resource Recovery & Reuse Series. 2 vols. International Water Management Institute.

Ogunwande, , G. A., Osunade, J. A. & Ogunjimi, L. A. O., 2008. Effects of Carbon to Nitrogen Ratio and Turning Frequency on Composting of Chicken Litter in TurnedWindrow Piles. Agricultural Engineering International: the CIGR Ejournal, 16(07).

Sherman, R., 1999. Large scale organic materials composting, NC State university.

Sharma, V. K., Canditelli, M., Fortuna, F. & Cornacchia, G., 1997. Processing of Urban and agro-industrial residues by aerobic composting: Review. Energy conservtion and management, 38(05), pp. 453-478.

Strauss, M., Drescher, S., Zurbrügg, C. & Montangero, A., 2003. Co-composting of Faecal Sludge and Organic Municipal Solid Waste, Ghana: International Water Management Institute.

Tweib, S. A., Rahman , R. A. & Kalil, M. S., 2011. A literature review on the Composting. s.l., International Conference on Environmental and Industrial Innovation.

Varma , S. V. & Kalamdhad, . A. S., 2013. Composting of Municipal Solid Waste (MSW) mixed with cattle manure. International Journal of Environmental Sciences, 6(3).

Wong, . J. et al., 2001. Co-composting of soybean residues and leaves in Hong Kong. Bioresource Technological Journal, 76(02), pp. 99106.

Zafari, Abedin, and Mohammad Hosein Kianmehr. 2012. "Effect of Temperature, Pressure and Moisture Content on Durability of Cattle Manure Pellet in Open-end Die Method." *Journal of Agricultural Science* IV (5): 203-208.

ANNEXURE

Labor requirement to produce 1 MT of compost

Table – Man hour requirement to produce 1MT of compost

Task	**No of Workers**	**Man Hours**
Sorting of short-term bio-degradable	3	2-3
Weighing	3	1
Piling of compost	3	2-3
Watering	1	10-15 min
Turning	2	1-2
Sieving 1.Manually 2.Mechanically	2 3	10-12 5
Collection of DFS	3	4
TOTAL	**Aver. 2**	**15 – 22***

*varies on the sieving method

Labor requirement for pelletizing (to produce 50 kg of pellets)

Table - Working time for pelletizing

Task	**No of Workers**	**Working Hours**
Adding Water	1	30-60 min
Checking Moisture		
Mixing of additives	1	10 min
Pelletizing	1	2
Packing	2	10–20 min
TOTAL	**1**	**3 – 3.5**

Tool List

- Mammootty
- Spade Shovel
- Watering hose
- Buckets
- Eekle Broom
- FS collecting buckets
- Pelletizer
- Sieves
- Balances
- Watering sprayer
- Rakes
- Bob-cat
- Poly-sack bags