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Synthetic Aggregates Produced by Different Wastes as a Soil Ameliorant, a Potting Media Component and a Waste Management Option.

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1. Introduction

In most developed and developing countries with increasing population, prosperity and urbanization, one of the major challenges for them is to collect, recycle, treat and dispose of increasing quantities of solid waste and wastewater. It is now well known that waste generation and management practices have increased several alarming issues on the socio-economics, human health, aesthetics and amenity of many communities, states, and nations around the world (Meyers et al., 2006; Louis, 2004). Industrialized economies extract vast quantities of natural resources from the environment to provide modern amenities and commodities. On the other hand, pollutants associated with the production and consumption of commodities, as well as post-consuming commodities, go back into the environment as residues (Moriguchi, 1999). Although varying in degree and intensity, the solid waste problem around the world is exacerbated by limited space and dense populations (Melosi, 1981). The problem of collecting, handling and disposing of wastes is dealt with using different techniques and approaches in different regions. A waste management hierarchy based on the most environmentally sound criteria favors waste prevention/minimization, waste re-use, recycling, and composting. In many countries, a large percentage of waste cannot presently be re-used,re-cycled or composted and the main disposal methods are land filling and incineration. In addition, traditionally, managing domestic, industrial and commercial waste consisted of collection followed by disposal, usually away from urban activity, which could be waterways, Open ocean or surface areas demarcated for the purpose viz. landfills. With the increased volume and variety of hazards posed by new waste products, the situation has exceeded its saturation point at many localities (McCarthy, 2007). In 2006 the USA land filled 54% of solid wastes, incinerated 14%, and recovered, recycled or composted the remaining 32% (EPA, 2008). The percentage of solid waste disposed at landfills accounted for 3% in Japan (2003), 18% in Germany (2004), 36% in France (2005), 54% in Italy (2005) and the USA (2005), and 64% in the UK (2005). As legislation becomes more stringent and land filling becomes less cheap option. For example, there has been a significant reduction in the amount of wasteland filled in the UK and Italy. In 1995, Italy land filled 93% of solid waste, and the UK 83%. Recent studies have revealed that waste disposal processes have considerable impacts on climate change due to the

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associated greenhouse gases (GHGs) emission (Elena, 2004; Sandulescu, 2004; USEPA, 2002). Land filling processes are found to be the largest anthropogenic source of CH_4 emission in the United States. In 2004, there were 140.9 Tg of CO_2 equivalent of CH_4 (approximately 25% of the United States' annual CH_4 emission) emitted from the landfills, which shared 2.65% of the national global-warming damage. In addition, 19.4 and 0.5 Tg of CO_2 equivalent of CO_2 and N_2O were, respectively, released from the combustion processes (USEPA, 2006). These evidences show that waste disposal systems are one of the most significant contributors to potential climate change, as the associated-emission cannot be effectively mitigated under current management conditions. Moreover, Incineration is also cannot be recommended as an efficient method since it is also creating toxic gases and GHGs. In addition, wide range of waste materials (sewage sludge, industrial waste) is increasingly spread on agricultural land as soil amendments. These undoubtedly produce a number of positive effects on soil quality, but also raise concern about potential short-term (e.g. pathogen survival) and long-term effects (e.g. accumulation of heavy metals). Climate change will also become a major incentive to the use of biosolids on agricultural land, especially in regions where longer periods of low rainfall and mean higher temperatures are expected. In many parts of the world (e.g. Europe, USA) agricultural soils receive large volumes of soil amendments. Approximately 5.5 million dry tones of sewage sludge are used or disposed of annually in the United States and approximately 60% of it is used for land application (NRC, 2000). The application of biosolids to soil is likely to increase as a result of the diversion of waste away from landfill sites, and due to increasing cost of artificial fertilizers (UNEP, 2002; Epstein, 2003). Simply application of waste as an amendment to agricultural lands made some environmental problems such as air pollution due to tiny particles of coal fly ash (CFA). Therefore, it is worthwhile to find out alternative methods for waste disposal. Consequently, unconventional synthetic aggregates were produced from different waste materials (sewage sludge, paper waste, oil palm waste, sugarcane trash, starch waste, CFA, wood chips, coir dust, cattle manure compost, chicken manure compost etc…) to utilize them in agriculture as a soil amendment, fertilizer support, and potting media for containerized plant cultivation (Jayasinghe & Tokashiki, 2006; Jayasinghe et al., 2005, 2008, 2009 a,b,c,d,e,f,g). These synthetic aggregates proved that they can be utilized in agriculture very effectively. Moreover, these kinds of unconventional synthetic aggregate production have not much been reported in the literature. Therefore, this chapter describes the production, characterization and different utilization methods of synthetic aggregates in agriculture.

2. What is a Synthetic Aggregate (SA)?

Aggregate structure is schematically shown in Figure 1. It is composed with rigid or composite materials, fibrous materials and a binder.

2.1 Rigid or composite materials

Sewage sludge, sugarcane trash, wood chip, CFA, compost, soil etc. can be regarded as rigid materials. The rigid materials give the rigidity and the strength of the aggregate by enmeshing into fibrous matrix. Figure 2 shows the scanning electron microscopic (SEM) image of a coal fly ash paper waste aggregate, which is showing the rigid CFA particles are enmeshed into the fibrous paper waste matrix by the binder.

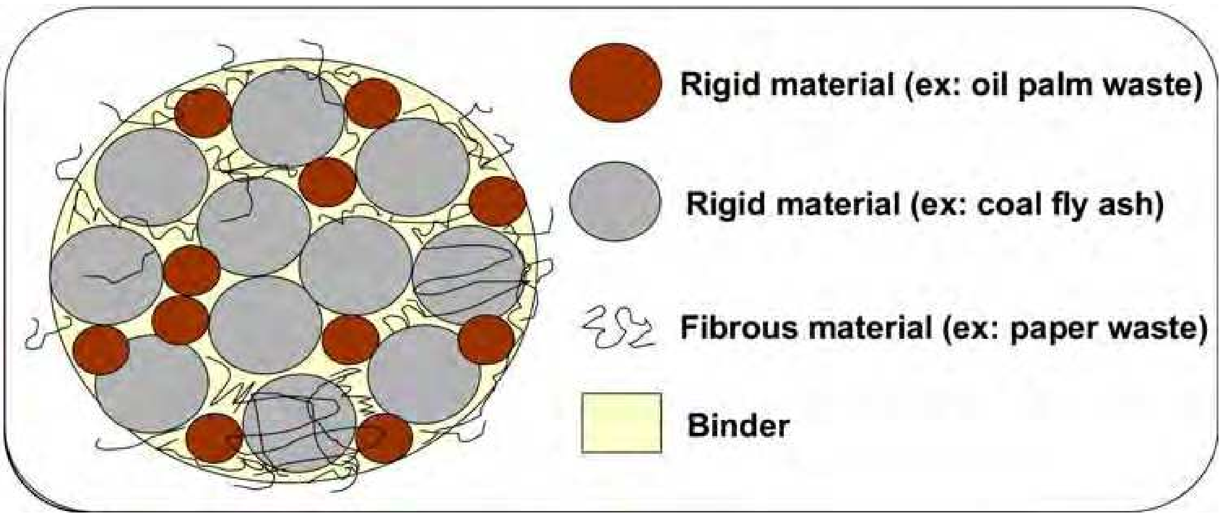

Fig. 1. Schematic diagram of the synthetic aggregate.

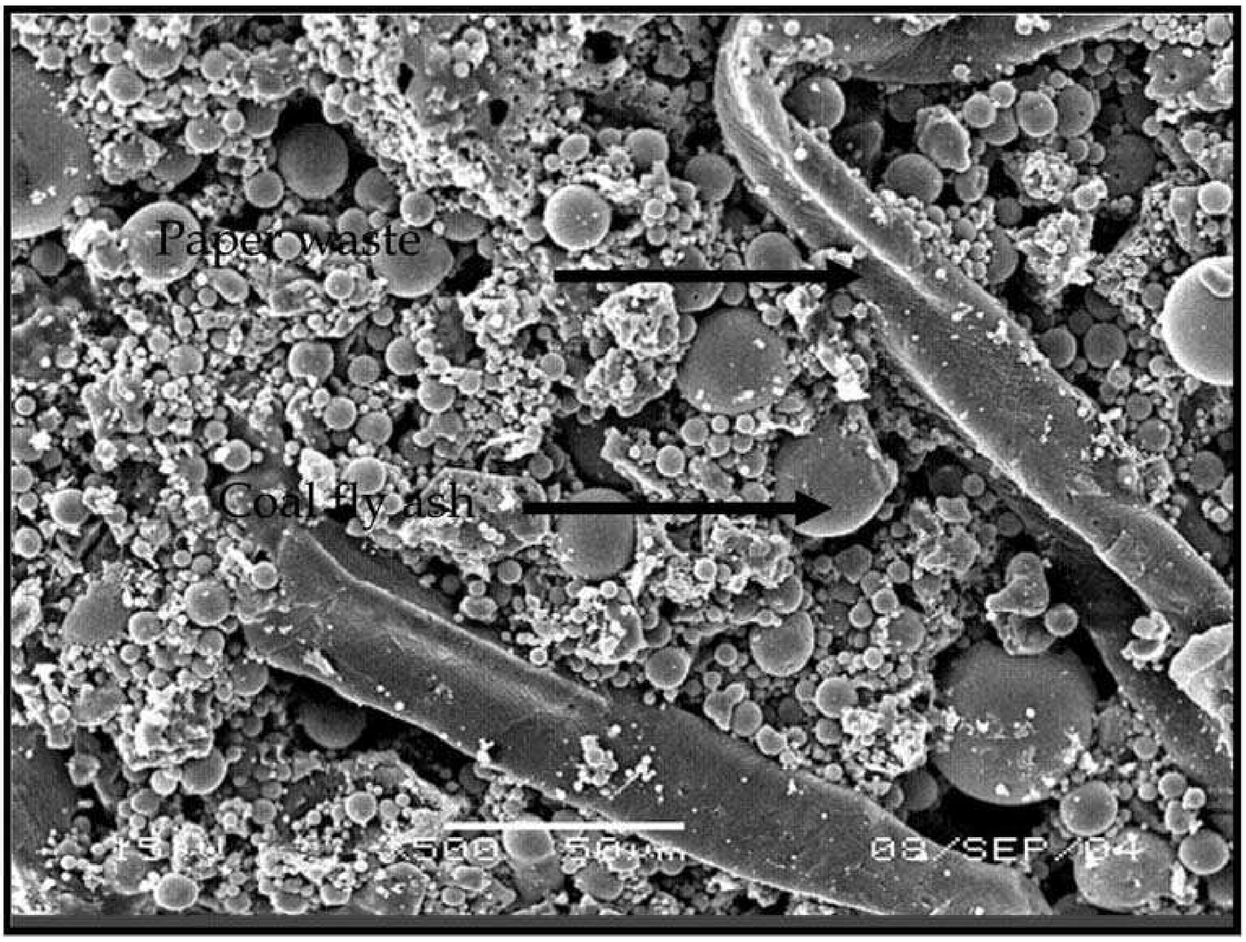

Fig. 2. Scanning electron micrograph of a coal fly ash-paper waste synthetic aggregate.

2.2 Fibrous materials

The formation of aggregate requires a matrix to adhere the rigid particles. Then this matrix can form the aggregate structure by binding the rigid particles into the matrix by the binder. Paper waste, coco fiber, wheat and rice straw and oil palm fiber can be used as the fibrous materials. Figure 2 shows the porous paper waste matrix, which provides the binding sites to the CFA particles. Porous spaces can be observed within the aggregate, which can improve the aeration and the water holding capacity of the aggregates as a growth substrate (Jayasinghe et al., 2007). Fibrous materials in the aggregates also assist to increase the micro pores in the aggregate-soil amendment mixtures during the humification of aggregates by microbes after mixing them into the soil as an amendment.

2.3 Binder

The formation of aggregate requires both physical rearrangement of particles and the stabilization of the new arrangement. Therefore effective binder should be added in order to obtain stable aggregates. Several binding mechanisms exist between organic polymers and mineral surfaces to provide stable aggregates. Organic polymers have been used quite effectively to stabilize soil structure in recent years. Many researchers have shown that the application of polyacrylamide maintained high infiltration rate during rainfall and reduced soil surface sealing and runoff soil losses (Ben-Hur & Keren, 1997; Sojka et al., 1998; Green et al., 2000). Polysaccharides added to soil as soil conditioners improve soil's physical properties that are important for plant growth and increase soil's resistance against disruptive forces and erosion. Organic polymers have been used quite effectively to stabilize soil structure in recent years. Polysaccharides stabilize soil aggregates because of their contribution as cements and glues. (Taskin etal., 2002).There is a considerable amount of starch which is a polysaccharide coming out as waste material from Okinawa flour industry (Okinawa, Seifun ltd). Utilization of the starch waste is currently under the potential capacity. Therefore, the starch waste was utilized as an organic binder for the synthetic aggregate production. In addition, several inorganic binders can be used to produce synthetic aggregates. Acryl resin emulsion binder EMN-coat /21 and Calcium hydroxide with calcium sulfate can also be used as the binder to produce aggregates.

2.4 Production of synthetic aggregates

Production process of aggregates is given in Figure3. EIRICH mixer, Ploughshare mixer or Pelleger machine can be used for the production of heterogeneous aggregates. Heterogeneous aggregates means the aggregates containing different particle sizes. Pelleter machine can be utilized to produce homogenous (same size) aggregates. EIRICH mixer was used for small scale aggregate production and pelleger machine and pelleter was used in major scale aggregates production. Different proportions of raw materials were mixed in the pelleger or EIRICH mixer for 1-3 minutes. Then binder was added and mixed for another 1-2 minutes. Finally whole mixture was mixed for another 2-5 minutes in high speed rotation to form aggregates. Raw materials with binder mixture were inserted to the pelleter machine for the production of homogenous aggregates. Moreover, diameter and the length of the aggregates can be adjusted according to the requirement.

2.5 Different types of aggregates with various types of wastes.

Different types of aggregates can be developed with the available waste in the site or area. Some of the developed aggregates from different wastes are described below (Figure 4). Basically aggregates can be divided into two types.

1. Heterogeneous aggregates

   These aggregates contain different sized aggregates. Following are some of the heterogeneous aggregates developed from various materials.

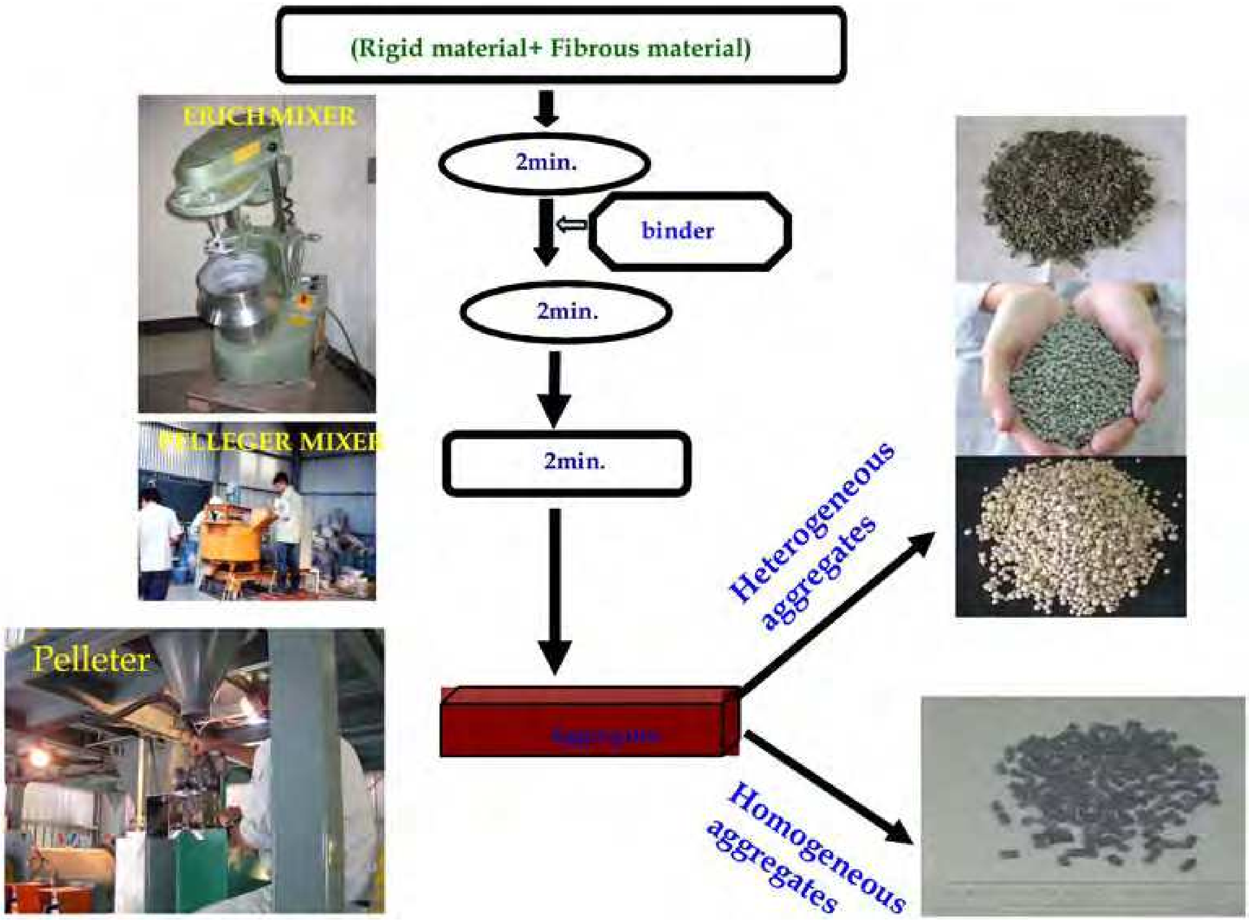

Fig. 3. Production process of different types of aggregates.

  i. Coal fly ash based aggregates
     These aggregates were developed from CFA, paper waste or oil palm waste with organic or inorganic binders (Figure 4a).
  ii. Soil aggregates
     These were developed from low productive acidic red soil with paper waste, coco fiber, or oil palm waste (Figure 4b) with organic or inorganic binders.
  iii. Acid soil-coal fly ash aggregates
     These were developed by acid soil and the coal fly ash with paper waste, sewage sludge (SS), CFA with organic or inorganic binder. (Figure 4 c)
  iv. Sewage sludge based aggregates
     These aggregates were developed from sewage sludge and zeolite with an inorganic binder. (Figure 4d)
  v. Compost based aggregates
     These were produced from different types of composts and soil with organic or inorganic binders (Figure 4e)

2. Homogenous aggregates
   These aggregates have same sized aggregates and pelleter machine was used for the production of these aggregates.
   These aggregates are called as synthetic pellet aggregates. Coal fly ash (CFA), soil, compost, paper waste, coco fiber, oil palm waste, sewage sludge and organic or inorganic binders can be utilized as raw materials for these types of aggregates. (Figure 4f)

Fig. 4. Different types of aggregates produced from different materials.
(a) coal fly ash paper waste aggregates, (b) soil aggregates,
(c) acid soil coal fly ash aggregates, (d) sewage sludge based aggregates,
(e) compost based aggregates, (f) pellet aggregates (homogeneous aggregates)

3. Physical and chemical properties of synthetic aggregates

3.1 Physical properties

Particle size distributions of synthetic aggregates developed by different materials are given in the Table 1. Particle size distribution of a substrate is important because it determines pore space, air and water holding capacities (Raviv et al., 1986). Mean distribution of the aggregate media showed that fraction between 5.60 and 2.00 mm was the most abundant fraction in all types of synthetic aggregates (Table 1). An excess of fines in a substrate clogs pores, increases non-plant-available water holding capacity and decreases air filled porosity (Spiers & Fietje, 2000). Therefore, these synthetic aggregates which are having higher percentage of larger- sized particles can be utilized to enhance the properties of problematic soils having higher finer particles to improve its porosity and hydraulic conductivity. Synthetic aggregates developed from low productive acid soil and paper waste addition to the problematic grey soil in Okinawa, Japan significantly enhanced the particles >2.00 mm and hence the hydraulic conductivity and porosity were significantly increased (Jayasinghe et al., 2009d). All of synthetic aggregates shown in the Table 1 are heterogeneous which are having different sized aggregates. Synthetic pellet aggregates can be developed with single particle sized diameter which are called as homogenous aggregates. These pellet aggregates can be produced with the required diameter as a tailor made production. In addition, aggregate diameter of heterogeneous aggregates depends upon the material type and quantity, binder type and quantity and the mixing time. Therefore, suitable particle sizes of heterogeneous synthetic aggregates can be designed according to the requirement. Synthetic aggregates particle sizes are varying with the required situation. For an example particle sizes for a potting medium are different from particle sizes required as a soil ameliorant. As a potting medium relatively higher percentage of smaller sized-diameter particles should be utilized to improve the potting media characteristics.

Aggregate type	>5.60 mm	5.60-3.35 mm	3.35-2.00 mm	2.00-1.00 mm	1.00-0.50 mm	>0.50 mm
A	25.61	30.19	28.32	8.54	5.20	2.14
B	10.77	19.85	36.98	13.15	7.91	11.34
C	23.86	28.14	25.74	9.44	8.09	4.73
D	6.34	16.92	16.98	19.44	21.23	19.09
E	26.20	30.28	27.54	8.73	5.02	2.23
F	7.10	15.21	18.77	15.91	22.87	20.14

A: coal fly ash paper waste aggregates with starch binder (Jayasinghe et al., 2009b),
B: acid soil aggregates with starch binder (Jayasinghe et al., 2008),
C: acid soil coal fly ash aggregates with starch binder, (Jayasinghe et al., 2008),
D: acid soil compost aggregates with inorganic binder,
E: coal fly ash aggregates with inorganic binder (Jayasinghe et al., 2009a),
F: sewage sludge aggregates with inorganic binder.

Table 1. Particle size distribution of synthetic aggregates.

Bulk density, particle density, hydraulic conductivity, water holding capacity and aggregate strength of the synthetic aggregates are given in the Table2. Bulk density of a substrate gives a good indication of porosity, which determines the rate at which air and oxygen can move through the substrate. Bulk density values of all substrate given in the table showed low values compared to red soil (1.26 gcm^{-3}) in Okinawa Japan. These low values are due to the coal fly ash, paper waste, and sewage sludge in the developed synthetic aggregates. It is also evident that there were significant differences between bulk density values of aggregates produced with different coal fly ash additions to red soil (Jayasinghe et al., 2005). The particle density of the synthetic aggregates was also low compared to the red soil. Red soil gave a particle density of 2.61 gcm^{-3}. Hydraulic conductivity of a substrate is a measure of the ability of air and water to move through it. Hydraulic conductivity is influenced by the size, shape and continuity of the pore spaces, which in turn depend on the bulk density, structure and the texture. Hydraulic conductivity of the aggregates showed higher values compared to the red soil and grey soil studied in Okinawa, Japan. The red soil and grey soils showed hydraulic conductivity values of 6.62 x10^{-5} and 6.67 x10^{-5}, respectively. The water holding capacity of the synthetic aggregates given in the table varied between 0.59 and 0.68 kgkg^{-1}, which are increased values compared to the red soil (0.48 kgkg^{-1}) in Okinawa Japan (Jayasinghe et al., 2009e). Aggregate strength of the produced aggregates varied between 2.58-4.01 kgcm^{-2}. Synthetic aggregates developed by using coal fly ash, paper waste, and starch waste gave an average aggregate strength in the range of 2.05-3.58 kgcm^{-2}, which can be considered as higher aggregate strengths (Jayasinghe et al., 2005, 2006, 2008). Higher aggregate strengths indicate resistance of the aggregate to the erosion. Therefore, these synthetic aggregates can withstand to erosion compared to soil particles.

3.2 Chemical properties

Chemical properties of the different types of synthetic aggregates are given in the Table 3. It is evident that pH of aggregates were varied in a wide range from 4.57 to 10.72. A, C, E and

G aggregates having higher pH values were produced by using CFA as a material in the aggregates. The original pH of the CFA used to produce synthetic aggregates was varied in the range of 11.36-11.80. Therefore, CFA aggregates gave alkaline pH values. The hydroxide and carbonate salts in CFA gave one of its principle beneficial chemical characteristics, the ability to neutralize acidity in soils (Pathan et al., 2003). Therefore, these alkaline synthetic aggregates can be used as a buffer material to neutralize the acidic problematic soils. Jayasinghe et al., (2006) reported that 25% of synthetic CFA based aggregates addition increased the acidic pH (4.62) of red soil into 6.25.Type B aggregates were developed from acidic red soil with paper wastes showed acidic pH of 4.57 due to acidic soil. Type D aggregates were produced from acidic red soil with cattle manure compost which neutralized the acidic pH of the red soil and gave a pH of 6.40. Type F aggregates gave a pH of 7.58 due to the alkaline sewage sludge (pH=7.72) in the aggregates. It is evident that the pH of the aggregates depends on the materials which were used to form the aggregates. Aggregates showed high electrical conductivity (EC) except type B due to high essential and non essential elements in the aggregates. Type B aggregates produced from red soil and paper waste, which did not contain much element concentrations, gave the lowest EC. But coal fly ash had high concentrations of different elements, which subsequently raised the EC of the CFA based aggregates. The EC and metal content of soil increases with increasing amount of CFA application (Sikka & Kansal, 1994). Aggregates developed from sewage sludge (SS) also showed high EC due to the presence of high concentrations of elements in the sewage sludge (SS). Gil et al., (2008) reported that SS was characterized by higher EC. The High EC in SS may be due to presence of high concentrations of different types of elements.

Aggregate type	Bulk density (gcm^{-3})	Particle density (gcm^{-3})	Hydraulic conductivity (cms^{-1})	Water holding capacity (kgkg^{-1})	Aggregate strength (kgcm^{-2})
A	0.56	2.48	2.80×10^{-2}	0.62	3.91
B	0.87	2.44	1.87×10^{-2}	0.63	2.58
C	0.80	2.20	3.74×10^{-2}	0.68	3.06
D	0.64	2.48	2.80×10^{-2}	0.67	3.76
E	0.64	2.31	1.87×10^{-2}	0.59	3.88
F	0.54	2.08	2.24×10^{-2}	0.61	4.01
G	0.52	2.20	2.80×10^{-2}	0.60	3.92

A: coal fly ash paper waste aggregates with starch binder,
B: acid soil aggregates with starch binder,
C: acid soil coal fly ash aggregates with starch binder,
D: acid soil compost aggregates with inorganic binder,
E: coal fly ash aggregates with inorganic binder,
F: sewage sludge aggregates with inorganic binder,
G: synthetic pellet aggregates (diameter is 10 mm).

Table 2. bulk density, particle density, hydraulic conductivity, water holding capacity and aggregates strength of the synthetic aggregates.

	A	B	C	D	E	F	G
pH	9.82	4.57	9.71	6.40	10.72	7.58	9.28
EC(mSm^{-1})	96.16	6.36	57.50	48.76	90.40	156.26	80.76
C (g kg^{-1})	120.82	85.40	66.21	101.12	55.22	291.80	113.61
N (g kg^{-1})	0.71	0.40	0.40	1.06	0.42	29.10	0.62
P (g kg^{-1})	0.11	0.08	0.05	0.46	0.06	14.65	0.20
Na (g kg^{-1})	0.87	0.24	0.44	0.71	0.78	0.54	0.88
K (g kg^{-1})	1.51	0.18	0.76	2.34	1.56	0.62	1.61
Mg (g kg^{-1})	0.72	0.38	0.47	0.87	0.73	4.12	0.91
Ca (g kg^{-1})	3.34	1.10	2.31	2.12	37.25	65.64	3.18
B (mg kg^{-1})	16.86	0.12	10.33	0.42	19.34	0.51	12.17
Mn (mg kg^{-1})	15.82	20.28	18.73	24.14	19.20	109.66	14.88
Cu (mg kg^{-1})	18.47	13.21	16.22	22.66	18.50	188.02	19.12
Zn (mg kg^{-1})	34.63	21.35	28.93	32.12	34.60	485.07	31.98
Cr (mg kg^{-1})	7.62	1.21	5.45	0.98	7.60	34.42	7.02
Cd (mg kg^{-1})	ND	ND	ND	ND	ND	0.40	ND
Se (mg kg^{-1})	ND	ND	ND	ND	ND	ND	ND
Pb (mg kg^{-1})	7.56	3.01	5.88	3.66	7.60	26.33	8.02
As (mg kg^{-1})	ND	ND	ND	ND	ND	ND	ND

A: coal fly ash paper waste aggregates with starch binder,
B: acid soil aggregates with starch binder,
C: acid soil coal fly ash aggregates with starch binder,
D: acid soil compost aggregates with inorganic binder,
E: coal fly ash aggregates with inorganic binder,
F: sewage sludge aggregates with inorganic binder,
G: synthetic pellet aggregates (diameter is 10 mm).
EC: electrical conductivity, ND: not detected.

Table 3. Chemical properties of synthetic aggregates.

Carbon (C) content of aggregates also varied in a greater range and depends on the material type in the aggregate. The N content of the aggregate types of A, B, C, E and G showed low N amount. But D and F gave high N content. Aggregate D contains cattle manure compost while F contains sewage sludge. Moreover, aggregates enriched with N, P and K can be developed by adding respective N, P and K chemical fertilizer as a material to produce aggregates. All of the aggregates gave low phosphorous (P) content except the type E since it is composed with high P containing SS. Aggregates having CFA, compost and SS (A, C, D, E and F) gave high concentrations of Na, K, Mg and Ca in the aggregates. Chemically, 90–99% of CFA is comprised of silicon (Si), aluminum (Al), Ca, Mg, Na and K (Adriano et al., 1980). Aggregates developed from coal fly ash gave high boron (B) content compared to other aggregates. This is due to high B content of the CFA. CFA contains significant levels of B (Lee et al., 2008).

Heavy metal concentrations of the different aggregates are given in Table 3. Selenium (Se) and Arsenic (As) were not detected in any aggregates, and Cadmium (Cd) was detected only in F. The copper (Cu), chromium (Cr), manganese (Mn), zinc (Zn) and lead (Pb) concentrations were generally well below the maximum pollutant concentrations of individual metals for land application suggested by the US Environmental Protection Agency (USEPA, 1993). The maximum pollutant concentrations of individual heavy metal content for land application of sewage sludge given by the US Environmental Protection Agency are (all in mg/kg); As 41, Cr 1200, Cu 1500, Zn 2800, Pb 300, Cd 39 and Se 36, respectively (USEPA, 1993). Furthermore, average concentrations of heavy metals reported in uncontaminated soils are (all in mgkg^{-1}); 6 As, 70 Cr, 30 Cu, 90 Zn, 35 Pb and 0.35 Cd, respectively (Adriano, 2001). Though the concentrations of heavy metals were below the uncontaminated soil values and not alarming, there should be routine inspections to ensure that heavy metal concentrations remain within safe limits.

4. Aggregate utilization

4.1 Synthetic aggregates as a soil ameliorant to problematic soils

4.1.1 Synthetic aggregates as a soil ameliorant to low productive acidic red soil.

4.1.1.1 Coal fly ash paper waste starch binder aggregates

Widely spread red soil ("Kunigami Mahji") in sub-tropical Okinawa, Japan, is not suitable for crop production due to its poor physical (Tokashiki et al., 1994) and chemical properties, such as its acidic nature, low organic matter content, and poor nutrient availability (Kobayashi & Shinagawa, 1966; Hamazaki, 1979).Therefore, CFA paper waste aggregates developed with CFA, paper waste and starch binder were used as a soil ameliorant to improve the low productive acidic soil. Aggregates were produced by combining CFA and paper waste using an Eirich mixer (R-02M/C27121) with starch binder.500 g of coal fly ash and 50 g of paper waste were mixed in the Eirich mixer by adding 250 ml of starch binder to produce aggregates. Developed aggregates were used as a soil ameliorant to low productive acidic soil with the objective of enhancing the soil physical and chemical properties to improve the growth and development of Komatsuna (*Brasica rapa*) which is a popular vegetable in Japan. The different amendment rates of the experiment are given in Table 4.

Treatments	Description
T1	Aggregates only
T2	75 % of aggregates
T3	50% of aggregates
T4	25% of aggregates
T5	10% of aggregates
T6	Acidic red soil only.

Table 4. Different treatments were used under the study.

4.1.1.1.1 Influence of aggregate addition to red soil on the growth and development of Komatsuna

Aggregate addition of 25% with acidic red soil ("Kunigami Mahji") as a soil amendment, favorably improved Komatsuna yield by giving the highest significant increase in plant height, fresh and oven dry yield over other treatments (Table 5). Treatments of 10% of aggregate addition gave the second highest average values of yield. Aggregates only (T1) and acid soils only (T6) showed the lowest mean values of height and yield (Table 5). Therefore, aggregate addition to the soil as a soil amendment improves the crop production in comparison with acidic red soil. Aggregate addition percentages of 50% and 75% did not show any significant difference between them, but, significantly differed from the treatments of 25% of aggregate addition and acidic red soil only. Aggregate addition modified the acidic pH conditions to nearly neutral conditions at the 10% and 25% percentages. Therefore, synthetic aggregates, which were produced from coal fly ash, buffer the acidic red soils, while forming conducive crop growth environment by binding soil particles with coal fly ash aggregates, which improves the crop growth and soil physico – chemical properties.

Treatments	Dry weight (gpot^{-1})	Fresh weight (gpot^{-1})	Height (cm)
T1	0.25^{d}	1.50^{e}	5.02^{d}
T2	2.33^{c}	12.50^{d}	14.13^{c}
T3	2.92^{c}	17.00^{c}	16.16^{c}
T4	8.10^{a}	48.00^{a}	24.21^{a}
T5	7.13^{b}	45.00^{b}	21.08^{b}
T6	0.30^{d}	2.00^{e}	6.11^{d}

(Means followed by the different superscript letter in the same column differed significantly according to Duncan's multiple range test (P=0.05).

Table 5. Influence of aggregates as a soil ameliorant on crop growth and yield of Komatsuna.

4.1.1.1.2 Effect of aggregate addition on soil characteristics

Aggregate addition to acidic red soil significantly improves the water holding capacities (Table 6) of the soil. Addition of 25% of aggregates increased the water holding capacity by 6%. Moreover, aggregates addition significantly improved the hydraulic conductivity (Table 6) of the soil. Addition of 25% of aggregates increased the hydraulic conductivity of the aggregate soil mixture by 10 times. Moreover, aggregate addition up to 25% significantly reduced the bulk density (Table 6) of the red soil from 1.23 gcm^{-3} to 1.05 gcm^{-3},which improves the soil porosity. Addition of aggregates, improves the soil porosity, water holding capacity and soil hydraulic conductivity. Acidic red soil has originally a very low permeability and it leads to heavy erosion due to run off (Hamazaki, 1979). Addition of these stable aggregates can be suggested as an alternative method to minimize the erosion in acidic red soil. Because high Ca content in these aggregates came from CFA can enhance the aggregation of` soil particles together (Jayasinghe & Tokashiki, 2006). Aggregate addition neutralized the acidic soil pH. Aggregate addition percentage of 25% level changed the original pH value of the soil from 4.62 to 6.25, which was nearly a neutral value. Furthermore, electrical conductivity (EC) of soil mixture increases with the addition of aggregates (Table 6). C/N ratios of the soil-aggregate mix also show a significant variance. Application of these aggregates helps to build up C content in the soil as well (Table 6). Aggregate addition of 25 % increased organic carbon from 1.62 to 28.80 gkg^{-1}. Therefore, innovative coal fly ash aggregates addition as a soil amendment improves soil physical and chemical properties of problematic low productive acidic red soil, which automatically improves crop production in the soil.

Characteristics	T1	T2	T3	T4	T5	T6
EC (mSm^{-1})	73.67^a	55.24^b	39.64^c	18.57^d	10.06^e	3.27^f
pH	9.26^a	8.37^b	7.86^c	6.25^d	5.78^e	4.62^f
WHC	0.61^a	0.59^b	0.57^b	0.54^c	0.53^{cd}	0.51^d
SHC (cms^{-1})	2.20×10^{-2a}	6.22×10^{-3b}	$2.24 \times 10^{-3\,b}$	$2.94 \times 10^{-4\,c}$	$2.73 \times 10^{-4\,c}$	$6.62 \times 10^{-5\,d}$
C (gkg^{-1})	110.25^a	83.18^b	55.97^c	28.80^d	12.56^e	1.62^f
N (gkg^{-1})	0.60^a	0.52^a	0.54^a	0.46^a	0.48^a	0.47^a
C/N ratio	200^a	162^b	116^c	65^d	31^e	4^f
BD (gcm^{-3})	0.61^e	0.87^d	0.98^c	1.05^{bc}	1.12^b	1.23^a

EC: electrical conductivity,
WHC: water holding capacity,
SHC: saturated hydraulic conductivity,
BD: bulk density. (Means followed by the different superscript letter in the same row differed significantly according to Duncan's multiple range test (P=0.05).

Table 6. Physico-chemical characteristics of soil – aggregate amendments

4.1.1.2 Coal fly ash paper waste inorganic binder aggregates (CSA)

CSA (see type E from the Table 1, 2 and 3) were produced by combining coal fly ash and paper waste using an Eirich mixer (R-02M/C27121) with calcium hydroxide and calcium sulfate. 1000 g of coal fly ash and 75 g of paper waste were mixed in the Eirich mixer with 50 g of calcium hydroxide and 50 g of calcium sulfate by adding 350 ml of water to produce CSA. Particle size distribution, physical and chemical properties of CSA were given in Table 1, 2 and 3.

4.1.1.2.1 Scanning Electron Microscopy (SEM)

SEM images of Figure 5-A and B represent detailed micro-morphology of CFA particles. SEM images of CFA particles showed crystalline and amorphous silicate glasses ("stable glasses") of various sizes (Figure 5-A-a) according to 4 typical phases of CFA described by Klose et al ., (2003). CFA consists of many glass-like particles, which are mostly spherical shaped and ranged in particle size from 0.01 to 100μm (Davison et al., 1974). Physically, CFA occurs as very finer particles having an average diameter of <10μm and has low to medium bulk density, high surface area and light texture (Jala & Goyal, 2006). CFA particles are hollow empty spheres called as cenospheres (Figure5-B-c) filled with smaller amorphous particles and crystals (Plerosphers). These tiny CFA particles are easily airborne (Hodgson & Holliday, 1966). Therefore, initial idea of CSA production was to bind tiny airborne CFA particles into fibrous paper waste matrix by starch waste. Figure 5-C and 5-D show the micro-morphological configuration of CSA, where paper waste matrix provides the structural surface to adhere CFA particles. Figure 5-C shows aggregation of CFA particles to paper waste matrix with the assistance of starch. Paper waste matrix increased the surface area of CSA (Figure 5-D). SEM images of SA revealed that SA is a dual composite material having greater surface area with well enmeshed CFA particles in paper waste matrix with the help of starch waste providing porous spaces within the CSA. In a previous study it was reported that CFA showed an increased surface area, capillary action, and nutrient-holding capacity when incorporated to soil (Fisher et al., 1976). Therefore, CSA can be regarded as a material having a higher surface area, which can be utilized to improve the nutrient holding capacity, when incorporated to the soil as a soil amendment.

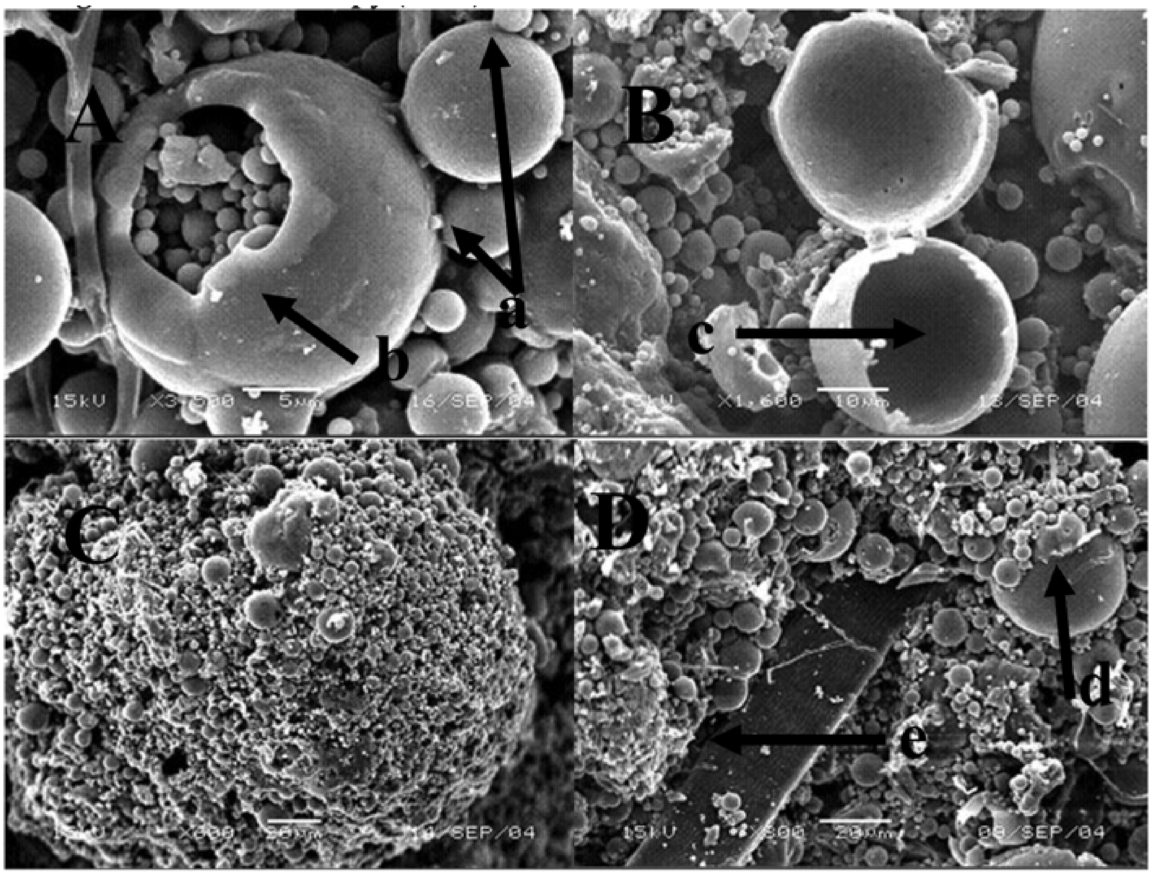

Fig. 5. (A and B) Scanning electron micrographs of CFA particles, showing the micro morphology and varies sizes of coal fly ash particles. (a) stable glasses of various sizes (b and c) cenospheres: (C and D) part of a macro-aggregate (CSA) is produced by CFA and paper waste (d: coal fly ash, e: paper waste).

4.1.1.2.2 Coal fly ash paper waste aggregates as a soil ameliorant to red soil for Komatsuna production

The different aggregate amendment ratios used in the experiment are given in Table 7. Komatsuna (*Brassica rapa* var. Pervidis), also known as Japanese mustard spinach, was grown in a pot experiment to study the influence of CSA amendment in acidic red soil on crop production.

Treatments	Description
T1	Red soil only
T2	CSA :Red soil (1:1) (V/V)
T3	CSA: Red soil (1:5) (V/V)
T4	CSA :Red soil (1:10) (V/V)

CSA: Coal fly ash based synthetic aggregates

Table 7. Different treatments were used under the study.

4.1.1.2.2.1 Effects of CSA amendment on soil physical and chemical properties of the soil

4.1.1.2.2.1.1 Physical properties

CSA addition significantly ($P < 0.05$) decreased the soil bulk density by about 30, 14 and 11% in T2, T3 and T4, respectively. Since, CSA reduced the soil bulk density; it can enhance the porosity and permeability. CSA addition enhanced the hydraulic conductivity of the soil, which may have improved the red soil. Hydraulic conductivity values of treatments T2, T3 and T4 were significantly higher ($P < 0.05$) than that of original red soil (T1) which had a very low hydraulic conductivity of 6.62×10^{-5} cm s^{-1} (Table 8). The addition of CSA increased hydraulic conductivity of T3 and T4 by ten times and T2 by 100 times. CSA addition to red soil also reduced particle density compared with the original soil. Particle densities of the T2, T3 and T4 were reduced by 7.10, 5.28 and 2.26%, respectively in comparison with original soil (T1). Water holding capacity of the T2 (0.59 $kgkg^{-1}$) was increased by 23% compared to the T1 due to incorporation of CSA. This fraction in T3 and T4 were 12.5 and 10%, respectively.

Treatments	Bulk density (gcm^{-3})	Saturated hydraulic conductivity (cms^{-1})	Particle density (gcm^{-3})	Water holding capacity ($kgkg^{-1}$)
T1	1.26^{a}	6.62×10^{-5c}	2.65^{a}	0.48^{c}
T2	0.89^{d}	5.52×10^{-3a}	2.46^{d}	0.59^{a}
T3	1.08^{c}	2.81×10^{-4b}	2.51^{c}	0.54^{b}
T4	1.12^{b}	2.72×10^{-4b}	2.59^{b}	0.53^{b}

(Means followed by the different superscript letter in the same column differed significantly according to Duncan's multiple range test (P=0.05).

Table 8. Physical properties of different treatments used under the study.

The particle size distribution of the different growth media used in the study are shown in Table 9. It showed that red soil had a larger amount of particles < 2 mm. CSA contains 84.02% of particles > 2 mm, while this fraction in red soil (T1) was 44.30%. More over, coal fly ash particles ranging from 0.01 to 100 μm (Page et al. 1979), which can easily become air borne. Production of CSA from CFA significantly increased the particle size diameters (Table 9). CSA production reduced the finer fraction and increased the larger particles, which would reduce handling difficulties. Incorporation of CSA into red soil significantly ($P < 0.05$) increased the fraction > 2 mm by 65.34, 53.34, and 46.36%, in T2, T3 and T4, respectively. Moreover, red soil had a high percentage (29.14 %) of particles < 0.5 mm, while this fraction in CSA, T2, T3 and T4 were 2.23, 10.18, 15.86 and 18.32 %, respectively. CSA as a

Treatments	>5.60mm (Weight %)	5.60-3.35 mm	3.35-2.00 mm	2.00-1.00 mm	1.00-0.50 mm	< 0.50 mm
CSA	26.20^{a}	30.28^{a}	27.54^{a}	8.73^{d}	5.02^{e}	2.23^{e}
T1	6.61^{e}	18.93^{d}	18.76^{c}	14.86^{b}	11.70^{d}	29.14^{a}
T2	19.18^{b}	25.87^{b}	20.29^{b}	11.88^{c}	12.60^{c}	10.18^{d}
T3	14.12^{c}	20.56^{c}	18.66^{c}	14.84^{b}	15.96^{b}	15.86^{c}
T4	9.24^{d}	18.52^{d}	18.60^{c}	17.92^{a}	17.40^{a}	18.32^{b}

CSA: coal fly ash based aggregates, (Means followed by the different superscript letter in the same column differed significantly according to Duncan's multiple range test (P=0.05).

Table 9. Particle size analyses of the CSA, red soil, and CSA-soil amendment mixtures.

soil amendment considerably increased percentage of particles > 2 mm and decreased particles < 0.5 mm. In addition, CSA addition gave a uniform distribution of particles across each particle size class.

4.1.1.2.2.1.2 Chemical properties

The chemical properties of the different treatments are shown in Table 10. The pH values of red soil, coal fly ash and CSA were 5.12, 10.87 and 10.72, respectively. Addition of alkaline CSA to the acidic red soil significantly ($P < 0.05$) decreased the pH, such that T3 and T4 were almost neutral. CSA improved the acidic pH of the red soil to values suitable for plant growth. The EC of the CSA produced was 90.40 mS m^{-1} compared with 4.18 mS m^{-1} in the original red soil. CSA addition to the red soil increased the soil EC; the EC values in T2, T3 and T4 were 60.28, 20.13 and 14.48 mS m^{-1}, respectively. CSA addition to soil significantly increased the Na, K, Mg and Ca concentrations compared to original soil (Table 10). Therefore, CSA addition as a soil amendment not only improves soil physical and chemical properties but also it can improve the soil fertility by supplying nutrients such as Ca, Mg and K. The CEC values of T2, T3 and T4 were significantly ($P < 0.05$) higher than the original red soil, which had CEC of 4.30 $Cmol_{c}kg^{-1}$ (Table 10). The CEC increments in T2, T3 and T4 were 1.86, 1.76 and 1.62 $cmol_{c}$ kg^{-1}, respectively compared to T1. It is evident that CSA addition to the red soil increased the CEC in comparison with the original soil. C content of all treatments with CSA additions increased compared with the original soil (Table 10), due to incorporation of paper waste with a C content of 374.8 g kg^{-1}. The N and P contents of the different treatments were low (0.30-0.50 and 0.03-0.05 g kg^{-1}) and not significantly different between treatments.

Treatments	pH	EC (mSm^{-1})	C (gkg^{-1})	N (gkg^{-1})	P (gkg^{-1})	CEC ($Cmol_{c}kg^{-1}$)	Na (gkg^{-1})	K (gkg^{-1})	Mg (gkg^{-1})	Ca (gkg^{-1})
T1	5.12^{d}	4.18^{d}	1.73^{d}	0.40^{a}	0.03^{a}	4.30^{b}	0.06^{d}	0.05^{d}	0.02^{d}	0.07^{d}
T2	8.59^{a}	60.28^{a}	18.55^{a}	0.50^{a}	0.04^{a}	6.16^{a}	0.43^{a}	0.72^{a}	0.39^{a}	11.36^{a}
T3	7.13^{b}	20.13^{b}	7.80^{b}	0.40^{a}	0.05^{a}	6.06^{a}	0.24^{b}	0.47^{b}	0.26^{b}	3.45^{b}
T4	6.37^{c}	14.48^{c}	4.12^{c}	0.30^{a}	0.03^{a}	5.92^{a}	0.19^{c}	0.29^{c}	0.16^{c}	1.78^{c}

(Means followed by the different superscript letter in the same column differed significantly according to Duncan's multiple range test (P=0.05). (n=3). (EC: electrical conductivity, CEC: cation exchange capacity).

Table 10. Chemical properties of different treatments used under the study

Heavy metal concentrations of the different amendment mixtures are given in Table 11. The Cu, Cr, Mn, Zn and Pb concentrations were higher in the amendment mixtures compared with original red soil. Se and Cd were not detected in any treatments, and As was detected only in T2. Heavy metal concentrations of the amendment mixtures were generally well below the maximum pollutant concentration of individual metals for land application suggested by the US Environmental Protection Agency (USEPA, 1993). The average concentrations of heavy metals reported in uncontaminated soils are (all in mg kg^{-1}): As 6, Cr 70, Cu 30, Zn 90, Pb 35, Mn 1000, and Cd 0.35, respectively (Adriano, 2001). The heavy metal concentrations in all amendment mixtures in this experiment were generally below the heavy metal concentrations reported in uncontaminated soils. Kim et al. (1994) reported that heavy metals did not accumulate in a paddy soil following CFA addition at 120 Mg ha^{-1}. Though the concentrations of heavy metals were below uncontaminated soil values and not alarming, there should be routine inspections to ensure that heavy metal concentrations remain within safe limits.

Treatments	Cu ($mgkg^{-1}$)	Cr ($mgkg^{-1}$)	Zn ($mgkg^{-1}$)	Pb ($mgkg^{-1}$)	Cd ($mgkg^{-1}$)	Se ($mgkg^{-1}$)	As ($mgkg^{-1}$)	Mn ($mgkg^{-1}$)
T1	11.7^b	5.8^b	29.8^b	5.6^b	ND	ND	ND	20.7^a
T2	19.77^a	7.1^a	44.2^a	9.4^a	ND	ND	0.1	21.1^a
T3	18.54^a	6.7^a	40.6^a	8.3^a	ND	ND	ND	20.8^a
T4	13.65^b	5.9^b	35.1^b	6.7^b	ND	ND	ND	20.3^a
USEPA	1500	1200	2800	300	39	36	41	-
Y*	30	70	90	35	0.35	0.4	6	1000

(Means followed by the different superscript letter in the same column differed significantly according to Duncan's multiple range test (P=0.05). (n=3).USEPA =US Environmental Protection Agency standards (1993). Y*: uncontaminated soil (* Adriano, 2001), ND; not detected

Table 11. Heavy metal concentrations of different amendment mixtures.

4.1.1.2.2.2 Influence of CSA as a soil amendment in red soil for Komatsuna cultivation

The growth parameters and the nutrient contents in Komatsuna grown in red soil with different ratios of CSA additions are shown in Table 12. CSA as a soil amendment significantly increased growth and yield parameters of Komatsuna (*Brassica rap*a) compared with the red soil control (T_1). The CSA: soil of 1:5 (T3) and 1:10 (T4) increased plant height and fresh weight yield of Komatsuna about three and 12 times, respectively. The CSA: soil of 1:1 (T2) increased plant height and fresh weight yield by approximately two times and four times, respectively. These yield increases were due to the enhanced physical and chemical properties of the soil from CSA amendment. The CSA addition also enhanced water holding capacity, hydraulic conductivity, CEC and pH compared to original soil, which created a conducive environment to attain higher crop growth and yield parameters. The CSA: soil of 1:5 (T3) and 1:10 (T4) increased soil pH from acidic 5.12, to 7.13 and 6.37, respectively (Table 10). The CECs of T3 and T4 were 40 and 37% higher than the original soil due to CSA incorporation. In a previous study it was reported that, mixed application of CFA and paper factory sludge caused appreciable change in soil physical and chemical properties, increased pH and increased rice (*Oryza sativa*) crop yield (Molliner & Street, 1982). In addition, a mixture of CFA with organic matter is expected to further enhance biological activity in soil (Jala & Goyal, 2006), reduce leaching of major nutrients and beneficial for vegetation (Tripathi et al., 2004).

The nutrient content of plants grown in different substrates is given in Table 12. The N content in shoot tissues from the CSA-amended mixtures was higher than that of the red soil (Table 12). CFA in CSA generally increases plant growth and nutrient uptake (Aitken et al., 1984), and has been shown to supply essential nutrients to crops on nutrient deficient soils and to correct deficiencies of Mg, Ca, K, molybdenum, sulfur and Zn (El-Mogazi et al., 1988). The decreased P content in shoot tissues obtained from red soil is probably due to reduced P availability at a higher soil pH and higher Ca content following CFA amendment (Wong & Wong, 1990). The CSA: soil of 1:1 gave an alkaline pH of 8.59, which did not

Treat ments	Plant height (cm)	Fresh weight (gpot^{-1})	Dry weight (gpot^{-1})	N (%)	P (%)	K (%)	Mg (%)	Ca (%)	Cu (mgkg^{-1})	Mn (mgkg^{-1})	Zn (mgkg^{-1})	Pb (mgkg^{-1})
T1	7.25^{c}	3.84^{c}	0.29^{c}	1.46^{c}	0.56^{a}	2.9^{c}	0.6^{c}	0.5^{b}	3.0^{a}	92.64^{a}	30.4^{d}	0.4^{a}
T2	14.36^{b}	15.19^{b}	2.91^{b}	1.87^{b}	0.26^{d}	3.8^{a}	1.5^{a}	4.5^{a}	3.2^{a}	39.74^{d}	36.7^{a}	0.5^{a}
T3	23.44^{a}	46.95^{a}	8.87^{a}	2.21^{a}	0.32^{c}	3.6^{ab}	1.4^{ab}	4.4^{a}	3.1^{a}	50.12^{c}	35.2^{b}	0.5^{a}
T4	21.03^{a}	43.59^{a}	7.25^{a}	2.18^{a}	0.44^{b}	3.4^{b}	1.2^{b}	4.3^{a}	3.3^{a}	54.16^{b}	34.1^{c}	0.4^{a}

(Means followed by the different superscript letter in the same column differed significantly according to Duncan's multiple range test (P=0.05).(n=3).

Table 12. The growth parameters and the nutrient content in the Komatsuna plants.

improve growth and yield parameters of Komatsuna, which needs a pH of 6.0–7.5 for healthy growth. It is likely that the high pH (8.59), high EC (60.28 mS m^{-1}) and its related nutrient bioavailability accounted for the reduced growth and yield parameters of Komatsuna in the T2 treatment compared with T3 and T4. High pH of substrate can sharply decrease availabilities of P, iron (Fe) and Mn (Peterson, 1982). The lowest shoot concentration of Mn was given by plants grown in T2 treatment (Table 12). Similar results were found in a previous study conducted using CFA as an amendment to container substrate for *Spathiphyllum* production by Chen & Li (2006). The growth and yield parameters of Komatsuna grown in red soil were significantly lower than the CSA-amended treatments. Red soil had acidic pH of 5.12, which can decrease plant availability of Ca and Mg but increase solubility of micronutrients. Shoot concentrations of Ca and Mg were lower but Mn was higher in plants grown red soil (T1) than those grown in CSA addition treatments (Table 12). Additionally, low pH was reported to directly affect the permeability of root cell membranes and leakage of various ions from roots (Yan et al., 1992). Moreover, the K, Mg and Ca concentrations of shoots in the CSA mixtures significantly increased because CSA was enriched with these elements. Both shoot K, Ca and Mg contents were all above the deficiency limits of 0.7-1.5 % (Chapman 1966), 0.14 % (Loneragen & Snowball, 1969) and 0.06 % (Chapman, 1966), respectively. The highest Mn concentration was reported in the shoots from the red soil. Nevertheless, the Mn concentrations were much higher than the diagnostic deficiency level of 20 mg kg^{-1} (Chapman 1966). Zn concentrations in the CSA mixtures were higher than in red soil but well below the toxicity limit of 150 mg kg^{-1} (Elseewi et al., 1980). Se and Cd were not detected in any tissues. Therefore heavy metal content in plant tissue was below the toxicity limits. CSA as a soil amendment can be suggested as a good practice for Komatsuna production in this low-productive acidic red soil, due to enhanced soil physical and chemical properties. The CSA: soil of 1:5 and 1:10 gave the maximum growth and yield parameters of Komatsuna.

4.1.1.3 Other types of coal fly ash based aggregates as a soil ameliorant

CFA based aggregates can be developed by including oil palm waste and coco fiber and also can be used as a soil amendment to improve low productive red soil to enhance crop production. Since CFA aggregates did not contain high N content, aggeragets can be developed by adding N fertilizer source to the aggeragets and those aggregates can be used as a fertilizer and a soil ameliorant for crop production. One of our experiments (Jayasinghe et al., 2009b) showed that these kind of N added aggeragets improved physical and chemical properties of low productive acidic soil and improved the growth and yield parameters of Komatsuna in red soil compared to original soil. In addition, homogenous synthetic aggeragets also can be produced with CFA, paper waste and organic or inorganic binder and can be used as a soil ameliorant for low productive acidic soils. Moreover, CFA, paper waste and starch binder pellet aggregates as a soil ameliorant for acidic red soil and problematic grey soil improved the respective chemical and physical properties of the soil and crop growth and yield of *Brassica campestris.* In conclusion, we can emphasis that different types of aggregates produced from different waste materials can be effectively utilized as a soil ameliorant to enhance the crop production.

4.1.1.4 Synthetic red soil aggregates

4.1.1.4.1 Synthetic aggregates (SA) production

SA was produced by combining red soil and paper waste in an Eirich mixer (R-02M/C27121) with starch as the binder. First of all 1000g of red soil and 125g of paper wastes were mixed well in the pan of the Eirich mixer for 2 minutes. Subsequently, 225 mL of prepared starch paste was added to the above mixture and mixed well for another 2 minutes to produce SA (30 g of starch wastes was added to 200 mL hot water in 50°C and heated to 80°C in order to obtain sticky paste as the aggregate binder).

4.1.1.4.2. Effect of synthetic soil aggregates as a soil amendment to enhance properties of problematic grey ("Jahgaru") soils in Okinawa, Japan.

Grey soils ("Jahgaru") in Okinawa Japan spread over 20% of the total land area showed low infiltration, strong stickiness and plasticity and alkalinity (National Institute of Agro Environmental Sciences, 1996). It also exhibits a poorly developed soil structure and poor air and water permeability characteristics (Okinawa Prefecture Agricultural Experiment Station, 1999). Crop production on this grey soil is challenged due to possible disasters (i.e. drainage problems, poor permeability), which can be resulted due to poor properties of the soil. Moreover, soil structure has been found to be of paramount importance in soil productivity and is becoming limiting factor of the crop yield (Allison, 1973).Therefore, SA was utilized as a soil ameliorant to improve the problematic properties of grey soil to enhance ornamental plant production. Therefore, French marigold (***Tagetes patula***) was selected as the ornamental plant in this study. The objectives of the present study were to study the characteristics of the grey soil amended with SA and to study the influence of the SA addition as a soil ameliorant on the growth parameters of French marigold (***Tagetes patula***). Experiments were conducted to study the impact of SA as a soil amendment to improve poor properties of grey soil. Widely using French marigold (***Tagetes patula***), which is a popular ornamental plant in Japan was grown in the experiment. All 8 treatments are shown in Table 13. Grey soil was amended with SA at the rates of 10%, 20%, 30%, 40%, and 50% respectively.

4.1.1.4.2.1.Effect of aggregate addition on particle size distribution and Mean weight diameter (MWD) of soil

Particle size distribution and mean weight diameter (MWD) of different treatments used in the experiment are given in Table 14. Particle size distribution of a substrate is important because it determines pore space, bulk density, air and water holding capacities (Raviv et al., 1986). The mean particle size distribution of treatments showed that the fraction < 0.25 mm was the most abundant fraction in T1 (29.28 %) and T8 (22.47 %). More over, the particle percentages > 3.35 mm are the lowest in T1 (grey soil) and T2 (red soil) treatments.

Treatments	Description
T1	Grey soil only
T2	10% SA addition
T3	20% SA addition
T4	30% SA addition
T5	40% SA addition
T6	50% SA addition
T7	SA only
T8	Red soil only

SA: synthetic aggregates

Table 13. Different treatments utilized under the study

Treatments	>5.60 mm	5.60-3.35 mm	3.35-2.00 mm	2.00-1.00 mm	1.00-0.50 mm	0.50-0.25 mm	0.25-0.00 mm	MWD (mm)
T1	0.00	5.08h	15.02f	14.98c	17.47b	18.17b	29.28a	1.090h
T2	0.34f	11.72f	16.30e	17.58b	15.17c	16.57c	22.32c	1.452f
T3	1.25e	13.75e	16.26e	17.54b	16.90b	14.97d	19.33d	1.618e
T4	2.19d	17.49d	19.81d	15.22c	14.59c	13.66e	17.04e	1.894d
T5	4.15c	19.90c	23.42c	17.65b	15.02c	10.50f	9.36f	2.270c
T6	5.36b	22.80b	24.29b	16.97b	14.11d	8.83g	7.64g	2.491b
T7	9.77a	26.82a	30.98a	18.15a	5.91e	4.28h	4.09h	3.129a
T8	0.00	8.28g	11.23g	18.85a	20.15a	19.02a	22.47b	1.204g

(Means followed by the different letter in the same column differed significantly according to Duncan's multiple range test (P=0.05).Values are mean (n=3)).

Table 14. Particle size distribution and Mean weight Diameter (MWD) of the different treatments used in the experiment

The highest particle percentage >3.35 mm was given by T7 (SA only). Production of SA from red soil with paper waste significantly ($P<0.05$) increased the particle size diameters compared to red soil only. In a previous study conducted by Jayasinghe etal., (2008) to produce SA from red soil and coal fly ash, gave increased particle size diameters compared to original red soil. Dominance of finer particles in a substrate clogs pores, increase non-plant available water holding capacity and decrease air filled porosity (Spiers & Fietje,2000), while dominance of larger particles in a substrate increase aeration and decrease water retention (Benito et al., 2006). Accordingly, red soil and grey soil had higher percentage of finer particles, which led to decrease air filled porosity of the medium. Addition of higher percentage of SA as a soil amendment significantly ($P<0.05$) decreased the finer particles < 0.25 mm and significantly ($P<0.05$) increased the larger particles. Moreover, addition of higher SA percentages significantly increased the MWD compared to original soil (Table 14). MWD of grey soil (1.090mm) had increased to 1.452, 1.618, 1.894, 2.270, 2.491 mm at SA amendment of 10%, 20%, 30%, 40%, and 50% of SA, respectively. It is evident that the amelioration of the grey soil with SA had significantly ($P<0.05$) increased the MWD of original grey soils.

4.1.1.4.2.2 Effect of aggregate addition on Water stable aggregates (WSA), organic matter content and C content

The percentage of WSA > 0.25 mm, organic matter content and the C content of different treatments are given in the Figure 6. It is evident that WSA percentage is significantly (P<0.05) increased with the addition of SA to grey soil. WSA varied from 40.72 % to 86.63 % and the lowest WSA given by grey soil with no SA amendment (T1) and the highest was given by SA only (T7). Aggregate stability, a measure of the soil's resistance to externally imposed disruptive forces, was increased with increasing SA amendment percentages. It has been shown that the addition of organic matter improved soil properties such as aggregation, water holding capacity, hydraulic conductivity, bulk density, the degree of compaction, fertility, and resistance to water and wind erosion (Franzluebbers, 2002). Generally, crop residues, turfs, paper wastes, manures, forest under story leaf falls, and compost from organic wastes have been used to increase soil organic matter content and accordingly to improve soil physical properties in crop lands (Stratton et. al., 1995).

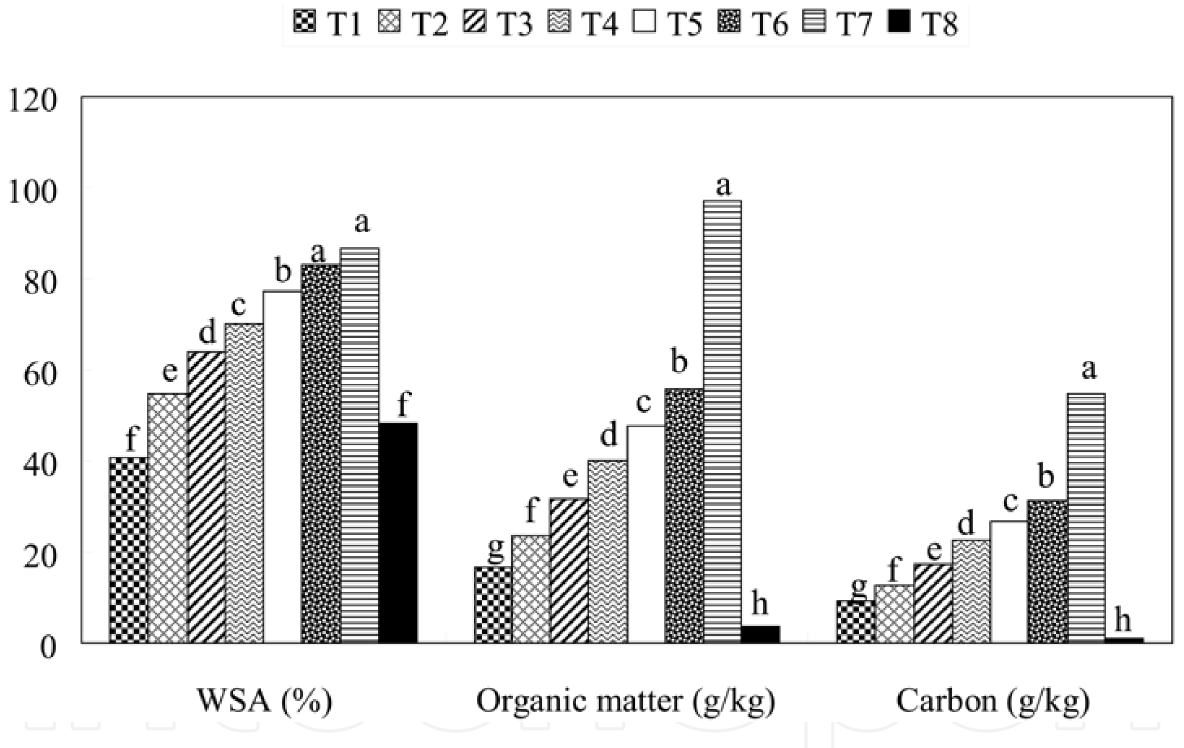

Fig. 6. Water stable aggregates (WSA), organic matter content and the carbon content of the different treatments studied under the study.(Different letters on the top of the bars differed significantly according to Duncan's multiple range test, n=3).

Aggregation is maintained by the presence of organic matter (Lynch & Bragg, 1985) and therefore changes in organic matter content can lead to changes in aggregation (Dexter, 1988). SA addition increased the soil organic matter (Figure 6) due to incorporation of paper waste and starch waste to develop SA. Paper waste in the SA is also a rich source of C (Rasp & Koch, 1992) and improves soil organic matter contents, water holding capacity, soil structure and bulk density (Simard et al., 1998). Highest organic matter content is reported in SA only (97.15 gkg^{-1}). The lowest percentage of organic matter was given by red soil (3.78 gkg^{-1}) and the second lowest organic matter content was given by the grey soil (16.74 gkg^{-1}). Addition of SA to grey soil significantly ($P<0.05$) increased the organic matter content. Moreover, high correlation between aggregate stability and soil organic matter has been reported by Chaney & Swift (1984). More over SA addition significantly enhanced the soil C content (Figure 6). The C amounts of red and grey soils were 1.16 and 9.42 gkg^{-1}, respectively, which were the two lowest values reported among all other treatments. Original red soil and the grey soil showed very low amount of C. T7 gave the highest amount of C (54.72 gkg^{-1}) content due to the paper waste and starch waste. The C content of the paper waste and starch waste were 374.8 gkg^{-1} and 312.5 gkg^{-1}, respectively. Therefore, SA can be considered as a significant source of C. Several previous studies revealed that a trend of positive relationship between C content of the soil and the aggregate stability and MWD (Adesodun et al., 2005). Soil aggregation, which is important to crop establishment, water infiltration and resistance to erosion and compaction, is also influenced by soil C content (Wright & hons, 2005).

4.1.1.4.2.3. Effect of aggregate addition on physical properties of Soil-SA amendment mixtures

Physical properties of different amendment mixtures are given by Table 15. The bulk density of the treatments has been decreased with the increasing percentages of SA amelioration. SA addition significantly ($P<0.05$) decreased the soil bulk density by about 5.17 %, 9.48 %, 13.79%, 17.24% and 21.55% in SA addition treatments of T2, T3, T4, T5 and T6, respectively. Bulk density depends on soil structure and is an indicator of soil compaction, aeration and development of roots especially in soils with high clay contents. The bulk density of the grey soil was 1.16 gcm^{-3}.The lowest bulk density (0.85gcm^{-3}) was given by SA only treatment. The organic matter content in red soil, SA and grey soil were 3.78, 16.74 and 97.15 gkg^{-1}, respectively. Bulk density decreased with the increased amount of soil organic matter (Nyakatawa et al., 2001). Moreover, red soil showed the highest bulk density (1.21 gcm^{-3}) and it was reduced to 0.85 gcm^{-3} by 29.95% after producing SA with paper waste. Porosity values were increased by 3.41 %, 5.82 %, 8.63 %, 11.04 % and 13.68 % in SA addition treatments of T2, T3, T4, T5 and T6, respectively. Highest porosity (63.68 %) was given by the T7 treatment. The increased porosity is especially important to crop development since it may have a direct effect on soil aeration and can enhance root growth (Sugiyanto et al., 1986).SA addition significantly ($P<0.05$) increased the water holding capacity of the soil compared to grey soil only (T1). Water holding capacity was increased by 8.51 %, 10.64%, 19.15 %, 23.40 % and 8.51 %, in T2, T3, T4, T5 and T6, respectively compared to T1. Red soil (T8) gave the lowest water holding capacity (0.43 $kgkg^{-1}$) and it was increased to 0.50 kg kg^{-1} in SA only (T7) by 16.28 % compared to red soil after converting into SA with paper waste. It can be suggested that, water holding capacity increases are due to the improved soil microspores, which resulted after SA addition, subsequently responsible for the holding of water within the soil. Hydraulic conductivity values of SA addition treatments showed significant differences ($P<0.05$) compared to T1 control except T2 (Table 15). Hydraulic conductivity values were increased by 10 times in SA addition treatments of T3, T4, T5 and T6 compared to original grey soil (T1).

Treatments	BD (gcm^{-3})	PD (gcm^{-3})	Porosity (%)	WHC ($kgkg^{-1}$)	Permeability (cms^{-1})
T1	1.16ab	2.54a	54.33g	0.47c	6.671×10^{-5}a
T2	1.10b	2.51ab	56.18f	0.51b	7.471×10^{-5}a
T3	1.05c	2.47b	57.49e	0.52b	1.031×10^{-4}b
T4	1.00cd	2.44bc	59.02d	0.56a	1.334×10^{-4}b
T5	0.96d	2.42c	60.33c	0.58a	1.031×10^{-4}b
T6	0.91e	2.38cd	61.76b	0.51b	1.867×10^{-4}b
T7	0.85f	2.34d	63.68a	0.50b	1.601×10^{-3}c
T8	1.21a	2.58a	53.10h	0.43d	4.916×10^{-5}a

(Means followed by the different letter in the same column differed significantly according to Duncan's multiple range test (P=0.05).Values are mean (n=3)).

Table 15. Physical properties of the treatments used in the study

4.1.1.4.2.4 Aggregate addition on chemical properties of Soil-SA amendment mixtures

Chemical properties of the different treatments are shown in Table 16. The pH of grey (T1) and red soil (T2) were 8.36 and 4.46, respectively. It is evident that grey soil is an alkaline soil and the red soil is an acidic soil. Produced SA from red soil also showed acidic pH of 4.42. It is evident that mixing of the acidic SA to grey soil decreased the alkaline pH values. For an example 30% SA addition to grey soil gave a pH value of 7.72. EC of grey soil showed significantly ($P<0.05$) higher values compared to red soil and other treatments. This may be due to high concentrations of cations in grey soil (Table 16). The highest concentrations of Ca, Mg, K and Na concentrations were given by grey soil while the lowest was given by red soil. The N content of the grey soil and the SA amendment did not show any significant differences.

Treatments	pH	EC	Ca (gkg^{-1})	Mg (gkg^{-1})	K (gkg^{-1})	Na (gkg^{-1})	N (gkg^{-1})
T1	8.36a	69.3a	11.45a	1.28a	0.04a	0.10a	0.74a
T2	8.28a	67.8b	10.34b	1.19b	0.04a	0.10a	0.69a
T3	8.10b	65.1b	9.25c	1.11c	0.04a	0.09a	0.65a
T4	7.72c	62.7c	8.27d	1.03d	0.03a	0.08b	0.62a
T5	7.51c	60.2c	7.23e	0.96e	0.03a	0.08b	0.58a
T6	7.42d	58.8c	6.19f	0.88f	0.03a	0.07b	0.55a
T7	4.42e	8.82d	0.97g	0.51g	0.01b	0.04c	0.40b
T8	4.46e	5.36e	0.94g	0.54g	0.01b	0.04c	0.42b

(Means followed by the different letter in the same column differed significantly according to Duncan's multiple range test (P=0.05). (n=3)).

Table 16. Chemical properties of the treatments studied under the experiment

4.1.1.4.2.5 Influence of SA addition on plant growth parameters

It is evident that the plant growth parameters of French marigold were significantly ($P<0.05$) increased with the addition of SA as a soil ameliorant to grey soil (Table17). The lowest growth parameters are reported in French marigold grown in the grey and red soil, while the highest growth and yield parameters were given by 30 % (T4) SA addition. The plant height, number of flowers per plant, shoot fresh weight, shoot dry weight, root length, root fresh weight and root dry weight in T4 were increased by 1.5, 2.9, 3.5, 4.7, 3.4, 4.3 and 9 times, respectively compared to T1. These increased growth parameters were because of the enhanced particle size distribution, aggregate stability, soil organic matter, soil C, bulk density, soil porosity, water holding capacity, hydraulic conductivity and pH due to the SA amelioration compared to original grey soil. An increase in pore size and the continuity of pore space eases root penetration and flow of water and gases, directly related to plant growth (Tejada & Gonzalez, 2003).The lowest growth parameters of French marigold in grey soil and red soil may be due to its poor soil structure. Improvement in soil aggregation by aggregate addition positively affects germination of seeds and the growth and development of plant roots and shoots (Van Noordwijk et al., 1993). The highest root length (190.33 mm) was reported in the SA only treatment (T7) due to the increased porosity. The root length of French marigold has been increasing with increasing percentage of SA addition. This may be due to the improved soil porosity of the soil after SA addition. More over, growth reduction in red soil (T8) and SA only (T7) may be due to acidic pH. The acidic pH of the red soil and the SA were 4.46 and 4.42, respectively. The pH values of 30% and 40% SA additions to grey soils were 7.72 and 7.52 compared to grey soil pH of 8.36.

Treatments	Plant height (cm)	Number of flowers per plant	Shoot fresh weight (gplant^{-1})	Shoot dry weight (gplant^{-1})	Root length (mm)	Root fresh weight (gplant^{-1})	Root dry weight (gplant^{-1})
T1	14.23f	6.33f	5.89e	0.72e	53.30f	0.45g	0.03e
T2	16.27d	8.66d	7.81d	0.96d	90.00d	0.63f	0.05e
T3	18.21b	15.66b	14.22b	2.30b	120.33c	1.35d	0.11d
T4	21.42a	18.66a	20.74a	3.35a	180.00b	1.92a	0.27a
T5	20.66a	17.66a	20.24a	3.26a	178.66b	1.85a	0.25a
T6	17.13c	14.00b	11.64c	2.38b	182.00b	1.41c	0.16c
T7	16.33d	11.00c	10.63c	1.32c	190.33a	1.23e	0.11d
T8	15.66e	7.33e	6.29d	0.85f	84.66e	0.48g	0.04e

(Means followed by the different letter in the same column differed significantly according to Duncan's multiple range test (P=0.05). (n=3)).

Table 17. Effects of SA amendment on the growth of French marigold

The mineral element concentrations in French marigold shoots are given in Table 18. It is evident that shoot concentrations of N in SA addition treatments have been increasing compared with the T1 control but again decreasing in T7 and T8 treatments. Moreover, plants grown in grey soil and SA amendments gave higher K, Mg and Ca concentrations in plant shoots compared to plants grown in red soil and SA. It is evident that shoot concentrations of K, Ca and Mg were low but Mn concentration was significantly ($P<0.05$) higher in plants grown in red soil (T8) and the SA only (T7) compared with other treatments. This may be due to the acidic pH values T7 and T8 treatments, which can decrease bio availability of Ca and Mg but increase solubility of micronutrients. It is likely that the low pH and its related nutrient bioavailability accounted for the reduced growth of French marigold grown in red soil and SA only treatments. In addition, the lowest iron (Fe) concentration was reported in the plants grown in grey soil (T1). This may be due to the high pH of the grey soil compared to other treatments. It has been found that high pH of the substrate sharply decrease the availability of Fe in the substrate (Peterson, 1982). Addition of 30% to 40% of SA to problematic grey soil can be recommended as a better practice for French marigold production, which gave the best growth parameters compared to original grey soil.

Treatments	N (gkg^{-1})	K (gkg^{-1})	Mg (gkg^{-1})	Ca (gkg^{-1})	Fe ($mgkg^{-1}$)	Cu ($mgkg^{-1}$)	Mn ($mgkg^{-1}$)	Zn ($mgkg^{-1}$)
T1	29.21d	33.71a	12.18a	42.49a	44.78c	3.49b	62.01c	33.10b
T2	30.86c	33.65a	12.22a	42.44a	45.91c	3.54b	61.98c	33.21b
T3	31.24b	33.64a	12.24a	42.27a	46.77c	3.56b	63.41b	33.15b
T4	33.12a	32.58a	12.37a	42.30a	46.82b	4.07a	64.16b	35.11a
T5	33.25a	32.49a	12.28a	42.36a	47.28b	4.19a	65.55b	35.23a
T6	33.18a	32.31a	12.21a	42.24a	47.12b	4.10a	68.75b	35.47a
T7	24.16e	22.32b	8.38b	6.72b	79.25a	3.24c	109.56a	32.12c
T8	24.28e	22.45b	8.45b	6.77b	78.54a	3.22c	110.72a	32.09c

(Means followed by the different letter in the same column differed significantly according to Duncan’s multiple range test (P=0.05).Values are mean (n=3)).

Table 18. Element concentrations in plant shoots

4.2 Synthetic aggregates as a potting media

4.2.1 Coal fly-ash-based synthetic aggregates as alternative container substrates for ornamentals.

Experiment was conducted using CFA paper waste aggregates and oil palm waste as a potting media for ornamental French marigold (***Tagetes patula***) production. Utilized container substrates under the experiment are given in table 19. Zeolite was the standard substrate.

Substrate	Formulation
T1	CSA (100%)
T2	CSA 1 :Palm waste 5 (V/V)
T3	CSA1 :Palm waste 10 (V/V)
T4	Palm waste (100%)
T5	Zeolite

CSA: coal fly ash based synthetic aggregates

Table 19. Composition of container substrates used in the experiment

4.2.1.1 Physical properties of the container substrates

The particle size distribution of different substrates utilized in this study is given by the Table 20. The mean distribution showed that the fraction greater than 3.5 mm was the most abundant fraction in CSA and zeolite substrates. 55.80 % of the CSA particles were greater than 3.5 mm while this fraction in zeolite, oil palm waste, T2 and T3 were 80.52%, 8.44 %, 34.68% and 21.76%, respectively. The best substrate is that with medium to coarse texture, equivalent to a particle size distribution between 0.25 and 2.00 mm, as the optimal range for a plant growth medium that allow retention of enough readily available water together with adequate air content (Abad et al., 1993; Benito et al., 2006). T1 and T5 gave less than 15% of particles between 0.25 and 2.00 mm whereas this fraction in T2, T3 and T4 were 45%, 62% and 80%, respectively. CSA (T1) and Zeolite (T5) did not give sufficient particle percentages in the optimal range (0.25 and 2.00 mm) for plant growth whereas oil palm waste gave the highest fraction in this range. T2 and T3 had higher percentages of particles between 2.00 and 0.25 mm compared with T1 and T5. Moreover, T2 and T3 had a uniform distribution of particles in every particle size diameter class because of mixing comparatively larger particles of CSA and smaller particles of palm waste.

Substrate	>5.6mm (Weight %)	5.6-3.35 mm	3.35-2.00 mm	2.00-1.00 mm	1.00-0.50 mm	0.50-0.25 mm	<0.25 mm
T1	25.61^a	30.19^b	28.32^a	8.54^d	5.20^d	1.08^e	1.06^d
T2	14.12^b	20.56^c	18.76^b	13.84^c	16.96^c	14.05^c	1.71^c
T3	8.24^c	13.52^d	14.60^c	23.92^b	19.40^b	18.44^b	1.88^b
T4	0	8.44^e	9.24^e	29.24^a	22.48^a	28.37^a	2.23^a
T5	0	80.52^a	13.09^d	2.46^e	1.14^e	1.62^d	1.17^d

(Means followed by the different superscript letter in the same column differed significantly according to Duncan's multiple range test (P=0.05).Values are mean (n=3))

Table 20. Particle size analysis of the container substrates

Table 21 shows the main physical properties of the different container substrates used in the study. Bulk density values of different substrates were significantly different ($P<0.05$). Abad et al., (2001) defined the bulk density requirement of an ideal substrate should be less than 0.40 gcm^{-3}. CSA and the zeolite media exceeded these limits. However T2, T3, and T4 substrates were within the ideal range. Mixing CSA with oil palm waste at the ratio of 1:5 and 1:10 decreased the bulk density by 51% and 55% compared to CSA (T1) and 63% and 65% compared to zeolite (T5), respectively. Particle density values of T2, T3, and T4 are in the range of established particle density limit (1.4-2.0 gcm^{-3}) described by Abad et al., (2001). Air space values for an ideal substrate should be within 20-30% according to De Boot & Verdonck, (1972). Zeolite showed highest air space while oil palm waste showed lowest

Substrate	BD (gcm^{-3})	PD (gcm^{-3})	Air space (%)	Total pore space (%)	Total water holding capacity (mLL^{-1})
T1	0.56^b	2.48^b	25.82^b	77.42^c	516^d
T2	0.27^c	1.81^c	22.08^c	85.08^b	630^c
T3	0.25^d	1.76^d	20.59^d	85.79^b	652^b
T4	0.22^e	1.70^e	19.36^e	87.06^a	677^a
T5	0.72^a	2.61^a	31.71^a	72.41^d	407^e
IS^X	<0.40	1.4-2.0	20-30	>85	600-1000

IS^X: Ideal Substrate according to De Boodt and Verdonck, (1972) and Abad et al., (2001); BD: bulk density, PD: particle density:(Means followed by the different superscript letter in the same column differed significantly according to Duncan's multiple range test (P=0.05).Values are mean (n=3)).

Table 21. Physical properties of the container substrates

value compared to the established ideal range. High air space means that water should be applied frequently, and in small amounts to avoid leaching (Benito et al., 2006). The ideal total pore space should exceed 85% (De Boodt & Verdonck, 1972). T2, T3, and T4 growth media exceeded this ideal limit while other media were below than the ideal value. Ideal total water holding capacity of an ideal substrate should be in the range of 600-1000 mLL^{-1} according to De Boodt and Verdonck, (1972). T2, T3, and T4 substrates were in the ideal substrate range whereas T1 and T5 were not within the ideal range. Physical properties such as bulk density, particle density, air space, total pore space and total water holding capacity of the T2 and T3 substrates were in the ideal substrate range compared to T1 and T5. Moreover, the physical properties of the T4 substrate were in the ideal range except the air space.

4.2.1.2 Chemical properties of the container substrates

The CSA (T1) showed an alkaline pH value of 9.82 (Table 22). Oil palm waste and Zeolite showed pH values of 4.34 and 8.77, respectively. Mixing ratio of CSA with oil palm waste at the ratio of 1:5 and 1:10 gave pH values of 7.21 and 6.18. Established pH limits for an ideal substrate are 5.3-6.5 (Abad et al., 2001). T3 was the only substrate lies within the ideal substrate range with respect to pH values. The EC values showed significant differences ($P<0.05$) among all substrates. Established EC limits for an ideal substrate are 50 mSm^{-1} (Abad et al., 2001). The T2, T3, and T4 substrates were in the range of established ideal substrate range while EC values of T1 and T5 were not in the ideal range. C contents of all container substrates were significantly differed ($P<0.05$) with each other. Nitrogen content of all container substrates was very low and varied between 0.4 and 5.2 gkg^{-1}. The carbon and nitrogen (C/N) ratio, an indicator of organic matter origin, was different for all the substrates. The CSA and the zeolite showed the highest C/N ratios because of the low nitrogen contents. High C/N ratios could be cause immobilization of soluble nitrogen when those substrates were used as a growing medium for containerized plant production. Established range of C/N ratio for ideal substrate is 20-40 (De Boodt & Verdonck, 1972). T2, T3 and T4 substrates were closest to the ideal value. CSA and the zeolite media showed significantly ($P<0.05$) higher concentrations of cations (Table 22) compared to other substrates. Oil palm waste showed the lowest concentration of the cation compared to all substrates studied under this study. In addition, substrates having a mixture of CSA and oil palm waste (T2 and T3) reduced the cation concentration compared to CSA (T1) and zeolite (T5). CSA showed the highest concentration of heavy metals compared with other substrates. Cd and Se were not detected in all substrate samples. The standard maximum pollutant concentrations of individual metals for land application suggested by the US Environmental protection Agency (USEPA, 1993) are 41 mgkg^{-1}As, 1200 mgkg^{-1}Cr, 1500 mgkg^{-1}Cu, 2800 mgkg^{-1}Zn, 300 mgkg^{-1}Pb and 39 mgkg^{-1} Cd, respectively. It is evident that, heavy metal concentrations in all substrates used in this experiment were generally below the maximum pollutant concentration of individual metals for land application suggested by the US Environmental protection Agency (USEPA, 1993).

4.2.1.3 Effect of different substrates on the growth and yield parameters of French marigold.

The shoot fresh weight, shoot dry weight, root fresh weight, root dry weight, plant height and number of flowers per Marigold plant grown in different container substrates after 3 months of growing period are shown in Table 23. There were significant differences ($P<0.05$) in growth and yield parameters of Marigold grown in different growth substrates. The lowest shoot fresh weight, shoot dry weight, root fresh weight, root dry weight and plant

Substrate	pH	EC (mSm^{-1})	C (gkg^{-1})	N (gkg^{-1})	C/N ratio	Na (gkg^{-1})	K (gkg^{-1})	Mg (gkg^{-1})	Ca (gkg^{-1})	As (mgkg^{-1})	Cr (mgkg^{-1})
T1	9.82^{a}	96.1^{a}	120.82^{d}	0.71^{d}	172.60^{a}	0.87^{a}	1.51^{a}	0.72^{a}	3.34^{b}	0.21^{a}	7.62^{a}
T2	7.21^{c}	48.8^{c}	179.11^{c}	3.58^{c}	49.75^{c}	0.34^{c}	0.72^{c}	0.37^{c}	1.41^{c}	0.12^{a}	5.13^{b}
T3	6.18^{d}	42.4^{d}	190.24^{b}	4.22^{b}	45.29^{d}	0.25^{d}	0.55^{d}	0.29^{d}	1.03^{d}	0.11^{a}	3.59^{c}
T4	4.34^{e}	32.3^{e}	210.80^{a}	5.17^{a}	40.54^{e}	0.10^{e}	0.37^{e}	0.21^{e}	0.46^{e}	0.12^{a}	0.28^{e}
T5	8.77^{b}	59.8^{b}	28.27^{e}	0.38^{e}	70.68^{b}	0.56^{b}	0.91^{b}	0.45^{b}	3.78^{a}	0.22^{a}	1.41^{d}

EC: electrical conductivity (Means followed by the different superscript letter in the same column
according to Duncan's multiple range test (P=0.05). Values are mean (n=3)).

Table 22. Chemical properties of the container substrates

Substrate	Shoot Fresh weight (gplant^{-1})	Shoot dry weight (gplant^{-1})	Root fresh weight (gplant^{-1})	Root dry weight (gplant^{-1})
T1	11.68^{e}	1.59^{e}	4.55^{e}	0.65^{e}
T2	141.59^{b}	19.54^{b}	49.25^{b}	7.39^{b}
T3	165.17^{a}	23.87^{a}	56.34^{a}	8.90^{a}
T4	101.37^{d}	11.00^{d}	33.88^{d}	3.31^{d}
T5	109.37^{c}	12.37^{c}	36.36^{c}	3.56^{c}

(Means followed by the different superscript letter in the same column differed significantly acco
range test (P=0.05).Values are mean (n=3)).

Table 23. Effects of container substrates on the growth of French marigold

height were given by plant grown in T1 substrate. French marigold requires a substrate pH of 5.5-6.8 for healthy growth. The reduced growth and yield parameters of the French Marigold grown in T1 substrate are due to the high substrate pH (9.82) and EC (96.1 mSm^{-1}) and its related nutrient bioavailability. Substrate T3 was most sufficient to promote the growth of French marigold because of its optimal chemical and physical properties (e.g.pH, EC, bulk density, total pore space, water holding capacity, etc.). The growth and yield parameters of French marigold grown in the zeolite (T5) were significantly ($P<0.05$) lower than that of T2 and T3 substrates but significantly higher than that of oil palm waste (T4) and CSA (T1). Shoot concentrations of Ca and Mg were low but Mn concentration was significantly higher in plants grown in oil palm waste (T4) compared with other treatments. This may be due to the acidic pH value (4.34) of oil palm waste, which can decrease bio availability of Ca and Mg but increase solubility of micronutrients. pH and its related nutrient bioavailability accounted for the reduced growth of French marigold grown in the oil palm waste. Mixing CSA with the oil palm waste at the ratio of 1:10 (T3), which is an ideal substrate, can be suggested as an alternative container substrate for French marigold production compared with zeolite. In addition, production of CSA using waste CFA with paper waste and mixing them with oil palm waste as a container substrate can be suggested as an alternative waste management practice.

4.2.2 Utilization of synthetic soil aggregates as a containerized growth medium component to substitute peat in the ornamental plant production

An investigation was under taken to study the characteristics and utilization of synthetic soil aggregates (SA) formed by low productive acidic soil with paper and starch waste for production of French marigold (*Tagetes patula*) as a partial peat substitution in growing substrate. Five different growth substrates utilized in this study were peat only, peat 75%: SA 25%, peat 50%: SA 50%, peat 25%: SA 75% and SA only. Peat 75%: SA 25% enhanced substrate physical and chemical properties into the established ideal substrate range (Jayasinghe et al., 2009 e). Plant height, numbers of flowers, fresh shoot weight, dry shoot weight, root length, fresh root weight and dry root weight of French marigold grown in the substrate of peat 75%: SA 25% increased by 13.28, 23.07, 28.51, 27.41, 6.66, 68.33 and 7.40%, respectively compared with peat substrate. Peat 50%:SA50% gave similar growth parameters to peat only substrate. Nitrogen (N) content of plants grown in peat 75%:SA25% was higher than peat substrate. The normal ranges of Cu, Fe, Mn and Zn in plants were 3-20, 30-300, 15-150 and 15-150 mg kg^{-1}, respectively (Adriano 2001). The critical toxicity concentrations range for Cu, Fe, Mn and Zn were 25-40, 400-1000, 400-2000 and 500-1500 mg kg^{-1}, respectively (Romheld & Marschner 1991). The Cu, Fe, Mn and Zn concentrations in plant shoots were in the normal range and well below the phytotoxic limits. In addition, As, Se and Cd concentrations were not detected in any plant tissues obtained from all substrates. Furthermore, Pb concentration was not significantly differed among all plant tissues. Therefore, growth substrates with 25% and 50% of SA can be recommended as the most effective substrates to substitute expensive and less available peat in environmental point of view. Therefore, synthetic aggregates can be recommended as a viable alternative to substitute expensive peat in horticulture.

4.2.3 Other aggregates as a potting media component

Aggregate formed from sewage sludge with inorganic binder also can be used as potting media component for plant production to substitute congenital expensive peat media. These aggeragets can be used with different amounts of peat, coco fiber or oil palm waste to develop potting media. An experiment conducted with sewage sludge aggregates with different percentage of the peat showed that the highest plant height, number of flowers per plant, fresh shoot weight, shoot dry weight, root length, root fresh weight and root dry weight obtained from the treatment having sewage sludge aggregates and peat at 40% and 60% increased by 13.69%, 23.53%, 41.46%, 58.95%, 2.43%, 39.09% and 21.68%, respectively compared to peat control. Moreover, sewage sludge aggregates addition increased the N, P, Ca and Mg contents in the plant tissues. The aggregates application did not significantly increase the Cu, Cd, Cr and Pb in the plant tissues but accumulation of Zn was increased significantly. Aggregate addition did not pose any phytotoxicity in French marigold plants. Therefore, sewage sludge aggregates can be suggested as a viable potting media component to substitute widely using expensive peat in horticulture. Synthetic red soil aggeragets with different types of compost (sewage sludge sugarcane trash compost, cattle manure compost, chicken manure compost etc.) can also be used as a potting media for plant production. Increased biomass production of lettuce was reported from the sewage sludge sugarcane trash compost and synthetic red soil aggregate assayed media compared to peat media. Moreover, due to physical and chemical characteristics of the media developed by sewage sludge sugarcane trash compost and synthetic red soil aggregate based media can be considered as valuable partial peat substitutes for lettuce, especially at the rates of 40% of sewage sludge sugarcane trash compost, 20% of red soil aggregates and 40% of peat, which gave the maximum growth parameters and the highest biomass yield of the lettuce when compared to peat (Jayasinghe et al., 2009f). In addition, red soil synthetic aggregates and zeolite can be used as an alternative medium for French marigold production which gave higher growth and yield (Jayasinghe et al., 2009g). Therefore, potting media developed by using sewage sludge, sugarcane trash, paper waste and low productive soil can be considered as a suitable method for recycling and reducing the environmental impact of these residues.

5. Conclusions

Synthetic aggregates can be developed from wide range of wastes types and can be utilized in different ways. Different types of aggregates can be developed according to the required utilization method. Moreover, the sizes of the aggregates can be decided with respect to the requirement. Aggregates can be designed according to the availability of the waste materials in the area or the region. Developed aggregates can be utilized as a soil amendment to problematic soils to enhance their challenged physical and chemical characteristics. Coal fly ash aggregates as a soil amendment to acidic soil improve the soil poor properties and subsequently improved the crop growth parameters. In addition, synthetic aggregates effectively can be used as a potting media component to substitute conventional media. Aggregates addition to the soil as an amendment improved the microspores due to microbial activities with the assistance of the fibrous materials in the aggregates, which lead to enhance the soil water holding capacity, porosity and permeability. Synthetic aggregate production from different wastes can be recommended as a potential way of waste management. Waste materials contain considerable contents of trace elements that can be detrimental to human and therefore routine investigations should be undertaken to get confirmed the trace element concentrations are below the permissible levels in the waste materials. Future studies should be undertaken to study the potential utilization of these aggregates for different range of crop varieties.

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7. References

Abad, M., Martinez-Herrero M. D., Martinez Garcia J & Martinez C. (1993). Evaluacion agronomica de los sustratos de cultivo (Agricultural evaluation of crop media).I Jornadas de sustratos. Actas de Horticultura,11:141-154, SECH.

Abad, M., Noguera P., & Bures. S. (2001). National inventory of organic wastes for use as growing media for ornamental potted plant production: case study in Spain, Biores.Technol.77, 197–200.

Adesodun, J. K., Mbagwu, J. S. C. & Oti, N. (2005). Distribution of carbon, nitrogen and phosphorous in water stable aggregates of an organic waste amended Ultisol in Southern Nigeria. Bioresour. Technol. 96, 509-516.

Adriano, D. C. (2001). Trace Elements in Terrestrial Environment. Biochemistry, Bioavailability, and Risks of Metals. Springer, New York.

Adriano, D. C., Page, A.L, Elseewi, A. A, Chang, A. C & Straughan, I. (1980). Utilization and disposal of fly ash and other coal residues in terrestrial ecosystems: a review. J. Environ. Qual.9, 333–344.

Aitken, R. L., Campbell, D. J., & Bell L. C. (1984). Properties of Australian fly ash relevant to their agronomic utilization. Aus.J.Soil Res.22, 443-453

Allison, F. E. (1973). Soil organic matter and its role in Crop Production. Elsevier Scientific, New York, USA. Ben-HurM, Keren R. (1997). Polymer effects on water infiltration and soil aggregation. Soil Sci. Soc. Am. J. 61, 565-570.

Benito, M., Masaguer, A. Moliner, A. & Antonio, R. D. (2006). Chemical and physical properties of pruning waste compost and their seasonal variability Bioresour Technol. 97, 2071-2076.

Chaney, K., & Swift, R. S. (1984). The influence of organic matter on aggregate stability in some British soils. J.Soil.Sci.1984 (35), 223-230

Chapman, H. P. (1966). Diagnostic Criteria for plants and soils, University of California. Division of Agricultural and Natural Science. Oakland, CA, USA.

Chen, J., & Li, Y.(2006). Coal fly ash an amendment to container substrate for *Spathiphyllum* production.Bioresour Technol.97, 1920-1926

Davison, R. L., S. Natusch, D.F., & Wallace, J.R, Evans, C. A. (1974) Trace elements in fly ash; dependence of concentration on particle size. Environ. Sci.Technol. 8, 1107-1113

De Boodt, M. & Verdonck, O. (1972). The physical properties of the substrates in horticulture, Acta. Hort.26, 37–44

Dexter, A. R. (1988). Advances in characterization of soil structure. Soil Till Res.11, 199-238.

Elena, S. (2004). The contribution of waste management to the reduction of greenhouse gas emissions with applications in the city of Bucharest. Waste Management & Research. 22, 413-426.

EL-Mogazi, Lisk, D. J. & Weinstein,L. H. (1988). A review of physical, chemical and biological properties of fly ash and effects on agricultural ecosystems. Science of the Total Environment. 74, 1-37.

Elseewi A. A., Straughan I. R., & Page A. L. (1980). Sequential cropping of fly ash amended soils: effects on soil chemical properties and yield and elemental composition of plants. Sci. Total Environ. 15, 247–259.

EPA. (2008). Municipal Solid Waste. Basic Information. US Environmental Protection Agency. http://www.epa.gov/msw/facts.htm.

Epstein, E. (2003). Land Application of Sewage Sludge and Biosolids. Lewis Publishers, Boca Raton, USA.

Fischer, G. L., Chang, D. P. Y., & Brummer, M. (1976). Fly ash collected from electrostatic precipitator. Microcrystalline structures and the mystery of the spheres. Science.19, 553-554

Gil, M. V., Calvo, L. F., Blanco, D., & Sanchez, M. E. (2008). Assessing the agronomic and environmental effects of the application of cattle manure compost on soil by multivariate methods. Bioresour. Technol.99, 5763-5772

Green, V. S., Stott, D. E., Norton, L. D., & Graveel, J. G. (2000). Polyacrylamide molecular weight and charge effects on infiltration under simulated rainfall. Soil Sci. Soc. Am. J. 64, 1786-1791.

Hamazaki, T. (1979). Parent materials and soils of Nansei-shoto in Japan, Pedologist. 23, 43–57.

Hodgson, D. R. & Holliday, R. (1966). The agronomic properties of pulverized fuel ash. Chem. Ind. 20, 785–790.

Jala, S. & Goyal, D.(2006). Fly ash as a soil ameliorant for improving crop production—a review. Bioresour Technol. 97, 1136–1147

Jayasinghe, G. Y., Tokashiki, Y., & Kitou, M. (2005). Development of synthetic soil aggregates utilizing coal fly ash and mine clay as waste materials. Tropical Agriculture Research and Extension. 8, 1-12

Jayasinghe, G. Y. & Tokashiki, Y. (2006). Utilization of coal fly ash for the production of artificial aggregates as a crop growth medium with acidic “Kunigami Mahji” soils in Okinawa, Japan. Journal of Solid Waste Technology and Management.32, 1-9.

Jayasinghe, G. Y., Tokashiki, Y., & Kitou, M. (2008). Characteristics of synthetic soil aggregates produced by mixing acidic “Kunigami Mahji” soil with coal fly ash and their utilization as a medium for crop growth, Soil.Sci.plant.Nutr. 54, 264–276.

Jayasinghe, G.Y., Tokashiki, Y., & Kitou, M. (2009a). Evaluation of coal fly ash based synthetic aggregates as a soil ameliorant for the low productive acidic red soil, Water Air Soil pollut. 2009(204), 29-41. DOI 10.1007/sl1270-009-0023-y.

Jayasinghe, G. Y., Tokashiki, Y., Kitou, M. & Kinjo, K. (2009b). Recycling of coal fly ash and paper waste to improve low productive red soil in Okinawa, Japan, Clean Soil Air Water. 37(9), 687-695

Jayasinghe, G. Y., Tokashiki, Y., Kitou, M. & Kinjo, K. (2009c). Coal fly ash based synthetic aggregates as potential alternative container substrate for ornamentals, Plant. Nutr. Soil. Sci. 2009, 172(5), 720- 728. DOI10.1002/jpln.200700296.

Jayasinghe, G.Y., Tokashiki, Y., Kitou, M. & Kinjo, K. (2009d). Effect of synthetic soil aggregates as a soil amendment to enhance properties of problematic grey (“Jahgaru”) soils in Okinawa, Japan, Commun. Soil Sci.Plant.Anal. (In press).

Jayasinghe, G. Y., Tokashiki, Y., & Kitou, M. (2009e). Use of soil aggregates as a containerized growth medium component to substitute peat in the ornamental plant production, Archives of Agronomy and Soil Science (In press). DOI: 10.1080/03650340902914024.

Jayasinghe, G. Y., Tokashiki, Y., Liyana Arachchi, I. D., & Arakaki, M. (2009f). Sewage sludge trash based compost and synthetic aggregates as peat substitutes in containerized media for crop production. J.Hazard.Mater 2010 (174), 700-706: DOI; 10.1016/j.jhazmat.2009.09.107

Jayasinghe, G. Y., Tokashiki, Y., Liyana Arachchi, I. D. & Kinjo, K. (2009g). Evaluation of the use of synthetic red soil aggregates and zeolite for ornamental plant production. Journal of plant nutrition. (In press).

Klose, S., Tolle, R., Baucker, E. & Makeschin, F. (2003). Strategic distribution of lignite-derived atmospheric deposits in forest soils of the upper Lusatian region, East Germany. Water, Air, and Soil pollution, 142, 3-25

Kobayashi, T. & Shinagawa, A. (1966). Studies on the soils of Nansei Islands in the subtropical region of Japan. Bull. Fac. Agric. Univ. Kagoshima.16, 11–55.

Lee S. B., Lee, Y. B., & Lee, C. H. (2008). Characteristics of boron accumulation by fly ash application in paddy soil. Bioresour Technol. 99(13):5928–32.

Loneragan, J. F. & Snowball, K. (1969). Calcium Requirements of Plants, Aus.J.of Agric.Res. 20, 465-478.

Louis, G.E. (2004). A historical context of municipal solid waste management in the United States. Waste Management and Research. 22, 306–322.

Lynch, J. M. & Bragg, E. (1985). Microorganisms and soil aggregate stability. Adv. Soil.Sci.198, 133-171.

McCarthy, J. E. (2007). Interstate Shipment of Municipal Solid Waste: 2007 Update.CRS Report for Congress. RL34043. Resources, Science and Industry Division, Washington, DC, USA.

Melosi, M. V. (1981). Garbage in the Cities: Refuse, Reform and the Environment, 1880–1980. Texas A&M University Press, College Station, USA.

Meyers, G. D., McLeod, G. & Anbarci, M. A. (2006). An international waste convention: measures for achieving sustainable development. Waste Management and Research. 24, 505–513.

Molliner, A. M. & Street, J. J. (1982). Effect of fly ash and lime on growth and composition of corn (*Zea mays* L.) on acid sandy soils. Proc. Soil Crop Sci. Soc. 41, 217–220.

Moriguchi, Y. (1999). Recycling and waste management from the viewpoint of material flow accounting. Journal of Material Cycles and Waste Management 1, 2–9.

National Institute of Agro Environmental Sciences. (1996). Classification of cultivated soils in Japan, Third Approximation, National institute of agro-environmental sciences, Tsukuba, Japan.

NRC (2000). Biosolids Applied to Land: Advancing Standards and Practices. National Research Council (NRC), National Academy Press, Washington, DC, USA.2000.

Nyakatawa, E. Z., Ready, K.C. & Sistani, K.R. (2001). Tillage, cover cropping and poultry litter effects on selected soil chemical properties. Soil Til.Res. 58, 69-79.

Okinawa Prefecture Agricultural Experiment Station. (1999). Soils in Okinawa prefecture and measures to improve their quality, Okinawa International Center, Japan international cooperation Agency (JICA), Okinawa, Japan.

Pathan, S. M., Aylmore, L. A. G., & Colmer, T. D. (2003). Properties of several fly ash materials in relation to use as soil amendments. J. Environ.Qual. 32, 687-693.

Peterson, J.C. (1982). Modify your pH perspective. Florists' Rev.169 (34/35), 92-94

Rasp, H. & Koch. E. (1992). Waste product from the paper production and their use in agriculture-An experience report. In. Conference Proc. on Waste material from paper manufacture and its utilization in agriculture one experience. VDLUFA-Kongress, Gottingen, Germany, 14-19, September, pp 345-348.

Raviv, M., Chen, Y. & Inbar, Y. (1986). Peat and peat substitutes as growth media for container-grown plants. In: Chen, Y., Avnimelech, Y. (Eds.), The Role of Organic Matter in Modern Agriculture.Martinus Nijhoff Publishers, Dordrecht, pp. 257–287.

Romheld, V. & Marschner, H. (1991). Functions of micronutrients in plants. In:Mordvedt,J.J., Cox, F.R. Shuman, LM., Welch, RM (Eds.),Micronutrient in Agriculture,SSSA book Series No.4. Madison, WI pp. 297-328.

Sandulescu, E. (2004). The contribution of waste management to the reduction of greenhouse gas emissions with applications in the city of Bucharest. Waste Management & Research. 22 (6), 413-426

Sikka, R. & Kansal, B. D. (1994). Characterization of thermal power plant fly ash for agronomic purposes and to identify pollution hazards. Bioresour. Technol. 50, 269–273.

Simard, R. R., Baziramakenga, R., Yelle, S. & Coulombe, J. (1998). Effects of de-inking paper wastes on soil properties and crop yields, *Can. J. Soil Sci.* 78, 689–697.

Sojka, R. E., Lentz, R. D. & Westermann, D. T. (1998). Water and erosion management with multiple application of polyacrylamide in furrow irrigation. Soil Sci. Soc. Am. J. 62, 1672-1680.

Spiers, T. M. & Fietje, G. (2000). Green waste compost as a component in soil less growing media. Compost Sci.Util, 8, 19-23

Stratton, M. L., A. V. Barker and J. E. Rechcigl. (1995). Compost. In: Rechcigl, J.E. (Ed).Soil amendments and Environmental quality. CRC Press,USA, pp 249-309.

Sugiyanto, Y., Soekodarmodjo, S., Suparnawa, S. H., & Notohadisoewarno, S. (1986). soil Physical properties affecting the rootsdistribution of mature rubber on Red - Yellow Podsolic soil, North Sumatra (Indonesia). Bull.perkaretan Indonesia. 4, 82-88.

Taskin, O., Ali, K. O. & Ekrem L. A. (2002). International Conference on Sustainable Land Use and Management / 2002-Çanakkale, Turkey.

Tejada, M., & Gonzalez, J. L. (2003). Effects of the application of a compost originating from crushed cotton gin residues on wheat yield under dry land conditions. Eur. J.Agron. 19, 357-368.

Tokashiki, Y., Yamada, T., Shimo, M., & Onaga, K. (1994). Physical properties of the surface and the runoff soils of made land in Okinawa Island, Jpn. J. Soil Sci. Plant Nutr. 65, 115–125.

Tripathi, R. D., Vajpayee, Singh, Rai, U. N., Kumar, A., Ali, M. B., Kumar, B. & Yunus, M. (2004). Efficacy of various amendments for amelioration of fly ash toxicity: growth performance and metal composition of *Cassia siame*a Lamk. Chemosphere.54, 1581-1588.

UNEP (1993). Biosolids Management: An Environmentally Sound Approach for Managing Sewage Treatment Plant Sludge – An Introductory Guide for Decision-Makers. United Nations Environment Programme, United Nations University, International Network on Water, Environment and Health, Osaka, Japan.2002.

USEPA (United States Environmental Protection agency).(1993).Standard for the Use or Disposal of Sewage Sludge: Final Rules 40 CFR parts 257,403 and 503.Fed. Reg. 58(32) 9284-9415. USEPA, Washington, DC.

US Environmental Protection Agency (USEPA). (2002). Solid waste management: a local challenge with global impacts. Solid Waste and Emergency Response. EPA530-F-02-026 (5306W) second ed.

US Environmental Protection Agency (USEPA). (2006). Inventory of U.S. Greenhouse Gas Emissions and Sinks.

Van Noordwijk, M., Schonsderbeek, D. & Kooistra, M. J. (1993). Root-soil contact of grown winter wheat.Geoderma. 56, 277-286.

Wong, J. W. C., & Wong, M. H. (1990). Effects of Fly ash on Yields and Elemental Composition of Two Vegetables, *Brassica parachinensis* and *B. chinensis*. Agr. Ecosyst. Environ. 30, 251–264.

Wright, A. L., & Hons, F. M. (2005). Soil Carbon and nitrogen storage in aggregate from different tillage and crop regimes. Soil Sci.Soc. Am.J.69, 141-147

Yan, F., Schubert, S. & Mengel, K. (1992). Effect of low root medium pH on net proton release, root respiration, and root growth of corn and broad bean. Plant Physiol. 99, 415-421.

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Solid Waste Management is one of the essential obligatory functions of the Urban Local Bodies/Municipal Corporation. This service is falling too short of the desired level of efficiency and satisfaction resulting in problems of health, sanitation and environmental degradation. Due to lack of serious efforts by town/city authorities, garbage and its management has become a tenacious problem. Moreover, unsafe disposal of garbage and wastewater, coupled with poor hygiene, is creating opportunities for transmission of diseases. Solutions to problems of waste management are available. However, a general lack of awareness of the impact of unattended waste on people's health and lives, and the widespread perception that the solutions are not affordable have made communities and local authorities apathetic towards the problems. The aim of this Book is to bring together experiences reported from different geographical regions and local contexts. It consolidates the experiences of the experts from different geographical locations viz., Japan, Portugal, Columbia, Greece, India, Brazil, Chile, Australia and others.

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