DEVELOPMENT AND UTILIZATION OF SYNTHETIC SOIL AGGREGATES AS A PLANT GROWTH MEDIUM PRODUCED BY USING DIFFERENT TYPES OF WASTE MATERIALS

（種々の廃棄物利用による植物栽培用土の造粒体の開発と利用）

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GUTTILA YUGANTHA
JAYASINGHE

The United Graduate School of Agricultural Sciences, University of Kagoshima, Japan.

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DEDICATED TO MY

LOVING PARENTS AND

TEACHERS

Abstract

Series of investigations were carried out to study the production, characterization and utilization of synthetic aggregates developed from different types of waste materials (i.e. coal fly ash, paper waste, oil palm waste, sugarcane trash, cattle manure) as an effective alternative waste management practice in Okinawa, Japan. Production and utilization of synthetic aggregates as a crop growth medium for agronomic purposes can be regarded as a novel way for waste utilization, which has not much been reported in the existing literature. Different experiments were undertaken using different types of synthetic aggregates derived from different waste materials under this study and their production, property evaluation and utilization as a medium in agriculture were examined. Physical, chemical and micro morphological properties of the aggregates were determined in order to check out their suitability as a crop growth medium, a component of potting media and a soil ameliorant. Synthetic aggregates developed from coal fly ash, paper waste and starch binder were utilized as a soil amendment with the objective of enhancing the problematic low productive acidic red soil in Okinawa to improve the leafy vegetable (*Brassica rapa Var.Pervidis*) production. Aggregates had low bulk density (0.58-0.62 g/cm^3), high water holding capacity (0.60-0.64 kg/kg), high saturated hydraulic conductivity (2.34×10^{-2} cm/s), high mean weight diameter (MWD) (4.32-4.48 mm), alkaline pH (8.58-8.61), high electrical conductivity (EC) (82.18-84.35 mS/m), high carbon (C) content (68.71-70.07 g/kg) and high cation concentrations compared to the acidic red soil. The trace element concentrations of the developed SA were below the maximum recommended levels. Incorporation of aggregates to the low productive acidic red soil improved the soil fertility and soil physical and chemical properties such as neutralizing soil pH, increasing electrical conductivity, decreasing bulk density, enhancing hydraulic conductivity, increasing water holding capacity and increasing soil C content. SA addition to red soil improved the growth and yield parameters of *Brassica rapa Var.Pervidis* compared to red soil with no SA addition.

In another experiment, aggregates derived from coal fly ash, paper waste and inorganic binder (calcium sulfate and calcium hydroxide) were used as a soil ameliorant to the low productive acidic soil at different soil aggregate addition ratios to improve the *Brassica rapa Var.Pervidis* production. Experiment results showed that incorporation of aggregates in the acidic soil improved not only fertility, but also soil physical and chemical properties. In addition, aggregate addition to acidic soil at 1:5 and 1:10 ratio produced no adverse effects on plant growth and was successful as a growth medium for *Brassica rapa Var.Pervidis*. The higher concentrations of N, Ca, K, Mg, Cu and Zn in shoot tissues grown in CSA: soil at either 1:5 or 1:10 (V/V) compared to acidic soil only control indicated that the aggregate–soil amendment mixtures provided good conditions for plant growth.

Another experiment was performed in Okinawa, Japan to examine the characteristics and potential utilization of synthetic soil aggregates produced from mixing acidic soil with coal fly ash, paper waste and starch, as a crop growth medium. A series of different aggregates were produced by incorporating various percentages (i.e. 0%, 20%, 40%, 60%, 80% and 100%) of coal fly ash into the acidic soil. The effects of the addition of coal fly ash on physical, chemical and structural properties of aggregates were also determined. Increased percentages of added coal fly ash significantly decreased the particle density and bulk density of aggregates compared with the original soil. The particle density of the aggregates varied between 2.39 and 2.14 g/cm^3, while the bulk density varied between 0.72 and 0.81 g/cm^3, according to the various ash additions from 20% to 100%. Saturation permeability coefficient (average value 2.86×10^{-2} cm/s) and water holding capacity (average value 0.66 kg/kg) of the aggregates were improved by the addition of coal fly ash. Aggregates produced without the addition of ash had a pH of 4.57. The

addition of coal fly ash, paper waste and starch to the soil to form aggregates increased aggregate pH (range 6.70–9.96), electrical conductivity (range 38.80–66.80mS/m), exchangeable cation concentration and cation exchange capacity (CEC). The addition of coal fly ash up to 60% increased the aggregate strength. The highest aggregate strength (i.e.3.10 kg/cm^2) was found with 60% of ash application. Aggregates had carbon concentrations between 63.7 and 84.0 g/kg and very low nitrogen content (0.4 g/kg).The growth and yield of *Brassica rapa Var.Pervidis.* and *Glysine max* crops with aggregates as a crop growth medium was assessed. Both crops showed the highest growth and yield when grown with aggregates containing 20% of coal fly ash. Aggregates containing more than 20% of coal ash reduced plant growth and yield. Therefore, aggregates produced from acidic soil with 20% of coal fly ash, paper waste, and starch can be successfully utilized as a crop growth medium.

In another study, two different types of homogenous coal fly ash based pellet aggregates (PA) having 5 mm and 10 mm diameters were produced and utilized as soil amendment and a fertilizer to enhance poor physicochemical properties of problematic grey soil in Okinawa, Japan for the cultivation of *Brassica campestris*. Experiment was conducted with four treatments. Two treatments were conducted by adding 5mm PA only and 10mm PA only to supply required nitrogen to *Brassica campestris.* Another treatment was conducted by adding both 5 mm and 10 mm PA as a soil amendment and nitrogen fertilizer supplements. Grey soil only was used as the control. An experimental plot (2.5m×0.8m×0.6m) study was conducted. The physicochemical properties of soil-PA mixtures were analyzed. The growth and yield parameters of *Brassica campestris* were determined. It was revealed that PA addition as an amendment and a fertilizer support improved the physicochemical properties such as bulk density, water holding capacity, and particle size distribution etc. of the amendment mixtures compared to grey soil. Moreover; PA addition increased the growth and yield parameters of the *Brassica campestris* compared to control. Plant height, plant fresh weight and plant dry weights of PA amended soil were increased by in the ranges of 15.22-43.28%, 43.65-100.81% and 43.51-73.14%, respectively compared to control. Therefore, pellet aggregates can be utilized as a soil amendment and a fertilizer supplement to improve the crop production in problematic grey soil in Okinawa, Japan.

Synthetic aggregates were developed from low productive red soil, paper and starch waste and utilized them to improve poor physical and chemical properties of grey soil as a soil ameliorant. The grey soil was amended with aggregates at the percentages of 10%, 20%, 30%, 40% and 50% and used for the cultivation of French marigold (*Tagetes patula*). Physico-chemical parameters of soil amended with SA and plant growth parameters on aggregate amended soil were analyzed. Aggregate addition enhanced bulk density, porosity, water holding capacity, hydraulic conductivity, pH, organic matter and carbon of the original grey soil. The plant height, number of flowers per plant, shoot fresh weight, shoot dry weight, root length, root fresh weight and root dry weight in 30% of SA addition were the highest and were increased by 1.5, 2.9, 3.5, 4.7, 3.4, 4.3 and 9 times, respectively compared to grey soil. It can be concluded that aggregates developed by red soil with paper and starch waste can be utilized as a soil ameliorant to improve poor physical and chemical properties of grey soil.

A research was carried out to study the characteristics and the potential utilization of coal fly-ash-based synthetic aggregates (CSA) with oil palm waste as an alternative container substrate for ornamental plant production. CSA only, oil palm waste only and two mixing ratios of CSA with oil palm waste at the ratio of 1:5 and 1:10 (V/V) were utilized under this study. Zeolite was utilized as a standard substrate to compare characteristics of other substrates. The physical and chemical properties of all substrates were characterized. Scanning electronic microscopic (SEM) study of coal fly ash and CSA were conducted in order to study the structural configuration of the CSA. Developed CSA gave an alkaline pH (9.82), high electrical conductivity ($96.1mSm^{-1}$), high cation concentration, high water holding capacity and low bulk density (0.56gcm^{-3}) compared to zeolite. Mixing of CSA with oil palm waste at the ratio of 1:10 gave enhanced physical and chemical properties such as bulk density (0.25 gcm^{-3}), particle density (1.76 gcm^{-3}), air space (20.59%), total pore space (85.79%), total water holding capacity (652 mLL^{-1}), pH (6.18) and electrical conductivity (42.4mSm^{-1}),which were in the established ideal substrate range. Moreover, SEM study revealed that CSA is a dual composite material, which had well enmeshed coal fly ash particles in the fibrous paper waste matrix creating porous spaces within the aggregate. The growth of French marigold (*Tagetes patula*), which is a popular ornamental plant in Japan was assessed using these newly developed substrates. The mixing ratio of CSA and oil palm wastes at 1:10 ratio reported the best maximum growth and yield parameters of French marigold, with increase in shoot fresh weight, shoot dry weight, root fresh weight, root dry weight, plant height and number of flowers per plant by 51%, 93%, 54%, 150%, 19%, and 61%, respectively compared to the zeolite. It is revealed that a mixture of CSA and oil palm waste at the ratio of 1:10 can be successfully utilized as an alternative container substrate for French marigold production.

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Another study was conducted to investigate 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. 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. Nitrogen (N) content of plants grown in peat 75%:SA25% was higher than peat substrate. Cu, Fe, Mn and Zn concentrations in all plant shoots were in the normal range and well below the phytotoxic range. 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.

Another research was undertaken to evaluate the influence of zeolite and synthetic aggregates (SA) produced with acidic red soil and paper waste, on the growth of French marigold (*Tagetes patula*), which is a popular ornamental plant in Japan. Five different media studied were, SRA only, SA: Zeolite 3:1, SA: zeolite 1:1, SA: zeolite 1:3 and zeolite only. Mixing SA with zeolite improved the physical and chemical properties of the media such as particle size distribution, bulk density, total porosity, water holding capacity, and pH compared to zeolite. SA and zeolite at 1:1 gave the best maximum growth parameters of French marigold. Zeolite based mixtures increased the N, K, Mg, and Ca concentrations in plant tissues compared to SA medium. Addition of zeolite led to reduce K leaching from the substrate compared to SA. SA and Zeolite at 1:1 can be recommended as a better substrate for French marigold cultivation. Effect of partial substitution of peat in growth media by sewage sludge sugarcane trash based compost (SSC) and synthetic aggregates (SA) on the physical and chemical characteristics of the growth media and on the growth and nutrition of lettuce (*Lactuca sativa* L.) grown in the substituted media was investigated under another study. SSC was produced from sugarcane trash and sewage sludge. Unconventional SA were produced by low productive acidic red soil with paper waste and starch waste. The treatments assayed were: SSC (40%) + Peat (60%), SA (40%) + Peat (60%), SSC (60%) + SA (40%), SSC (40%) + SA (20%) + Peat (40%) and SSC (40%) + SA (40%) + Peat (20%). Peat only was used as the control. The physical and chemical properties of all growing media were analyzed. SSC-SA based substrates showed adequate physical and chemical properties compared to peat for their use as growing media in horticulture. In relation to the plant growth in peat control, plants grown in the SSC–SA based substrates reached better growth and nutrition. The concentration of trace elements in plant tissues was far lower than the ranges considered phytotoxic for plants. Utilization of SSC and SA can be considered as an alternative media component to substitute the widely using expensive peat in horticulture.

Another study was conducted to examine the potential utilization of containerized media developed from cattle manure compost (CMC) and synthetic aggregates (SA) on the growth and nutrition composition of ornamental French marigold (*Tagetes patula*). For preparing growing media, CMC was added at the rate of 0%, 20%, 40%, 60% and 100% with SA at 100%, 80%, 60%, 40% and 0%, respectively. Peat only was used as the control. CMC-SA based media showed adequate physical and chemical properties compared to peat for their use as containerized media in horticulture. In relation to the plant growth in peat control, plants grown in the CMC–SA based substrates reached better growth and nutrition. 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 mixture of CMC and SA at 40% and 60% treatment were increased by 27.01%, 42.86%, 37.09%, 67.29%, 5.14%, 45.58% and 34.26%, respectively compared to peat control. Utilization of CMC and SA can be considered as an alternative media to substitute the widely using expensive peat in horticulture.

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AS	Ammonium sulfate
Al	Aluminum
As	Arsenic
B	Boron
BD	Bulk density
C	Carbon
CEC	Cation exchange caapcity
CFA	Coal fly ash
Ca	Calcium
Cd	cadmium
Cr	Chromium
Cu	Copper
EC	Electrical conductivity
F	Fluorine
Fe	Iron
GDP	Gross domestic product
Hg	Mercury
K	Potassium
MWD	Mean weight diameter
Mg	Magnesium
Mn	Manganese
N	Nitrogen
Na	Sodium
OECD	Organization for Economic Cooperation and Development
OP	Oil palm waste
P	Phosphorous
PD	Particle density
PE	Peat
PL	Perlite
PW	Paper waste
Pb	Lead
S	sulfur
SA	Synthetic aggregates
SEM	Scanning electronic microscopy
SHC	Saturated hydraulic conductivity
SZ	Synthetic zeolite
Se	Selenium
WHC	Water holding capacity
WSA	Water stable aggregates
Zn	Zinc

Chapter 1

General introduction

1.1. Waste production

Human activities have always generated waste. This was not a major issue when the human population was relatively small and nomadic, but became a serious problem with urbanization and the growth of large conurbations. Poor management of waste led to contamination of water, soil and atmosphere and to a major impact on public health. In medieval times, epidemics associated with water contaminated with pathogens decimated the population of Europe and even more recently (19th century), cholera was a common occurrence. Some of the direct health impacts of the mismanagement of waste are well known and can be observed especially in developing countries. As science and technology developed, the management of an ever increasing volume of waste became a very organized, specialized and complex activity. The characteristics of waste material evolved in line with changes in lifestyle, and the number of new chemical substances present in the various waste streams increased dramatically. The long-term health effects of exposure to substances present in the waste, or produced at waste disposal facilities are more difficult to measure, especially when their concentrations are very small and when there are other exposure pathways (e.g. food, soil). Nonetheless, lack of evidence can cause public concern. Well-publicized industrial accidents, often unrelated to waste management activities, have produced a NIMBY (not in my backyard) syndrome that causes fierce opposition to the construction of landfills, incinerators, or other waste disposal facilities.

The mass of waste produced in the world has been growing considerably for many decades especially in affluent countries as shown by the link between national gross domestic product (GDP) and waste generation per capita (World Bank, 1992; OECD, 2003). Though waste data on waste arising is often incomplete and in some cases unreliable, recent estimates suggest that the municipal solid waste (MSW) alone generated globally exceeded 2 billion tones per year at the turn of the millennium (e.g. KeyNote, 2007). In 2006, the USA produced more than 228 million tones (EPA, 2008; OECD, 2008a, b) of MSW, or 750 kg per capita. The quantity of MSW generated in the OECD area in 2006 was more than 619 million tones, or 580 kg per inhabitant (OECD, 2008b). In 2006, the 15 countries of the European Union (Austria, Belgium, Denmark, Finland, France, Germany, Greece, Italy, Ireland, Luxembourg, Netherlands, Portugal, Spain, Sweden, and UK) generated 219 million tones of MSW, or 560 kg/yr/capita (OECD, 2008a, b). As less developed countries such as China and India industrialize and their populations urbanize, huge amounts of municipal waste are disposed of, though the production per capita (less than 0.5 kg/day/capita in India and less than 0.9 kg/day/capita in China) is still relatively small compared to the production in most individual OECD counties (up to 2.1 kg/day/capita in the USA). Concerns over the environmental impacts of the increasing volume and the toxicity of waste have emerged dramatically in the last tow decades. Improper management of waste has caused numerous cases of contamination of soil and ground water and threats to the health of the exposed population. Existing disposal facilities are reaching saturation and difficulties enlarge in the siting of new facilities.

1.2. Sources of waste

All human activities are potential sources of waste. Wastes can be classified according to their major sources, which include: municipal waste, industrial waste, agricultural waste, energy generation waste, mining and quarrying waste. The relative importance of the various sources of wastes varies between countries and according to their economic structure.

1.3. Waste streams

Waste can also be classified according to different waste streams such as paper, plastics, glass, metals and organic matter. Wastes from industrial process include a wide range of materials which may have varied chemical composition and physical state. Depending on the different industrial sectors, they may contain varying proportions of organic and inorganic compounds. It is their heterogeneity, which makes their treatments and disposal difficult. Major categories of industrial wastes, which are considered hazardous, include solvents, waste paint, waste containing heavy metals, acids, and oil waste. Waste from mining activities includes top soil, rock and dirt and may occur as inert or mine tailings, which are contaminated by metals and chemicals from mining process. Large amounts of ash are often the product of energy generation process. Other waste streams of concern for their increased amount and toxicity are sewage sludge, agricultural, demolition, and hospital waste. Sewage sludge from the treatment of domestic and industrial waste water and dredged spoils from harbors and rivers generally concentrate heavy metals and synthetic organic compounds. Sewage sludge and agricultural manure are organic wastes with high contents of nutrients. In addition, waste from agricultural activity may contain high concentrations of pesticide residues. Demolition and construction waste, including asphalt road planning and concrete, steel, timber and cement, may also contain relevant concentrations of toxic substances such as asbestos. Hospital wastes contain contaminated materials and generally required to be segregates from other municipal waste. Specific regulations are generally adopted for radioactive wastes.

1.4. Different waste types

1.4.1. Municipal waste

Municipal wastes are composed of wastes generated by households and wastes of similar character from shops, market, and offices, open areas and treatment plant sites. Materials that can be classified under the municipal wastes are food wastes, rubbish, ashes and residues, demolition and construction wastes, special wastes (street sweepings, roadside litter, catch-basin debris, dead animals, etc) and treatment plant wastes and dredged soil. Municipal wastes have increased markedly over recent decades.

1.4.2. Industrial waste

Industrial process wastes include a very wide range of materials and the actual compositions of industrial wastes in a country will depend on the nature of the industrial base. Wastes may occur as relatively pure substances or as complex mixtures of varying composition and in varying physiochemical states. Examples of the materials, which may be found under category are general factory rubbish, organic wastes from food processing, acids, alkalis, metallic sludge and tarry residues. The most important feature of industrial wastes is that a significant proportion is regarded as hazardous or potentially toxic, thus requiring special handling, treatment and disposal.

1.4.3. Agricultural waste

Agricultural wastes consist of horticulture and forestry wastes, crop residues, animal manure, animal carcasses, agrochemical residues and containers. The importance and composition of agricultural wastes vary across countries according to agricultural systems. Most agricultural residues are organic and biodegradable and hence should be suitable to conversion by biological, chemical and physical process into energy, animal feed or organic fertilizer. However, problems for their management arise from their occurrence in large volumes and high concentrations, and as a result of the increased use of chemicals in agriculture. In general, farm crops produce significant amounts of residues. Intensification of agriculture and livestock farming is the cause of increased pressure on the environment due to increased quantities and concentration of such residues. Opportunities for recycling are still not fully exploited.

1.4.4. Mining and quarrying wastes

Mine tailings or spoils are the waste materials that are extracted in the process of mining minerals of economic value. The waste materials may include topsoil, rock and dirt. It may be inert, such as materials from china clay mining, but mine tailings from ore extraction are contaminated with metals or chemicals that have been used for mineral separation. Mechanization of under ground mining process has also increased the amount of spoil reaching the surface and needing disposal. Reduction in spoil from mechanized extraction seems unlikely in the developed world, and the amount of spoil arising in developing countries could be increase substantially with rising mechanization rates. Arising of mining wastes is likely to be of some significance in many developing countries, where extraction and processing of minerals are important economic activities.

1.4.5. Energy production wastes

Coal fly ash from the thermal power plants is the major concern. It may be used as a component of building material, (i.e. an additive to cement), land filling and soil amendment for agriculture. Recently, global coal fly ash production is increased at alarming rates and their utilization is not properly addressed.

1.4.6. Hazardous wastes

Hazardous wastes can stem from any of above sources. There is no agreed definition of the term of “hazardous wastes”. Some countries define “hazardous waste” only in terms of danger to human health, whilst others include damage to the environment. Hazardous characteristics of wastes include, but are not limited to human health toxicity, corrosivity, infectiousness, flammability, reactivity, explosivity, and ecotoxicity. It is almost impossible to obtain reliable information on hazardous waste arising in any country because of poor data collection methods, infrequency of surveys, reluctance of industry to supply data, and because of ambiguities in the definitions of what constitutes a hazardous waste and even continuously changing definitions of “hazardous wastes” within the same country (OECD, 2000). As pointed out earlier, industry is the major source of hazardous wastes. The chemical and allied products industry produces 50-70% of all hazardous wastes, while around 10-15% of total industrial wastes are hazardous.

1.5. Waste management

A number of serious and highly publicized pollution incidents associated with incorrect waste management practices, led to public concern about lack of controls, inadequate legislation, environmental and human health impact. This in turn forced many national and federal governments to introduce new regulatory frameworks to deal with hazardous and unsustainable waste management operations. 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. During last two decades, various countries have established different control systems for the management of waste, giving increased attention to waste prevention strategies. However, despite the increasing emphasis on waste prevention, wastes have increased dramatically.

1.5.1. Waste recycling and waste minimization

The most satisfactory approaches to managing hazardous waste are those help to minimize the quantity of waste requiring disposal. These methods are beginning to be more widely used. By modifying production processes, the volumes of wastes generated can often be reduced. Many wastes contain useful materials which can be reclaimed and reused. Most waste streams contain significant amounts of valuable materials, which can be recovered and reused in production process or other useful applications. Reuse and recycling activities have the advantage of reducing the demand for raw materials and for energy while minimizing the impact of waste disposal. The range of different recycling efforts varies enormously between countries. Overall, recycling is increasing in around the world.

1.5.2. Incineration

The main goal of incineration is volume reduction, with the sterilization of the waste as a significant side effect. The incineration process may also be used to produce steam and electricity. In most developing countries, household produce high density waste. Hence, volume reduction through incineration will be considerably lower than for wastes incinerated in developed countries. Moreover, as moisture contents will be high and calorific value low, a self sustaining combustion processes not possible (Bhide and Sundaresan, 1983). However, increasing difficulties have been encountered by public agencies insisting new incineration plants, since the significant contribution of these plants to the total emissions of toxic substances to the atmosphere has become evident. In 2000, about 18% of MSW was incinerated and 25% recycled in Western Europe, whereas incineration and recycling accounted for 6% and 9%, respectively, in central and eastern Europe (Eurostat, 2002). Industrial and municipal wastes, hazardous wastes and sewage sludge may all be suitable for incineration. Although incineration is not a complete method of disposal, its main advantage is that is produces a residue that is substantially reduced in volume and may be relatively inert (Suess, 1985). Incineration, however, expensive and supplementary fuel may be required if the moisture content of the waste is high and its combustible content low. Except where mandatory to ensure the complete destruction of highly toxic and persistent organic wastes such as polychlorinated biphenyl (PCB), incineration is used mostly when land fill options are restricted. Incineration of municipal wastes will not be viable disposal option in the near future in developing countries because of high cost and the high moisture content of the municipal waste stream.

1.5.3. Composting

Organic materials present in municipal wastes can be converted to a suitable form either aerobically or an anerobically. The final product can be used as an organic fertilizer on land; such application at the same time might improve the structure of the soil. Environment problems may arise when waste is composted without non compostible matter like metals and plastics being removed. Hazardous substances like heavy metals may then be found in the compost, which in turn may be taken up in the food chain when compost is used on agricultural land. To prevent this situation, sorting at the composting plant or even at the household level might be called for, though the additional operations would raise the price of the compost or require a sophisticated collection system. Other ways of utilizing organic waste include the production of biogas to recover energy from agricultural residue.

1.5.4. Land filling

Provided that there is no shortage of land with suitable geological formations, landfill remains the principal final disposal route for the majority of wastes, even in highly industrialized countries. In Europe, land filling is the main disposal method. In 1999, 57% of MSW was land filled (67% in 1995) in Western Europe, and 83.7% in central and eastern Europe (DHV CR, 2001). In 2006 the USA land filled 54% of MSW, incinerated 14%, and recovered, recycled or composted the remaining 32%. The percentage of MSW disposed at landfills accounted for 3% in Japan (in 2003), 18% in Germany (in 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 a less cheap option, alternative solutions are considered. For example, there has been a significant reduction in the amount of waste land filled in the UK and Italy. In 1995, Italy land filled 93% of MSW, and the UK 83%. The main environmental problem associated with land filling is pollution of ground water. Moreover, due to rapidly escalating world population the land area available for landfilling is rapidly decreasing and therefore, landfills are reaching their saturation levels. The type of waste management practices adopted in each country are mostly a function of economic considerations, but are also a reflection of technical aspects due to the type of waste to be handled. For example, if houses and buildings are heated by coal burning, large amounts of coal ash may end up disposed together with other urban waste. As coal ash contains high concentrations of heavy metals and other potential contaminants, this type of mixed urban waste cannot be easily composted. Coal ash also makes incineration less efficient. A change of energy source from coal to gas can thus have important beneficial effects on waste management options. This is important for many developing countries. Land filled putrescible waste causes gas and leachate production. In Europe, the EU Directive 1999/31/EC on the landfill of waste has stimulated the diversion of organic matter to composting or specialized landfill sites, especially in the Netherlands, Sweden, Denmark, and Austria. Waste separation at source allows the removal of hazardous (flammable, toxic) items, better recycling and composting options, and a reduction of MSW to be disposed of. Therefore, knowledge of waste composition is of vital importance for the choice of waste treatment and disposal.

1.6. Waste utilization in agriculture

It is worth mentioning that a 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). A number of studies have shown that organic wastes such as urban solid wastes, sewage sludge, paper waste, pruning waste, spent mushroom and even green wastes, or different types of composts developed from different wastes can be efficiently utilized to improve the crop production (Benito et al., 2005; Bustamante et al., 2008; Garcia-Gomez et al., 2002; Moral et al., 2009; Ostos et al., 2008). Many studies (Hil and Lamp, 1980; Weinstein et al, 1989) have demonstrated that coal fly ash can be utilized as a soil amendment and subsequently increases crop yields of alfalfa *(Medicago sativa*), barley *(Hordeum* *vulgare*), bermuda grass (*Cynodon dactylon)* and white clover (*Trifolium repens)* and can improve the physical and chemical characteristics of the soil. Land application of composted sewage sludge represents one of the most cost effective methods for treatment and final disposal of sewage sludge, because the high levels of valuable components (N, P, K, organic matter and other necessary nutrients for plant growth) in stable sludge can be recycled and the properties of soil can be improved (Wang et al., 2008; Wong et al., 2003; Jamali et al., 2009; He et al., 2009). 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. Therefore, it is worthwhile to find out alternative methods for waste disposal to minimize that kind of handling problems. Consequently, unconventional synthetic aggregates were produced using different waste materials (sewage sludge, paper waste, oil palm waste, sugarcane trash, starch waste, coal fly ash, 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 and Tokashiki, 2006a,b; Jayasinghe et al., 2005, 2008, 2009 a,b,c,d,e,f,g).

1.7. Synthetic aggregates as a waste management practice

Most of the wastes are generation at alarming and exponential rate and their utilizations were not properly met. Subsequently, current waste management processes are not much efficient. Incineration will not be a viable waste disposal option in the future because of high cost and high moisture content of the organic waste and the generation of toxic gases. Due to rapidly escalating world population the available land area for land filling is rapidly reducing and therefore, landfills are reaching their saturation levels. Therefore, seeking novel methods for proper waste management practices is a worth while investment. Production of SA from different waste materials can be regarded as an alternative waste management practice. This kind of unconventional SA production is not much reported in the literature.

1.7.1. Soil Aggregate formation

Soil aggregate formation and aggregate stability have an important role in crop production and sustainable agricultural management (Alagoz and Yilmaz, 2009). The formation and maintenance of stable aggregates is the essential feature of the soil tilth, a qualitative term used to describe that highly desirable physical condition in which soil is optimally loose, friable and contains a porous assemblage of stable aggregates. This in turn permits free entry and movement of water and air, easy cultivation as well as germination, and emergence of seedlings and growth of roots (Harris et al., 1965; Hillel, 1998; Kaczynskij, 1963). Aggregates formation in the soil takes very long time and influenced by several factors such as soil organic matter, binding agents, soil fauna, environmental variables, microorganisms and roots (Six et al., 2004). Therefore, in this study a novel idea of synthetic aggregates formation within very short time less than several hours was originated and different types of waste materials (i.e. coal fly ash, soil, paper waste, starch) were utilized to produce different types of synthetic aggregates.

1.7.2. What is a synthetic aggregate?

Aggregate structure is schematically shown in Figure 1.1. It is composed with rigid or composite particles, fibrous materials and a binder.

(A) 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 1.1 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.

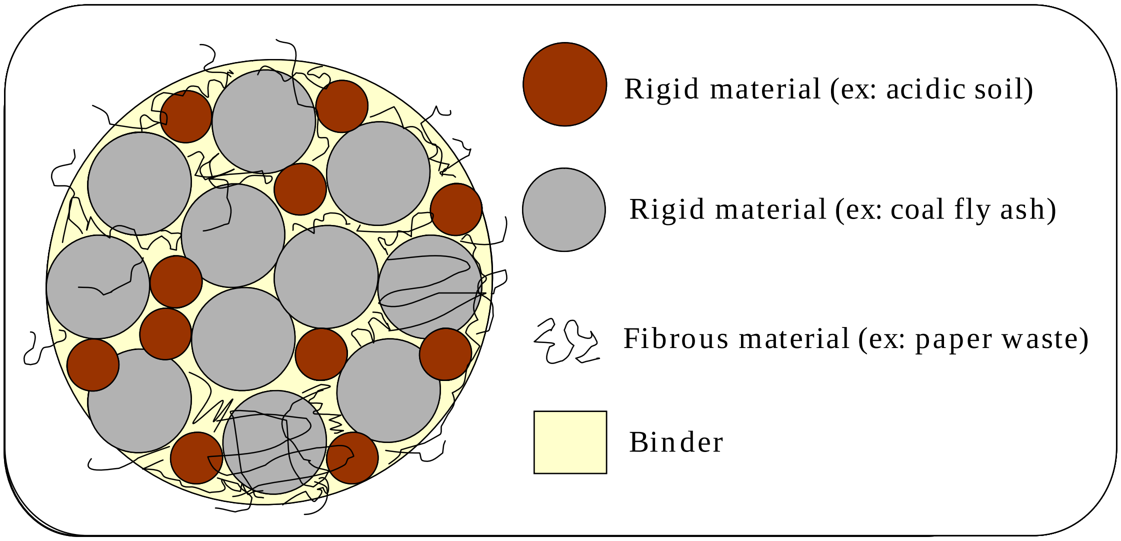


Figure 1.1. Schematic diagram of the aggregate structure.

(B) Fibrous material: 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, oil palm fiber etc.. can be used as the fibrous materials. In Figure 1.1 paper waste was utilized to form the aggregate matrix, which gives the porous spaces and efficient binding surface which clearly explained by the scanning electron micro-graphs (Figure 1.2). 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). Moreover, organic matter is an important agent responsible for aggregate formation (Oades and waters, 1991). These fibrous materials are also a source of organic matter which can improve the aggregate formation.

(C)Aggregate 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 and Keren, 1997; Sojka et al., 1998; Green et al., 2000). The main binding polymers in aggregation are considered to be carbohydrates (Emerson and Greenland 1990). 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.

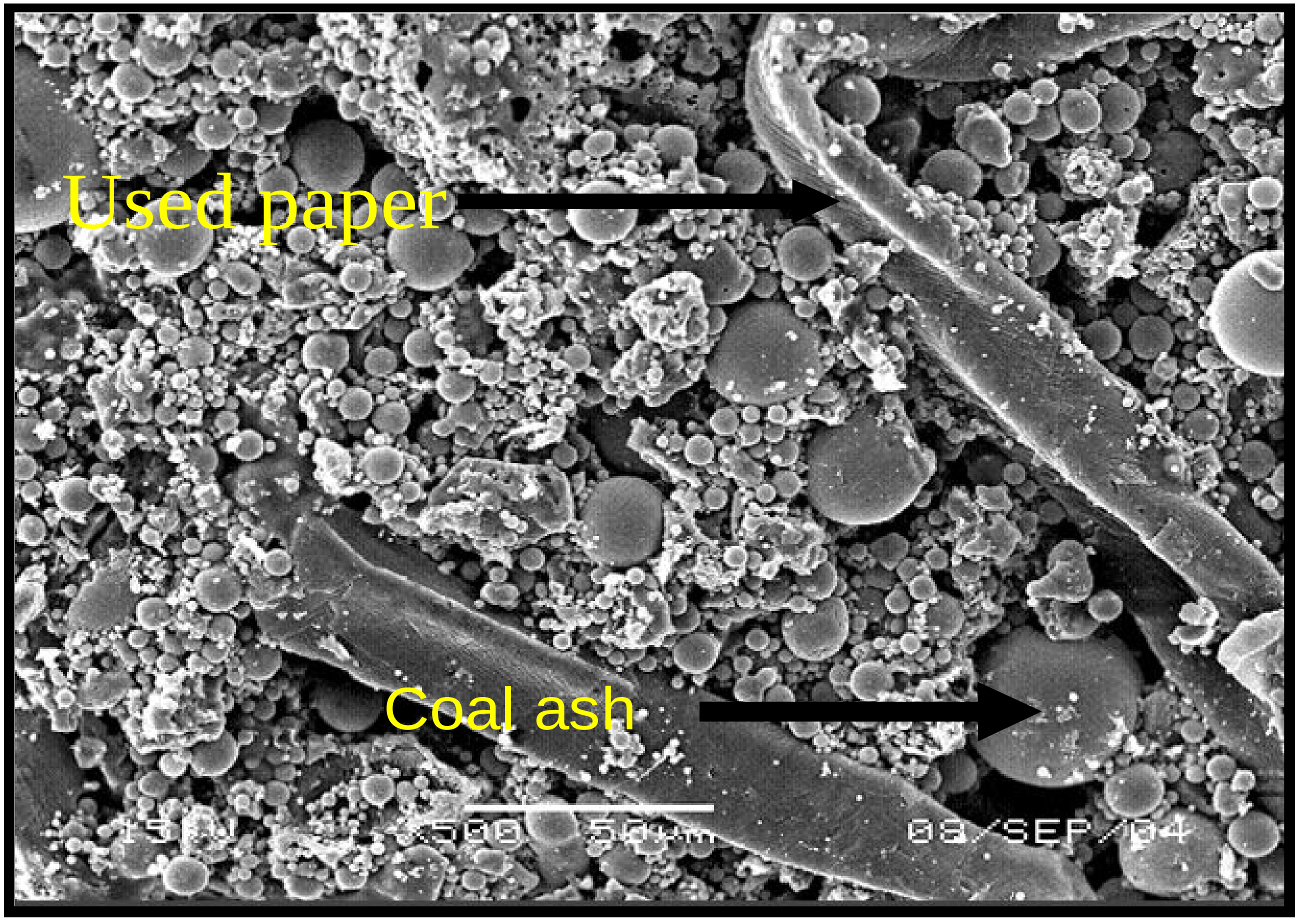


Figure 1.2. Scanning electronic micrograph of a coal fly ash-paper waste aggregate.

1.8. Materials utilized in the production of synthetic soil aggregates

1.8.1. Coal fly ash (CFA)

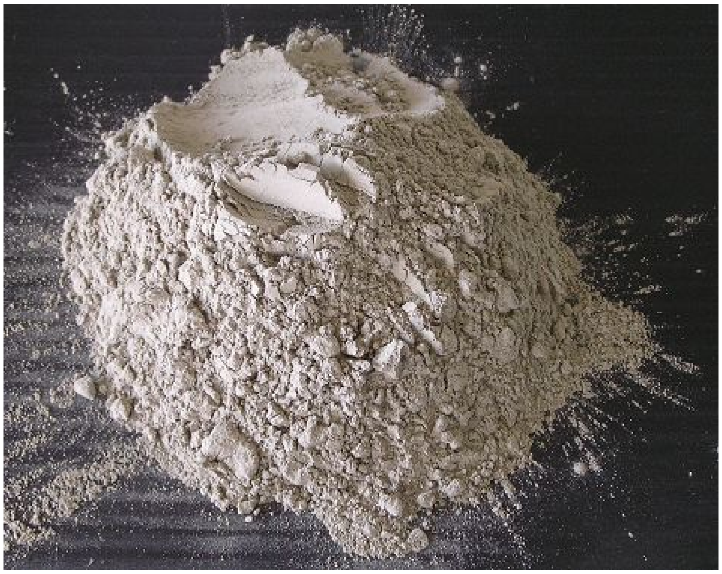


Figure 1.3. Coal fly ash.

Coal accounts for around 25% of total global primary energy; however, its utilization as an energy source generates a great amount of coal fly ash (CFA). The global generation of CFA (Figure 1.3) is estimated to be above 600 million tons per annum (Raza et al., 2000) and the global recycling rate of CFA is about 15% (Claus 1994). Japan is one of the major coal-importing countries in the world. As a consequence of its use, it is estimated that approximately 9.9 million tons of CFA is produced every year. (Centre for coal utilization in Japan, 2005). Disposal of unused CFA is costly and a burden for the power industry. The CFA is the portion of the combustion residue that enters the flue gas stream in power-generating facilities and consists of many small, glass-like particles ranging in size from 0.01 to 100 µm (Davison et al., 1974). Chemically, CFA contains oxides, hydroxides, carbonates, silicates, and sulfates of calcium, iron, aluminum, and other metals as well as some non-combustible residues of the coal (Page et al., 1979 ;Adriano et al., 1980). Most CFA materials are disposed in landfills or slurry ponds. Land filling of CFA may serve as a major source of environmental pollution through erosion and leaching of heavy metals (Carlson et al., 1993: Gupta et al., 2002). Although, CFA contains moderate quantities of trace and heavy metals, radioactive elements, but its effect on ground water soil and health and uptake by plants are probably negligible (Zacharia et al., 1996). Utilization of CFA as a resource has been studied for decades, in many research areas such as invaluable element extraction (Lakshmanan, et al., 1990), in environmental engineering (Polettini etal., 2004), in ceramic products (Leroy et al., 2004), in paint and plastic industry, in building products (Sunil *et al.*, 2002). Research has shown CFA have some absorption capacity, which may allow it to be used for environmental benefit rather than being disposed of as a waste. Also CFA has been shown to have a reasonable capacity of absorbing soluble Phosphorous (Donald, 2003). A literature survey revealed that CFA has been used for removing heavy metals (Weng and Hung, 1994: Bulewicz et al., 1997) and radionuclide (Aptak et al., 1996) from aqueous solutions. The material's chemical composition, as well as its physical properties makes CFA a useful material, mainly in the construction industry. The CFA can be used as a partial replacement for cement in concrete production. After mixing the CFA with different materials including other by-products, pellets are formed that can be used in concrete as aggregates (Valenti, 1995). The CFA also has a vast potential for use in agriculture. Use of fly ash is in agriculture since the hydroxide and carbonate salts give CFA one of its principal beneficial chemical characteristics, the ability to neutralize acidity in soils (Matsi and Keramidas, 1999; Pathan et al., 2003).

Agricultural utilization of CFA has been proposed due to its considerable contents of Potassium (K), Calcium (Ca), Magnesium (Mg), sulfur (S) and Phosphorous (P) (Kalra et al., 1997). The CFA amendments have been reported to modify soil pH (Bilski et al., 1995: Korcak, 1993) and provide essential plant nutrients for increasing crop production. Moreover, experiment results showed that CFA addition alters physical properties of soil such as texture, bulk density, water holding capacity and particle size distribution (Capp et al., 1977: Grewal et al., 2001). The addition of appropriate quantities of CFA can alter the soil texture. CFA addition@ 70t ha^{-1} has been reported to alter the texture of sandy and clayey soil to loamy (Fail and Wochock, 1977).The grain size distribution especially the silt size range of CFA affects the bulk density of soil. Chang et al (1977) observed that among five soil types Reyes silty clay showed increase in bulk density from 0.89 to 1.01 g cm^{-3} when the corresponding rates of CFA amendment increased from 0 to 100%.But soils with bulk densities varying between 1.25 and 1.60 g cm^{-3}, a remarked decrease in bulk density was observed by the addition of CFA. Page etal (1979, 1980) reported that fly ash amendment to a variety of agricultural soils tend to decrease the bulk density. Optimum bulk density in turn improves the soil porosity, the workability of the soil, the root penetration and moisture retention capacity of the soil. Chang et al (1977) reported that an addition of 8% by weight CFA increased the water holding capacity of the soil. Many workers (Page et al., 1979:Grewal et al., 2001:Hill and Lamp, 1980:Weinstein et al., 1989: Adriano et al., 1978: Sale et al., 1996: Sikka and Kansal, 1995: Khan and Khan, 1996) have demonstrated that CFA utilization in agriculture has increased crop yield of alfalfa (*Medicago sativa*), Bermuda grass (*Cynodon dactylon*), Corn (*Zea mays* L.), Bush bean (*Phaseolus vulgaris* L.), Barley (*Hordeum vulgare* L. var. ‘Leduce’),Rice (*Oryza sativa* cv. ‘PR 106’),Tomato (*Lycopersicon esculentum* Mill. cv. ‘Pusa Ruby’),wheat (*Triticum aestivum* L. and white clover (*Trifolium repens*) and improved the physical and chemical characteristics of the soils. Moreover, CFA can be successfully utilized as an amendment to container substrate (Chen and Li, 2005). Use of CFA as a soil-amending agent has been investigated for a variety of other crops (Tolle et al., 1983:Wallace et al., 1980:Mittra et al., 2003). However, agricultural use of CFA thus far represents only 0.01 million tons per year according to the ACAA (2003). However, its utilization in agriculture and agronomy sector is limited due to concerns about presence of toxic elements viz., cadmium (Cd), arsenic (As) and nickel (Ni) (Carlson and Adriano, 1993; Gupta et al., 2002; Jala and Goyal, 2006). Application of CFA to soil generally results in increased soil concentrations of trace elements such as barium (Ba),lead (Pb), molybdenum (Mo), selenium (Se), As, and strontium (Sr). Element content in soil may also be enriched depending on the rate of application, type and composition of the soil and properties of the CFA (Adriano et al., 1980; Bilski et al., 1995). Moreover, CFA has been shown to supply essential nutrients to crops on nutrient-deficient soils and has been reported to correct deficiencies of B, Mg, Mo, S and Zn. The availability of Mg, Mo, S and Zn in some CFA is comparable to the availability of these nutrients in commonly used fertilizers (EL-Mogazi et al., 1988). CFA is often used as a soil amendment (Gupta et al., 2002; Jala and Goyal, 2006; Sikka and Kansal, 1995; Tripathi et al., 2004; Mittra et al., 2005) due to its beneficial properties. Given the large volume of coal fly ash that requires disposal, new application technologies are constantly being sought. Therefore, several benefits can be obtained by finding an alternative use for CFA. Attempts have therefore been made to produce synthetic soil aggregates from CFA as a medium for crop production, fertilizer support, soil amendment and a potting media component.

1.8.2. Paper waste (PW)

Figure 1.4. Paper waste.

Historically, paper industry has been considered to be a major consumer of natural resources (wood, water) and energy (fossil fuels, electricity) and a significant contributor of pollutant discharges to the environment. Each year paper industry generates several million dry metric tons of PW (Figure 1.4) as a by-product. This PW is disposed of by burning or as a soil conditioner (Wong et al., 1995). During the last few decades, the disposal of PW has become a more difficult and severe problem. In densely populated industrial countries, regulations to protect the environment and the potential risk to groundwater quality have led to a drastic reduction in the amount of available landfill space and a steep rise in the cost of land disposal of waste. Most of the paper industries and municipal authorities are facing increased regulatory and cost-related pressures regarding the handling, treatment and disposal of PW by products. Since PW mainly consists of cellulose, kaolinite, calcite and talc, the content is high in C, SiO_2, Al_2O_3, CaO, and MgO but is normally extremely low in potentially toxic components. Uptake properties of heavy metals by as-received PW have been reported by Calace et al., 2002 and Calace et al., 2003 and Ballaglia et al (2003). For example, Calace et al (2003) reported that the cation exchange capacity of PW is about 0.07 meq/g and the uptake capacities for Pb^{2+}, Cu^{2+}, Cd^{2+} and Ag^{+} at pH 4 were 3.13, 0.15, 0.09 and 0.078 mmol/g, respectively. The PW is also an important industrial waste that can be used effectively in agriculture (Rasp, 1992: Zhang et al., 1993). The PW is a rich source of carbon and improves soil organic matter content, water holding capacity, soil structure and bulk density (Sharma 1989). Paper waste sludges are mainly used in agriculture and in restoration of sites to favor plant growth, soil C, soil water retention and soil cationic exchange capacity (CEC) (Chantigny et al., 2000; Fierro et al., 1997, Fierro et al., 1999 and Fierro et al., 2000; Simard et al., 1998; Trépanier et al., 1996). Addition of PW to soil can enhance plant growth and yield (Bellamy et al., 1995). Organic materials such as farm yard manure, crop residues and PW are commonly used to improve soil properties. The formation of synthetic soil aggregates requires an effective surface to adhere the rigid particles to form the stable aggregates. Accordingly, PW was incorporated to provide an efficient binding matrix for the enmeshment rigid particles like coal fly ash and “Kunigami Mahji” soil particles, which can create porous space within the produced synthetic aggregates.

1.8.3. Aggregate Binders

(A) Organic binders

(i) Starch

Wheat has been consumed as part of the human diet for thousands of years. In addition to providing basic nutrition, components of wheat (particularly dietary fiber) can provide numerous health benefits. Wheat flour which is a polysaccharide is being used for the production of noodles and pasta, bread and confectionery items. During the commercial process considerable amount of waste starch is being produced as a by product. This starch by product is utilized as an ingredient for animal feed, fertilizer etc. Starch waste coming out as a waste material from flour industry in Okinawa, Japan was used as a binder to develop aggregates under our previous studies (Jayasinghe et al., 2005; Jayasinghe and Tokashiki, 2006a,b; Jayasinghe, 2007). In this research starch waste was utilized as a binder for the production of synthetic soil aggregates.

(B) Inorganic binders

Oxides and calcium have been reported as being the dominant binding agent in aggregate formation (Oades et al. 1989).

(i) Calcium hydroxide and calcium sulfate

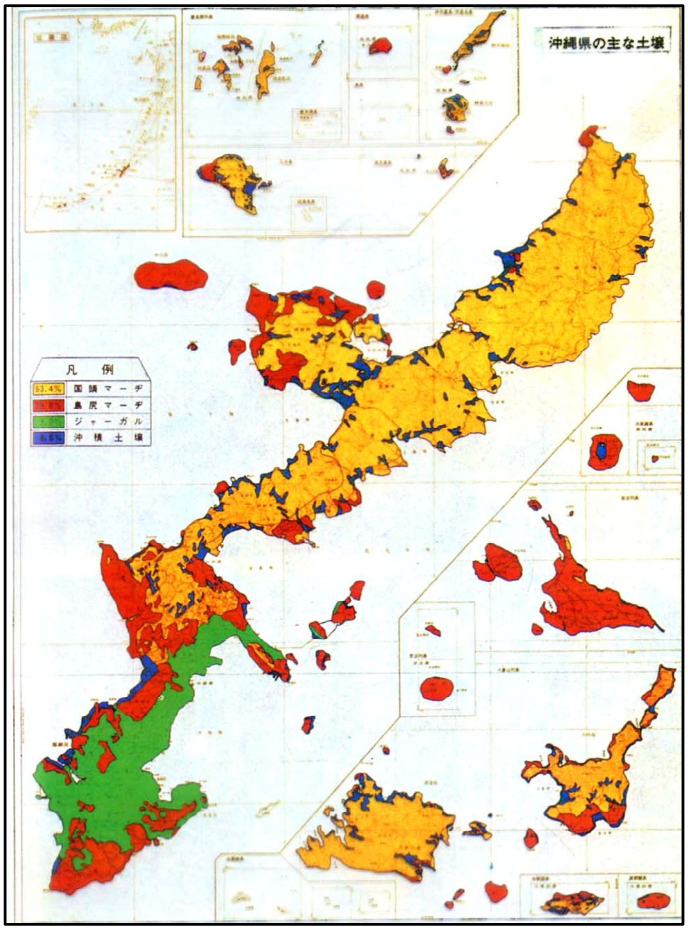
Several studies have used lime materials (calcium oxides and calcium hydroxides) and gypsum (calcium sulfate) to bind CFA particles (Rush et al., 2002; Kumar 2002, 2003; Clough and Skjemstad 2000). Therefore, calcium hydroxide and gypsum were utilized to bind CFA particles and PW in the present study.

1.8.4. “Kunigami Mahji” Soil (Red yellow soil)

Okinawa soils classified into three major groups, called “Kunigami Mahji” (Red yellow soil), “Shimajiri Mahji” (Dark red soil) and “Jahgaru” (Grey terrace soil) with reference to the locality and the local dialect (Onaga and Yoshinaga, 1988). Figure 1.5 shows the division of the Okinawa soil on the basis of the distributed area. “Kunigami Mahji” soil accounts for about 55% from the total land area in Okinawa. Widely spread “Kunigami Mahji” soil in sub-tropical Okinawa, Japan, which is classified as an ultisol, is not suitable for crop production due to its poor physical (Tokashiki et al., 1994) and chemical properties, such as its highly acidic nature, low organic matter content and poor nutrient availability (Kobayashi and Shinagawa 1966: Hamazaki 1979). This prompted for the development of two methods to improve the low productive “Kunigami Mahji” in this study. One method was addition of alkaline coal fly ash-based alkaline synthetic aggregates as a soil amendment to improve the properties of the soil. Second way was an effective method of converting “Kunigami Mahji” soil in to a fertile, arable growth media by incorporating organic and inorganic materials in order to improve its physical and chemical properties for the enhanced crop production.

1.8.6. Jahgaru soil (Grey soil)

Grey soils ("Jahgaru") in Okinawa Japan spread over 20% (Figure 1.5) 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. Under the current study synthetic aggregates were incorporated as a soil amendment to improve the challenged poor properties of the grey soil to enhance the crop production.



🟨 Kunigami Mahji

🟥 Shimajiri Mahji

🟩 Jahgaru

Figure 1.5. Soil distribution in Okinawa, Japan.

1.9. Production of synthetic aggregates

Production process of synthetic aggregates is given in Figure 1.6. EIRICH mixer or Pelleger machine can be used for the production of heterogeneous aggregates. Heterogeneous aggregates have different sized aggregates. Pelleter machine can be utilized to produce homogenous aggregates. Aggregates in the homogeneous category are same-sized. EIRICH mixer was used for small scale aggregate production and pelleger machine and pelleter was used in larger scale aggregates production Different proportions of raw materials were mixed in the pelleger or EIRICH mixer for 1-3 minutes. Then binder (organic or inorganic) was added and mixed for another 1-2 minutes. Finally another 2-5 minutes mixed in high speed rotation to for aggregates. To develop homogenous aggregates, the raw materials and binder mixture taken from the Pelleger or EIRICH machine was inserted to the pelleter machine and required size of aggregates can be developed. In addition, compost or different fertilizer materials (N, P, K by chemical fertilizers) to add required nutrients to the aggregate can also be mixed with the raw materials to produce aggregates.

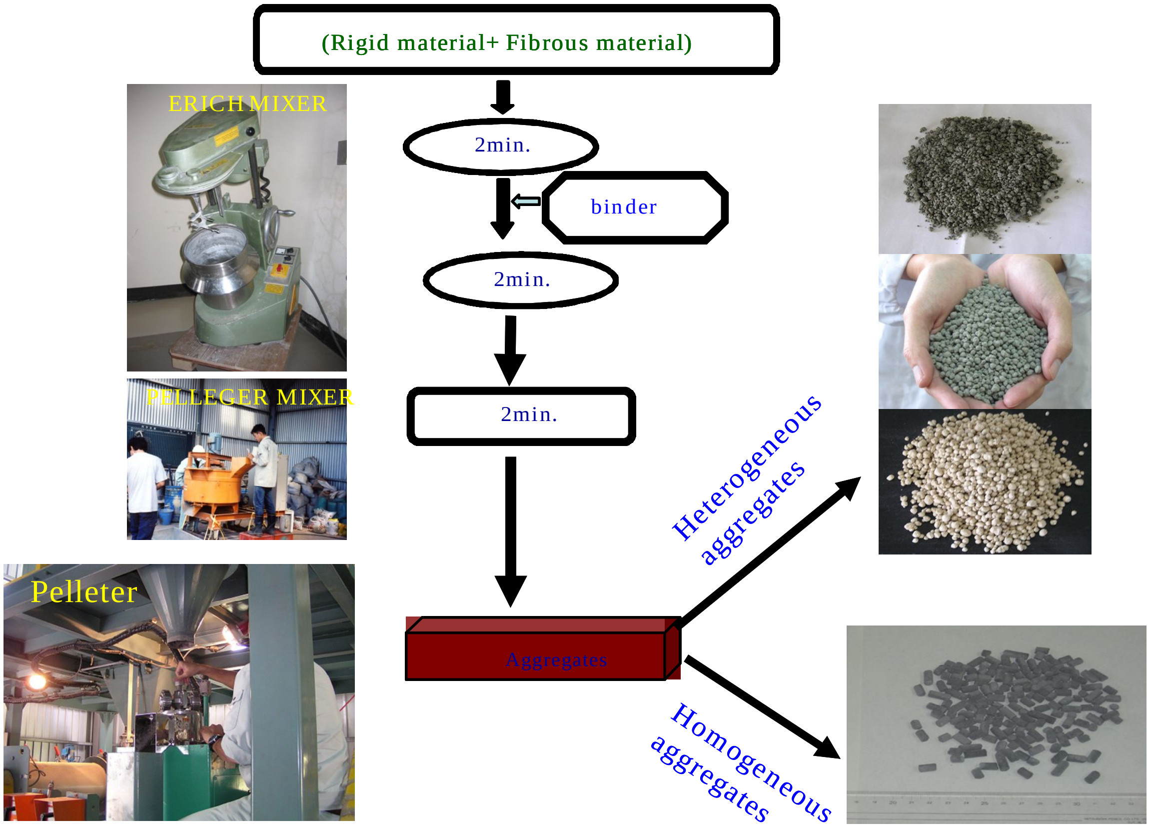


Figure 1.6. Production process of different types of aggregates.

1.10. Different types of aggregates developed with various types of wastes under this study

Different types of aggregates were developed with the available waste in the site or area. Some of the developed aggregates from different wastes are described below (Figure 1.7). Basically aggregates can be divided into two types.

1.10.1. Heterogeneous aggregates

These aggregates have different-sized aggregates. Following types of aggregates were produced under heterogeneous category.

(A) Coal fly ash based aggregates

These aggregates were developed from CFA, paper waste or oil palm waste with organic or inorganic binders (Figure 1.7a).

(B) Soil aggregates

These are developed from low productive acidic red soil with paper waste, coco fiber, or oil palm waste (Figure 1.7b) with organic or inorganic binders.

(C) Acid soil-coal fly ash aggregates

These are developed by acid soil and the coal fly ash with paper waste, sewage sludge (SS), CFA with organic or inorganic binder (Figure 1.7c).

(D) Sewage sludge based aggregates

These aggregates were developed from sewage sludge and zeolite with an inorganic binder (Figure 1.7d).

(E) Compost based aggregates

These were produced from different types of composts and soil with organic or inorganic binders (Figure 1.7e).

1.10.2. 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 1.7f).

Figure 1.7. 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)

1.11. Objectives of the study

The objectives of the entire study are

- To envisage the development, evaluation, characteristics and micro morphological observations of synthetic aggregates produced from different proportions of waste materials.
- To investigate the potential ability of synthetic soil aggregates as a soil amendment to improve the crop production in low productive “Kunigami Mahji” and “Jahgaru” soils in Okinawa, Japan and to study the physical and chemical characteristics of the aggregate-soil amendments.
- To study the utilization of synthetic aggregates as an alternative potting media component for crop production and to study the effect of synthetic aggregates on the physical and chemical properties of the potting media and the nutrition composition of the cultivated crops.
- To check out the potential utilization of the synthetic aggregates and different compost based media as peat substitutions for ornamentals and vegetables cultivation by studying their effects on vegetative and nutritional aspects to determine if there are any limitations on their use.

Chapter 2

Synthetic aggregates as a soil ameliorant to improve the crop production in low productive acidic soil (“Kunigami Mahji”) in Okinawa, Japan.

2.1. Recycling of coal fly ash and paper waste to form synthetic aggregates (SA) with starch binder and their utilization to improve the low productive red soil for crop production in Okinawa, Japan.

2.1.1. Introduction

Coal fly ash (CFA) has proven beneficial in land reclamation efforts; the fineness of the particles has limited its usefulness as a soil amendment where larger particles are desired (Fretz et al., 1980). Moreover, simply mixing only CFA with soil introduced many handling difficulties (Adriano et al., 1980). In a previous study, Jayasinghe et al (2005, 2006ab, 2007) developed a new method for SA production with CFA and paper waste (PW), which reduced the handling difficulties of airborne CFA particles. Recent investigations suggested that CFA can find better applications if combined with organic amendments and N (Tripathi et al., 2004; Rautaray et al., 2003;Rai et al., 2004). Therefore this research was conducted to introduce an original method of utilizing CFA by converting them into SA by mixing with organic amendments such as PW, starch waste and ammonium sulfate (AS) to supply N to utilize SA as a fertilizer and a soil amendment. The N requirement of SA was supplied by AS resulted during the process of entrapping carbon dioxide, which is a green house gas coming out from coal combustion in Okinawa electric company, Japan. Carbon dioxide reacts with ammonia and calcium sulfate to produce calcium carbonate and AS. SA formation requires both physical rearrangement of particles and stabilization of the new arrangement. Accordingly, PW was incorporated as an efficient binding matrix for aggregation of CFA particles. Starch, which is a waste material, was used as an aggregate binder (Jayasinghe et al., 2005, 2006a,b). Okinawa Seifun Corporation in Okinawa, Japan producing 9000 kg of starch waste during the extracting process of gluten from wheat flour and the management of resulting considerable amount of starch waste is a big management problem. Moreover, widely spread red soil (“Kunigami Mahji”) in sub-tropical Okinawa, Japan, which is classified as an Ultisol, is not suitable for crop production due to its poor physical (Tokashiki et al., 1994) and chemical properties, such as its highly acidic nature, low organic matter content and poor nutrient availability (Kobayashi and Shinagawa, 1966: Hamazaki, 1979). Therefore, developed aggregates were used to improve the problematic red soil properties to enhance the crop production in red soil. In this study, the idea of using CFA for the production of SA with PW and starch is an unconventional method of CFA utilization and have not much been reported in the literature.

2.1.2. Objective of the study

The objective of this study was to produce SA, study their characteristics and evaluate their potential utilization as a nitrogen fertilizer and a soil amendment to improve physical and chemical properties of low productive acidic red soil for the Komatsuna (*Brassica Rapa* var. *Pervidis*) production.

2.1.3. Materials and methods

2.1.3.1. Sample collection

Samples of CFA were collected from the thermal power plant located at Gushikawa, Okinawa, Japan. The pH and EC of CFA were 10.87 and 92.70 mS/m, respectively. Exchangeable Na, K, Mg and Ca content in CFA were 1.02, 1.68, 0.87 and 3.45 g/kg, respectively. C and N content of CFA were 43.26 and 0.52 g/kg, respectively. The As, chromium (Cr), copper (Cu), Manganese (Mn), zinc (Zn), Pb and boron (B) content of CFA were 0.3, 12.8, 32.5, 66.6, 48.4, 13.6, 20.30 mg/kg, which were below the maximum pollutant concentration of individual metals for land application of sewage sludge given by the US Environmental Protection Agency (USEPA,1993). PW was collected from Ojiryokka Company, Tokyo, Japan. The pH, EC, C and N content of PW were 5.70, 10.28 mS/m, 374.8 g/kg and 0.38 g/kg, respectively. Starch waste was collected from Okinawa Seifun Corporation in Okinawa, Japan. The pH, EC, C and N content of starch waste were 3.80 mS/m, 20.98 mS/m, 312.5 g/kg and 0.42 g/kg, respectively. AS was obtained from the Okinawa electric company located at Gushikawa, Okinawa, Japan. Red soil samples were collected from Miyagi-Sajibaru, Higashi-Son, Kunigami-Gun, Okinawa, Japan. The soil texture was clay and is classified as an Ultisol. Collected soil samples were air-dried and then sieved through a 10-mm mesh screen. A portion of this soil was sieved through a 2-mm mesh sieve, and used for chemical analysis. pH and EC of the soil were 5.12 and 4.18 mS/m, respectively.

2.1.3.2 Synthetic aggregate (SA) production

Three types of SA (A, B and C) were produced by combining CFA and PW in an EIRICH mixer (R-02M/C27121) with starch. Different sizes of the produced aggregates are shown in Figure 2.1. Different proportions of raw materials were used in the production process are given in Table 2.1. Three different SA were produced with three different N levels by mixing three different AS amounts. First of all respective quantities of CFA, PW, and AS were mixed well in the pan of EIRICH mixer for 2 minutes. 300 ml of prepared starch paste was added to above mixture and mixed for another 2 minutes to produce the SA. (25 g of starch was added to 200 ml hot water at 50^{0}C and heated to 80^{0}C in order to obtain sticky paste).

Table 2.1. Different proportions of raw materials used to produce SA

Materials	A	B	C
CFA(g)	500	500	500
PW(g)	25	25	25
Starch paste (ml)	300	300	300
AS (g)	10	15	20

CFA: coal fly ash, PW: paper waste, AS: ammonium sulfate.

2.1.3.3. Scanning electronic microscopy (SEM) of the CFA and SA

SEM study was undertaken to examine the structural arrangement of the SA. The CFA and SA samples were dried by heating at 105^{0}C for 24 hours and stored in desiccators. Subsequently it was dried in a critical point drier JCPD-3 (JEOL, Japan). Then samples were mounted on brass stubs with double adhesive carbon tape and gold coated (20 nm thick) in a Fine Coat-Ion Sputter JFC1100 (JEOL, Japan) for 3 minutes. Micro-morphology of the samples was examined under high vacuum conditions (HV) at 10-12 kV using a JSM-5600 LV scanning electron microscope (JEOL, Japan) equipped with a black scattered electron detector as described by Davey (1978).

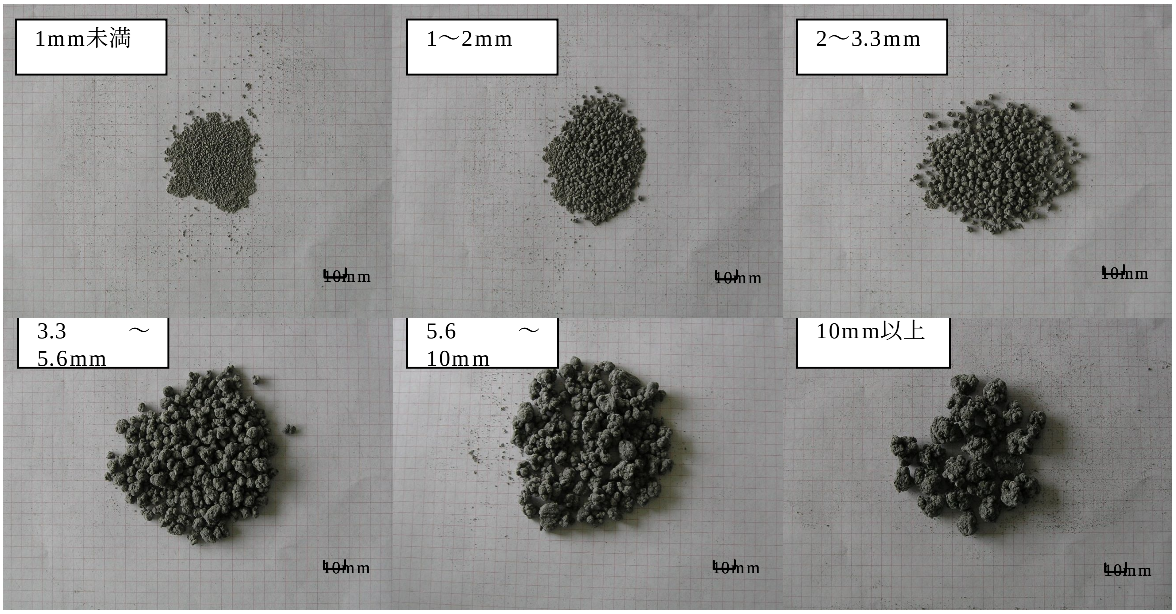


Figure 2.1. Different sizes of developed aggregates (A, B and C).

2.1.3.4. Physical and chemical properties of SA and soil-SA mixtures

Samples for bulk density measurements of soil, SA, and soil-SA mixtures were taken with a core samplers of volume 100 cm^3, oven dried, and weighed (Blake and Hartage, 1986). Saturated hydraulic conductivities of the samples were determined by falling head method (Klute, 1965). The samples were used to fill 100 cm^3 core- samplers and were saturated for 48 h, and kept for another 24 h until gravitational water drained off. Then, the amount of water held by each sample at the field capacity was calculated as water holding capacity (kg/kg). All measurements were replicated three times. Air dried red soil, SA, and soil-SA amendment mixtures were sieved through a 10 mm mesh screen and were passed through a series of sieves from 5.60 to 0.50 mm to analyze the aggregate size distribution using the dry sieving method (Yoder, 1936). Wet aggregate stability of all samples was studied. Aggregates were placed on the top sieve of a nest of sieves and they were allowed to equilibrate in shallow water and then shaken under water for 30 min at a frequency of 30 strokes per minute with a stroke length of 32 mm. The proportion of aggregates remaining on the sieves was used to compute water stable aggregates (WSA) (Yoder, 1936) after drying at 105 ^{0}C. Percentage of WSA > 0.50 mm and the mean weight diameter (MWD) were calculated according to the method described by Kemper and Rosenau (1986).

The pH was measured in water extracts of soil, SA and soil-SA amendment mixtures using a glass electrode (sample: distilled water ratio of 1:2.5), and EC was measured using an EC meter (D-54, Horiba) (sample: distilled water ratio of 1:2.5). Of each dried substrate sample, 1g was utilized to determine C and N by using CN analyzer (Micro coder JM 10). C and N in dried substrate samples were burnt into CO_2, NOx and N_2 during the analysis and C and N in the samples were automatically detected using a standard calibration curve. The extractable cations of the air-dried substrate samples were extracted by using 1 M ammonium acetate. Then the extracts were used to analyze the cation concentration by atomic absorption spectrophotometer (Solaar 969, Thermo Corporation, Tokyo, Japan). Substrates were digested in HNO_3, HCl and H_2O_2 (USEPA, 1996) and analyzed for heavy metals by atomic absorption spectrophotometer (Solaar 969, Thermo Corporation, Tokyo, Japan).

2.1.3.5. Aggregate decomposition test

Aggregate strength of SA and commercial granular fertilizer (CGF) was determined by hardness testing machine (Kiya Digital Hardness Tester, KHT-20, Japan). The CGF is a widely using high analysis compound fertilizer for crop cultivation, which is having N: P: K at the ratio of 15:15:15 (Wako Nozai Co.ltd. Osaka, Japan). Five randomly selected samples of SA and CGF were used to determine the average aggregate strength. Moisture contents of SA and CGF were analyzed by gravimetric method. 5 g of three different air dried SA (A, B and C), CGF and AS were put into a net bag and buried under a soil depth of 30cm (Figure 2.2). Buried bags were taken out after 10, 20, 30, 40, and 50 days intervals, respectively and their respective air dry weights, MWD, WSA and C content were determined. Each measurement was replicated three times.

2.1.3.6. Utilization of SA for the Komatsuna production in red soil as a fertilizer and a soil amendment

Komatsuna (*Brassica rapa* Var.*Pervidis*) also known as Japanese mustard spinach was grown in a pot experiment. The experiment was a completely randomized design with four treatments and three replicates. All four treatments are shown in Table 2.2. Each pot was filled with 4 kg of red soil. Total N requirement per 4 kg of red soil was 1g according to the recommended fertilizer requirement for Komatsuna given by the Prefecture Agricultural Department, Okinawa, Japan for Komatsuna (Okinawa Prefecture Agricultural Research Station, 2006). N contents of A, B and C type SA were 1.72, 2.17 and 3.29 g/kg, respectively. N requirements of Komatsuna were supplied by A, B and C types of SA. Nitrogen requirement of T1 (Control) was supplied by AS (4.9 g/ pot). SA requirements to supply equivalent N content to each pot in T2, T3 and T4 were 550, 450 and 300g, respectively (Table 2.2).

Table 2.2. Different treatments were used under the study

Treatment	Description
T1	N supplied with AS (control)(AS 4.9 g/pot)
T2	N supplied with A type SA (550 g/pot)
T3	N supplied with B type SA (450 g/pot)
T4	N supplied with C type SA (300 g/pot)

SA: synthetic aggregates, AS: ammonium sulfate, N: nitrogen

Respective quantities of A, B and C SA to supply N requirements of Komatsuna were mixed with red soil and filled into each pot without unnecessary compaction. K and P requirements of each treatment were supplied by chemical fertilizer as per the requirement recommended by the Prefecture Agricultural Department, Okinawa, Japan for Komatsuna (Okinawa Prefecture Agricultural research station, 2006). K_2O (50%) and P_2O_5 (17%) requirements per pot were 1.2 and 2.5g, respectively to supply equivalent K and P amounts to all treatments. Ten seeds were initially sown and thinned 1 week after germination, leaving five plants per pot. Pots were arranged in a green house and 200 mL of water was added once in every 2 days to each pot. Experiment was terminated after 42 days after planting. Experiment were conducted during September to October, 2007.Temperature ranged from 20-31^{0}C during the growth season. Plant height and plant fresh weight were determined. Subsequently, plants were oven dried at 70^{0}C for 48 h to determine the dry weight. N content of plant tissues were analyzed by CN analyzer. Mineral element concentrations of plant shoots were analyzed by atomic absorption spectrophotometer. Oven-dried plant tissues were ground and passed through 2-mm mesh sieve and digested with nitric acid for the mineral element analysis.

Synthetic aggregates

Commercial fertilizer control

10 Days 20 Days 30 Days 40 Days 50 Days

Figure 2.2. Aggregate decomposition test.

2.1.3.7. Statistical Analysis

Data were subjected to analysis of variance (ANOVA) for determination of the treatment effects. Duncan's multiple comparison range test (DMRT) procedure was employed to denote significant differences between the treatments using SAS package (SAS institute, 1990).

2.1.4. Results and discussions

2.1.4.1. Scanning Electron Microscopy (SEM)

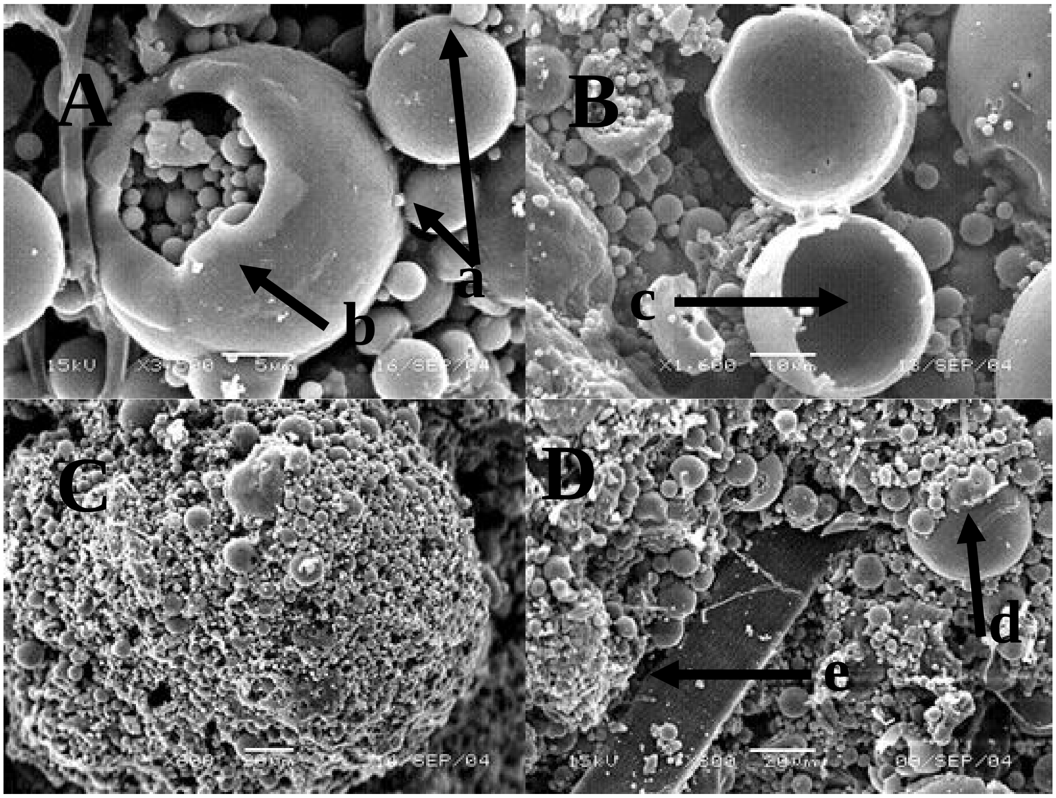


Figure 2.3. Scanning electron micrographs of CFA and synthetic aggregates. (A and B) Scanning electron micrographs of CFA particles, showing the micro morphology and varies sizes of CFA particles. (a) stable glasses of various sizes (b and c) cenospheres: (C and D) Part of macro-aggregate (SA) is produced by CFA and PW (d: CFA, e: PW).

SEM images of Figure 2.3-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 2.3-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 and Goyal, 2006). CFA particles are hollow empty spheres called as cenospheres (Figure 2.3-B-c) filled with smaller amorphous particles and crystals (Plerosphers). These tiny CFA particles are easily airborne (Hodgson and Holliday, 1966). Therefore, initial idea of SA production was to bind tiny airborne CFA particles into fibrous PW matrix by starch waste. Figure 2.3-C and D show the micro- morphological configuration of SA, where PW matrix provides the structural surface to adhere CFA particles. Figure 2.3-C shows aggregation of CFA particles to PW matrix with the assistance of starch. PW matrix increased the surface area of SA (Figure 2.3-D). SEM images of SA revealed that SA is a dual composite material having greater surface area with well enmeshed CFA particles in PW matrix with the help of starch waste providing porous spaces within the SA. In a previous study it was reported that CFA showed an increased surface area, capillary action, and nutrient-holding capacity when incorporated to soil (Fischer et al., 1976). Therefore, SA 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.

2.1.4.2. Physical and chemical properties of different SA and soil utilized in the study

Table 2.3. Physical and chemical properties of different types of SA and the soil used in the experiment

Parameter	A	B	C	Soil
BD (g/cm^3)	0.58^{b}	0.60^{b}	0.62^{b}	1.26^{a}
WHC (kg/kg)	0.64^{a}	0.62^{a}	0.60^{a}	0.48^{b}
SHC (cm/s)	$1.87x10^{-2a}$	$2.24x10^{-2a}$	$2.80x10^{-2a}$	$6.62x10^{-5b}$
Particle size distribution				
>5.60 mm	27.20^{a}	28.19^{a}	29.02^{a}	6.60^{b}
5.60-3.35 mm	30.28^{a}	31.87^{a}	32.18^{a}	15.93^{b}
3.35-2.00 mm	26.64^{a}	24.29^{a}	25.24^{a}	15.76^{b}
2.00-1.00 mm	8.43^{b}	8.88^{b}	7.02^{c}	18.86^{a}
1.00-0.50 mm	5.32^{b}	4.60^{c}	4.23^{c}	13.71^{a}
0.50-0.00 mm	2.13^{b}	2.18^{b}	2.31^{b}	29.14^{a}
MWD(mm)	4.32^{a}	4.40^{a}	4.48^{a}	2.10^{b}
WSA (%)	97.87^{a}	95.38^{a}	94.71^{a}	70.86^{b}
pH	8.67^{a}	8.58^{a}	8.61^{a}	5.12^{b}
EC(mS/m)	83.37^{a}	82.18^{a}	84.35^{a}	4.18^{b}
C(g/kg)	70.07^{a}	69.18^{a}	68.71^{a}	1.73^{b}
N(g/kg)	1.72^{c}	2.17^{b}	3.29^{a}	0.40^{d}
Exchangeable cations				
Na(g/kg)	0.81^{a}	0.78^{a}	0.75^{a}	0.06^{b}
K(g/kg)	1.40^{a}	1.33^{a}	1.35^{a}	0.05^{b}
Mg(g/kg)	0.82^{a}	0.84^{a}	0.80^{a}	0.02^{b}
Ca(g/kg)	3.52^{a}	3.29^{a}	3.38^{a}	0.07^{b}
Trace elements				
As(mg/kg)	0.20^{a}	0.10^{a}	0.10^{a}	ND
Cr(mg/kg)	6.40^{a}	5.80^{a}	5.30^{b}	1.20^{c}
Cu(mg/kg)	20.10^{a}	19.60^{a}	18.70^{b}	13.80^{c}
Mn(mg/kg)	18.70^{b}	16.80^{c}	17.60^{b}	20.60^{a}
Se(mg/kg)	ND	ND	ND	ND
Cd(mg/kg)	ND	ND	ND	ND
Zn(mg/kg)	44.71^{a}	35.40^{b}	30.80^{b}	27.32^{c}
Pb(mg/kg)	9.40^{a}	8.62^{b}	7.30^{c}	4.73^{d}
B(mg/kg)	16.86^{a}	17.05^{a}	16.94^{a}	0.05^{b}

BD: bulk density, WHC: water holding capacity, SHC: saturated hydraulic conductivity, MWD: mean weight diameter, WSA: water stable aggregates, EC: electrical conductivity. (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)).

Physical and chemical properties of A, B and C types of SA and red soil are given in the Table 2.3. Average bulk densities of A, B and C were 0.58-0.62 g/cm^3. The average bulk density of red soil was almost two times than that of SA. Water holding capacities of A, B and C were higher than that of red soil. Average water holding capacity of SA was 30% higher than original red soil. Red soil showed a very low hydraulic conductivity value of 6.62×10^{-5} cm/s, while the respective values for A, B and C were varied in the range of $1.87\text{-}2.80 \times 10^{-2}$ cm/s (Table 2.3). Red soil had a higher percentage (29.14 %) of particles < 0.5mm, while this fraction in A, B and C was comparatively very low. A, B and C gave a higher percentage of particles >5.60 mm compared to red soil. The MWD and WSA of A, B and C were higher than that of red soil. The pH of red soil was 5.12, and pH values A, B and C were varied between 8.58 and 8.67. The EC of A, B and C varied between 82.18 and 84.35 mS/m compared to red soil (4.18 mS/m). C content of A, B and C had higher values compared to red soil. N content of A, B and C were 1.72, 2.17 and 3.29 g/kg, respectively. N content of red soil was 0.40 g/kg and C/N ratio of A, B, C and red soil were 40.74, 31.88, 20.88 and 4.33, respectively. Exchangeable Na, K, Mg and Ca concentrations in SA were significantly higher than soil. This may be due to high concentration of cations in SA containing CFA. Boron (B) content of A, B and C were high compared to red soil.Trace element concentrations in SA were below the maximum pollutant concentration of individual metals for land application of sewage sludge given by the US Environmental protection Agency (USEPA, 1999). The maximum pollutant concentration of individual trace element 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, 1999). Furthermore, average concentrations of trace elements reported in uncontaminated soils are (all in mg/kg); 6 As, 70 Cr, 30 Cu, 90 Zn, 35 Pb and 0.35 g Cd, respectively (Adriano, 2001). CFA contains non essential elements (eg: As, Cd, and Se) that adversely affect crop growth, soil and ground water quality (Adriano et al 1978; Page et al., 1979). It is evident that the trace element concentrations in A, B and C type SA were below the trace element concentrations reported in uncontaminated soils. The amount of trace element released from coal into CFA depends on coal type, composition, modes of element occurrence and combustion technology (Jala and Goyal, 2006; Spears et al., 1998). Present results support earlier work on CFA that showed the trace element concentration was very low and unlikely to affect ground water quality (Ghodrati et al., 1995). Though the concentrations of trace element were below the uncontaminated soil values and not alarming, there should be routine inspections to ensure that trace element concentrations remain within safe limits.

2.1.4.3. Aggregate decomposition test

Retained weights, MWD, WSA and C content of different substrates, which were buried under 30 cm soil depths in decomposition test are given in Table 2.4. There was no remaining AS after 10 days and only 26% of CGF remained after 10 days. In contrast weight loss of A, B and C showed minimum values. Weight loss percentages of A, B and C after 10 days were varied in the range of 6%-10%. Retained percentages of A, B, C, CGF, and AS after 50 days were 60%, 58%, 62%, 6% and 0%, respectively. MWD and WSA of A, B and C were decreasing with the time but higher than the red soil. It can be suggested that A, B and C can serve as a fertilizer medium and a soil amendment for longer time than CGF. A, B and C gave higher average aggregate strength in the range of 3.67-3.83 (kg/cm^2) compared to CGF value of 1.55 (kg/cm^2). Moisture content of A, B, C and CGF varied between 2.55%-2.68%. Initial C contents in the SA were varied in the range of 68.71-70.07 g/kg. C content of A, B and C were decreasing with time. But C content of SA were still remaining in the range of 48.77-50.29 g/kg after 50 days. This fast decomposition of C may be due to microbial activities on the SA with the increased N content in the SA and the conducive subtropical conditions in Okinawa, Japan. Further investigations should be conducted to study the detailed description of C decomposition with the time.

2.1.4.4. Utilization of SA for Komatsuna production in red soil as a fertilizer and a soil amendment

The effect of SA addition on the growth and nutrient contents of Komatsuna are shown in Table 2.5. Different treatments used in the study are shown in the Figure 2.4. SA addition (T2, T3 and T4) significantly increased the growth and yield parameters of Komatsuna compared to red soil (T1). T2 and T3 did not show any significant difference between them but differed significantly with T4. Plant height, plant fresh weight and plant dry weight of T2 increased by 1.4, 2.1 and 7.0 times compared to T1. Growth and yield parameters of Komatsuna grown in red soil were significantly lower than SA addition treatments of T2, T3 and T4. It is likely that low pH (5.12) and its related nutrient bioavailability accounted for the reduced growth and yield parameters of Komatsuna produced from red soil (T1). Acidic pH of red soil can decrease the bioavailability of Ca and Mg but increase the solubility of micronutrients. Shoot concentrations Ca and Mg were lower but Mn was higher in plants grown in red soil than that grown in SA addition treatments (Table 2.5). Similar results were found in a previous study conducted using CFA as an amendment to container substrate for *Spathiphyllum* production by Chen and Li (2005). 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). The N content in plant shoots from T2, T3 and T4 were higher than that of red soil (T1). N content of all treatments were above the deficiency level of 15g/kg according to Chapman (1966). Se and Cd were not detected in all treatments. In addition, K, Cu, and Zn concentrations in plants grown in T2, T3 and T4 were increased compared to red soil control (T1). This may be due to higher concentrations of those nutrients in the SA (see Table 2.3). Researchers have shown that CFA is a readily available plant nutrient source and it can improve crop yield (Jala and goyal. 2006: EL-Mogazi et al., 1988; Rautaray et al., 2003; Singh et al., 2003). Shoot K, Ca and Mg contents were all above the deficiency limit of 7-15 g/kg (Chapman, 1966), 1.4g/kg (Loneragan and Snowball, 1969) and 0.6 g/kg (Chapman, 1966), respectively. The normal ranges of Cu, Mn, and Zn in plants were 3-20, 15-150 and 15-150 mg/kg, respectively (Adriano et al., 1978). The critical toxicity concentrations range for Cu, Mn, Pb and Zn were 25-40, 400-2000, 100-400 and 500-1500 mg/kg, respectively (Romheld and Marschner, 1991).Therefore, Cu, Mn, Pb and Zn concentrations in plants were within the normal range and well below the phytotoxic limits. Significantly higher B concentrations were found in Komatsuna grown in SA amendment treatments than in control soil but all were in normal B level (7-75 mg/kg) in plant foliage given by Chaney (1983). Typical visible symptom of B toxicity is leaf burn in the form of chlorotic and or necrotic patches, often at the margins and tips of older leaves (Benett, 1993). In this study, B phytotoxicity was not observed during the experiment. Lee et al (2008) applied CFA at 0, 40, 80, and 120 Mg/ ha in paddy soil to determine B uptake by rice and characteristics of B accumulation in the soil. Results indicated that in all CFA treatments, B content in rice leaves and available B in soil at all growing stages were higher than those of control but all were below toxicity levels. Boron occluded in amorphous iron and aluminium oxides was 20–39% of total B and was not influenced by CFA application. Most of the B accumulated by fly-ash application was residual B which is of plant-unavailable form and comprised >60% of the total B in soil. Therefore, it could reasonably be stated that CFA could be a good soil amendment for rice production without B toxicity (Lee et al., 2008). Since the B concentrations in the plants were below the toxicity limits, we can emphasis SA can be used as a soil amendment to improve the growth and yield of Komatsuna with out B toxicity. But routine investigations should be carried out to maintain the B level in the SA within the non toxic levels. In addition plants which are having B tolerance can be effectively used to minimize the B toxicity.

Table 2.4. Decomposition test results of SA

Days	Weight retained(g)					MWD (mm)			WSA (%)			C (g/kg)		
	A	B	C	CGF	AS	A	B	C	A	B	C	A	B	C
0	5.00	5.00	5.00	5.00	5.00	4.32	4.40	4.48	97.87	95.38	94.71	70.07	69.18	68.71
10	4.70	4.60	4.50	1.30	0.00	3.76	3.92	4.03	89.23	88.42	89.12	68.04	66.29	65.27
20	4.60	4.10	4.30	0.60	0.00	3.34	3.54	3.68	79.91	78.29	78.65	63.86	63.17	62.02
30	4.00	3.80	3.90	0.40	0.00	3.23	3.41	3.53	77.37	76.55	77.43	60.06	60.28	57.23
40	3.20	3.30	3.50	0.30	0.00	3.14	3.28	3.42	76.47	75.28	75.86	54.10	57.12	55.24
50	3.00	2.90	3.10	0.30	0.00	3.01	3.14	3.28	74.06	73.32	74.03	49.86	50.29	48.77

MWD: mean weight diameter, WSA: water stable aggregates, CGF= commercial granular fertilizer, AS: ammonium sulfate. Values are mean (n=3).

Table 2.5. Effects of SA on the growth of Komatsuna in red soil

Substrate	Height (cm)	Fresh weight (g/plant)	Dry weight (g/plant)	N (g/kg)	K (g/kg)	Mg (g/kg)	Ca (g/kg)	Cu (mg/kg)	Mn (mg/kg)	Se (mg/kg)	Cd (mg/kg)	Pb (mg/kg)	Zn (mg/kg)	B (mg/kg)
T1	13.92^{c}	8.86^{c}	0.39^{c}	28.12^{b}	27.11^{c}	6.36^{c}	9.18^{c}	2.71^{b}	92.18^{a}	ND	ND	0.34^{b}	31.42^{c}	3.54^{b}
T2	19.65^{a}	18.76^{a}	2.75^{a}	34.28^{a}	38.36^{a}	15.48^{a}	46.41^{a}	3.23^{a}	60.17^{b}	ND	ND	0.43^{a}	36.71^{a}	6.70^{a}
T3	19.25^{a}	16.85^{a}	2.74^{a}	34.19^{a}	36.64^{a}	14.10^{a}	44.62^{a}	3.12^{a}	62.21^{b}	ND	ND	0.40^{a}	35.24^{a}	6.16^{a}
T4	17.45^{b}	11.78^{b}	2.12^{b}	33.86^{a}	31.87^{b}	12.23^{b}	35.37^{b}	3.34^{a}	63.77^{b}	ND	ND	0.41^{a}	33.12^{b}	6.02^{a}

(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)).

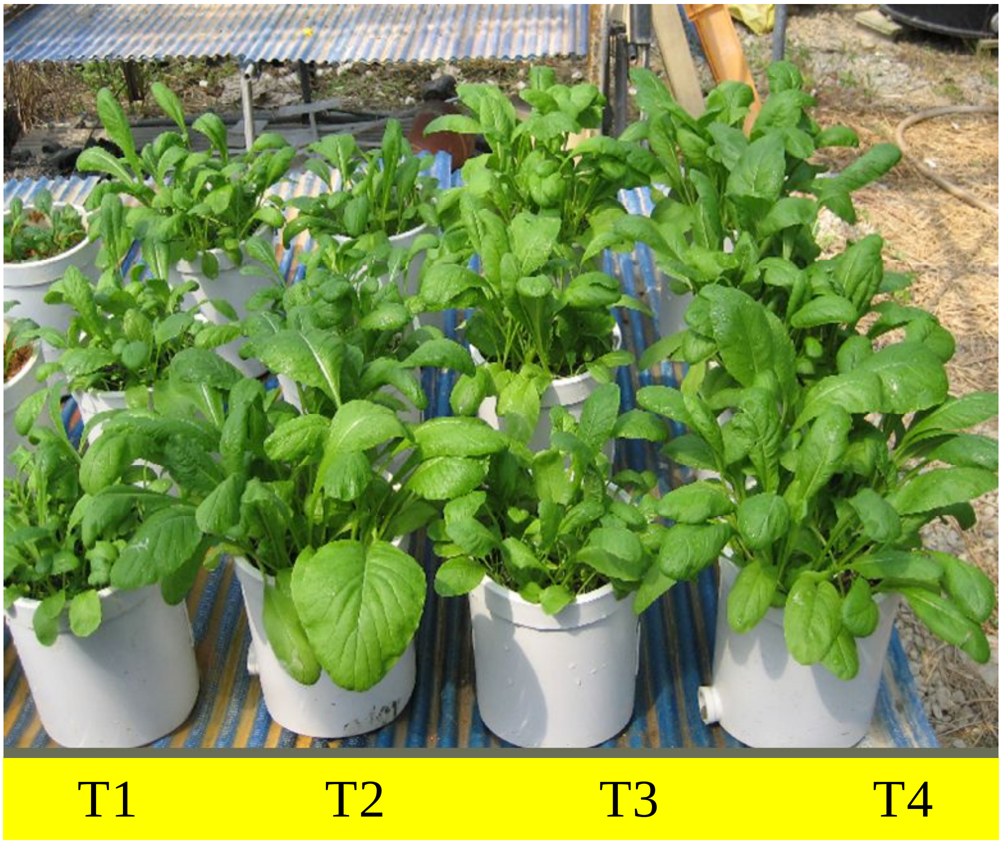


Figure 2.4. Different treatments used in the experiment.

Physical and chemical properties of different treatments are given in Table 2.6. SA addition to red soil improved chemical and physical properties of soil. It is evident SA addition to red soil significantly decreased ($P<0.05$) the bulk density (Table 2.6) by about 31%, 27%, and 17% in T2, T3, and T4, respectively compared to T1. This result is probably due to low bulk density of SA containing CFA and PW. Mixing of CFA amendments to a variety of agricultural soils tend to decrease the bulk density (Campbell et al., 1983; Page et al., 1979). PW is a rich source of C and can improve soil structure and bulk density (Simard et al., 1988). Water holding capacities of T2, T3 and T4 were increased by 20%, 17% and 12.5%, respectively compared to T1. In a previous study, it was emphasized that CFA usually dominated by silt-sized particles (Adriano et al., 1980; Ghodrati et al., 1995) and thus, if incorporated at a sufficient rate could benefit on soil water holding capacity (Aitken et al., 1984). Soil hydraulic conductivity is a measure of the ability of air and water to move through it. Saturated hydraulic conductivity of T2, T3 and T4 were significantly ($P<0.05$) higher than that of original soil (T1) (Table 2.6). Hydraulic conductivity values of T2 and T3 were greater than T4. Hydraulic conductivity of T2 was hundred times higher than that of the original red soil. The greater the bulk density, the greater the air entry suction and the smaller the hydraulic conductivity (Miyazaki, 1996; Miller and Miller, 1956). T2, T3 and T4 showed lower bulk densities between 0.87 and 1.05 g/cm^3 and red soil gave a higher bulk density value of 1.26 g/cm^3. Therefore, T2, T3 and T4 gave higher hydraulic conductivity than red soil due to low bulk density.

The particle size distribution of a substrate is important because it determines pore space, bulk density, air, hydraulic conductivity, and water holding capacity. An excess of fines clogs pores and increases non-plant available water holding capacity and decrease air filled porosity

(Spiers and Fietje, 2000). Addition of SA as a soil amendment increased particle sizes > 2 mm (Table 2.6). Red soil had a larger percentage (29.14 %) of particles <0.5mm, while this fraction was comparatively low in all soil-SA amendments. Fraction of particle sizes > 5.6 mm was higher in T2, T3 and T4 except in T1. T2 and T3 did not show any significant difference in particle size distribution but differed with T4. This may be due to mixing amounts of A, B and C type SA in soil-amendment mixtures. MWD and WSA of T2, T3 and T4 were significantly ($P<0.05$) increased compared to T1. WSA varied from 70.66 % to 82.11 % and the lowest was given by T1. Aggregate stability, a measure of soil's resistance to externally imposed disruptive forces, was increased with SA amendment. It has been reported that the addition of organic matter improved soil properties such as aggregation, water holding capacity, hydraulic conductivity, bulk density, the degree of compaction, fertility, resistance to water and wind erosion (Carter and Stewart, 1996; Zebarth et al., 1999; Franzluebbers, 2002). Therefore, we can suggest that addition of SA, which is containing CFA, PW and starch can increase soil organic matter and can improve soil physical properties. SA addition significantly neutralized original soil pH (5.12), which leads to improve bioavailability of nutrients that may be caused for the increased growth and yield of Komatsuna. This is due to addition of alkaline CFA in SA. Ca-rich CFA has been frequently found useful for crop production (Mishra and Shukla, 1986) and neutralizing acidic soils (Beresniewicz and Nowosielsky, 1987). SA addition improved acidic pH of soil to values suitable for plant growth. Moreover, SA addition increased soil EC. EC and the metal content of soil increases with increasing CFA application (Sikka and Kansal, 1994). Enrichment of CFA in SA with several essential and non essential elements may give higher EC values in soil-SA mixtures compared to original red soil. C contents of T2, T3 and T4 increased significantly ($P<0.05$) compared to original soil (Table 2.6). C content of the original soil was increased by 2 to 3 times after SA addition. This is due to addition of high C aggregates because of CFA and PW (Table 2.3). SA addition to soil significantly increased the cation (Na, K, Mg and Ca) and trace elements (Zn, Cu, Cr and Pb) concentration compared to red soil. This is due to higher concentrations of cations and trace elements in CFA and also in the SA (Table 2.3). Chemically, CFA is comprised of Si, Al, Fe, Ca, Mg, Na and K (Adriano et al., 1980) and substantially rich with trace elements like Cu, Mn, Zn and B (Jala and Goyal, 2006). But the trace elements concentrations in the soil-SA mixtures were below the maximum pollutant concentration of individual trace elements for land application of sewage sludge given by the US Environmental Protection Agency (USEPA, 1999) Trace element concentrations in soil-SA amendment mixtures were below the trace element concentrations reported in uncontaminated soils. Our results were supported by Kim et al., (1997) showing that 15% CFA in pots increased Chinese cabbage yield by 13-15%, but the trace element concentrations in tissues did not increase with CFA application. In a silt loam treated consecutively with CFA at a rate of 90 Mg/ha for three years, soybean yields increased by about 10% but trace element uptake was not significantly different from the control (Kim et al.,1994) The B contents of T2, T3 and T4 were significantly increased compared to T1. One of the major concerns for plant grown in CFA amended soil is potential B toxicity due to significant levels of B in CFA. Although B is essential to plant growth, the difference between sufficiency and toxicity is the smallest among the micronutrient (Mengel and Kirkby, 1987). B concentrations of the SA were varied between 1.14 and 2.16 mg/kg. B contents of <4, 4-10, 11-20, 21-30 and >30 mg/kg were considered as non-toxic, slightly toxic, moderately toxic, toxic and highly toxic respectively (Bradshaw and Chadwick, 1980; Hodgson and Townsend, 1973)). B levels in T2, T3 and T4 were less than 4mg/kg, which can be classified as non toxic to the plant. Application of fresh CFA can produce B toxicity in some plants, but B toxicity was not observed in plants grown on soils amended with weathered CFA because most of plant available B readily leaches from soil (Clark et al., 2001). Since B is a relatively mobile element, water-soluble B in CFA undergoes a gradual decrease with time as leaching occurs during storage (Carlson and Adriano, 1993; Cope, 1962).

Table 2.6. Physical and chemical properties of the soil after incorporation of SA.

Parameter	T1	T2	T3	T4
BD (g/cm^{3})	1.26^{a}	0.87^{d}	0.92^{c}	1.05^{b}
WHC (kg/kg)	0.48^{b}	0.58^{a}	0.56^{a}	0.54^{a}
SHC(cm/s)	6.61x10^{-5a}	6.22x10^{-3c}	2.24x10^{-3c}	2.73x10^{-4b}
Particle size distribution				
>5.60 mm	6.60^{c}	10.37^{a}	10.33^{a}	8.71^{b}
5.60-3.35 mm	15.93^{c}	22.25^{a}	22.19^{a}	20.35^{b}
3.35-2.00 mm	15.76^{b}	20.18^{a}	20.40^{a}	19.76^{a}
2.00-1.00 mm	18.86^{c}	17.16^{a}	16.73^{a}	15.22^{b}
1.00-0.50 mm	13.71^{a}	12.15^{b}	12.16^{b}	12.30^{b}
0.50-0.00 mm	29.14^{a}	17.59^{c}	18.19^{c}	23.56^{b}
MWD(mm)	2.10^{c}	3.67^{a}	3.68^{a}	3.45^{b}
WSA (%)	70.86^{c}	82.11^{a}	81.81^{a}	76.34^{a}
pH	5.12^{d}	6.57^{a}	6.33^{b}	5.92^{c}
EC(mS/m)	4.18^{c}	20.80^{a}	19.34^{a}	16.57^{b}
C(g/kg)	1.73^{d}	9.17^{a}	8.32^{b}	5.88^{c}
Exchangeable cations				
Na(g/kg)	0.06^{c}	0.19^{a}	0.17^{a}	0.12^{b}
K(g/kg)	0.05^{c}	0.22^{a}	0.19^{a}	0.15^{b}
Mg(g/kg)	0.02^{d}	0.14^{a}	0.11^{b}	0.08^{c}
Ca(g/kg)	0.07^{c}	0.48^{a}	0.41^{a}	0.38^{b}
Trace elements				
As(mg/kg)	ND	ND	ND	ND
Cr(mg/kg)	1.20^{c}	3.11^{a}	2.80^{a}	2.02^{b}
Cu(mg/kg)	13.80^{b}	19.20^{a}	18.71^{a}	16.51^{b}
Mn(mg/kg)	20.60^{a}	21.41^{a}	20.42^{a}	20.83^{a}
Se(mg/kg)	ND	ND	ND	ND
Cd(mg/kg)	ND	ND	ND	ND
Zn(mg/kg)	27.32^{c}	31.60^{a}	30.52^{a}	29.21^{b}
Pb(mg/kg)	4.73^{b}	5.12^{a}	5.40^{a}	4.92^{ab}
B(mg/kg)	0.05^{d}	2.06^{a}	1.71^{b}	1.14^{c}

BD: bulk density, WHC: water holding capacity, SHC: saturated hydraulic conductivity, MWD: mean weight diameter, WSA: water stable aggregates, EC: electrical conductivity. (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)).

Since the B content in the SA was below the toxicity level, we can suggest that SA can be used as a soil amendment with routine inspections to maintain the B limit within the safe limits. The enhanced physical and chemical properties of soil-SA amendment mixtures due to SA addition improved the growth parameters of the Komatsuna compared to original soil. Experiment results revealed that addition of higher amount of SA with low N (i.e. 550 g of A type SA with 1.72g/kg of N) improved soil physical and chemical properties and enhanced crop growth parameters than addition of lower amount of SA with high N (i.e. 300 g of C type SA with 3.29

g/kg of N) as a fertilizer and a soil amendment. SA addition to red soil as a fertilizer and a soil amendment can be suggested as a good practice for the Komatsuna production.

2.1.5. Conclusions

This study has aimed to provide information regarding SA produced by CFA, PW, AS and starch as a N fertilizer and a soil ameliorant to develop crop production in low productive red soil in Okinawa, Japan. SA had low bulk density (0.58-0.62 g/cm^3), high water holding capacity (0.60-0.64 kg/kg), high saturated hydraulic conductivity (2.34×10^{-2} cm/s), high mean weight diameter (MWD) (4.32-4.48 mm), alkaline pH (8.58-8.61), high electrical conductivity (EC) (82.18-84.35 mS/m), high carbon (C) content (68.71-70.07 g/kg) and high cation concentrations compared to the acidic red soil. The trace element concentrations of the developed SA were below the maximum pollutant concentration of individual metals for land application of sewage sludge given by the US Environmental Protection Agency. Scanning electron microscopic (SEM) study showed higher structural surface area of SA, where round shape CFA particles were embedded into the fibrous PW matrix. Incorporation of SA to the low productive acidic red soil can improve the soil fertility and soil physical and chemical properties such as neutralizing soil pH, increasing electrical conductivity, decreasing bulk density, enhancing hydraulic conductivity, increasing water holding capacity and increasing soil C content. SA addition to red soil improved the growth and yield parameters of Komatsuna compared to red soil with no SA addition. Long term effect of C, organic matter and B on soil after SA addition should be conducted in future studies. Additional researches should be conducted to increase the N content in SA to reduce applying SA quantity to soil as an amendment. Further researches should be undertaken for wide variety of plant species to check out the suitability of the SA as a fertilizer and a soil amendment.

2.2. Evaluation of coal fly ash based synthetic aggregates (CSA) developed from coal fly ash, paper waste, calcium sulfate and calcium hydroxide as a soil ameliorant for the low productive acidic red soil

2.2.1. Introduction

There is an urgent need to solve the disposal problems of this increasing generation of CFA. CFA has been examined as a resource material and has been found to comprise most of constituents, except nitrogen (N) and humus, required for growth of agricultural crops. It can be used to correct nutrient deficiencies and to prevent metal toxicity by neutralizing soil acidity (Adriano et al., 1980). Several researches have been undertaken on CFA utilization in agriculture (Bhumbla et al., 1991). The uptake of various nutrients and some toxic trace elements by crops after CFA amendment has been studied and plant production has been found safe for consumption (Sen et al., 1997). Several past studies have shown that CFA has positive effects as a liming agent, soil conditioner, and a source of essential plant nutrients and is also effective in reclamation of waste, degraded land and mine spoil (Ram et al., 1999, 2006). CFA increases the surface area available for element adsorption, improves soil physical properties (Gorman et al., 2000), neutralizes acidic soil pH and renders most cationic metals less mobile (Ciccu et al., 2003). Using CFAs as soil amendments would solve several problems by reducing the amount of land fill used for ashes, reducing consumption of soil amendments (fertilizers) and decreasing the metal mobility and availability in soil (Ciccu et al., 2003; Mittra et al., 2005). Furthermore, the strong correlation between pH correction and nutrient availability in soil suggests that most elements in CFA are associated with the mineral phase. One can therefore expect that interaction between the predominantly inorganic CFA and organic matter may further enhance its beneficial effect on plant growth in problematic soils (Page et al., 1979; Molliner and Street 1982). Increased microbial activity was reported for ash-amended soils containing sewage sludge (Pitchel 1990). While CFA has proven beneficial in land reclamation efforts, the fineness of the particles has limited its usefulness as a soil amendment where larger particles are desired (Fretz et al., 1980). Moreover, simply mixing only CFA with soil created many handling difficulties (Adriano et al. 1980). Therefore, the work presented here introduces a new method of utilizing waste CFA by converting it into unconventional granular synthetic aggregates (CSA) by mixing with paper waste (PW), lime and gypsum. Several studies have used lime materials (calcium oxides and calcium hydroxides) and gypsum (calcium sulfate) to bind CFA particles (Rush et al., 2002; Kumar 2002, 2003). Therefore, calcium hydroxide and gypsum were utilized to bind CFA particles and PW in the present study. Developed aggregates were utilized as a soil amendment to improve the low productive red soil in Okinawa, Japan.

2.2.2 Objectives of the study:

This study was conducted with the objective of improving the properties of this acidic red soil to form an arable crop growth medium by amending it with CSA.

2.2.3. Materials and methods

2.2.3.1. Sample collection

Some of the physical and chemical properties of CFA, PW and red soil used in this study are given in Table 2.7. CFA was collected from the thermal power plant of the Okinawa electric company located at Gushikawa, Okinawa, Japan. PW was collected from Ojiryokka Company, Tokyo, Japan. Red soil samples were collected from Miyagi-Sajibaru, Higashi-Son, Kunigami-Gun, Okinawa. The soil texture was heavy clay and is classified as an Ultisol. Collected soil samples were air-dried and then sieved through a 10-mm mesh screen and utilized as a growing medium. A portion of this soil was used to analyze the particle size distribution using the dry sieving method (Yoder 1936); another portion was sieved through a 2-mm mesh sieve, and used for chemical analysis.

2.2.3.2. Production of CSA and CSA–soil amendment mixtures

CSA (Figure 2.5) were produced by combining CFA and PW using an Eirich mixer (R-02M / C27121) with calcium hydroxide and gypsum. 1000 g of CFA and 75 g of PW were mixed in the Eirich mixer with 50 g of calcium hydroxide and 50 g of gypsum by adding 350 ml of water to produce CSA (Figure 2.5). Three different CSA–soil mixtures were used to enhance properties of the red soil to form an arable growth medium for crop production. The different treatments of the experiment are given in Table 2.8. Mixing ratios of CSA: soils were 1:1 (T2), 1:5 (T3) and 1:10 (T4) (V / V), respectively. The control (T1) was red soil only.

Figure 2.5. Developed aggregates.

2.2.3.3. Analytical methods

2.2.3.3.1. Physical properties:

Samples for bulk density measurements of CFA, CSA, T1, T2, T3 and T4 (Table 2.8) were taken with a core sampler of volume 100 cm^3, oven-dried, and weighed (Blake and Hartage 1986a). Particle densities of CFA, CSA, T1, T2, T3 and T4 were determined by the pycnometer method (Blake and Hartage 1986b). Saturated hydraulic conductivities of the T1, T2, T3 and T4 were determined by the falling head method (Klute 1965). CSA, T1, T2, T3 and T4 were used to fill 100 cm^3 core-samplers and were saturated with water for 48 h and kept for 24 h until gravitational water drained off. Then, the amount of water held by each sample at field capacity was calculated as water holding capacity (kg kg^{-1}). All measurements were replicated three times. Aggregate strength of CSA was determined by hardness testing machine (Kiya Digital Hardness Tester, KHT-20, Japan). Five randomly selected samples of CSA were used to determine the average aggregate strength. Samples of air-dried CSA, T1, T2, T3 and T4 were passed through a series of sieves, from 5.6 mm to 0.25 mm, to determine their particle size distribution.

2.2.3.3.2. Chemical properties

The pH was measured in water extracts of all media samples using a glass electrode (sample: distilled water ratio of 1:2.5), and electrical conductivity (EC) was measured using an EC meter (D-54, Horiba) (sample: distilled water ratio of 1:5). One gram of each dried substrate sample was utilized to determine C and N contents by using CN coder (Micro coder JM 10). C and N contents in the dried substrate samples were burnt to CO_2, NOx and N_2 during analysis and the C and N contents in the samples were automatically detected using a standard calibration curve. Total concentrations of sodium (Na), potassium (K), magnesium (Mg) and calcium (Ca) of the substrates were determined (Schollenberger and Simon 1945). The cations of the air-dried substrate samples were extracted using 1 M ammonium acetate. Then the extracts were used to analyze the cation concentration by atomic absorption spectrophotometry (AAS; Solaar 969, Thermo Corporation, Tokyo, Japan). The substrates were digested in nitric acid (USEPA 1996) and analyzed for heavy metals by AAS (Solaar 969). Total phosphorous (P) of samples was determined by spectrophotometer.

Table 2.7 Selected physical and chemical properties of CFA, PW CSA and red soil used in the experiment.

Particulars	CFA	PW	CSA	Red soil
Bulk density (gcm^{-3})	0.92±0.06	-	0.64±0.08	1.26±0.03
Particle density (gcm^{-3})	2.14±0.07	-	2.31±0.09	2.65±0.06
pH	10.87±0.20	5.70±0.32	10.72±0.26	5.12±0.04
EC (mSm^{-1})	92.70±0. 80	10.28±0.52	90.40±0.90	4.18±0.08
C (gkg^{-1})	43.26±1.88	374.8±2.76	55.22±2.04	1.73±0.04
N (gkg^{-1})	0.52±0.06	0.38±0.10	0.42±0.08	0.40±0.04
CEC ($cmol_ckg^{-1}$)	5.22±0.08	-	6.27±0.10	4.30±0.04
P (gkg^{-1})	0.07±0.01	0.06±0.01	0.06±0.01	0.03±0.01
Na (gkg^{-1})	1.02±0.05	0.24±0.09	0.78±0.09	0.06±0.01
K (gkg^{-1})	1.68±0.14	0.32±0.05	1.56±0.21	0.05±0.01
Mg (gkg^{-1})	0.87±0.12	0.47±0.11	0.73±0.26	0.02±0.00
Ca (gkg^{-1})	3.45±0.17	0.63±0.17	37.25±0.23	0.07±0.01
As ($mgkg^{-1}$)	0.3±0.00	ND	0.2±0.00	ND
Cr ($mgkg^{-1}$)	12.8±1.23	3.7±0.34	7.6±0.17	1.2±0.10
Cu ($mgkg^{-1}$)	32.5±2.04	8.5±0.49	18.5±0.12	13.8±0.22
Se ($mgkg^{-1}$)	ND	ND	ND	ND
Mn($mgkg^{-1}$)	18.90±2.30	6.52±1.26	19.20±2.42	20.6±1.95
Cd ($mgkg^{-1}$)	ND	ND	ND	ND
Zn ($mgkg^{-1}$)	48.4±1.38	10.1±0.42	34.6±0.12	27.3±29.8
Pb ($mgkg^{-1}$)	13.6±0.85	0.63±0.16	7.6±0.02	4.7±0.06
Aggregate strength ($kgcm^{-2}$)	-		3.88±0.16	-

CFA: coal fly ash, PW: paper waste, CSA: coal fly ash based synthetic aggregates: Values are mean ±Standard Deviation (n=3): ND = Not Detected.

Table 2.8. Different treatments were used under the study.

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

2.2.3.4. Pot experiment

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. The experiment was a completely randomized design of four treatments and three replicates. The diameter and the height of the pots were 16 and 20 cm. All four treatments are shown in Table 2.8. Soil (T1) and CSA-soil mixtures (T2, T3 and T4) were filled into each pot leaving a distance of 1 cm from the top of the pot without unnecessary compaction. All pots were saturated and kept for 48 h to attain their respective field capacities. Ten seeds were initially sown and thinned 1 week after germination, leaving four plants per pot. Pots were arranged in a greenhouse and 200 mL of water was added once in every 2 days to each pot. Experiments were terminated 42 days (6 weeks) after planting. In addition, 2 g of fertilizer (N:P:K=15%:15%:15%) was incorporated as a basal dressing in each pot before seeding and after saturation. Plant height and fresh weight were determined. Subsequently, plants were oven-dried at 70°C for 48 h to determine the dry weight. Mineral element concentrations of plant shoots (aboveground parts) were analyzed by AAS (Solaar 969). Plant materials were ground and passed through 2mm mesh sieve and digested with nitric acid for the analysis.

2.2.3.5. Statistical analysis

Obtained data were subjected to analysis of variance to determine the treatment effects. Duncan's multiple comparison range test was used to determine significant differences between the treatments using SAS package (SAS Institute 1990).

2.2.4. Results and Discussion

2.2.4.1. Effects of CSA amendment on soil physical and chemical properties

2.2.4.1.1. Physical properties

CSA addition affected physical properties of the red soil (Table 2.9). CSA addition significantly ($P < 0.05$) decreased the soil bulk density by about 30, 14 and 11% in T2, T3 and T4, respectively. This result is probably due to both CFA and PW, which composed the CSA. Indeed, CFA amendments to a variety of agricultural soils tend to decrease the bulk density, which in turn improves soil porosity and workability (Page et al., 1979; Campbell et al., 1983). The large proportions of silt-sized particles in CFA induce a decrease in soil bulk density (Adriano et al., 1980; Aitken et al., 1984). In addition, PW can also improve the bulk density (Simard et al., 1998). Since, CSA reduced the soil bulk density; it can enhance the porosity and permeability. The greater the bulk density, the greater the air entry suction and the smaller the hydraulic conductivity (Miller and Miller 1956; Miyazaki 1996). Average bulk densities of the treatments where CSA added were between 0.89 and 1.12 gcm^{-3}. In contrast red soil showed a higher bulk density value of 1.26 gcm^{-3}. Soil hydraulic conductivity is a measure of the ability of air and water to move through it and is influenced by size, shape, and continuity of the pore spaces, which in turn depends on density, structure, and texture. 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 2.9). The maximum average saturated hydraulic conductivity value of 5.52×10^{-3} cm s^{-1} was given by T2 where CSA: soil was 1:1. T3 and T4 were not significantly different from each other but were significantly different from T2. The addition of CSA increased hydraulic conductivity of T3 and T4 by ten times and T2 by 100 times. Chang et al (1977) reported that hydraulic conductivity of soils increased with CFA application and surface encrustation was reduced. Therefore, CFA in CSA can enhance the hydraulic conductivity of soils. CSA addition to red soil also reduced particle density compared with the original soil. The CSA: soil of 1:1 (T2) gave the lowest particle density of 2.46 g cm^{-3}. 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). The water holding capacity of T1 was 0.48 kg kg^{-1}, which was significantly different ($P < 0.05$) from that of CSA addition treatments of T2, T3, and T4. 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. This may be due to CFA and PW in the CSA. CFA is usually dominated by silt-sized particles (Adriano et al., 1980; Aitken et al., 1984; Ghodrati et al., 1995) and thus if incorporated at a sufficient rate could benefit soil water holding capacity (Chang et al., 1977; Aitken et al., 1984). Chang et al (1977) reported that the water holding capacity of soils increased by 8% due to CFA amendment; and similarly, PW can also enhance soil water holding capacity (Bellamy et al., 1995; Simard et al., 1998).

Table 2.9. Physical properties of different treatments used under the study

Treatments	Bulk density (gcm^{-3})	Saturated hydraulic conductivity (cms^{-1})	Particle density (gcm^{-3})	Water holding capacity ($kgkg^{-1}$)
T1	1.26 ± 0.06^{a}	$6.62\times10^{-5}\pm0.00^{c}$	2.65 ± 0.04^{a}	0.48 ± 0.04^{c}
T2	0.89 ± 0.04^{d}	$5.52\times10^{-3}\pm0.00^{a}$	2.46 ± 0.05^{d}	0.59 ± 0.03^{a}
T3	1.08 ± 0.03^{c}	$2.81\times10^{-4}\pm0.00^{b}$	2.51 ± 0.09^{c}	0.54 ± 0.02^{b}
T4	1.12 ± 0.04^{b}	$2.72\times10^{-4}\pm0.00^{b}$	2.59 ± 0.04^{b}	0.53 ± 0.03^{b}

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

The particle size distribution of a growing medium is important because it determines pore space, air and water holding capacities. An excess of fine particles clogs pores, and increases non-plant available water holding capacity and decreases air-filled porosity (Spiers and Fietje 2000). The particle size distribution of the different growth media used in the study are shown in Table 2.10. 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, CFA 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 2.10). CSA production reduced the finer fraction and increased the larger particles, which would reduce handling difficulties. Incorporation of CSA in 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 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. Thus, the addition of CSA with its larger particle sizes increased porosity and permeability of the red soil.

Table 2.10. Particle size analyses of the CSA, red soil, and CSA-soil amendment mixtures.

Treatments	>5.60mm (Weight %)	5.60-3.35mm	3.35-2.00mm	2.00-1.00mm	1.00-0.50mm	< 0.50mm
CSA	26.20 ± 2.20^{a}	30.28 ± 1.40^{a}	27.54 ± 1.42^{a}	8.73 ± 0.20^{d}	5.02 ± 0.14^{e}	2.23 ± 0.06^{e}
T1	6.61 ± 0.30^{e}	18.93 ± 1.50^{d}	18.76 ± 1.90^{c}	14.86 ± 0.30^{b}	11.70 ± 0.20^{d}	29.14 ± 1.90^{a}
T2	19.18 ± 1.80^{b}	25.87 ± 1.20^{b}	20.29 ± 1.20^{b}	11.88 ± 0.34^{c}	12.60 ± 0.20^{c}	10.18 ± 0.15^{d}
T3	14.12 ± 1.20^{c}	20.56 ± 1.20^{c}	18.66 ± 0.40^{c}	14.84 ± 0.28^{b}	15.96 ± 0.60^{b}	15.86 ± 0.50^{c}
T4	9.24 ± 0.60^{d}	18.52 ± 1.00^{d}	18.60 ± 0.65^{c}	17.92 ± 0.86^{a}	17.40 ± 0.63^{a}	18.32 ± 0.88^{b}

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

2.2.4.1.2. Chemical properties

The chemical properties of the different treatments are shown in Table 2.11. The pH values of red soil, CFA and CSA were 5.12, 10.87 and 10.72, respectively (Table 2.7). Addition of alkaline CSA to the acidic red soil significantly ($P < 0.05$) decreased the pH, such that T3 and T4 were almost neutral. This is due to the alkaline CFA, lime and gypsum in the CSA. The Ca-rich CFA has been frequently found useful for crop production (Mishra et al., 1986) and neutralizing acidic soils (Beresniewicz and Nowosielsky 1987). Application of CFA to increase the pH of acidic soils (Phung et al.,1979) and improve soil texture (Chang et al., 1977) has been investigated for agronomic benefits (Adriano et al., 1980). 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. The EC and metal content of soil increases with increasing amount of CFA application (Sikka and Kansal 1994). Chemically, 90–99% of CFA is comprised of silicon (Si), aluminum (Al), Ca, Mg, Na and K (Adriano et al., 1980). Enrichment of CFA with several essential and non-essential elements may give higher EC values in CSA-amended mixtures compared to original soils. An increase in EC with CFA addition was accompanied by increased Ca and Mg concentrations, in agreement with previous findings (Page et al., 1979; Elseewi et al., 1980). There are considerable amounts of Ca and Mg in CFA, and also in the CSA produced (Table 2.7). CSA addition to soil significantly increased the Na, K, Mg and Ca concentrations compared to original soil (Table 2.11). Application of CFA can improve the nutrient status of soil, which can improve the crop production (Rautaray et al., 2003). 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 $\text{cmol}_c\,\text{kg}^{-1}$ (Table 2.11). The CEC increments in T2, T3 and T4 were 1.86, 1.76 and 1.62 $\text{cmol}_c\,\text{kg}^{-1}$, respectively compared to T1. It is evident that CSA addition to the red soil increased the CEC in comparison with the original soil. CFA has also been reported to improve the nutritional status of soils through increased CEC and by provision of some essential nutrients (Roberts 1966; Carlson and Adriano 1993; Summers et al., 1998). C content of all treatments with CSA additions increased compared with the original soil (Table 2.11), due to incorporation of PW with a C content of 374.8 g kg^{-1} (Table 2.7). PW incorporation can significantly enhance soil C content (Einsphar et al., 1984; Simard et al., 1998). The N and P contents of the different treatments were low (0.03–0.05 g kg^{-1}) and not significantly different between treatments. CFA does not seem to be an optimal source of P and has been found inferior to monocalcium phosphate (Martens 1971).

Heavy metal concentrations of the different amendment mixtures are given in Table 2.12. The copper (Cu), chromium (Cr), manganese (Mn), zinc (Zn) and lead (Pb) concentrations were higher in the amendment mixtures compared with original red soil. Selenium (Se) and cadmium (Cd) were not detected in any treatments, and arsenic (As) was detected only in T2. Heavy metal concentrations were generally well below the maximum pollutant concentration of individual metals for land application suggested by the US Environmental Protection Agency (USEPA 1999). Moreover, the heavy metal concentrations of CFA and CSA used were also low compared with the USEPA levels (Table 2.7). CFA contains trace and heavy metals that adversely affect crop growth, soil and ground water quality (Adriano et al., 1978; Page et al., 1979). The amount of heavy metals released from coal into CFA depends on coal type, composition, modes of element occurrence and combustion technology (Spears et al., 1998; Jala and Goyal 2006). Adriano et al (1978) reported that at higher CFA levels, some heavy metals might become more active and hinder microbial activity. These metals form complexes, which undergo transformation, influenced by various factors like pH, moisture, cation exchange and microbial activity (Milovsky and Kononov 1992). Leaching of CFA is a function of its physical and chemical characteristics and the hydrogeology and climatic conditions of the site (Kopsick and Angino 1981; Goetz 1983). 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. The low heavy metal concentrations in the CFA and CSA (Table 2.7) used in this experiment support earlier work on CFA that showed that the heavy metal content was very low and unlikely to affect ground water quality (Ghodrati et al., 1995). 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 in the present study were below uncontaminated soil values and not alarming, there should be routine inspections to ensure that heavy metal concentrations remain within safe limits.

2.2.4.2. 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 (Figure 2.6) with different ratios of CSA additions are shown in Table 2.13. CSA as a soil amendment significantly increased growth and yield parameters of Komatsuna 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 may be 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 (Tables 2.9 and 2.10) 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 5). The Ca-rich CFA has been frequently found useful for crop production (Mishra and Shukla, 1986; Dwivedi et al. 2007) and neutralizing acidic soils (Beresniewicz and Nowosielsky, 1987). Addition of CFA up to 8% in acidic soils increased yield of several agronomics crops (Page et al., 1979). CFA addition to soils has increased crop yield of alfalfa (*Medicago sativa*), barley (*Hordeum vulgare*), Bermuda grass (*Cynodon dactylon*) and white clover (*Trifolium repens*) and improved the physical and chemical characteristics of the soil (Page et al., 1979; Weinstein et al., 1989). 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 (Hill and Lamp 1980; Molliner and Street 1982). In addition, a mixture of CFA with organic matter is expected to further enhance biological activity in soil (Jala and Goyal 2006), reduce leaching of major nutrients (Sajwan et al., 2003) and be beneficial for vegetation (Rautaray et al., 2003; Tripathi et al., 2004). Co-utilization of mixtures of CFA, paper sludge and lime at a 60:30:10 ratio had a beneficial soil ameliorating effect (Reynolds et al., 1999). Furthermore, CSA as a soil amendment improved soil physical properties and also enhanced the soil nutrient content (Table 5). The CECs of T3 and T4 were 40 and 37% higher than the original soil due to CSA incorporation. CFA has also been reported to improve soil nutritional status through increased CEC and provision of some essential nutrients (Roberts 1966; Carlson and Adriano 1993; Summers et al., 1998).

Nutrient content of plants grown in different substrates is given in Table 2.13. CFA 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). N content in shoot tissues from the CSA-amended mixtures were higher than that of red soil (Table 2.13). A greenhouse experiment conducted by Sikka and Kansal (1995) showed that application of 2–4% CFA significantly increased N content of rice.

Table2.11. Chemical properties of different treatments used under the study

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 ± 0.04^{d}	4.18 ± 0.08^{d}	1.73 ± 0.20^{d}	0.40 ± 0.05^{a}	0.03 ± 0.00^{a}	4.30 ± 0.20^{b}	$0.06^{d}\pm0.01$	$0.05^{d}\pm0.01$	$0.02^{d}\pm0.00$	$0.07^{d}\pm0.01$
T2	8.59 ± 0.06^{a}	60.28 ± 0.22^{a}	18.55 ± 0.46^{a}	0.50 ± 0.07^{a}	0.04 ± 0.01^{a}	6.16 ± 0.06^{a}	$0.43^{a}\pm0.07$	$0.72^{a}\pm0.08$	$0.39^{a}\pm0.02$	$11.36^{a}\pm0.25$
T3	7.13 ± 0.07^{b}	20.13 ± 0.15^{b}	7.80 ± 0.50^{b}	0.40 ± 0.01^{a}	0.05 ± 0.01^{a}	6.06 ± 0.10^{a}	$0.24^{b}\pm0.05$	$0.47^{b}\pm0.07$	$0.26^{b}\pm0.08$	$3.45^{b}\pm0.23$
T4	6.37 ± 0.04^{c}	14.48 ± 0.08^{c}	4.12 ± 0.30^{c}	0.30 ± 0.02^{a}	0.03 ± 0.00^{a}	5.92 ± 0.06^{a}	$0.19^{c}\pm0.04$	$0.29^{c}\pm0.08$	$0.16^{c}\pm0.09$	$1.78^{c}\pm0.24$

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

Table 2.12. Heavy metal concentrations of different amendment mixtures

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 ± 0.22^{b}	5.8 ± 0.12^{b}	29.8 ± 1.16^{b}	5.6 ± 0.06^{b}	ND	ND	ND	20.7 ± 1.12^{a}
T2	19.77 ± 0.36^{a}	7.1 ± 0.18^{a}	44.2 ± 1.27^{a}	9.4 ± 0.11^{a}	ND	ND	0.1 ± 0.00	21.1 ± 1.24^{a}
T3	18.54 ± 0.41^{a}	6.7 ± 0.13^{a}	40.6 ± 1.41^{a}	8.3 ± 0.14^{a}	ND	ND	ND	20.8 ± 1.32^{a}
T4	13.65 ± 0.34^{b}	5.9 ± 0.16^{b}	35.1 ± 1.36^{b}	6.7 ± 0.08^{b}	ND	ND	ND	20.3 ± 1.06^{a}
USEPA	1500	1200	2800	300	39	36	41	-
UCS *	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).Mean±standard deviation (n=3).USEPA =US Environmental Protection Agency standards (1993). (*UCS, Adriano, 2001).

Table 2.13. The growth parameters and the nutrient content in the Komatsuna plants

Treatments	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 ± 0.25^{c}	3.84 ± 0.09^{c}	0.29 ± 0.04^{c}	1.46 ± 0.34^{c}	0.56 ± 0.18^{a}	2.9 ± 0.25^{c}	0.6 ± 0.11^{c}	0.5 ± 0.13^{b}	3.0 ± 0.13^{a}	92.64 ± 0.24^{a}	30.4 ± 0.45^{d}	0.4 ± 0.02^{a}
T2	14.36 ± 0.11^{b}	15.19 ± 0.20^{b}	2.91 ± 0.19^{b}	1.87 ± 0.25^{b}	0.26 ± 0.14^{d}	3.8 ± 0.11^{a}	1.5 ± 0.20^{a}	4.5 ± 0.20^{a}	3.2 ± 0.20^{a}	39.74 ± 0.21^{d}	36.7 ± 0.20^{a}	0.5 ± 0.03^{a}
T3	23.44 ± 0.42^{a}	46.95 ± 0.44^{a}	8.87 ± 0.13^{a}	2.21 ± 0.43^{a}	0.32 ± 0.10^{c}	3.6 ± 0.13^{ab}	1.4 ± 0.10^{a}	4.4 ± 0.25^{a}	3.1 ± 0.15^{a}	50.12 ± 0.14^{c}	35.2 ± 0.34^{b}	0.5 ± 0.02^{a}
T4	21.03 ± 3.37^{a}	43.59 ± 4.65^{a}	7.25 ± 1.32^{a}	2.18 ± 0.21^{a}	0.44 ± 0.16^{b}	3.4 ± 0.19^{b}	1.2 ± 0.30^{b}	4.3 ± 0.20^{a}	3.3 ± 0.25^{a}	54.16 ± 0.32^{b}	34.1 ± 0.28^{c}	0.4 ± 0.03^{a}

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

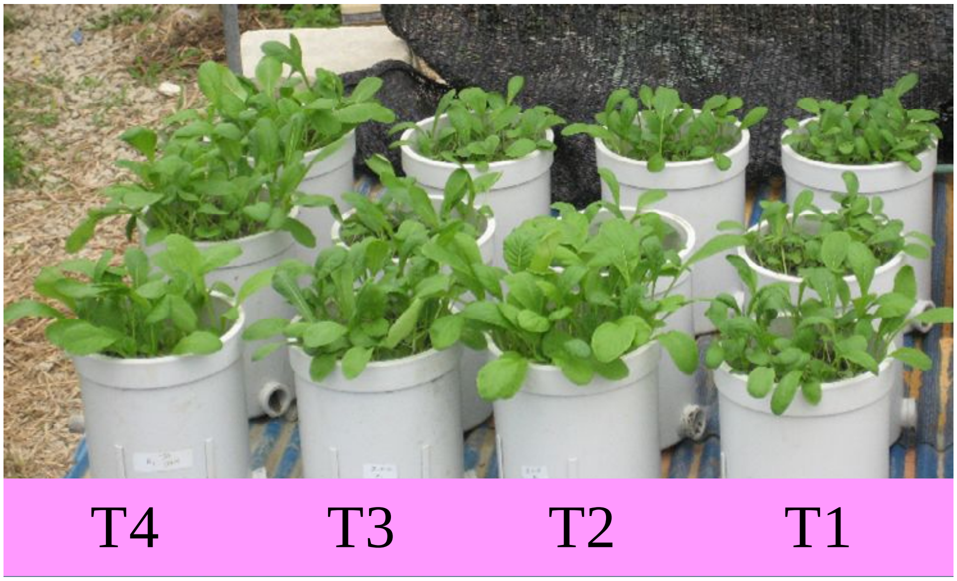


Figure 2.6. Different treatments used in the study

N content in T1 treatment was slightly below the deficiency level of 1.5% and N content in other treatments were above that level (Chapman 1966). The T2 treatment had the lowest P content in shoot tissue, and the highest was in T1. Nevertheless, P contents were still above the deficiency limits of 0.2 % suggested by Chapman (1966). The decreased P content in shoot tissues is probably due to reduced P availability at a higher soil pH and higher Ca content following CFA amendment (Wong and Wong 1990). The CSA: soil of 1:1 gave an alkaline pH of 8.59, which did not 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 2.13). Similar results were found in previous study conducted using CFA as an amendment to container substrate for *Spathiphyllum* production by Chen and 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 2.13). 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). It is likely that low pH and its related nutrient availability accounted for reduced Komatsuna growth in the red soil. Moreover, the K, Mg and Ca concentrations of shoots in the CSA mixtures significantly increased because CSA was enriched with these elements (Table 2.7). Furr et al. (1978) demonstrated that alfalfa, sorghum (*Sorghum bicolor*), field corn (*Zea mays*), onion (*Allium cepa*), beans (*Phaseolus vulgaris*), cabbage (*Brassica oleracea*), potatoes (*Solanum tuberosum*) and tomatoes (*Lycopersicon esculentum*) could be grown on acidic soil treated with 125 Mg ha^{-1} of CFA and the plants had higher concentrations of Na, K, Mg, Ca and Fe. Both shoot K, Ca and Mg contents were all above the deficiency limits of 0.7-1.5 % (Chapman 1966), 0.14 % (Loneragen and 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). There were no significant differences in Pb levels in tissues of all treatments, and Se and Cd were not detected in any tissues. Therefore heavy metal content in plant tissue was below the toxicity limits. Our results were supported by Kim et al (1997) showing that Chinese cabbage yield increased by 13-15% in pots treated with 15% CFA, but that the heavy metal contents in the tissues did not increase following the CFA application. In silt loam treated consecutively with CFA at 90 Mg ha^{-1} for three years, soybean yields increased by about 10%,but heavy metal uptake was not significantly different from control (Kim et al.1994). 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.

2.2.5. Conclusions

The results demonstrated the beneficial effects of CSA amendment on Komatsuna growth in a low-productive red soil. Incorporation of CSA in this soil improved not only fertility, but also soil physical and chemical properties by neutralizing soil pH, increasing EC, increasing CEC, decreasing bulk density, enhancing hydraulic conductivity, increasing water holding capacity, improving particle size distribution and increasing soil C content. In addition, heavy metal concentrations in the CSA-amended soil were below uncontaminated soil levels. The higher concentrations of N, Ca, K, Mg, Cu and Zn in shoot tissues grown in CSA: soil at either 1:5 or 1:10 (V/V) compared to control indicated that the CSA–soil mixtures provided good conditions for plant growth. The CSA addition to red soil at 1:5 and 1:10 produced no adverse effects on plant growth and was successful as a growth medium for Komatsuna. However, the present study did not examine the long-term effects of CSA amendment on soil for issues like nutrient availability, soil physical properties and availability of trace elements such as As, Cd and Se. Such issues require further study to assess and develop the most appropriate means to recycle these waste products for beneficial agricultural use. In addition, different plant species should be grown to study the suitability of CSA–soil mixtures as growth media. The production of CSA with different waste materials can be regarded as an effective waste management process in Okinawa.

2.3. Characterization and utilization of synthetic soil aggregates (SSA) developed from acidic soil, coal fly ash (CFA) and paper waste (PW).

2.3.1. Introduction

Coal fly ash (CFA) has also been reported to improve the nutritional status of the soil via increases in cation exchange capacity (Carlson and Adriano, 1993: Roberts, 1966) and by provision of some essential nutrients. Moreover, CFA consists of almost all naturally existing elements (Summers *et al*., 1998). Acidic "Kunigami Mahji" soil in Okinawa is not suitable for crop production due to its poor physical (Tokashiki *et al.*, 1994) and chemical properties because of high acidic conditions, low organic matter content and poor nutrient availability (Hamazaki, 1979).Therefore, an attempt was done to develop synthetic soil aggregates (SSA) from alkaline CFA, acidic red soil, paper waste (PW) and starch binder as a crop growth medium for the Komatsuna and Soybean production.

2.3.2. Objective of the Study

The objective of this study is to investigate the characteristics of synthetic soil aggregates produced by incorporating CFA, PW and starch waste to acidic "Kunigami Mahji"soil and their suitability as a crop growth medium for Komatsuna and Soybean.

2.3.3 Materials and methods

2.3.3.1. Collection of sampled materials

The CFA was collected from the thermal power plant (J-Power Company) located at Ishikawa, in Okinawa, Japan. The PW was collected from Ojiryokko Company, Okinawa. Starch was collected from Seifun Corporation, Okinawa, Japan. Soil samples were collected from Miyagi-Sajibaru, Higashi-Son, Kunigami-Gun, Okinawa, Japan. The texture of the soil was clay and was classified as an Ultisol. Collected soil samples were air dried and then sieved through a 10 mm mesh screen and utilized for SSA production. A portion of this soil was used to analyze the particle size distribution by using the dry sieving method (Yoder, 1936). A portion of this soil sample was sieved through a 2-mm mesh sieve, and used for chemical analysis.

2.3.3.2Aggregate production and property evaluation

2.3.3.2.1. Synthetic soil aggregate (SSA) production

A series of SSA were produced combining "Kunigami Mahji" soil, CFA and PW using an EIRICH mixer (R-02M/C27121) with starch as a binder. The different fractions of raw materials used in the production process are shown in Table 2.14. The percentages of CFA added to form SSA were 0%, 20%, 40%, 60%, 80% and 100% of the total weight of "Kunigami Mahji" soil. Starch paste, which was prepared at 70°C by adding 300 ml of hot water was mixed with the CFA, soil and PW mixture in the EIRICH mixer.

Table 2.14. Different proportions of raw materials used to produce synthetic soil aggregates

Materials	Coal fly ash addition (%)					
	0 (T_1)	20 (T_2)	40 (T_3)	60 (T_4)	80 (T_5)	100 (T_6)
Coal fly ash (g)	0	100	200	300	400	500
"Kunigami Mahji"soil (g)	500	500	500	500	500	500
Paper waste (g)	50	50	50	50	50	50
Starch (g)	100	100	100	100	100	100
Hot water (mL)	300	300	300	300	300	300

2.3.3.2.2. Physical properties of “Kunigami Mahji” soil, CFA, and SSA

Bulk density of the air dried SSA, “Kunigami Mahji” soil and CFA were determined (Culley, 1993). Each measurement was triplicated. The particle density values of CFA, “Kunigami Mahji” soil and SSA were determined by the pycnometer method (Blake and Hartage, 1986). Each measurement was triplicated. The Falling head method was used to determine the saturated permeability coefficient, as described by Klute (1965). Each measurement was triplicated. Water holding capacity of the SSA and soil was determined. Each measurement was triplicated.

2.3.3.2.3. Chemical properties of “Kunigami Mahji” soil, CFA, and SSA

The pH was measured in water extracts of SSA and soil using a glass electrode (Sample: distilled water ratio of 1:2.5), and electrical conductivity (EC) was measured using an EC meter (D-54, Horiba) (Sample: distilled water ratio of 1:2.5). Carbon contents of SSA and soil were determined by the Kosaka-Honda-Izeki wet digestion weight method (JSSSPN 1971), and total nitrogen content was determined by the Kjeldahl distillation method. Organic matter (OM) of the substrate samples were determined by loss of ignition at 430 °C for 24 h (Navaro et al., 1993). Exchangeable cations and cation exchange capacity (CEC) of “Kunigami Mahji” soil, CFA and SSA were determined by the method of Schollenberger and Simon (1945). For CEC determination, air dried SSA and soil samples were packed into an extraction tube, and ammonium was allowed to be absorbed using 1 M ammonium acetate for over 12 hours. After excess salt had been washed off with 80% ethanol solution, 3 M sodium chloride was dripped over 12 hours and the exchanged ammonium was measured by the Kjeldhal distillation method. Phosphorous contents of CFA, “Kunigami Mahji” soil and SSA were determined by the wet ashing method (JSSSPN, 1997). Initially the organic matter of the above samples was digested by using nitric acid and perchloric acid. Then the filtrate of the mixture was mixed with a solution of ammonium vanadate and hexaammonium heptamolybdate tetra hydrate. Finally, the phosphate content was determined at an absorbance of 440 nm. Heavy metals were extracted using 0.1M HCl and quantified using an ICP-OES (inductively coupled plasma optical emission spectrophotometer).

2.3.3.2.3. Aggregate stability of SSA

(a) *Mean weight diameter*

Wet and dry mean weight diameters of SSA were determined using method described byYoder (1936). Three replicates from each type of developed SSA were used for dry and wet sieving techniques. Mean weight diameter (MWD) (Van Bavel, 1949：Youker and McGuiness, 1956) was calculated using the following equation.

$$\mathrm{MWD} = \sum_{i=1}^{n} X_i W_i ,$$

Where, MWD = Mean weight diameter ; Xi is the mean diameter of each size class, and Wi is the fraction of the total sample mass occurring in the i^{th} size class. Mean weight diameter difference (MWDD; difference between dry MWD and the wet MWD) of the produced SSA was calculated as an indicator for the aggregate stability.

(b) *Analysis of aggregate dispersion under moving water in a mechanical shaker*

This experiment was undertaken to determine the dispersion percentage of aggregates under moving water in a mechanical shaker, which had a horizontal motion and an amplitude of 60 mm (Fujiwara Co.Ltd., Tokyo,Japan). Samples (50g) of each aggregate greater than 1 mm were put into a 200 mL bottle. Then 150 mL of water was added to the bottle and kept for 12 h of saturation. Subsequently saturated aggregates samples were shaken horizontally in the above mentioned mechanical shaker at 100 rpm for 5, 10, 24 and 48 hours. This measurement for each aggregate was triplicated. During the mechanical shaking the aggregates have a propensity to break into smaller particles because of the fast moving water. Thus, we calculated the average loss percentage of finer aggregate particles (smaller than 1 mm) as an indicator of dispersion.

2.3.3.2.5. Aggregate strength of SSA

Aggregate strength was determined using a hardness testing machine (Kiya Digital Hardness Tester, KHT-20, Japan). Five randomly selected samples of SSA were used to determine the average aggregate strength. Moisture contents of all SSA were determined by the gravimetric method.

2.3.3.3. Utilization of aggregates as a medium for crop growth

Pot experiments were conducted to study the influence of different types of SSA as a crop growth medium for crop production. Two types of crop were grown in two different pot experiments. Komatsuna, which is also known as Japanese mustard spinach (*Brassica rapa Var.Pervidis*) and Soybean (*Glycine max*), were grown in the pot experiment (pot size was 1/5000 a). The experimental design of the pot experiments was a completely randomized design (CRD) with seven treatments in both experiments. All seven treatments are shown in Table 2.15. All produced SSA were considered as treatments (T_1 to T_6), while “Kunigami Mahji” soil only (T_7) was considered as the control for both types of plants. Air dried SSA and air dried soil samples were filled into each pot leaving a distance of 1 cm from the top of the pot and without subjecting them to unnecessary compaction. All pots were saturated and kept for 48 hours to attain their respective field capacities. Each treatment (from T_1 to T_7) was replicated three times. Ten seeds were sown initially and thinning was done after 1 week of germination to leave four plants in each experiment. Pots were arranged in a green house and 300 ml of water was added once in every 2 days after the first 10 days to each pot. Experiments were terminated after 42 days (6 weeks) of planting in both trials. In addition, 2g of fertilizer (N: P: K; 15%:15%:15%) was incorporated as a basal dressing before seeding (but after saturation) to each pot. Plant height and plant fresh weight were determined. Subsequently, Plants were dried in an oven at 70^0C for 48 hours in order to determine the dry weight.

Table 2.15. Different treatments were used in the pot experiments.

Treatments	Description
T_1	Aggregates with no CFA addition
T_2	Aggregates produced by 20% CFA addition
T_3	Aggregates produced by 40% CFA addition
T_4	Aggregates produced by 60% CFA addition
T_5	Aggregates produced by 80% CFA addition
T_6	Aggregates produced by 100% CFA addition
T_7	Control (i.e. “Kunigami Mahji” soil only)

2.3.3.4. Statistical analysis

The obtained data were subjected to analysis of variance (ANOVA) for determination of the treatment effects. Duncan’s multiple comparison range test (DMRT) procedure was employed to denote significant differences between the treatments using the SAS package (SAS Institute, 1990).

2.3.4 .Results and discussions

2.3.4.1. Aggregate production and property evaluation

2.3.4.1.1. Physical and chemical properties of coal fly ash and “Kunigami Mahji” soil

Physical and chemical properties of coal fly ash and “Kunigami Mahji” soil are presented in Table 2.16. Results of CFA analysis gave particle density and bulk density values of 2.10 and 0.96 g/cm^3, respectively, and an alkaline pH of 11.7. In general, the pH of CFA varies from 4.5 to 12.0 depending largely on the sulfur content of the parent coal (Plank and Martens, 1974) and the type of coal used for combustion affects the sulfur content of CFA (Page et al., 1979). CFA contains considerable concentrations of exchangeable cations (Table 2.16). The sodium (Na), potassium (K), magnesium (Mg) and calcium (Ca) concentrations of the CFA were 0.8, 2.2, 1.3 and 6.2 cmol$_c$kg^{-1}, respectively. Electrical conductivity (EC) and cation exchange capacity (CEC) of the CFA were 69.60 mS/m and 5.14 cmol$_c$kg^{-1}, respectively. Enrichment of CFA with high concentrations of several elements gave high EC values. Nitrogen (N), phosphorous (P), carbon (C) and organic matter contents of CFA were 0.5, 0.04, 41.3 and 48g/kg, respectively. In contrast, the “Kunigami Mahji” soil used in the study had particle density and bulk density values of 2.67 and 1.23 g/cm^3, respectively. “Kunigami Mahji” soil also had an acidic pH (4.62), an EC value of 3.27mS/m and a CEC of 4.30 Cmol$_c$kg^{-1}. Na, K, Mg and Ca concentrations of the soil were 0.02, 0.1, 0.03 and 0.1 Cmol$_c$kg^{-1}, respectively. Moreover, N, P and C amounts were 0.4, 0.07 and 1.6 g/kg, respectively. The CFA may also contain non-essential elements (e.g., As, B, Cd and Se) that adversely affect crop growth, soil and ground water quality (Adriano *et al.*, 1978: Page et al., 1979). Heavy metal concentrations were found to exist in the CFA (Table 2.17). However, these concentrations were generally well below the maximum pollutant concentration of individual metals for land application suggested by the Japan Environmental Ministry (EQS, 1994). The present results support earlier work on CFA, showing that leaching of trace elements was very low and was unlikely to affect ground water quality (Ghodrati et al., 1995).

2.3.4.1.2. Physical properties of SSA

Table 2.16. Selected physical and chemical properties of CFA and “Kunigami Mahji” soil used in the experiments

Particulars	CFA	“Kunigami Mahji” soil
Bulk density (g/cm^3)	0.96±0.04	1.23±0.02
pH	11.70±0.13	4.62±0.03
Particle density (g/cm^3)	2.10±0.03	2.67±0.04
EC (mS/m)	69.60±0.05	3.27±0.08
Organic matter (%)	4.80±0.08	2.60±0.82
C (g/kg)	41.3±1.41	1.60±0.06
N (g/kg)	0.50±0.04	0.40±0.04
P (g/kg)	0.04±0.01	0.07±0.01
CEC (cmol$_c$kg^{-1})	5.14±0.08	4.30±0.04
Na (cmol$_c$kg^{-1})	0.80±0.02	0.02±0.00
K (cmol$_c$kg^{-1})	2.20±0.04	0.10±0.03
Mg (cmol$_c$kg^{-1})	1.30±0.03	0.03±0.01
Ca (cmol$_c$kg^{-1})	6.20±0.17	0.10±0.02

CFA: coal fly ash, Values are mean ±standard deviation (n=3).

Physical properties of all SSA (Figure 2.7) are shown in Table 2.18. It is evident that the addition of CFA, PW and starch has significant effects (at 0.05 significance level) on the particle density and bulk density values of SSA when compared with the original "Kunigami Mahji" soil (T_7). The particle density of SSA varied between 2.39 and 2.14 g/cm^3 from 20% (T_2) CFA application to 100% (T_6) CFA application. Particle density of the "Kunigami Mahji" soil was 2.67 g/cm^3. Particle density of the aggregates without CFA addition (T_1) was 2.44 g/cm^3, which represented a significant reduction from that of the "Kunigami Mahji" soil (T_7) due to the addition of PW and starch.

Table 2.17 Heavy metal concentrations in CFA.

Metal	Cd	Pb	Cr	As	Hg	Se	F	B	Cu	Zn
Concentrations (mg/kg)	0.003 ± 0.00	0.01 ± 0.00	0.04 ± 0.01	0.002 ± 0.00	0.0005 ± 0.00	0.005 ± 0.00	1.10 ± 0.3	0.68 ± 0.1	0.01 ± 0.00	0.41 ± 0.04
EQS*(mg/kg)	0.01	0.01	0.05	0.01	0.005	0.01	0.8	1.0	3.0	5.0

* Environmental Quality Standards. Values are mean ±standard deviation (n=3)

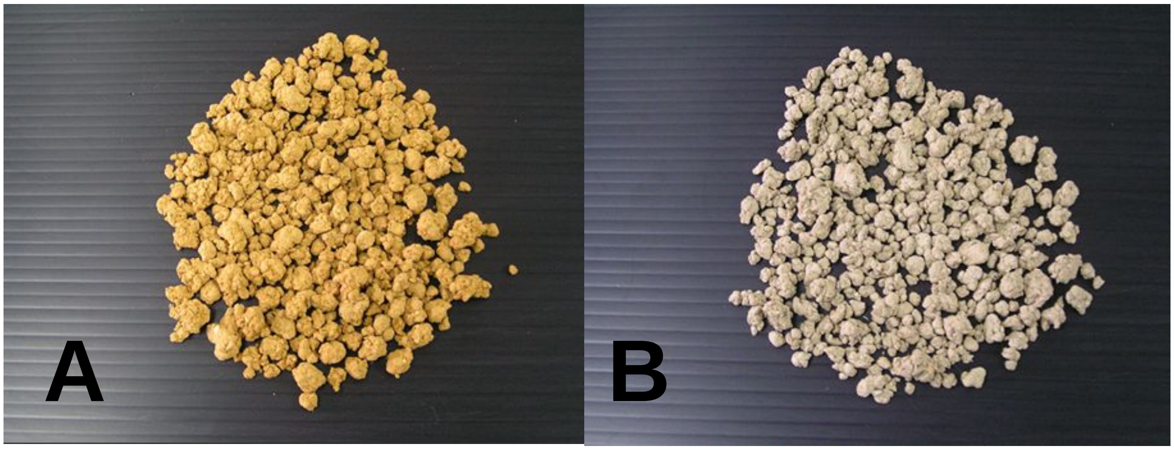


Figure 2.7: Aggregates produced from CFA, "Kunigami Mahji" soil, PW and starch binder. (A: Aggregates with no CFA B: Aggregates with CFA).

The CFA incorporation to produce SSA gave a reduction in particle density compared with SSA without CFA addition and the original "Kunigami Mahji" soil, because CFA had a low particle density of 2.10 g/cm^3. Bulk density of SSA reduced significantly in comparison with the original "Kunigami Mahji" soil (1.23 g/cm^3) and varied between 0.72 and 0.87g/cm^3 (Table 2.18). This represents about 30% reduction in bulk density compared with "Kunigami Mahji" soil. There was a significant effect (at 0.05 significance level) on the bulk density between SSA with no CFA addition (T_1) and "Kunigami Mahji" soil. This may be due to the addition of PW and starch. More over, there was a significant reduction (at 0.05 significance level) of the bulk density between SSA with no CFA addition (T_1) and SSA with CFA addition. This may be due to the low bulk density of CFA. The lowest bulk density (0.72 g/cm^3) was observed in the SSA which contained 20% of fly ash addition (T_2). The CFA addition generally decreased the bulk density of soils, which in turn improved soil porosity and workability and enhanced water retention capacity (Campbell *et al.*, 1983: Page *et al.*, 1979). The large proportion of silt–sized particles in CFA is presumably responsible for this effect on soil bulk density. There fore, these SSA can enhance the porosity and the permeability due to these low bulk density values. Water holding capacity of the original soil (T_7) was 0.51 kg/kg, which differed significantly (at 0.05 significance level) from that of produced SSA. Average water holding capacities of SSA varied between 0.63 and 0.68 kg/kg, and that represented about a 25% increment of the water holding capacity of SSA in comparison with soil (T_7). There was a significant difference in water holding capacities between SSA with no CFA addition (T_1) and the soil (T_7). This was due to the addition of PW. Furthermore, there was a significant difference in water holding capacities between SSA with no CFA addition (T_1) and SSA with CFA addition. The CFA is composed primarily of fine sand and silt particles, and therefore, if applied at sufficient rates, it can be used to change soil texture to increase soil water holding capacity (Adriano *et al.*, 1980: Aitken *et al.*, 1984: Gangloff *et al*., 2000). Water holding capacities are enhanced due to the dominance of silt-sized particles in CFA and the addition of CFA increased water holding capacity by factors of 7.2 and 13.5 for fine and coarse sands, respectively (Campbell *et al* .1983). The water holding capacity of sandy/loamy soils increased by 8% due to CFA amendment (Chang *et al.*, 1977). The hydraulic conductivity of soil 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 depends on the density, structure and the texture. Hydraulic conductivity values of SSA showed highly significant differences (at 0.05 significance level) in comparison with the original "Kunigami Mahji" soil (T_7). Original "Kunigami Mahji"soil (T_7) showed a very low hydraulic conductivity, which is very close to the impermeable (6.621×10^{-5}cm/s) level. The average saturated hydraulic conductivity value of the produced SSA was 2.86×10^{-2} cm/s. Moreover, the hydraulic conductivity values of produced SSA were a thousand times higher than that of the original "Kunigami Mahji" soil. Therefore, hydraulic conductivity can be significantly enhanced by the production of aggregates by incorporating PW, starch and CFA to the original "Kunigami Mahji" soil.

Table 2.18 Physical properties of different types of synthetic soil aggregate studied

Treatments	Particle density (g/cm ^{3})	Bulk density (g/cm ^{3})	Water holding capacity (kg/kg)	Saturated hydraulic conductivity (cm/sec)
T_1	2.44 ± 0.01^b	0.87 ± 0.03^b	0.63 ± 0.02^b	$1.867\times10^{-2}\pm0.00^a$
T_2	2.39 ± 0.02^c	0.72 ± 0.02^d	0.67 ± 0.01^a	$2.241\times10^{-2}\pm0.00^a$
T_3	2.36 ± 0.01^c	0.79 ± 0.03^c	0.68 ± 0.01^a	$2.801\times10^{-2}\pm0.00^a$
T_4	2.31 ± 0.02^d	0.79 ± 0.04^c	0.68 ± 0.02^a	$3.735\times10^{-2}\pm0.00^a$
T_5	2.20 ± 0.02^e	0.80 ± 0.04^c	0.68 ± 0.01^a	$3.735\times10^{-2}\pm0.00^a$
T_6	2.14 ± 0.03^e	0.81 ± 0.03^c	0.68 ± 0.02^a	$2.801\times10^{-2}\pm0.00^a$
T_7 (Control)	2.67 ± 0.03^a	1.23 ± 0.05^a	0.51 ± 0.03^c	$6.621\times10^{-5}\pm0.00^b$

(T_1=Aggregates with no CFA addition, T_2=Aggregates produced by 20% CFA addition, T_3=Aggregates produced by 40% CFA addition, T_4=Aggregates produced by 60% CFA addition, T_5=Aggregates produced by 80% CFA addition, T_6=Aggregates produced by 100% CFA addition, T_7="Kunigami Mahji" soil only). (Means followed by the different superscript letter in the same column differed significantly according to Duncan's multiple range test (P=0.05).s

2.3.4.1.3. Chemical properties of SSA

The chemical properties of SSA are shown in Table 2.19. SSA produced without CFA addition (T_1) had a pH value of 4.57, which was slightly lower than that of the original "Kunigami Mahji" soil (T_7), which had a pH value of 4.62. This may be due to the addition of PW and starch as a binder. The pH values of PW and starch were 5.70 and 3.80, respectively. Other SSA, to which, CFA was added, showed the expected increases in pH values varying between 6.70 and 9.96, compared with SSA without CFA addition (T_1). The pH values significantly increased (at 0.05 significance level) with the increasing percentages of CFA added to produce SSA. The addition of 20% CFA to form SSA with “Kunigami Mahji” soil (T_2) gave a pH value of 6.70, which is almost in the neutral range, while CFA addition over 20% gave highly alkaline SSA, which had pH values between 7.80 and 9.96. SSA with a wide range of pH values can be produced by adding different percentages of alkaline CFA to the acidic “Kunigami Mahji” soil. Electrical conductivity (EC) of produced SSA showed a significant increase compared with the original “Kunigami Mahji” soil (3.27 mS/m). The EC value of SSA without CFA addition also showed a significant difference (at 0.05 significance level) from the “Kunigami Mahji”soil (T_7) (see Table 2.19). The EC value of SSA having 20% of coal ash addition was 38.80 mS/m. EC values of SSA with CFA addition from 40% to 100% varied in the range of 50.60-66.80 mS/m. EC of SSA increased significantly with the incorporation of CFA. The EC of soil increases with increasing CFA application and so does the metal content in soil (Sikka and Kansal, 1994). Enrichment of CFA with several essential and non essential elements may give high EC values in the SSA. Figure 2.8 shows the exchangeable cation concentrations of the SSA. There was no significant difference between SSA with no CFA addition (T_1) and the “Kunigami Mahji” soil (T_7). It is evident that the exchangeable cation concentration increases with increasing percentage of CFA addition. The highest concentration was given at the 100% CFA addition. Therefore, an increase in EC with ash addition was accompanied by an increase in Ca and Mg concentrations, which is in agreement with previous findings (Elseewi *et al.*, 1980).

Table 2.19 Chemical properties of different types of synthetic soil aggregate studied

Treat ments	pH (water)	EC (mS/m)	Organic matter (g/kg)	CEC ($Cmol_c kg^{-1}$)	C (g/kg)	N (g/kg)	P (g/kg)
T_1	4.57 ± 0.06^f	6.36 ± 0.05^f	156 ± 3.22^a	6.08 ± 0.03^f	84.0 ± 0.72^a	0.4 ± 0.06^a	0.05 ± 0.07^a
T_2	6.70 ± 0.07^e	38.80 ± 0.11^e	148 ± 4.88^b	6.18 ± 0.02^e	77.8 ± 0.56^b	0.4 ± 0.02^a	0.05 ± 0.05^a
T_3	7.80 ± 0.05^d	50.60 ± 1.32^d	137 ± 5.38^c	6.36 ± 0.05^d	73.0 ± 0.27^c	0.4 ± 0.03^a	0.05 ± 0.02^a
T_4	9.10 ± 0.06^c	53.82 ± 0.56^c	112 ± 3.61^d	6.48 ± 0.03^c	69.3 ± 0.44^d	0.4 ± 0.02^a	0.05 ± 0.06^a
T_5	9.71 ± 0.07^b	57.50 ± 0.77^b	108 ± 2.65^d	6.57 ± 0.06^b	66.2 ± 0.66^d	0.4 ± 0.03^a	0.05 ± 0.03^a
T_6	9.96 ± 0.05^a	66.80 ± 1.07^a	106 ± 3.00^d	6.82 ± 0.02^a	63.7 ± 0.36^d	0.4 ± 0.06^a	0.05 ± 0.02^a
T_7	4.62 ± 0.04^f	3.27 ± 0.28^g	26 ± 0.72^e	4.30 ± 0.04^g	1.6 ± 0.20^e	0.4 ± 0.05^a	0.07 ± 0.04^a

(T_1=Aggregates with no CFA addition, T_2=Aggregates produced by 20% CFA addition, T_3=Aggregates produced by 40% CFA addition, T_4=Aggregates produced by 60% CFA addition, T_5=Aggregates produced by 80% CFA addition, T_6=Aggregates produced by 100% CFA addition, T_7=“Kunigami Mahji” soil only). (Means followed by the different superscript letter in the same column differed significantly according to Duncan’s multiple range test (P=0.05).Mean±standard deviation (n=3).

Organic matter content of all produced SSA increased (Table 2.19) significantly in comparison with the original soil due to the incorporation of PW and starch as a binder. The PW is a rich source of carbon and improves soil organic matter contents, water holding capacity, soil structure and bulk density (Simard *et al.*, 1998). Decomposition rate of the PW added to the soil depends on the environmental conditions of the site and PW incorporation into the soil can increase the soil organic matter content significantly (Einspahr *et al.*, 1984). There were significant differences in organic matter content between different types of SSA, compared with “Kunigami Mahji” soil. CEC values of the SSA showed a significant increase compared with the original “Kunigami Mahji” soil （Table 2.19).

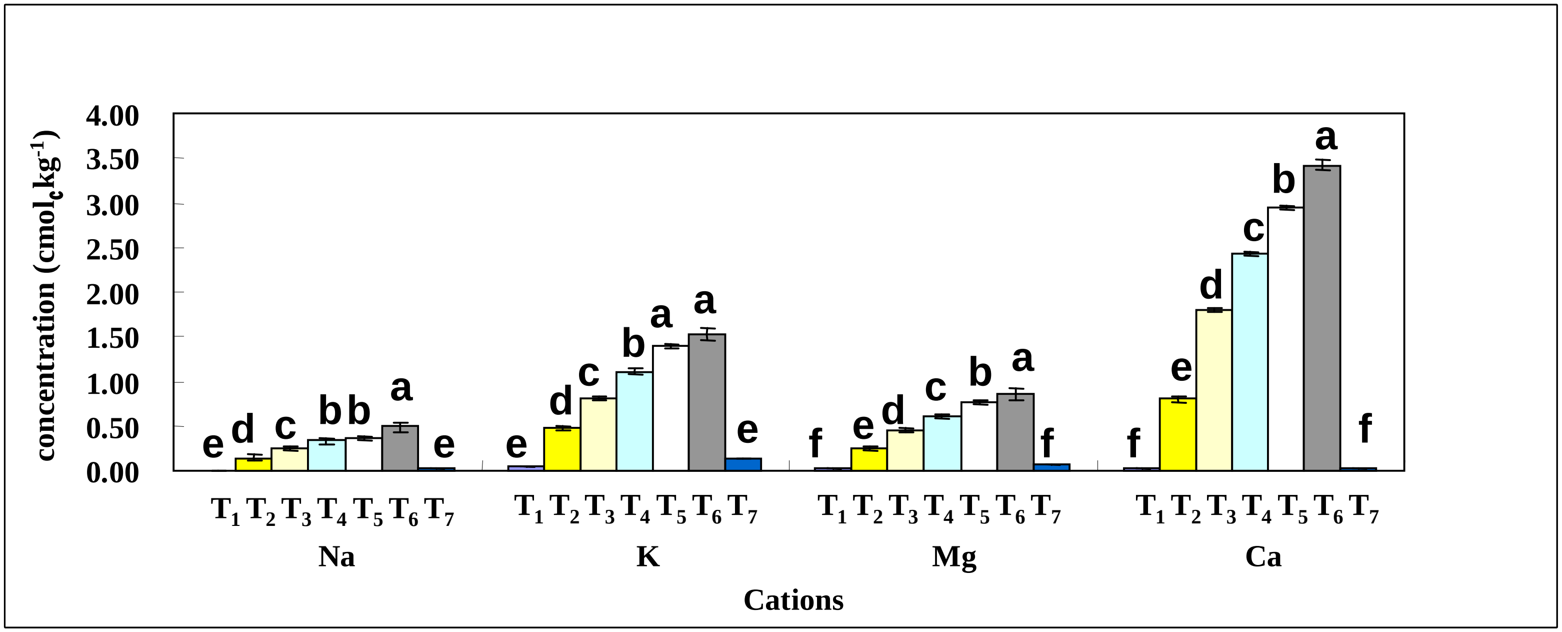


Figure 2.8. Exchangeable cation concentrations of the synthetic soil aggregates and "Kunigami Mahji" soil. (T_1=Aggregates with no CFA addition, T_2=Aggregates produced by 20% CFA addition, T_3=Aggregates produced by 40% CFA addition, T_4=Aggregates produced by 60% CFA addition, T_5=Aggregates produced by 80% CFA addition, T_6=Aggregates produced by 100% CFA addition, T_7="Kunigami Mahji" soil only).Error bars indicate the mean standard deviation of triplicates. Means with different letter on top of the bars differed significantly according to Duncan's multiple range test (P=0.05)

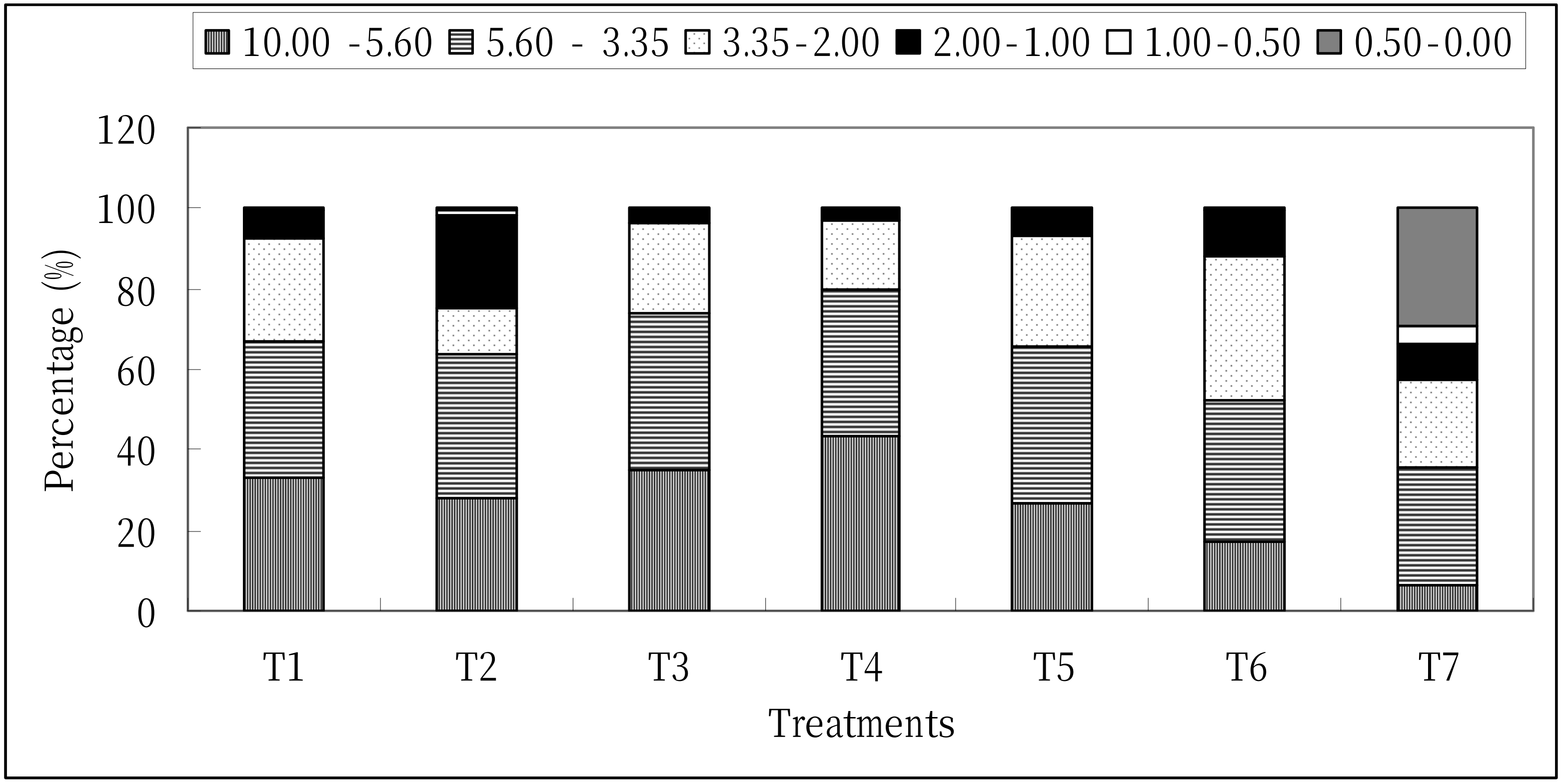


Figure 2.9. Particle size distribution of synthetic soil aggregates and "Kunigami Mahji" soil. (T_1=Aggregates with no CFA addition, T_2=Aggregates produced by 20% CFA addition, T_3=Aggregates produced by 40% CFA addition, T_4=Aggregates produced by 60% CFA addition, T_5=Aggregates produced by 80% CFA addition, T_6=Aggregates produced by 100% CFA addition, T_7="Kunigami Mahji" soil only)

SSA which had no CFA addition showed an increased CEC value of 6.08 $\mathrm{cmol_c kg^{-1}}$ compared with the original “Kunigami Mahji” soil (which had a CEC value of 4.30 $\mathrm{cmol_c kg^{-1}}$) due to the incorporated PW and starch. All other SSA, which had CFA added also showed a significant increase in CEC compared with no CFA added SSA (T_1) and the control (T_7). It is evident that aggregate production using CFA, PW and starch added to the “Kunigami Mahji” soil increased the CEC in comparison with the original soil. The CFA has also been reported to improve the nutritional status of soils through an increase in CEC and by provision of some essential nutrients (Carlson and Adriano, 1993: Roberts, 1966: Summers *et al.*,1998). Moreover, carbon (C) content showed a significant increase in the SSA compared with the original soil (T_7). This may be due to increased organic matter because of the incorporation of PWand starch as a binder. However, the nitrogen and phosphorous content of all SSA showed low values of 0.4 and 0.05 g/kg, respectively.

2.3.4.1.4. Aggregate particle size distribution

Figure 2.9 shows the particle size distribution of different types of SSA and “Kunigami Mahji” soil. Original particle sizes of “Kunigami Mahji” soil were in between 0 and 10 mm. It is evident that “Kunigami Mahji” soil contains a larger percentage of particles smaller than 0.5mm, while this fraction was comparatively very low in all SSA. The fraction of particle sizes between 10.00 and 3.35 mm was higher in all SSA than in “Kunigami Mahji” soil. It is evident that aggregate production with CFA, PW and starch added to “Kunigami Mahji” soil increased the aggregate particle size, which can there by improve the porosity of the medium.

2.3.4.1.5. Mean weight diameter and aggregate stability of SSA

Mean weight diameter (MWD), mean weight diameter difference (MWDD) and aggregate strength are shown in the Figure 2.10. Dry and wet Mean weight diameter did not show any significant differences among all SSA. However, MWDD showed significant differences in all SSA. MWDD is the difference between dry MWD and wet MWD. MWDD values indicate resistance of the aggregate to water during wet and dry sieving (i.e. a greater MWDD during the sieve analysis indicates a weaker aggregate strength). The highest MWDD (0.81 mm) was measured in SSA produced without CFA addition (T_1), which means that it had the lowest stability among the other SSA. The smallest MWDD of SSA was found in the SSA produced with 40% (T_3) of CFA addition (0.42mm) and 60% (T_4) of CFA addition (0.40mm).The second smallest MWDD of SSA (0.58mm) was found with 20% CFA addition (T_2). CFA addition of more than 60% did not give stable SSA. This shows that CFA addition up to 60% to the “Kunigami Mahji” soil gave stronger SSA than SSA produced without CFA addition. Aggregate strength also showed significant differences between treatments at the 0.05 significance level. The lowest aggregate strength (1.83 $\mathrm{kg/cm^2}$) was observed in SSA produced with no CFA addition, while the highest (3.10 $\mathrm{kg/cm^2}$) was found with 60% CFA addition. However, SSA produced using 20% and 40% CFA did not show any significant difference from the 60% CFA addition at the 0.05 significance level. The CFA addition at 80% and 100% gave aggregate strength values of 2.80 and 2.13 $\mathrm{kg/cm^2}$, respectively. SSA with CFA addition percentages up to 60% significantly increased the aggregate strength compared with SSA without CFA (T_1). Therefore, CFA addition at 20% - 60% could strengthen synthetic soil aggregates.

2.3.4.1.6. Analysis of aggregate dispersion under moving water in a mechanical shaker

This revealed that there was a significant relationship between decrease in the fraction of particles smaller than 1 mm and fraction of CFA in aggregate（Figure 2.11）.The lowest loss percentages of particles smaller than 1 mm were observed in the treatments of 20%, 40% and 60% (T_2, T_3 and T_4) CFA additions in all mechanical shaking time intervals. SSA produced without CFA addition gave the highest loss percentages in all shaking intervals. This indicated

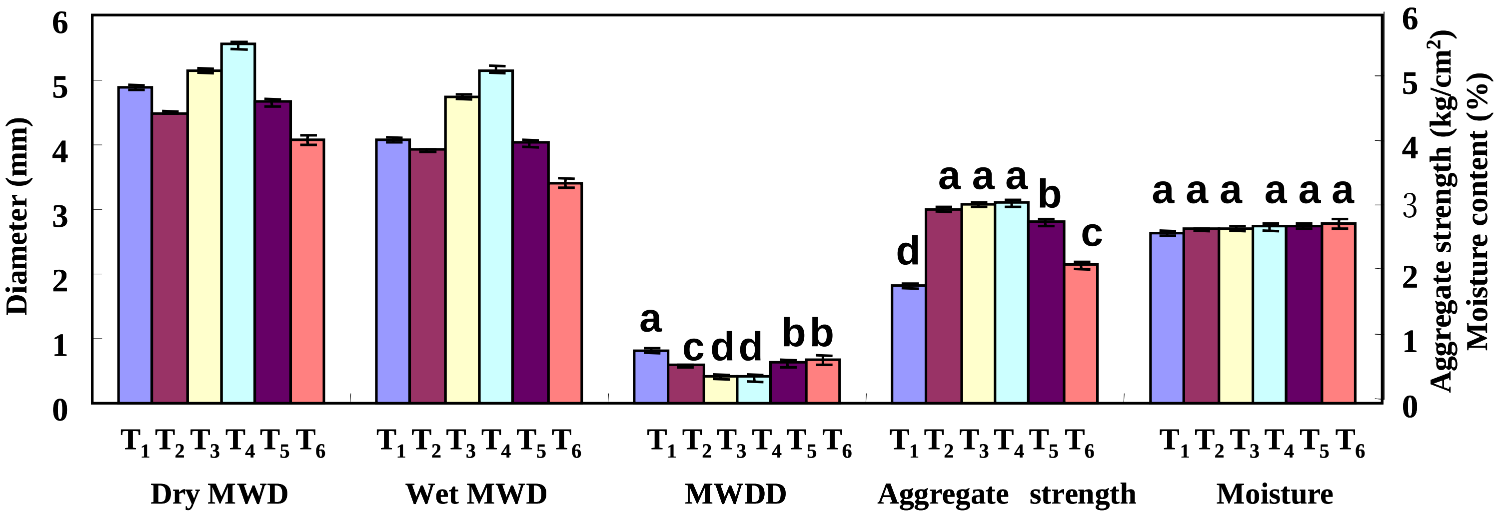


Figure 2.10. Mean weight diameter difference (MWDD), aggregate strength and moisture content of synthetic soil aggregates. (T_1=Aggregates with no CFA addition, T_2=Aggregates produced by 20% CFA addition, T_3=Aggregates produced by 40% CFA addition, T_4=Aggregates produced by 60% CFA addition, T_5=Aggregates produced by 80% CFA addition, T_6=Aggregates produced by 100% CFA addition).Error bars indicate the mean standard deviation of triplicates. Means with different letter on top of the bars differed significantly according to Duncan's multiple range test (P=0.05).

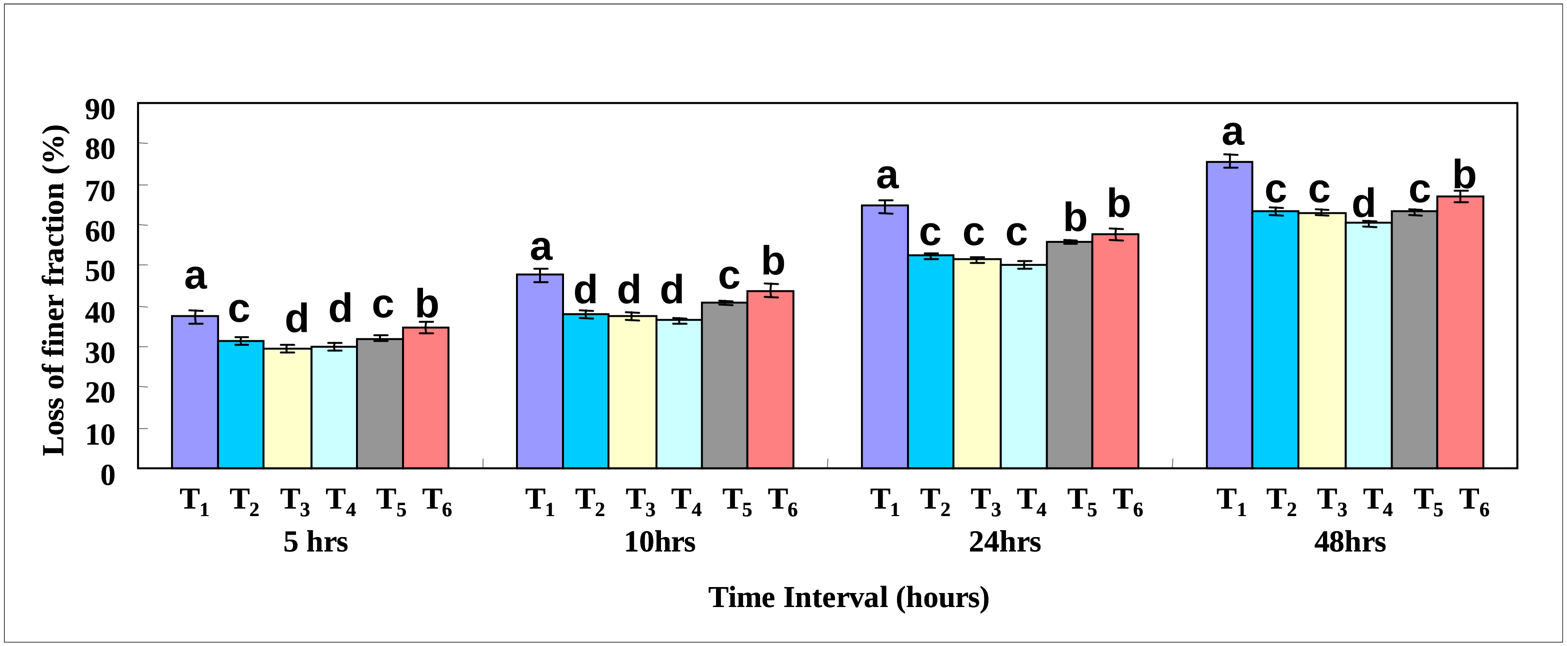


Figure 2.11 Loss of finer fraction (smaller than 1mm) under different time intervals in a mechanical shaker (T_1=Aggregates with no CFA addition, T_2=Aggregates produced by 20% CFA addition, T_3=Aggregates produced by 40% CFA addition, T_4=Aggregates produced by 60% CFA addition, T_5=Aggregates produced by 80% CFA addition, T_6=Aggregates produced by 100% CFA addition).Error bars indicate the mean standard deviation of triplicates. Means with different letter on top of the bars differed significantly according to Duncan's multiple range test (P=0.05).

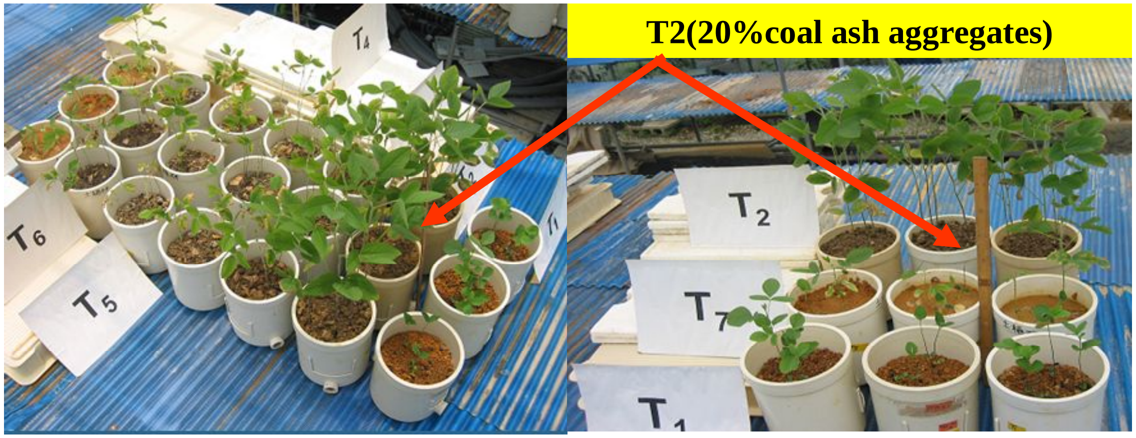


Figure2.12: Pot experiment conducted for soybean

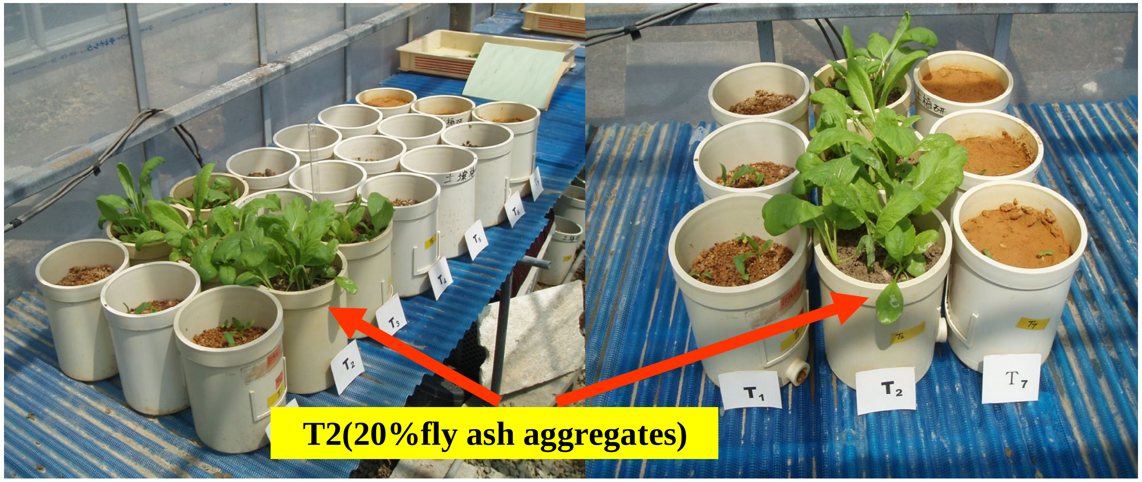


Figure 2.13: Pot experiment conducted for Komatsuna

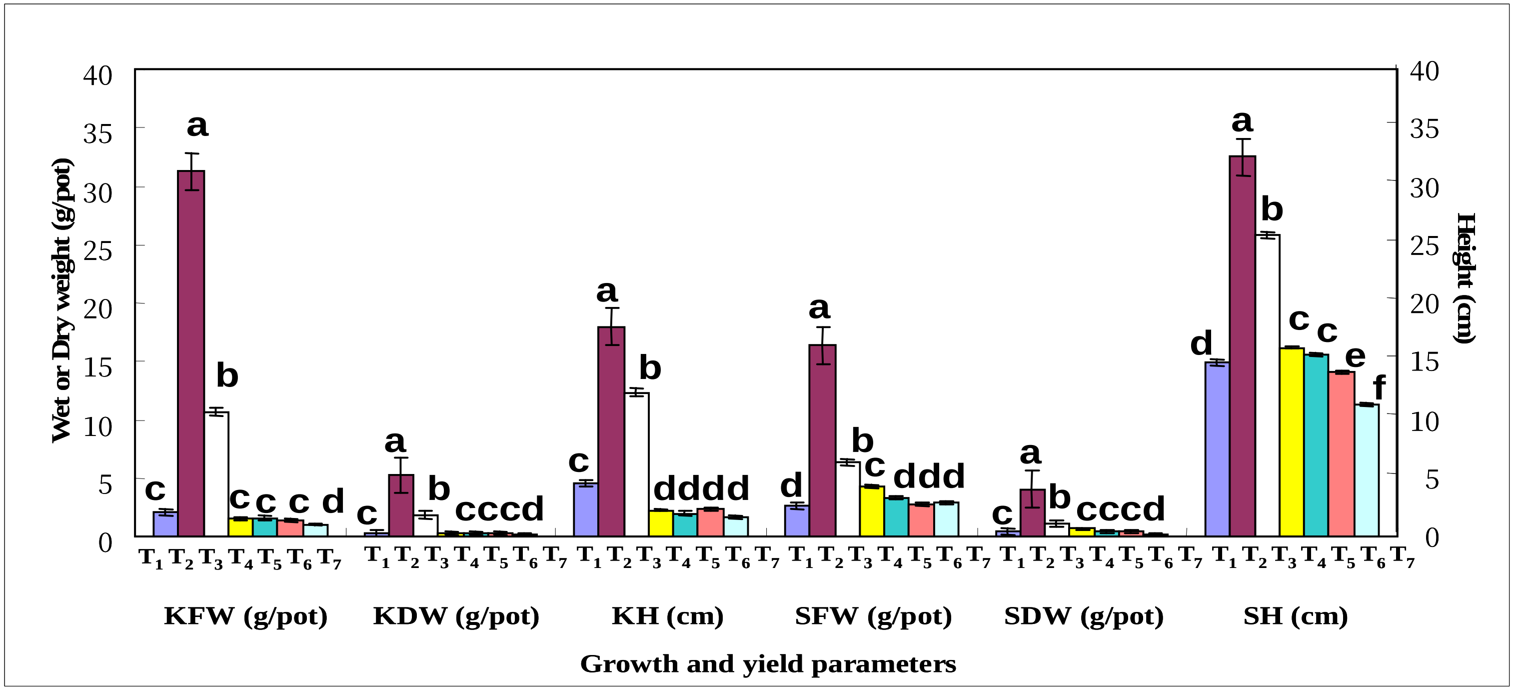


Figure 2.14. Growth and yield parameters of Komatsuna and soybean plants. KFW: Komatsuna Fresh Weight, KDF: Komatsuna Dry weight, KH: Komatsuna height.SFW: Soybean Fresh weight,SDW: Soybean Dry weight SH: Soybean Height.(T_1=Aggregates with no CFA addition, T_2=Aggregates produced by 20% CFAaddition, T_3=Aggregates produced by 40% CFA addition, T_4=Aggregates produced by 60% CFA addition, T_5=Aggregates produced by 80% CFA addition, T_6=Aggregates produced by 100% CFA addition, T_7=“Kunigami Mahji” soil only). Error bars indicate the mean standard deviation of triplicates. Means with different letter on top of the bars differed significantly according to Duncan’s multiple range test (P=0.05).

that SSA produced without CFA addition (T_1) are the weakest SSA, which gave the highest loss of the finer fraction of particles smaller than 1 mm, highest MWDD and lowest aggregate strength. This clearly indicates that SSA produced by adding CFA to "Kunigami Mahji" soil up to 60% gave more stable and strong SSA, which had a very low affinity to disperse when subjected to moving water. Treatments of 80 % (T_5) and 100% (T_6) CFA addition showed a comparatively higher loss percentage of smaller particles than treatments T_2, T_3 and T_4. It is evident that the addition of CFA greater 60% reduces the resistance to water. It was suggested that high CFA percentages lead to low aggregation due to limited binding surface in the used paper matrix (because PW quantity in the aggregates was limited to 50 g in all aggregate compositions). Therefore, CFA addition of 80% and 100% showed low aggregate strength and high dispersion percentage compared with low CFA additions.

2.3.4.2. Utilization of aggregates as a medium for crop growth

Different treatments conducted under the pot experiments are given in Figure 2.12 and 2.13.The plant height, fresh weight and dry weight of both komatuna (*Brassica rapa Var.Pervidis*) and soybean (*Glycine max*) grown in SSA after 7 weeks of growth are shown by Figure 2.13. SSA produced without addition of CFA (T_1) had a significant influence on the plant growth and yield of both komatsuna and soybean compared with the control (T_7). This may be because of the improved water holding capacity and permeability due to the incorporation of PW and starch to form SSA. SSA having 20% of CFA addition (T_2) gave the highest average plant height and highest average plant fresh weight and dry weights in both komatsuna and soybean plants. The highest plant height, fresh weight and dry weight of komatsuna were 18 cm, 31.25 g/pot and 5.22 g/pot, respectively. The highest plant height, fresh weight and dry weight of soybean were 32.50 cm, 16.38 g/pot and 4.03 g/pot, respectively. Addition of 20% of CFA with "Kunigami Mahji" soil to produce SSA (T_2) showed an increase of the dry weight about 20 times than that of the control (T_7). SSA produced by 40% addition of CFA (T_3) to the soil gave the second highest growth and biomass values. SSA produced by 20% addition of CFA improved the soil pH from 4.62 to 6.78, which was almost at the neutral level, which might be conducive for komatsuna and soybean growth. Similar yield increments following the addition of alkaline CFA to soils have been reported for various plant species (Plank *et al.*, 1975: Elsweei *et al.*, 1980: Khan and Khan 1996). Application of 5–20% CFA on a per weight basis increased both grain and straw yield of pearl millet (*Pennisetum sp.*) followed by wheat (Grewal *et al.*, 2001). The CFA applied at 25% resulted in higher yields of brinjal (*Solanum melongena*), tomato and cabbage (Shrama *et al.*, 2001 a, 2001 b). In the present study, PW was also utilized with CFA to improve the physical, chemical and structural properties of SSA. An appreciable change in the soil physical and chemical properties, increase in pH level and increased rice crop yield were obtained by mixed application of CFA and PW (Hill and Lamp, 1980; Molliner and Street, 1982). Utilization of slash and CFA mixture enhanced growth and yield of corn, potatoes and beans in pot experiments (Reynolds *et al.*, 1999: Rethman and Truter, 2001). SSA produced by adding more than 20% CFA content gave a high alkaline range of pH and EC values. The pH and EC values of SSA with CFA addition from 40% to 100% varied in the ranges of 7.80–9.96 and 50.60–66.80 mS/m, respectively. These extreme alkaline pH and EC values may possibly be harmful to sensitive crops, and particularly tree crops (Bresler *et al.*, 1982), which leads to a reduction in crop growth and yield. The results of this study have shown that SSA produced by adding 20% CFA to "Kunigami Mahji" soil, along with PW and starch as a binder, gave the highest growth and biomass yield of both crops. Hence, SSA produced using 20% CFA with "Kunigami Mahji" soil can be successfully used as a growth medium for komatsuna (*Brassica rapa Var.Pervidis*) and Soybean (*Glycine max*) cultivation. Moreover, production of these synthetic soil aggregates with the addition of CFA to "Kunigami Mahji" soil as a crop growth medium enhanced its physical, chemical and structural properties.

2.3.5. Conclusions

In this study, CFA, PW and starch were efficiently used to produce synthetic soil aggregates (SSA) with “Kunigami Mahji” soil in Okinawa, Japan. Produced SSA had low particle density, low bulk density, high saturated hydraulic conductivity, high water holding capacity, high organic matter content, and high CEC in comparison with original “Kunigami Mahji” soil. The CFA addition between 20% and 60% gave the highest aggregate strengths. It has indicated that SSA produced by adding 20% of CFA to “Kunigami Mahji” soil, along with PW and starch as a binder, can be successfully used as a growth medium for komatsuna (*Brassica rapa Var.Pervidis*) and soybean (*Glycine max*) cultivation.

Chapter 3

Synthetic aggregates as a soil ameliorant to improve the crop production in problematic grey soils ("Jahgaru") in Okinawa, Japan.

3.1. Influence of coal fly ash pellet aggregates on the growth and nutrient composition of *Brassica campestris* and physicochemical properties of grey soils in Okinawa, Japan.

3.1.1. Introduction

Increasing dependence on coal as an energy source in thermal power plants resulted in generation of enormous amounts of solid waste in the form of coal fly ash (Scheetz and Earle, 1998). Besides the application of coal fly ash in road making and brick kiln and cement industries, its disposal in agricultural land is a viable alternative. Addition of alkaline coal fly ash can increase the availability of trace metals, sulfate and other nutrients (Wong and Wong, 1989; Ko, 2000). Applications of coal fly ash in agricultural fields improve the physicochemical properties of the soil and suitable for better crop management (Singh et al., 1997). Coal fly ash is often used as soil amendment (Sikka and Kansal, 1995; Gupta et al., 2002; Tripathi et al., 2004; Mittra et al., 2005; Jala and Goyal, 2006) due to its beneficial properties. However, its usage in agriculture and agronomy sector is still limited (<10%) due to concerns about the presence of toxic elements viz., Cd, As and Ni (Carlson and Adriano, 1993; Gupta et al., 2002; Jala and Goyal, 2006). Recent investigations suggest that coal fly ash can find better application if combined with organic amendments, and nitrogen fertilizers (Rautaray et al., 2003; Tripathi et al., 2004; Rai et al., 2004). This work presented here introduces a new method of utilizing coal fly ash by converting them into pellet aggregates (PA) by mixing with paper waste, starch waste and ammonium sulfate, which are coming out as waste materials in Okinawa, Japan as an effective nitrogen fertilizer support and a soil amendment. 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 (Low, 1973; Allison, 1973).Therefore; an attempt was done to study the potential utilization of developed PA as a soil amendment and a fertilizer support to improve crop production in the problematic grey soils in Okinawa, Japan.

3.1.2. Objective of the study

The objective of this study was to produce PA and evaluate their potential utilization as a soil amendment and a fertilizer support to Okinawa problematic grey soil for the leafy vegetable *Brassica campestris* production.

3.1.3. Materials and methods

3.1.3.1. Collection of material samples

Samples of coal fly ash were obtained from the thermal power plant located at Ishikawa, in Okinawa, Japan. The pH and the electrical conductivity (EC) of coal fly ash were

9.87 and 92.70 mSm^{-1}, respectively. The C, N, P, Na, K, Mg and Ca content in the coal fly ash were 43.26, 0.52, 0.07, 1.02, 1.68, 0.87 and 3.45gkg^{-1}, respectively. Paper waste was collected from Ojiryokka Company, Okinawa, Japan. The pH, EC, C and N content of paper waste were 5.70, 10.28 mSm^{-1}, 374.8 gkg^{-1} and 0.38 gkg^{-1}, respectively. Starch waste was collected from Okinawa Seifun Corporation in Okinawa, Japan. The pH, EC, C and N content values of starch waste were 3.80, 20.98 mSm^{-1}, 312.5 gkg^{-1} and 0.42 gkg^{-1}, respectively. Ammonium sulfate was also obtained from Okinawa electric company located in Ishikawa, Okinawa, Japan. The texture of grey soil used in this study was clay and was classified as an Inceptisol. Collected soil samples were air dried and then sieved through a 10-mm mesh screen. A portion of this soil sample was sieved through a 2-mm mesh sieve, and used for chemical analysis.

3.1.3.2. Pellet aggregate (PA) production

Two types of PA (Figure 3.1) were produced combining coal fly ash and paper using an Eirich mixer (R-02M / C27121) and a pelleter machine with starch as the binder. Two sizes of PA were developed by changing the diameter of the pellets. Two different diameters were 5 and 10mm. Coal fly ash and paper waste amounts used in the production process were 500 and 25 g, respectively. 25 g of starch waste was added to 200 ml hot water at 50^{0}C and heated to 80^{0}C in order to obtain sticky paste. 300 ml of prepared starch paste was added to produce PA. 20 g of ammonium sulfate was added to maintain the N content at 8gkg^{-1} in both types of pellets. First of all the respective quantities of coal fly ash, paper waste and ammonium sulfate were mixed well in the pan of the Eirich mixer for 2 minutes. Subsequently, above mixture was put into the pelleter machine to make pellet aggregates. In addition, PA without N was also developed to use as a soil amendment. The pH and EC of produced 5 mm and 10 mm PA were 9.32 and 9.28 and 82.70 and 80.76 mSm^{-1}, respectively. The C, N, P, Na, K, Mg and Ca content in the 5 mm PA were 110.26, 8.00, 0.17, 0.98, 1.58, 0.87 and 3.25gkg^{-1}, respectively. The C, N, P, Na, K, Mg and Ca content in 10 mm PA were 113.61, 8.00, 0.20, 0.88, 1.61, 0.91 and 3.18 gkg^{-1}, respectively.

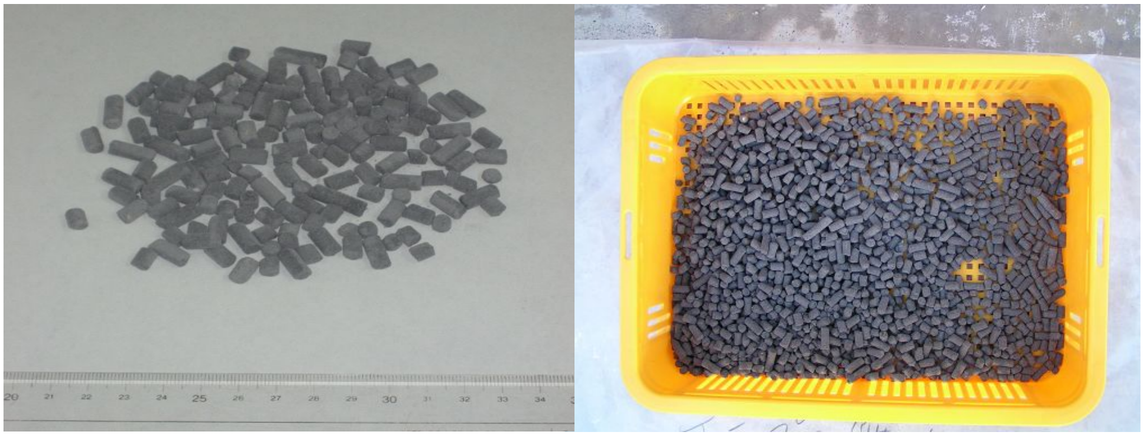


Figure 3.1. Aggregates used in the experiment.

3.1.3.3. Experiment lay-out

Plot experiments were conducted to study the impact of the PA as a fertilizer support and a soil amendment to the problematic grey soil. Widely using popular leafy vegetable *Brassica campestrisL* was grown in the plot experiment. The experimental design of the plot experiment was a completely randomized design (CRD) with 4 treatments. The experimental plot sizes were 2.5× 0.8×0.6 m^3. All four treatments are shown in Table 3.1.

Table 3.1.Different treatments used in the experiment

Treatment	Description
T1	Soil only (Control)
T2	Soil with small diameter (5mm) PA
T3	Soil with large diameter (10mm) PA
T4	Soil with both sized aggregates as a soil ameliorant and fertilizer

PA: Pellet aggregates.

Figure.3.2. Used experiment plots in the experiment.

T1 was used as the control, which is having grey soil only. In T2 and T3 4kg of 5mm and 10 mm PA was mixed, respectively to the grey soil. In T2 and T3 the respective PA amounts were calculated according to the N requirement of *Brassica campestris*. In T2 and T3, PA was used as a fertilizer support. The required PA in T2 and T3 were calculated according to the N requirement of *Brassica campestris* recommended by prefecture agricultural department, Okinawa, Japan (Okinawa prefecture agricultural experiment station, 1999).The N percentage of the both types of produced PA was 8 gkg^{-1}. The 5 mm and 10 mm PA quantities in T2 and T3 were 2kg each, respectively. In T4 20kg of 5 mm and 10 mm PA, which has no N, were added as a soil amendment and then 2kg each 5 mm and 10 mm PA with N were added to supply the N requirement. The PA amount as the soil amendment was calculated according to one of our previous pot experiment study, which reported that 25% of aggregates addition to acidic soil as a soil amendment improves the crop production and soil physical and chemical properties (Jayasinghe and Tokashiki, 2006a). Calculated quantities of different PA as soil amendment and as nitrogen requirements of the *Brassica campestris* were mixed with the soil in the plots without unnecessary compaction. Potassium (K) and phosphorous (P) requirements for each treatment were given by using chemical fertilizer as per the requirement recommended by the Okinawa agricultural station (Okinawa prefecture agricultural experiment station, 1999) for *Brassica campestris*. The K_2O (60%) and P_2O_5 (17%) per plot were 40 g and 106 g respectively to supply equivalent K and P amounts to all treatments. Each treatment (from T1 to T4) was replicated three times. Seeds were planted with the spacing of 10cm×10cm. Watering was done equally for all treatments everyday. Experiments were terminated after 7 weeks of planting. Temperature ranged from 20-31^0 C during the growth season. Plant height and plant fresh weight were determined. Ten plants were randomly selected from each plot to determine the fresh and dry weight. Subsequently, plants were dried in an oven at 70^{0}C for 48 hours in order to determine the dry weight. An acid digestion procedure was used to prepare the plant tissue samples for analysis by atomic absorption spectrophotometer to determine different nutrient contents in the plant tissues. Ground plant tissues were passed through 2 mm mesh sieve and mineralized by microwave acid digestion (USEPA 1996). The samples were then refluxed with nitric acid, filtered through Whatman filter paper and diluted to 100 ml for analyses.

3.1.3.4. Physico-chemical properties of PA and Soil-PA mixtures

Bulk densities of each treatment (T1, T2, T3 and T4) were measured with a core sampler of 100 cm^3 volumes, which were oven dried, and weighed (Blake and Hartage, 1986). Saturated hydraulic conductivities of the samples were determined by using falling head method, which is described by Klute (1965). The samples were taken using 100 cm^3 core-samplers and were saturated for 48 hours. Finally, all samples were kept for another 24 hours until the gravitational water drained off. Then, the water amount held by each sample at the field capacity was calculated as water holding capacity (kg/kg). All measurements were taken in triplicates. All treatment samples were sieved using 10mm mesh screen and were used to analyze the particle size distribution by using dry sieving method (Yoder, 1936). Utilized sieves for the dry sieving were 5.6 mm, 3.35 mm, 2.00 mm, 1.00 mm, 0.5 mm and 0.25 mm, respectively. Air, water and solid content in the soil were determined by Three-phase meter (digital three phase meter, FV-466). Mean weight diameter (MWD) was calculated according to the method described by Kemper and Rosenau (1986).

The pH of all treatment samples were measured in water extracts using a glass electrode (sample: distilled water ratio of 1:2.5), and EC was measured using an EC meter (D-54, Horiba) (sample: distilled water ratio of 1:2.5). Carbon (C) and nitrogen (N) contents of samples were determined by using CN analyzer (Micro coder JM 10). The cations (K,Mg and Ca) of air dried substrate samples were extracted by using 1 M ammonium acetate. Then the extracts were used to analyze the cation concentration using atomic absorption spectrophotometer (Solaar 969, Thermo Corporation, Tokyo, Japan). Total phosphorous (P) of substrate samples were determined by using spectrophotometer (Hafner, 1993).Substrate samples were mineralized by microwave acid-digestion (USEPA, 1996) and the concentrations of As, Se, B, Mn, Cu, Zn, Pb, Cd and Cr were determined by atomic absorption spectrophotometer (Solaar 969, Thermo Corporation, Tokyo, Japan). Organic matter (OM) of the substrate samples were determined by loss on ignition at 430 ◦C for 24 h (Navarro, 1993).

3.1.3.5. Statistical analysis

The obtained data were subjected to analysis of variance (ANOVA) for determination of the treatment effects. Duncan’s multiple comparison range test (DMRT) procedure was employed to denote significant differences between the treatments using the SAS package (SAS Institute, 1990).

3.1.4. Results and discussion

3.1.4.1. Particle size distribution of the different media

Particle size distribution and mean weight diameter (MWD) of different treatments used in the experiment are given in Table 3.2. The particle size distribution of a growing medium is important because it determines pore space, bulk density, air and water holding

Table3.2. Particle size distribution of the different growth media

Treatments	>5.60mm	5.60-3.35mm	3.35-2.00mm	2.00-1.00mm	1.00-0.50mm	0.50-0.25mm	0.25mm<	MWD(mm)
T1	2.02±0.25a	6.08±0.44a	12.03±0.27a	14.98±0.71a	17.44±0.38c	18.17±0.59d	29.28±0.46c	1.14±0.32a
T2	7.18±0.46b	14.88±0.57b	15.78±0.31a	16.61±0.48b	14.76±0.29b	14.12±0.38c	16.67±0.40b	2.00±0.27b
T3	13.11±0.70b	12.07±0.31b	14.09±0.28a	18.14±0.50c	15.12±0.51b	13.32±0.47b	14.15±0.37b	2.30±0.20b
T4	21.35±0.39c	18.09±0.40c	16.63±0.30a	16.15±0.44b	13.12±0.48a	8.78±0.62a	5.88±0.23a	3.22±0.28d

MWD; mean weight diameter (Means followed by the different letter in the same column differed significantly according to Duncan's multiple range test (P=0.05). Mean±standard deviation (n=3)).

Table 3.3. Physical properties of the different growth media

Treatments	Bulk density (g/cm^3)	Water holding capacity (kg/kg)	Permeability (cm/s)	Solid (%)	Air (%)	Water (%)
T1	1.16±0.12c	0.48±0.08a	8.89×10^{-5}±0.00a	44.44±0.54c	32.40±0.25a	23.20±0.86a
T2	1.06±0.20b	0.53±0.05b	9.83×10^{-5}±0.00a	42.42±0.43b	34.00±0.40b	24.60±0.54b
T3	1.08±0.08b	0.52±0.07b	9.34×10^{-5}±0.00a	41.18±0.37b	34.50±0.33b	24.40±0.65b
T4	0.96±0.10a	0.59±0.08c	1.70×10^{-4}±0.00b	33.60±0.33a	39.00±0.28c	27.40±0.42c

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

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 %). More over, the particle percentages > 3.35 mm are the lowest (8.10 %) in T1 (grey soil). An excess of smaller particles in a growth medium clogs pores, increase non-plant available water holding capacity and decreases air-filled porosity (Spiers and Fietje, 2000).Due to addition of PA to the soil increased particles >2.00 mm and decreased the particles <0.25 mm significantly, which would increased the porosity and permeability of the grey soil. Therefore, it can be suggested that addition of PA can increase the porosity and the hydraulic conductivity of the problematic grey soil. Aggregates developed from low productive acid soil and paper waste particles addition to the grey soil significantly improved the particles >2.00 mm and hence the permeability and porosity were significantly increased (Jayasinghe et al., 2009b).T4 gave the greatest percentage of particles >2.00 mm due to addition of large quantity of PA as soil amendment and then fertilizer support. PA addition also increased the MWD of the soil compared to the control. The average MWD of the T2, T3 and T4 was increased by 0.86, 1.16 and 2.08 mm compared to the original soil. This was supported by our previous studies (Jayasinghe and Tokashiki, 2006ab; Jayasinghe et al., 2008, 2009c,e); which explained the MWD increased with the subsequent aggregate addition.

3.1.4.2. Physical properties of the different media

The influence of PA addition on the physical properties of the grey soil is given in Table 3.3. PA addition tends to decrease the bulk density of the media. 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 (Celik et al., 2004). All treatments showed significant differences in the bulk density compared to the control. The bulk density of the T2, T3 and T4 was decreased by 8.62%, 6.90% and 17.24% compared to the control, respectively. Synthetic aggregates addition at the rate of 10%-25% decreased the soil bulk density of acidic red soil by 10-15% (Jayasinghe et al., 2009a).This can be due to the application of PA which contained coal fly ash and paper waste. Application of coal fly ash at 0%, 5%, 10% and 15% by weight in clay soil significantly reduced the bulk density and improved the soil structure, which in turn improves porosity, workability, root penetration and moisture-retention capacity of the soil (Garg et al., 2005, Kene et al., 1991). Large proportions of silt sized particles in coal fly ash induce a decrease in soil bulk density (Aitken et al., 1984). In addition, paper waste can also improve the bulk density (Simard, 1998).PA addition increased the water holding capacity of the soil. Water holding capacity of the T2, T3 and T4 increased by 10.41%, 8.33% and 22.91% compared to control. Synthetic aggregate addition to acidic red soil increased the water holding capacity of the soil (Jayasinghe and Tokashiki, 2006ab, 2007). This may be due to the coal fly ash and the paper waste in the PA. A gradual increase in fly-ash concentration in the normal field soil (0, 10, 20 up to 100% v/v) was reported to increase the porosity, water-holding capacity, conductivity and cation exchange capacity (Khan and Khan, 1996). Paper waste can also increase d soil water holding capacity (Bellamy et al., 1995; Simard et al., 1998).Soil hydraulic conductivity is a measure of the ability of air and water to move through it and is influenced by size, shape, and continuity of the pore spaces, which in turn depends on density, texture and structure. Hydraulic conductivity of the soil increased significantly in the T4 treatment by ten times than T2 and T3 compared to control. This may be due to increased proportion of the PA as the ameliorant than comparatively small quantities of PA in the T2 and T3. The greater the bulk density, the greater the air entry suction and the smaller the hydraulic conductivity (Miller and miller 1956; Miyazaki, 1996). PA addition decreased the bulk density in T4 significantly; therefore hydraulic conductivity may be increased subsequently in T4. More over, according to Jala and Goyal (2006), the Ca in fly ash readily replaces Na at clay exchange sites and thereby enhances flocculation of soil clay particles, keeps the soils friable, enhances water penetration and allows roots to penetrate compact soil layers. Chang et al., (1977) reported that hydraulic conductivity of the soils increased with the coal fly ash application and surface encrustation was reduced. Three phases of the soil (i.e. solid, air and water content) showed significant differences compared to the T1. It is evident that air and water content increased while the solid content is decreased after PA addition. This also indicates that the PA addition improves the soil air and water content which subsequently improved the crop production.

3.1.4.3. Chemical properties

PA addition increased the soil pH significantly in T2, T3 and T4 compared to control (Table 3.4). This is due to alkaline nature of PA formed from alkaline coal fly ash. The original pH of two types of PA was in the range of 8.85-9.04. An appreciable change in the soil physicochemical properties, an increase in pH and increased rice crop yield were obtained by mixed application of fly-ash, paper factory sludge and farmyard manure (Molliner and Street, 1982). Addition of the PA to soil increased the soil EC significantly compared to original soil. Our previous studies reported that addition of Synthetic coal fly ash aggregates to acidic soils increased the soil EC significantly (Jayasinghe and Tokashiki, 2006a; Jayasinghe et al., 2009a).The EC and the metal content of soil increase with increasing amount of coal fly ash application (Sikka and Kansal, 1995).Enrichment of coal fly ash with several essential and non essential elements may give higher EC values in soils. An increase in EC with coal ash addition was accompanied by increase in Ca and Mg concentrations, in agreement with previous findings (Elseewi et al., 1980). Soil C and OM content of the soil has increased with the addition of PA. This can be due to the paper waste content in the PA. Paper waste in the PA is also a rich source of C (Rasp and Koch, 1992) and improves soil organic matter contents, water holding capacity, soil structure and bulk density (Einsphar et al., 1984; Simard et al., 1998; Zhang et al.,

Table 3.4. Chemical properties of the different treatments used in the experiment

Particular	T1	T2	T3	T4
pH	7.23±0.15a	7.38±0.20b	7.39±0.16b	7.48±0.22c
EC(mSm^{-1})	44.37±0.12a	56.43±0.24b	55.29±0.31b	62.55±0.28c
OM (gkg^{-1})	20.58±4.35a	30.81±6.74b	29.64±5.10b	48.89±4.69c
C(gkg^{-1})	12.12±0.32a	17.48±0.42b	17.20±0.23b	28.10±0.37c
N(gkg^{-1})	0.74±0.11a	0.78±0.20a	0.79±0.18a	0.77±0.15a
P(gkg^{-1})	0.17±0.06a	0.31±0.05b	0.32±0.08b	0.45±0.07c
K(gkg^{-1})	0.18±0.10a	0.43±0.17b	0.50±0.12b	1.78±0.09c
Mg(gkg^{-1})	1.18±0.11a	1.44±0.09b	1.47±0.07b	3.12±0.12c
Ca(gkg^{-1})	10.28±0.21a	16.33±0.27b	17.21±0.19b	26.77±0.20c
B(mgkg^{-1})	3.34±0.44a	7.54±0.76b	7.33±0.50b	9.79±0.61c
As(mgkg^{-1})	ND	ND	ND	ND
Se(mgkg^{-1})	ND	ND	ND	ND
Cd(mgkg^{-1})	0.03±0.00a	0.05±0.00a	0.07±0.00a	0.09±0.00a
Mn(mgkg^{-1})	43.21±0.35a	46.29±0.25b	45.56±0.20b	54.25±0.18c
Cu(mgkg^{-1})	12.18±0.12a	15.12±0.15b	14.88±0.09b	22.23±0.16c
Zn(mgkg^{-1})	58.19±0.27a	65.23±0.31b	66.39±0.23b	101.28±0.30c
Pb(mgkg^{-1})	4.87±0.10a	4.94±0.16b	4.68±0.18b	5.45±0.20c
Cr(mgkg^{-1})	1.82±0.08a	1.93±0.12a	1.88±0.11a	2.56±0.13b

EC; electrical conductivity, OM; organic matter (Means followed by the different letter in the same column differed significantly according to Duncan's multiple range test (P=0.05): Mean±standard deviation (n=3)).

1993). N content of all treatments did not show any significant difference. This may be due to low N contents in coal fly ash and the paper waste. PA addition to the grey soil significantly increased the concentrations of P, Mg, K, Ca, B, in the soil compared to the original soil. Fly-ash contains essential macronutrients including P, K, Ca, Mg and S and micronutrients like Fe, Mn, Zn, Cu, Co, B and Mo (Basu et al., 2009). B concentrations of the T2, T3 and T4 were varied between 7.54 and 9.79 mg/kg. B contents of <4, 4-10, 11-20, 21-30 and >30 $mgkg^{-1}$ were considered as non-toxic, slightly toxic, moderately toxic, toxic and highly toxic respectively (Bradshaw and Chadwick, 1980, Hodgson and Townsend, 1973). B levels in T2, T3 and T4 were in the range of 4-10 $mgkg^{-1}$, which can be classified as slightly toxic to the plant. Heavy metal concentrations in T2, T3 and T4 were below the maximum pollutant concentration of individual metals for land application of sewage sludge given by the US Environmental protection Agency (USEPA, 1999). The maximum pollutant concentration of individual metals 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, 1999). Furthermore, average concentrations of heavy metals reported in uncontaminated soils are (all in mg/kg); 6 As, 70 Cr, 30 Cu, 90 Zn, 35 Pb and 0.35 Cd, respectively (Adriano, 2001). As and Se were not detected and Cd content was not differed significantly among all four treatments. Coal fly ash contains non essential elements (eg: As, Cd, and Se) that adversely affect crop growth, soil and ground water quality (Adriano et al., 1978; Page et al., 1979). It is evident that the heavy metal concentrations in T2, T3 and T4 were below the heavy metal concentrations reported in uncontaminated soils. The amount of heavy metals released from coal into coal fly ash depends on coal type, composition, modes of element occurrence and combustion technology (Jala and Goyal, 2006, Basu et al., 2009). Present results support earlier work on coal fly ash that showed the heavy metal concentration was very low and unlikely to affect ground water quality (Ghodrati et al., 1995). 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.

3.1.4.4. Influence of PA addition on *Brassica campestris* growth

Table 3.5. Influence of PA on plant growth parameters

Treatments	Plant height (mm)	Plant fresh weight (g)	Plant oven dry weight (g)
T1	143.13±4.00a	14.80±1.12a	1.08±0.32a
T2	164.91±3.20b	18.91±1.34b	1.42±0.24b
T3	175.00±9.45b	21.26±1.53b	1.55±0.26b
T4	210.80±3.40c	29.72±1.48c	1.87±0.31c

(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)).

The effect of PA addition on the growth of *Brassica campestris* are shown in Table 3.5. Different treatments used in the experiment are shown in the Figure 3.3. PA addition (T2, T3 and T4) significantly increased growth and yield parameters of *Brassica campestris* compared to grey soil (T1). T2 and T3 did not show any significant difference between them but differed significantly with T4. Plant height, plant fresh weight and plant dry weight of T2, T3 and T4 were increased by in the ranges of 15.22-43.28%, 43.65-100.81% and 43.51-73.14%, respectively compared to T1.These results were supported by our previous study, which reported that addition of coal fly ash based aggregates to low productive acidic red soils increased the growth and yield of (*Brassica rapa Var.Pervidis*) (Jayasinghe and Tokashiki, 2006a; Jayasinghe et al., 2009a).These yield increments may be due to the improved soil physical and chemical parameters due to the PA addition. PA addition improved the soil bulk density which can be improved the soil porosity and hydraulic conductivity. Moreover, PA addition increased the soil water holding capacity. 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 (Marinari et al., 2000; Tejada and Gonzalez, 2003). In addition PA incorporation increased the soil nutrient concentrations. The PA amount in T2 and T3 were 4kg each and the T4 the total PA amount was 24Kg.Therefore, PA addition increased the concentrations of the elements in the soil significantly. The high concentration of elements (K, Na, Zn, Ca, Mg and Fe) in coal fly-ash increases the yield of many agricultural crops(Basu et al., 2009). Many researchers (Garg et al., 2005;Grewal et al., 2001;Sridhar et al., 2006;Basu et al., 2006; Basu et al., 2009,Thetwar et al., 2007) have demonstrated that fly-ash increased the crop yield of wheat (*Tritiucm aestivum*), alfalfa (*Medicago sativa*), barley (*Hordeum vulgare*), bermuda grass (*Cynodon dactylon*),Sabai grass (*Eulaiopsis binata*), mung (*Vigna unguiculata*) and white clover (*Trifolium repens*) and improved the physical and chemical characteristics of the soil. Amendment of different coal fly-ash–soil combinations resulted in high yield of aromatic grasses, particularly palmarosa (*Cymbopogon martini*) and citronella (*Cymbopogon nardus*), which was due to increased availability of major plant nutrients (Asokan et al., 1995; Neelima et al., 1995). PA addition as a fertilizer and as a soil amendment increased the crop growth and yield of *Brassica campestris*.

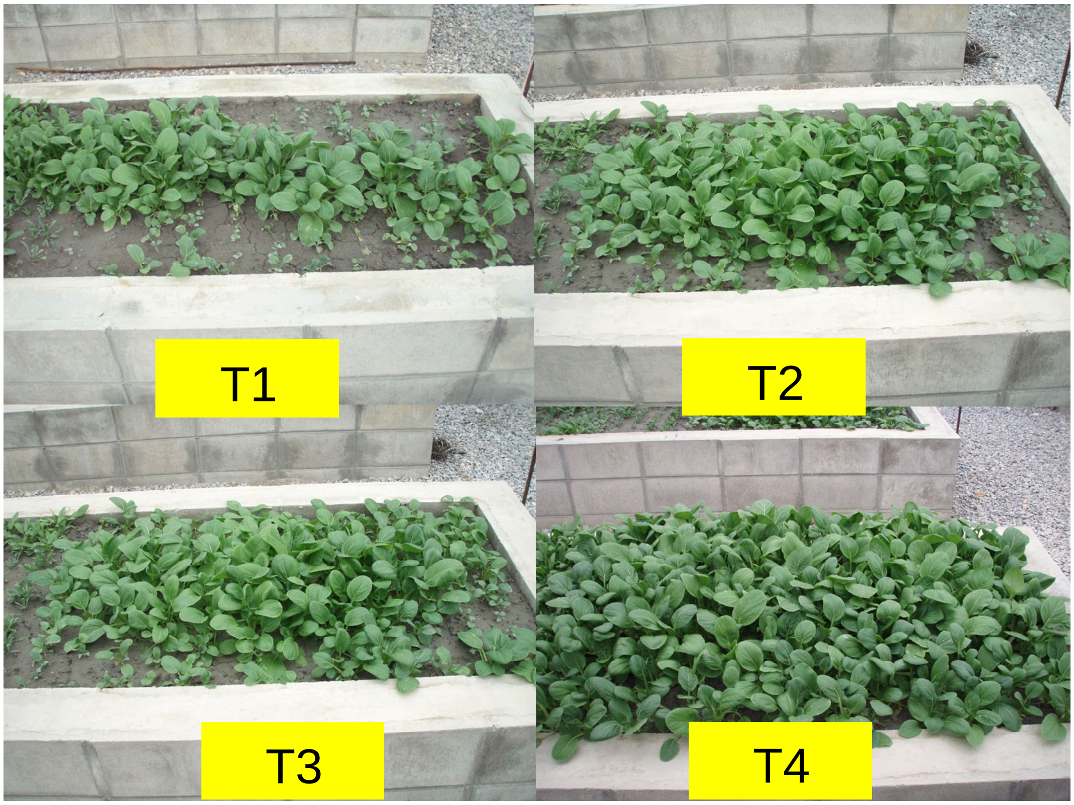


Figure 3.3. Different treatments studied in the experiment.

3.1.4.5. Nutrient status of *Brassica campestris*

The mineral element concentrations in plant tissues are given in Table 3.6. It is evident that shoot concentrations of N and P in PA addition treatments have been increasing compared with the T1 control. Moreover, plants grown in PA additions gave higher K, Mg and Ca concentrations in plant shoots compared to plants grown in grey soil. This may be due to the increased amount of K, Mg and Ca contents in the PA, which is having coal fly ash. Shoot K, Ca and Mg contents were all above the deficiency limit of 7-15 g/kg (Chapman 1966), 1.4g/kg (Loneragan and Snowball, 1969) and 0.6 g/kg (Chapman, 1966), respectively. The high concentration of elements like K, Na, Zn, Ca, Mg and Fe in fly-ash increases the yield of agricultural crops (Basu et al., 2009, Haynes,2009).Integrated nutrient treatments involving CFA at 10 ton ha^{-1}, organic wastes and chemical fertilizers resulted in higher uptake of N, P, K, Ca, Mg, Fe, Mn, Zn and Cu in rice grain than application of only chemical fertilizers, which in turn was responsible for higher rice yield (Sajwan 1995;Sarangi et al., 1997; Rautaray et al., 2003). One of the major concerns for plant grown in coal fly ash amended soil is potential B toxicity due to significant levels of B in coal fly ash. Although B is essential to plant growth, the difference between sufficiency and toxicity is the smallest among the micronutrient (Mengel and Kirkby, 1987). The B concentration of the plant tissues were increased due to PA addition. Application of fresh CFA can produce B toxicity in some plants, but B toxicity was not observed in plants grown on soils amended with coal fly ash because most of plant available B readily leaches from soil (Clark et al., 2001). Significantly higher B concentrations were found in *Brassica campestris* grown in PA amendment treatments than in control soil but all were in normal B level (7-75 mg/kg) in plant foliage given by Chaney (1983). Typical visible symptom of B toxicity is leaf burn in the form of chlorotic and or necrotic patches, often at the margins and tips of older leaves (Benett, 1993). In this study, B phytotoxicity was not observed during the experiment. The normal ranges of Cu, Mn, and Zn in plants were 3-20, 15-150and 15-150 mg/kg, respectively (Page et al., 1979). The critical toxicity concentrations range for Cu, Mn, Pb and Zn were 25-40, 400-2000, 100-400 and 500-1500 mg/kg, respectively (Romheld and Marschner, 1991). Therefore, Cu, Mn, Pb and Zn concentrations in plants were within the normal range and well below the phytotoxic limits. According to Mittra et al. (2003), the uptake of Zn, Cu, Cd and As by rice and peanut from coal fly-ash-amended soil were within the safe limits as given by Prevention of Food Adulteration Act (1997). Application of fly-ash-stabilized sludge to an acid loamy soil significantly increased the corn yield as well as reduced the uptake of heavy metals including Cu, Zn, Ni and Cd present in sludge (Su and Wong, 2003). Alkaline fly-ash was also reported to act as binding agent for fixation of heavy metals and nutrients in waste and organic matters (Vincini et al., 1994, Lin and Hsin, 1996; Sharma et al., 2007).Therefore, addition of PA developed by coal fly ash can be recommended as a fertilizer material and a soil amendment to improve the chemical and physical properties of the problematic grey soil which subsequently increased the growth and yield parameters of the *Brassica campestris*.

Table 3.6 Nutrient composition in plant tissues

Particular	T1	T2	T3	T4
N(gkg^{-1})	28.77±0.21a	32.14±0.32b	31.96±0.18b	32.12±0.20b
P(gkg^{-1})	0.63±0.05a	0.88±0.10b	0.76±0.09b	0.82±0.11b
K(gkg^{-1})	32.10±0.21a	34.12±0.18b	34.74±0.24b	36.12±0.32c
Mg(gkg^{-1})	14.22±0.27a	16.30±0.18b	15.89±0.24b	18.34±0.19c
Ca(gkg^{-1})	40.27±0.62a	42.35±0.54b	43.28±0.49b	46.85±0.51c
B(mgkg^{-1})	4.88±0.21a	7.77±0.32b	7.54±0.24b	8.43±0.30c
As(mgkg^{-1})	ND	ND	ND	ND
Se(mgkg^{-1})	ND	ND	ND	ND
Cd(mgkg^{-1})	ND	ND	ND	ND
Mn(mgkg^{-1})	89.39±1.06b	86.23±0.98a	86.97±0.87a	86.04±0.83a
Cu(mgkg^{-1})	4.08±0.08a	5.06±0.10b	5.12±0.06b	5.35±0.12b
Zn(mgkg^{-1})	44.85±0.33a	48.34±0.42b	47.39±0.48b	55.34±0.53c
Pb(mgkg^{-1})	2.33±0.12a	2.41±0.16b	2.36±0.15b	2.45±0.21c
Cr(mgkg^{-1})	0.47±0.03a	0.53±0.08a	0.50±0.04a	0.56±0.07b

(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)).

3.1.5. Conclusions

This paper has aimed to provide information regarding PA produced by coal fly ash, paper waste, ammonium sulfate and starch as fertilizer and a soil ameliorant to develop crop production in problematic grey soil in Okinawa, Japan. PA addition as a fertilizer and the soil amendment improved the soil physical and chemical properties such as bulk density, hydraulic conductivity, water holding capacity, electrical conductivity, nutrient concentration (K, Mg, Ca, Zn, Cu). The heavy metal concentrations in the PA added media were well below the permissible levels. SA addition to grey soil improved the growth and yield parameters of *Brassica campestris* compared to grey soil with no PA addition. Moreover, the heavy metal content of the plant tissues were well below the permissible level and no phytotoxic symptoms were shown. Long term effect of C, organic matter and B on soil after PA addition should be conducted in future studies. Further researches should be undertaken for wide variety of plant species to check out the suitability of the PA as a fertilizer and a soil amendment for grey soils.

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

3.2.1. Introduction

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, widely spread red soil ("Kunigami Mahji") in Okinawa, Japan, which is classified as an ultisol, is not suitable for crop production due to its poor physical (Tokashiki *et al*. 1994) and chemical properties, such as its highly acidic nature, low organic matter content, and poor nutrient availability (Kobayashi and Shinagawa 1966: Hamazaki 1979). Soil productivity can be enhanced by incorporating organic matter. Organic materials, such as farmyard manure, crop residues and paper waste are commonly used to improve soil properties. Therefore, an attempt was taken to develop an effective method of converting red soil into SA by incorporating paper and starch waste. In present context, paper industry also faces a growing solid waste problem as environmental regulations, are becoming increasingly stringent and land fill space is more scarce. Numerous studies showed that use of de-inking paper wastes in croplands increased soil C in silt loam soil (Simard et al., 1998) and clay loam soils (Aitken et al., 1998, Zibilske 1987). Moreover, addition of paper waste showed a clear relationship between total C, soil organic matter, soil aggregation, soil structure, bulk density, water retention and hydraulic conductivity (Khaleel et al., 1981, Benbi et al., 1998). Addition of paper waste to soil can enhance soil physico-chemical properties and plant growth and yield (Bellamy *et al*., 1995). In addition, Okinawa Seifun Corporation, Okinawa Japan is producing 9000 kg of starch waste per month, which is a considerable management problem, where alternative utilization methods are required. This starch was utilized as the aggregate binder to produce SA as an effective waste utilization method. Moreover soil structure has been found to be of paramount importance in soil productivity and is becoming limiting factor of the crop yield (Low, 1973; Allison, 1973).Therefore, SA was utilized as a soil ameliorant to improve the problematic properties of grey soil to enhance ornamental plant production. The ornamental plant production industry is the fastest growing major segment of Japan agriculture, accounted for 13% from the global production, has a production value of 3147 million Euros per annum (Wijnands, 2005). Therefore, French marigold (*Tagetes patula*) was selected as the ornamental plant in this study.

3.2.2. Objective of the 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*).

3.2.3. Materials and methods

3.2.3.1. Sample collection

Red and grey soil samples were collected from Miyagi-Sajibaru, Higashi-Son, Kunigami-Gun, Okinawa, Japan. Collected soil samples were air-dried and then sieved through a 10-mm mesh screen. A portion of this soil was sieved through a 2-mm mesh sieve, and used for chemical analysis. Paper waste was collected from Ojiryokka Company, Tokyo, Japan. The pH, electrical conductivity (EC), C and nitrogen (N) content of the paper waste were 5.70, 10.28 mSm^{-1}, 374.8 gkg^{-1} and 0.38 gkg^{-1}, respectively. Starch waste was collected from Okinawa Seifun Corporation, Okinawa, Japan. The pH, EC, C and N content of starch waste were 3.80, 20.98 mSm^{-1}, 312.5 gkg^{-1} and 0.42 gkg^{-1}, respectively.

3.2.3.2. Synthetic Aggregate (SA) production

SA (Figure 3.4) 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 50^0C and heated to 80^0C in order to obtain sticky paste as the aggregate binder.)

Figure 3.4. Aggregates used in the study.

3.2.3.3. Pot experiment

Pot 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 a pot experiment. The experiment was a completely randomized design of 8 treatments and three replicates. All 8 treatments are shown in Table 3.7.

Table 3.7. Different treatments utilized under the study

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.

Grey soil was amended with SA at the rates of 10%, 20%, 30%, 40%, and 50% respectively. T1, T7 and T8 treatments were used as controls, where grey soil only, SA only and red soil only, respectively. Pot sizes were 2.0 L. Pots were filled with respective amendment mixtures with out unnecessary compactions. All pots were arranged in a green house and saturated and kept for 48 h to attain their respective field capacities. 2 g of fertilizer (N: P: K; 15%:15%:15%) was incorporated as a basal dressing in each pot after saturation. Two weeks old French marigold plants were obtained from a prepared nursery were planted in each pot. The 1:1 peat: sand mixture (University of California mixture) was used for French marigold as a nursery, which is commonly used throughout the world as a nursery medium (De Boodt and Verdonck, 1972). Pots were arranged in a green house and 200 mLof water was added once in every 2 days to each pot. Temperature ranged from 20-31^0 C during the growth season. The experiment was terminated after 3 months of planting. Plant height, shoot fresh weight, shoot dry weight, root length, root fresh weight, root dry weight and number of flowers per plant were determined. Mineral element concentrations of shoots were analyzed using atomic absorption spectrophotometer (Solaar 969, Thermo Corporation, Tokyo, Japan). Plant materials were ground and passed through 2mm mesh sieve and digested with acid for analysis.

3.2.3.4. Physical and chemical properties of Soil-SA amendment mixtures

Grey soil, red soil, SA, and soil-SA amendment mixtures were sieved using 10 mm mesh screen and were used to analyze the particle size distribution by using dry sieving method (Yoder, 1936). Utilized sieves for the dry sieving were 5.60, 3.35, 2.00, 1.00, 0.50 and 0.25 mm, respectively. Wet aggregate stability of all samples was studied. The aggregates were placed on the top sieve of a nest of sieves having diameters of 5.60, 3.35, 2.00, 1.00, 0.50 and 0.25 mm. They were allowed to equilibrate in shallow water and then sieved under water for 30 min at a frequency of 30 strokes per minute with a stroke length of 32 mm. The water stable aggregates (WSA) in each size fraction were dried at 105 ^{0}C. The proportion of aggregates remaining on the sieves was used to compute WSA (Yodder, 1936). The percentage of WSA > 0.25 mm and the mean weight diameter (MWD) were calculated according to the method described by Kemper and Rosenau (1986). Samples for bulk density measurements of grey soil, red soil, SA, and soil-SA amendment mixtures were taken with a core sampler of volume 100 cm^3, oven dried, and weighed (Blake and Hartage, 1986a). Particle density of all treatments were analyzed by the method described by Blake and Hartage,(1986b). Porosity of the samples was computed by using bulk density and particle density values. Saturated hydraulic conductivities of the grey soil, red soil, SA, and soil-SA amendment mixtures were determined by falling head method (Klute, 1965). Grey soil, red soil, SA, and soil-SA amendment mixtures were used to fill 100 cm^3 core- samplers and were saturated with water for 48 h and kept for another 24 h until gravitational water drained off. Then, amount water held by each sample at field capacity was calculated as water holding capacity (kgkg^{-1}). All measurements were replicated three times.The pH was measured in water extracts of all treatment samples using a glass electrode (sample: distilled water ratio of 1:2.5), and electrical conductivity (EC) was measured using an EC meter (D-54, Horiba) (sample: distilled water ratio of 1:5). C and N contents of all treatment samples were determined according to standard procedures by using CN analyzer (Micro coder JM 10). The organic matter content of samples was determined by using loss of ignition method described by Storer (1984). Exchangeable cations and other trace elements of treatments were determined by using atomic absorption spectrophotometer.

3.2.3.5. Statistical analysis

Data were subjected to analysis of variance (ANOVA) for determination of treatment effects. Duncan’s multiple comparison range test procedure was employed to denote significant differences between the treatments using the SAS package (SAS Institute, 1990).

3.2.4. Results and discussions

3.2.4.1. Particle size distribution and mean weight diameter (MWD)

Particle size distribution and mean weight diameter (MWD) of different treatments used in the experiment are given in Table 3.8. 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. 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 by using red soil and coal fly ash gave increased particle size diameters compared to original red soil.

Table 3.8. Particle size distribution and Mean weight Diameter (MWD) of the different treatments used in the experiment

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)).

Dominance of finer particles in a substrate clogs pores, increase non-plant available water holding capacity and decrease air filled porosity (Spiers and 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 3.8). MWD of grey soil (1.090 mm) 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.

3.2.4.2. Water stable aggregates (WSA), organic matter content and C content

WSA percentage, organic matter content and the C content of different treatments are given in the Figure 3.5. 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 (Carter and Stewart, 1998: Zebarth et al., 1999; 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). Aggregation is maintained by the presence of organic matter (Lynch and Bragg 1985) and therefore changes in organic matter content can lead to changes in aggregation (Hamblin, 1985; Dexter, 1988; Paustin et al., 1977; Datta and Hundal, 1984). SA addition increased the soil organic matter (Figure 3.5) 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 and Koch, 1992) and improves soil organic matter contents, water holding capacity, soil structure and bulk density (Simard et al., 1998; Zhang et al., 1993). 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. Rapid changes in water stable aggregation have been associated with variations in soil organic matter (Cambardella and Elliot, 1993). Moreover, high correlation between aggregate stability and soil organic matter has been reported by Chaney and Swift (1984). More over SA addition significantly enhanced the soil C content (Figure 1). 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}, 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: Tisdall and Oades, 1982; Greenland, 1965). In addition, soil c also helps in the amelioration of soil structure (Mulumba and Lal, 2008). Soil aggregation, which is important to crop establishment, water infiltration and resistance to erosion and compaction, is also influenced by soil C content (Wright and Hons, 2005).

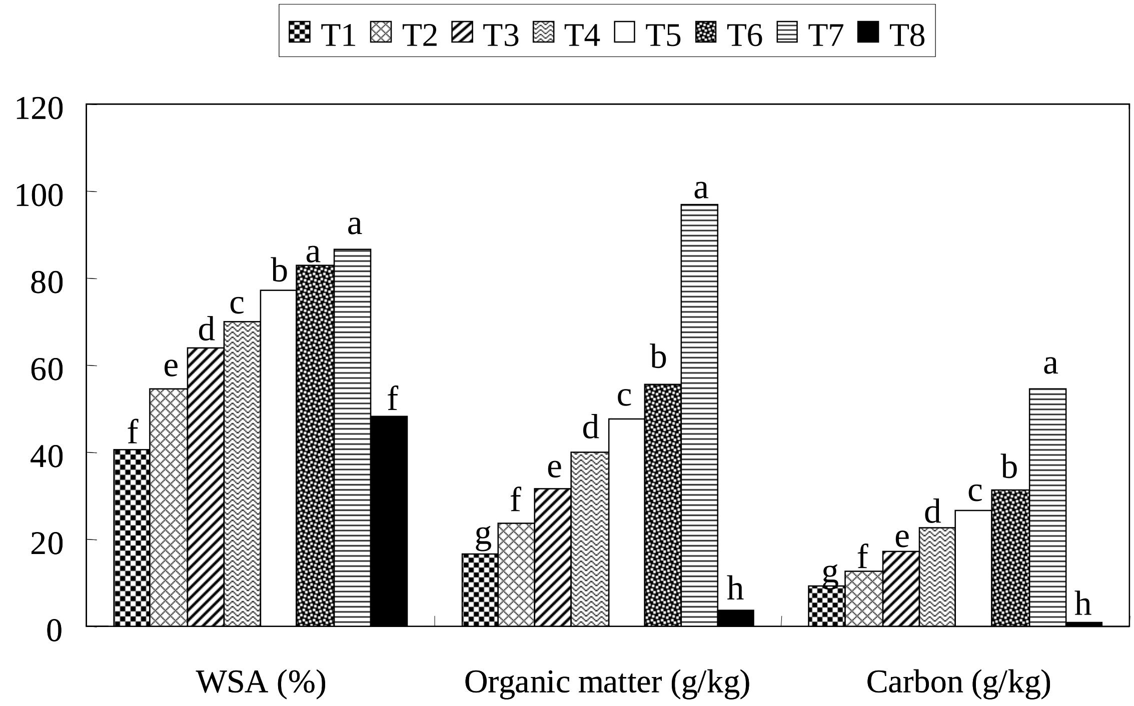


Figure 3.5. Water stable aggregates (WSA), organic matter content and the carbon (C) content of the different treatments studied under the study. (Means with different letters were significantly different according to Duncan's multiple range test ($P=0.05$).Values are mean ($n=3$)).

3.2.4.3. Physical and chemical properties of Soil-SA amendment mixtures

3.2.4.3.1. Physical properties

Physical properties of different amendment mixtures are given by Table 3.9. 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 (Celik et al., 2004). 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. This may be because of the high particle size distribution and the high organic matter content in SA. 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 (Paul and Clark, 1996; 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. Similar low bulk density values were found in SA produced with mine clay and paper waste by Jayasinghe and Tokashiki, (2005).

Table 3.9. Physical properties of the treatments used in the study

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 ($n=3$)).

Total porosity of treatments significantly ($P<0.05$) increased with increasing SA addition (Table 3.9). 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. The lowest porosity values were given by T1 (54.33%) and T8 (53.16%), where no SA addition were done. Highest porosity (63.68 %) was given by the T7 treatment. This may be due to low bulk density and the increased particle size diameter of SA. 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). The lowest water holding capacity was given by T1 (0.47gkg^{-1}) and T8 (0.43 gkg^{-1}). 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. Moreover, paper waste in the SA can improve water holding capacity of the soil. Paper waste is a rich source of C and improves soil organic matter, water holding capacity, soil structure, bulk density (Simard et al., 1998) and plant growth and yield (Bellamy et al., 1995). Soil hydraulic conductivity is a measure of ability of air and water to move through it, and is influenced by size, shape and continuity of the pore spaces, which in turn depends on density, structure and texture. Hydraulic conductivity values of SA addition treatments showed significant differences ($P<0.05$) compared to T1 control except T2 (Table 3.9). Hydraulic conductivity values were increased by 10 times in SA addition treatments of T3, T4, T5 and T6 compared to original grey soil (T1). The greater the bulk density, the greater the air entry suction and the smaller the hydraulic conductivity (Miller and Miller, 1956; Miyazaki, 1996). Grey soil showed the higher bulk density compared to SA amendment treatments (Table 3.9). Therefore, hydraulic conductivity of grey soil was greater than the treatments with SA addition.

3.2.4.3.2. Chemical properties of the treatments

Chemical properties of the different treatments are shown in Table 3.10. The pH 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 3.10). 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.

Table 3.10. Chemical properties of the treatments studied under the experiment

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 ($P=0.05$).Values are mean ($n=3$)).

3.2.4.4. Pot experiment

The growth parameters of French marigold grown in different soil-amendment mixtures are given in Table 3.11.The different treatments used in the experiment are shown in Figure 3.6. 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. 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 and it did not show any significant difference compared to 40% SA addition (T5). 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. This increased growth parameters may be 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 (Giusquiani et al., 1994: Marinari et al., 2000; Tejada and 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. The lowest growth parameters of grey soil may be due to its poor structural properties, alkaline pH and related nutrient availability. Extreme alkaline pH values may possibly be harmful to sensitive crops, and particularly tree crops (Bresler et al., 1982), leading to a reduction in crop growth and yield. 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. The best maximum growth and yield parameters of the 30% SA addition would be due to the improved particle size distribution, bulk density, porosity, water holding capacity, hydraulic conductivity, pH, organic matter, and soil C compared to grey soil.

Table 3.11 Effects of SA amendment on the growth of French marigold

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).Values are mean (n=3)).

The mineral element concentrations in French marigold shoots are given in Table 3.12. 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. Similar results were reported in a study conducted by Chen and Li (2006). Additionally, low pH was reported to directly affect the permeability of root cell membranes and leakage of various ions from the roots (Yan et al., 1992).

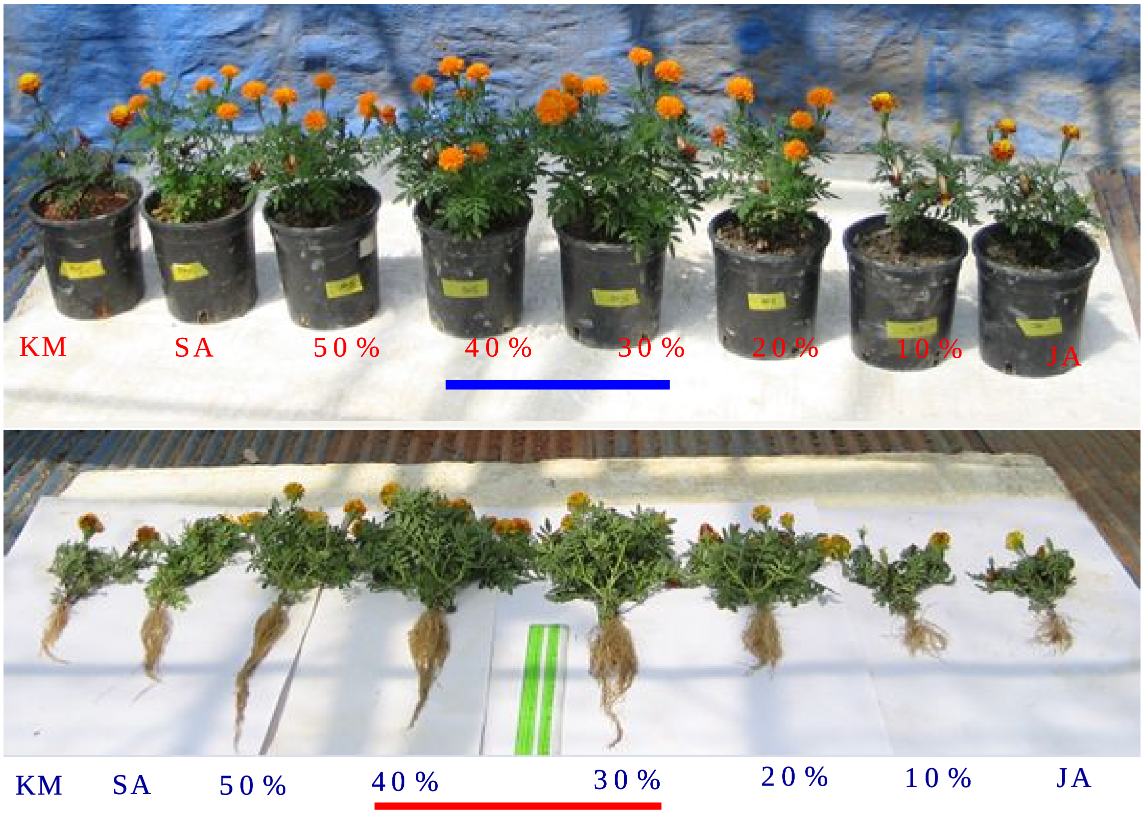


Figure 3.6. Different treatments used in the experiment.

Table 3.12. Element concentrations in plant shoots

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)).

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). But mixing of SA with grey soil at 30% and 40% gave the highest growth and yield parameters. Therefore, addition of 30% to 40% of SA produced from low productive red soil with paper waste 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.

3.2.5. Conclusions

Low productive red soil, paper waste and starch waste can be effectively utilized to produce SA. SA addition as a soil ameliorant improved the particle size distribution, bulk density, water holding capacity, porosity, hydraulic conductivity, pH, organic matter and soil C compared to original grey soil. Bulk density values were decreased by 5.17 %, 9.48 %, 13.79%, 17.24% and 21.55% in SA addition treatments of 10%, 20%, 30%, 40% and 50%, respectively compared to original grey soil. Porosity values were increased by 3.41 %, 5.82 %, 8.63 %, 11.04 % and 13.68 % in SA addition treatments of 10%, 20%, 30%, 40% and 50%, respectively compared to original grey soil. Water holding capacity was increased by 8.51 %, 10.64%, 19.15 %, 23.40 % and 8.51 %, in SA addition treatments of 10%, 20%, 30%, 40% and 50%, respectively compared to original grey soil. The alkaline pH of 8.36 in grey soil was decreased to 7.72 in 30% of SA addition. The highest growth parameters of French marigold were given by the treatments of 30% and 40% SA additions. The plant height, number of flowers per plant, shoot fresh weight, shoot dry weight, root length, root fresh weight and root dry weight in 30% of SA addition were increased by 1.5, 2.9, 3.5, 4.7, 3.4, 4.3 and 9 times, respectively compared to grey soil. It can be concluded that the SA developed by red soil and paper waste and starch waste can be utilized as a soil amendment to improve the physical and chemical properties of the grey soil. SA addition to grey soil at 30% and 40% as a soil amendment gave the best maximum growth parameters of French marigold, which is a popular ornamental in Japan.

Chapter 4

Coal fly ash aggregates and oil palm waste as potting media components

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

4.1.1. Introduction

Coal fly ash application to soil at a low rate has been reported to increase soil conductivity, microbial activity (Lal et al., 1996), soil porosity and water holding capacity (Ghodrati et al., 1995); and thus provides better conditions for growth of the plants. In addition, coal fly ash can be utilized as an amendment to container substrate for ornamental plant production (Menzies and Aitken, 1996; Chen and Li, 2006). However, agricultural use of coal fly ash thus far represents only 0.01million Mg per year according to the ACAA (2003). Therefore alternative ash utilization methods should be required. Moreover, several past studies have demonstrated the feasibility and the advantages of utilizing CSA (coal fly-ash-based synthetic aggregates) produced by coal fly ash with paper waste and starch waste (Jayasinghe and Tokashiki, 2006a;Jayasinghe et al., 2005,2007,2008). An addition of 25% of these CSA to an acidic low productive red soil ("Kunigami Mahji") as a soil ameliorant in Okinawa Japan, improved the soil physico-chemical properties and gave the highest yield and growth parameters of Komatuna (*Brassica rapa Var.Pervidis*) (Jayasinghe and Tokashiki, 2006a). Furthermore, oil palm industry has been gaining increasing importance all over the world. In Malaysia, the largest oil palm producer in the world produced 3 million tones (dry weight) of oil palm fiber annually (Singh, 1994). However, new utilization ways for these huge quantities of oil palm wastes are required. An attempt was done to utilize oil palm waste with CSA as a container substrate. The ornamental plant production industry is the fastest growing major segment of Japan agriculture, accounted for 13% from the global production, has a production value of 3147 million Euros per annum (Wijnands, 2005). The total area for ornamental plant production in Japan in 2004 was 22382 ha, out of which 51% was from protected houses (Wijnands, 2005). During last two decades due to improved popularity for the protected agriculture, evolution of plant growth techniques has increased demand for container substrates such as peat, zeolite, perlite etc, but the supply have been decreasing (Inbar et al., 1990). Depletion of a non-renewable resources and environmental deterioration together with the high prices of those substrates have favored the utilization of alternative materials as growth substrates (Abad et al., 2001).

4.1.2. The objectives of the study

The objectives of the present study were to examine physical and chemical properties of developed container substrates with CSA and oil palm waste and to determine their possible utilization as an alternative container substrate for the French marigold (*Tagetes patula*),which is a very popular ornamental in Japan.

4.1.3. Materials and methods

4.1.3.1. Sample collection and production of CSA

Coal fly ash was collected from the thermal power plant located at Ishikawa, in Okinawa, Japan. The particle density, bulk density, pH and electrical conductivity (EC) values of coal fly ash were 2.14 gcm^{-3}, 0.92 gcm^{-3}, 10.87 and 92.70 mSm^{-1}, respectively. The sodium (Na), potassium (K), magnesium (Mg) and calcium (Ca) concentrations of the coal fly ash were 1.02, 1.68, 0.87 and 3.45 gkg^{-1}, respectively. Nitrogen (N), phosphorous (P) and carbon (C) contents of coal fly ash were 0.52, 0.07 and 43.26 gkg^{-1}, respectively. Dewatered fibrous paper waste was collected from Ojiryokka Company, in Tokyo, Japan. The pH, EC, C and N content of the paper waste were 5.70, 10.28 mSm^{-1}, 374.8 gkg^{-1} and 0.38 gkg^{-1}, respectively. Starch waste was collected from Okinawa Seifun Corporation in Okinawa, Japan. The pH, EC, C and N content values of starch waste were 3.80, 20.98 mSm^{-1}, 312.5 gkg^{-1} and 0.42 gkg^{-1}, respectively. Commercial oil palm waste was obtained from the faculty farm in the University of the Ryukyus, Okinawa, Japan. The zeolite was obtained from Maeda Kensetsukogyo Corporation in Tokyo. CSA were produced by combining coal fly ash and paper waste using an Eirich mixer (R-02M/C27121, Eirich Co.Ltd, Tokyo, Japan) with starch waste as a binder. 500 g of coal fly ash and 50 g of paper waste was mixed in the Eirich mixer with the starch paste, which was prepared at 70°C by adding 300 mL of hot water to 100 g of starch waste until the production of CSA.

4.1.3.2. Container substrates utilized under the study

Table 4.1 shows the volumetric formulations of different container substrates used under the study. CSA (T1) was produced using coal fly ash, paper waste and starch waste. Two different mixing ratios of CSA with oil palm waste at the ratio of 1:5 (T2) and 1:10 (T3) and oil palm waste only (T4) were used as growth substrates while commercially available zeolite was utilized as the standard substrate to compare the characteristics of other substrates used under this study.

Table 4.1. Composition of container substrates used in the experiment

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.

4.1.3.3. Analytical methods

Samples of air dried growth substrates were passed through a series of sieves, from 5.60 mm to 0.25 mm, to determine their particle size distribution. The physical properties of each growth substrate materials were determined using the procedures described by Spomer (1990) and Pill et al (1995). Each moistened pre-plant media was placed in 12.5 cm diameter standard plastic pots. Each pot was irrigated for two weeks in the same manner. After two weeks of irrigation the container's drainage hole were sealed with duct tape. Water was then added to each medium until saturated. After determining the weight of the saturated media, the drainage holes were unsealed and the media were allowed to drain 24 h. Then the amount of water loss was determined as a result of drainage. Then the media were oven dried at 65^{0}C for 48h and weighed to determine the amount of water retained by the media after draining. The weight of the water needed to saturate each medium was divided by the medium bulk volume to determine the total pore space percentage. Media bulk density was determined by dividing the oven dried weight of each medium by the medium bulk volume. All analyses were done in triplicates. The pH was measured in water extracts of all container substrate samples using a glass electrode (Sample: distilled water ratio of 1:5), and electrical conductivity (EC) was measured using an EC meter (D-54, Horiba) (Sample: distilled water ratio of 1:5). One gram of each dried substrate sample was utilized to determine carbon (C) and nitrogen (N) contents by using CN coder (Micro coder JM 10). C and N contents in the dried substrate samples were burnt into CO_2, NOx and N_2 during the analysis and the C and N contents in the samples were automatically detected with the assistance of a standard calibration curve. Total concentrations of Na, K, Mg and Ca of the substrates were determined by using the method described by Schollenberger and Simon (1945). The cations of the air dried substrate samples were extracted by using 1 M ammonium acetate. Then the extracts were used to analyze the cation concentration using atomic absorption spectrophotometer (Solaar 969, Thermo Corporation, Tokyo, Japan).The substrates were digested in nitric acid (USEPA, 1996) and analyzed for heavy metals by using atomic absorption spectrophotometer (Solaar 969, Thermo Corporation, Tokyo, Japan).

4.1.3.4. Pot experiment

A green house pot experiment was conducted to study the impact of different substrates (see Table 4.1) used in this study on the growth and development of French marigold (*Tagetes patula*) production. The experimental design of the pot experiment was a completely randomized design with 5 treatments and three replicates. The container volume was 1.5 L. Prepared air dried substrate samples were filled into each pot leaving a distance of 1 cm from the top of the pot and without subjecting them to unnecessary compaction. All pots were arranged in a green house and saturated and kept for 48 hours to attain their respective field capacities. Two weeks old French marigold plants were obtained from a prepared nursery were planted in each pot. The 1:1 peat: sand mixture (University of California mixture) was used as a nursery, which is commonly used throughout the world as a nursery medium (De Boodt and Verdonck, 1972).Water and nutrient requirements of the plants were supplied equally to all treatments through a complete nutrient solution. The chemical composition of the nutrient solution was as follows (mgL^{-1}): N:210, P:80, K:270, Mg:40,Ca:164, Fe:1.8, Mn:1, Cu:0.02, Zn:0.05 (Otsuka house commercial formulation, Japan). 200 mL of nutrient solution was added to each pot once in two days. Temperature ranged from $20\text{-}31^{0}$ C during the growth season. Experiments were terminated after 3 months of planting. Plant height, shoot fresh weight, shoot dry weight, root fresh weight, root dry weight and number of flowers were determined. Mineral element concentrations of shoots were analyzed using atomic absorption spectrophotometer (Solaar 969, Thermo Corporation, Tokyo, Japan).

4.1.3.5. Statistical analysis

The obtained data were subjected to analysis of variance (ANOVA) for determination of the treatment effects. Duncan's multiple comparison range test procedure was employed to denote significant differences between the treatments using the SAS package (SAS Institute, 1990).

4.1.4. Results and discussion

4.1.4.1. Physical properties of the container substrates

Table 4.2. Particle size analysis of the container substrates

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)).

The particle size distribution of different substrates utilized in this study is given by the Table 4.2.The 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 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. Dominance of larger particles in a substrate increase aeration and decrease water retention (Benito et al., 2006),while dominance of fine particles clogs pores, increase non-plant available water holding capacity and decrease air filled porosity (Spiers and Fietje,2000). 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., 1992; 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 according to Abad et al., (1993) and Benito et al., (2006) 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 oil palm waste.

Table 4.3 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. Therefore these high bulk density values have the disadvantage of increasing the transportation costs (Corti et al., 1998). 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.While T1 and T5 were not within the established ideal range. Air space values for an ideal substrate should be within 20-30% according to De Boot and Verdonck (1972). T4 and T5 were not fallen into this ideal air space range. Zeolite showed highest air space while oil palm waste showed lowest 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).

Table 4.3 Physical properties of the container substrates

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 4.4. Chemical properties of the container substrates

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})	Cu (mgkg^{-1})	Mn (mgkg^{-1})	Zn (mgkg^{-1})	Pb (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}	18.47^{a}	15.82^{a}	34.63^{a}	7.56^{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}	10.82^{b}	12.61^{c}	25.12^{b}	6.72^{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}	8.68^{c}	10.67^{d}	11.61^{d}	5.89^{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}	2.02^{d}	2.81^{e}	1.17^{e}	0.41^{d}
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}	11.08^{b}	13.78^{b}	21.72^{c}	6.08^{b}

EC: electrical conductivity: (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 ($n=3$)).

The ideal total pore space should exceed 85% (De Boodt and Verdonck, 1972). T2, T3, and T4 growth media exceed 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. In addition, the water holding capacity of the CSA showed a significant increase ($P<0.05$) in comparison with the zeolite media. 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.

4.1.4.2. Chemical properties of the container substrates

Chemical properties of the container substrates are given in the Table 4.4. The pH showed significant differences ($P<0.05$) among all substrates. The CSA (T1) showed an alkaline pH value of 9.82. This may be due to the utilization of coal fly ash having alkaline pH of 10.87 to produce CSA. Coal fly ash showed an alkaline pH according to previous studies (Adriano, 1980; Cha et al., 1999; Dwivedi et al., 2007; Lee et al., 2007). 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; Bunt, 1988; De Boodt and Verdonck, 1972; Raviv et al., 1986). 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; Bunt, 1988; De Boodt and verdonck, 1972; Raviv et al., 1986).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. Carbon contents of all container substrates were significantly differed ($P<0.05$) with each other. Zeolite had the lowest carbon content compared to other substrates. CSA was developed using coal fly ash and paper waste. Coal fly ash contains substantial amount of black carbon (Klose and Makeschin, 2003). Adriano et al., (1978) reported that some coal fly ash can contain as much as 30% C by weight. Because of their high carbon contents, coal fly ash must be considered as carbon sources in forest soils near power plants (Klose et al., 2003). Subsequently, these carbonaceous ash particles are extremely stable against microbial degradation or chemical extraction (Goldberg, 1985; Klose and Makeschin, 2003). Due to low decomposition rates, C may accumulate in soil and may have an impact on the quantity and composition of soil organic matter (Schmidt et al., 1996). In addition, paper waste in the CSA is also a rich source of carbon (Rasp and Koch, 1992) and improves soil organic matter contents, water holding capacity, soil structure and bulk density (Simard et al., 1998; Zhang et al., 1993). The carbon content of the paper waste and the starch waste were 374.8 gkg^{-1} and 312.5 gkg^{-1}. Therefore, CSA can be considered as a significant source of carbon. 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 (Abad et al., 2002). Established range of C/N ratio for ideal substrate is 20-40 (De Boodt and Verdonck, 1972; Raviv et al., 1986). It is evident that the all substrates studied under this research exceeded the established ideal limits for C/N ratio due to the low nitrogen content, but T2, T3 and T4 substrates were closest to the ideal value. Consequently, the slight nitrogen deficit can be compensated by applying fertilization programmes when using these substrates as plant growth substrates. CSA and the zeolite media showed significantly ($P<0.05$) higher concentrations of cations (Table 4.4) compared to other substrates. This is due to the higher concentrations of Na, K, Ca and Mg in the coal fly ash (Page et al., 1979; Elseewi et al., 1980). Agricultural utilization of coal fly ash has been proposed due to its considerable contents of K, Ca, Mg, S and P (Kalra et al., 1997). 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).

Heavy metal concentrations of the substrates are given in the Table 4.4. CSA showed the highest concentration of heavy metals compared with other substrates. Cd and Se were not detected in all substrate samples. The As, Cr, Cu, Mn, Zn and Pb concentrations of the original coal fly ash used to produce CSA were 0.3, 12.8, 32.5, 66.64, 48.4 and 13.6 $mgkg^{-1}$, respectively. Coal fly ash contains trace and heavy metals that adversely affect crop growth, soil and ground water quality (Adriano et al., 1978; Page et al., 1979). The amount of heavy metals released from coal into coal fly ash depends on coal type, composition, modes of element occurrence and combustion technology (Jala and Goyal, 2006; Spears et al., 1998). Adriano et al., (1978) reported that at higher levels of coal fly ash, some heavy metals might become more active and hinder microbial activity. These metals form complexes, which undergo transformation, influenced by various factors like pH, moisture, cation exchange and microbial activity (Milovsky and Kononov, 1992). Leaching of coal fly ash is a function of physical and chemical characteristics of coal fly ash and hydrogeology and climatic conditions of the site (Kopsick and Angino, 1981; Goetz, 1983). The standard maximum pollutant concentrations of individual metals for land application suggested by the US Environmental Protection Agency (USEPA, 1999) 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 the coal fly ash and 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, 1999). The low heavy metal concentrations in the coal fly ash and CSA used in this experiment support earlier work on coal fly ash, showed that the heavy metal content was very low and was unlikely to affect ground water quality (Ghodrati et al., 1995).Though the release of heavy metals is within the permissible limit and not alarming, routine inspections should be done to maintain the heavy metal concentrations within the safe limits.

4.1.4.3. Growth and yield parameters of the 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 (Figure 4.1) after 3 months of growing period are shown in Table 4.5. 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 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. It has been found that high pH of the substrate sharply decrease the availability of phosphorous and iron in the substrate (Peterson, 1982). In addition, the high values of EC are detrimental to most of the crops (Bresler et al., 1982). 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.). Second best yield and growth was achieved with substrate T2 where CSA and oil palm waste mixed at 1:5 ratio. 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).The low growth of French marigold grown in oil palm waste may be due to its acidic pH.

4.1. Different treatments in the study.

Table 4.5 Effects of container substrates on the growth of French marigold

Substrate	Shoot fresh weight ($gplant^{-1}$)	Shoot dry weight ($gplant^{-1}$)	Root fresh weight ($gplant^{-1}$)	Root dry weight ($gplant^{-1}$)	Plant height (cm)	No of flowers per plant
T1	11.68^{e}	1.59^{e}	4.55^{e}	0.65^{e}	9.60^{e}	0
T2	141.59^{b}	19.54^{b}	49.25^{b}	7.39^{b}	31.33^{b}	56.00^{b}
T3	165.17^{a}	23.87^{a}	56.34^{a}	8.90^{a}	34.00^{a}	64.00^{a}
T4	101.37^{d}	11.00^{d}	33.88^{d}	3.31^{d}	25.33^{d}	38.33^{d}
T5	109.37^{c}	12.37^{c}	36.36^{c}	3.56^{c}	28.66^{c}	39.66^{c}

(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 4.6 Mineral element concentrations in shoots of plant shoots

Substrate	K (gkg^{-1})	Mg (gkg^{-1})	Ca (gkg^{-1})	Cu ($mgkg^{-1}$)	Mn ($mgkg^{-1}$)	Zn ($mgkg^{-1}$)	Pb ($mgkg^{-1}$)
T1	41.22^{a}	13.30^{b}	40.22^{b}	3.47^{a}	66.77^{b}	36.64^{a}	0.41^{a}
T2	36.31^{b}	12.22^{c}	41.44^{a}	3.22^{a}	64.14^{c}	33.11^{c}	0.43^{a}
T3	33.07^{c}	10.37^{d}	42.92^{a}	3.13^{ab}	62.31^{d}	34.57^{b}	0.39^{a}
T4	31.89^{d}	7.91^{e}	5.78^{c}	2.70^{b}	102.56^{a}	32.36^{d}	0.33^{a}
T5	43.36^{a}	15.13^{a}	40.26^{b}	3.46^{a}	67.82^{b}	31.70^{e}	0.40^{a}

(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)).

The mineral element concentrations in French marigold shoots are given in the Table 4.6. It is evident that shoot concentrations of Ca and Mg were low but Mn concentration was significantly (P<0.05) higher in plants grown in oil palm waste (T4) compared with other treatments. Similar results were found in a previous study conducted by using coal fly ash as an amendment to container substrate for *Spathiphyllum* production by Chen and Li, (2006).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 (Chen and Li, 2006).Additionally, low pH was reported to directly affect the permeability of root cell membranes and leakage of various ions from the roots (Yan et al., 1992). It is likely that the low pH and its related nutrient bioavailability accounted for the reduced growth of French marigold grown in the oil palm waste. But mixing of oil palm waste with CSA gave the highest growth and yield parameters. 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 coal fly ash with paper waste and mixing them with oil palm waste as a container substrate can be suggested as an alternative waste management practice.

4.1.5. Conclusions:

Developed CSA gave an alkaline pH (9.82), high electrical conductivity (96.1mSm^{-1}), high cation concentration, high water holding capacity and low bulk density (0.56gcm^{-3}) compared to zeolite. Mixing of CSA with oil palm waste at the ratio of 1:10 gave enhanced physical and chemical properties such as bulk density (0.25 gcm^{-3}), particle density (1.76 gcm^{-3}), air space (20.59%), total pore space (85.79%), total water holding capacity (652 mLL^{-1}), pH (6.18) and electrical conductivity (42.4mSm^{-1}),which were in the established ideal substrate range. The growth of French marigold (*Tagetes patula*), which is a popular ornamental plant in Japan was assessed using these newly developed substrates. The mixing ratio of CSA and oil palm wastes at 1:10 ratio reported the best maximum growth and yield parameters of French marigold, with increase in shoot fresh weight, shoot dry weight, root fresh weight, root dry weight, plant height and number of flowers per plant by 51%, 93%, 54%, 150%, 19%, and 61%, respectively compared to the zeolite. It is revealed that a mixture of CSA and oil palm waste at the ratio of 1:10 can be successfully utilized as an alternative container substrate for French marigold production.

Chapter 5

Synthetic aggregates developed from acidic red soil and paper waste as a potting media component

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

5.1.1. Introduction

Sphagnum peat has been the most widely used growing media constituent for the production of ornamental potted plants. However, since the late 1970s there has been a worldwide search for new peat substitutes (Raviv et al. 1986, Robertson 1993). One reason for this is the high price of high quality horticultural peat, especially in countries without peat moss resources. A second reason is questionable availability of peat in near future due to environmental constraints. Research on peat alternatives is of great interest in the future (Cull 1981, Ingelmo et al. 1998, Guerrero et al. 2002, Chong 2005, Wilson et al. 2006). In this context; different authors have suggested that some organic materials such as municipal solid waste, coco fiber, bio-solid compost and paper waste could be feasible materials for a partial peat substitution (Bugbee 2002, Guerrero et al. 2002). Moreover, in an effort to recycle and reclaim wastes, various residues generated by agriculture, livestock farming, forestry, industries and city centers are being successfully used as container media for ornamental plant production (Verdonck 1988, Abad et al. 1997, Ingelmo et al. 1998). Thus, an increase in the demand for solid wastes has been generated, and so these materials are now considered as useful and value-added products (Hauke et al. 1996, Bures, 1997). Widely spread red soil ("Kunigami Mahji") in sub-tropical Okinawa, Japan, which is classified as an Ultisol, 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). This acidic red soil accounts for about 55% from the total land area of Okinawa,Japan (Onaga & Yoshinaga 1988). These huge amounts of acidic red soil are not being properly utilized due to low productivity and acidity. This prompted for the development of an effective method of converting under utilized red soil in to fertile, arable SA by incorporating paper waste and starch waste in order to improve its physical and chemical properties. Starch waste obtained from Okinawa Seifun Corporation in Okinawa, Japan was used as the aggregate binder as described in our previous studies (Jayasinghe et al. 2005, 2007, 2008, Jayasinghe & Tokashiki 2006a). During last two decades due to improved popularity for protected agriculture, evolution of plant growth techniques has increased demand for container substrates such as peat, zeolite, perlite etc, but the supply have been decreasing (Inbar et al. 1990). Depletion of non-renewable resources and environmental deterioration together with high prices of those substrates have favored the utilization of alternative materials as growth substrates (Abad et al. 2001).

5.1.2. Objective of the study

The aim of the present research was to evaluate the characteristics of substrates formed with peat and synthetic aggregates (SA) produced by using underutilized acidic soil, paper waste and starch waste as a peat substitution, on the growth parameters of French marigold (*Tagetes patula*), which is a popular ornamental in Japan.

5.1.3.Materials and methods

5.1.3.1.Collection of sampled materials

Red soil samples were collected from Miyagi-Sajibaru, Higashi-Son, Kunigami-Gun, Okinawa, Japan. The soil texture was clay and is classified as an Ultisol. Collected soil samples were air-dried and then sieved through a 10-mm mesh screen and utilized for SA production. A portion of this soil was used to analyze particle size distribution by using dry sieving method (Yoder 1936); another portion of this soil sample was sieved through a 2-mm mesh sieve, and used for chemical analysis. Paper waste was collected from Ojiryokka Company, Tokyo, Japan. Starch waste and peat samples were obtained from Okinawa Seifun, Corporation ltd, Okinawa, Japan. Physical and chemical properties of the soil and paper waste are given in Table 5.1.

5.1.3.2.Production of synthetic soil aggregates (SA)

SA was produced by combining red soil and paper waste using an Eirich mixer (R-02M/C27121) with starch waste as a binder according to Jayasinghe et al (2005, 2007, 2008, 2009b, c, d, e, f, g). 1000 g of red soil, 100 g of waste paper and 25 g of lime were mixed in Eirich mixer by adding 225 ml of starch paste (starch paste was produced adding 25g of starch to 200 ml hot water) for the production of SA. Lime was added to neutralize soil pH and to produce aggregates having pH of 6.40.

Table 5.1. Selected physical and chemical properties of paper waste and red soil used in the experiment.

Particulars	PW	Red soil
Bulk density (gcm^{-3})	-	1.26±0.03
Particle density (gcm^{-3})	-	2.65±0.06
pH	5.70±0.32	4.96±0.14
EC (dSm^{-1})	0.10±0.001	0.04±0.001
C (gkg^{-1})	374.8±2.76	1.73±0.04
N (gkg^{-1})	0.38±0.10	0.40±0.04
P (gkg^{-1})	0.06±0.01	0.03±0.01
Na (gkg^{-1})	0.24±0.09	0.06±0.01
K (gkg^{-1})	0.32±0.05	0.05±0.01
Mg (gkg^{-1})	0.47±0.11	0.02±0.00
Ca (gkg^{-1})	0.63±0.17	0.07±0.01
As (mgkg^{-1})	ND	ND
Cr (mgkg^{-1})	3.70±0.34	1.20±0.10
Cu (mgkg^{-1})	8.50±0.49	13.8±0.22
Se (mgkg^{-1})	ND	ND
Mn(mgkg^{-1})	6.52±1.26	20.6±1.95
Cd (mgkg^{-1})	ND	ND
Zn (mgkg^{-1})	10.10±0.42	27.3±2.98
Pb (mgkg^{-1})	0.63±0.16	4.70±0.06

PW: paper waste, EC: electrical conductivity, ND = Not Detected; Values are mean ±Standard Deviation (n=5)

5.1.3.3. SA and peat mixtures utilized under the study

Table 5.2 shows volumetric formulations of different SA and peat mixtures used in the study.

Table 5.2. Composition of growth substrates used in the experiment

Substrate	Formulation
T1	Peat (100%) (V/V)
T2	Peat 75% : SA 25% (V/V)
T3	Peat 50%: SA 50% (V/V)
T4	Peat 25% :SA 75% (V/V)
T5	SA (100%) (V/V)

SA: Synthetic aggregates, V/V: Volume basis

5.1.3.4. Analytical methods

The pH was measured in water extracts of all substrate samples using a glass electrode (Sample: distilled water ratio of 1:5), and electrical conductivity (EC) was measured using an EC meter (D-54, Horiba) (Sample: distilled water ratio of 1:5). Carbon (C) and nitrogen (N) contents in substrate samples were determined by using CN analyzer (Micro coder JM 10; G-Science Laboratory, Tokyo, Japan). Concentrations of Na, K, Mg and Ca of substrate samples were extracted by using 1 M ammonium acetate (Schollenberger & Simon 1945) and the extracts were used to analyze the cation concentration using atomic absorption spectrophotometer (Solaar 969, Thermo Corporation, Tokyo, Japan). Red soil, paper waste and all other substrates used in the experiment were digested in nitric acid (USEPA, 1996) and analyzed for heavy metals (As, Cr, Cu, Se, Mn, Cd, Zn and Pb) by using atomic absorption spectrophotometer (Solaar 969, Thermo Corporation, Tokyo, Japan). Total P of substrate samples were determined by using spectrophotometer (JSSSPN 1997). Physical properties of each substrate materials were determined using procedures described by Spomer (1990) and Pill et al. (1995). Each moistened pre-plant substrate was placed in 12.5 cm diameter standard plastic pots. Each pot was irrigated for two weeks in the same manner. After two weeks of irrigation, container's drainage hole was sealed with duct tape. Water was then added to each substrate until saturated. After determining the weight of saturated substrate, the drainage holes were unsealed and substrates were allowed to drain 24 h. Then the amount of water loss was determined as a result of drainage. Then substrates were oven dried at 65^{0}C for 48h and the amounts of water retained by substrates after draining were determined. The weight of water needed to saturate each substrate was divided by the medium bulk volume to determine total pore space percentage. Substrate bulk density was determined by dividing oven dried weight of each substrate by substrate bulk volume. Samples of air dried substrates were passed through a series of sieves, from 5.6 mm to 0.25mm, to determine their particle size distribution. All measurements were carried out 5 times.

5.1.3.5. Utilization of SA and peat mixtures as a growth substrate for French marigold production

A green house pot experiment was conducted to study the influence of different substrates containing different ratios of SA and peat on ornamental plant growth. French marigold (*Tagetes patula*) was utilized as the ornamental plant in this study. Container volume was 1.5 L. Table 5.2 shows the volumetric formulations of different container substrates utilized in this study. The pH of the T1 (peat) was adjusted to 6.40 by adding lime. Experimental design of the pot experiment was a completely randomized design (CRD) with 5 treatments and 5 replicates. Prepared air dried substrate samples were filled into each pot leaving a distance of 1 cm from the top of the pot and without unnecessary compaction. All pots were arranged in a green house and saturated and kept for 48 h to attain their respective field capacities. Two weeks old French marigold plants obtained from a prepared nursery were planted in each pot. One plant was planted in each pot. Water and nutrient requirements of plants were supplied equally to all treatments through a complete nutrient solution. The chemical composition of the nutrient solution was as follows (mgL^{-1}): N:210, P:80, K:270, Mg:40,Ca:164, Fe:1.8, Mn:1, Cu:0.02, Zn:0.05 (Otsuka house commercial formulation, Japan). 200 mL of nutrient solution was added to each pot once in two days. Temperature ranged from 20-31^0 C during the growth season. Experiments were terminated after 3 months of planting. Plant height, shoot fresh weight, shoot dry weight, root length, root fresh weight, root dry weight and number of flowers were determined. The dried shoot material samples were digested in nitric acid and its mineral element concentrations were analyzed by using atomic absorption spectrophotometer (Solaar 969, Thermo Corporation, Tokyo, Japan). Aggregate strength of SA before and after pot experiment was determined by hardness testing machine (Kiya Digital Hardness Tester, KHT-20, Japan) as a aggregate stability parameter. Five randomly selected samples of air dried SA from each treatment (T2, T3, T4 and T5) before and after pot experiment were used to determine the average aggregate strength.

5.1.3.5. Statistical analysis

Obtained data were subjected to analysis of variance to determine the treatment effects. Duncan's multiple comparison range test was used to determine significant differences between the treatments using SAS package (SAS Institute 1990).

5.1.4. Results and discussion

5.1.4.1..Physical properties of the growth media

Particle size distribution of different growth media utilized in this study is given in Table 5.3. Particle size distribution of a growing medium is important because it determines pore space, air and water holding capacities. Mean distribution of the media showed that fraction > 2 mm was the most abundant fraction (67.60%) in SA (T5), where as this fraction was significantly ($P<0.05$) low in other four substrates compared with SA. This fraction in T1, T2, T3 and T4 were 18.34, 24.80, 34.25 and 49.27%, respectively. A surplus of larger particles in a growth substrate leads to excessive aeration and lower water retention (Benito et al. 2006). In addition the particle percentage <0.25mm in peat was the highest while SA substitutions T2, T3 and T4 significantly ($P<0.05$) decreased the finer particles <0.25mm. An excess of finer particles in a growth substrate clogs pores, increases non-plant available water holding capacity and decrease air filled porosity (Spiers & Fietje 2000). The highest percentage of particles of T1, T2 and T3 were in the range of 0.25-0.50 mm while the highest fraction of particles of T4 and T5 were in the range of 3.35-2.00 mm. The best substrate is one that has a medium to coarse texture, equivalent to a particle size distribution between 0.25-2.00 mm, as this is the optimal range for a plant growth medium as it allows retention of enough readily available water together with adequate air content (Abad et al. 1993; Benito et al. 2006). The particle size percentages of T1, T2, T3, T4 and T5 in the range of 0.25-2.00 mm were 67.30, 69.09, 59.91, 46.31 and 29.34 %, respectively. In comparison with SA and peat, the peat 75%: SA 25% substrate gave the highest particle size percentages in the range of 0.25-2.00 mm, which is regarded as the optimal range

Table 5.3. Particle size analysis of the container substrates used in the experiment

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	0	5.30±0.20e	13.04±1.12d	17.86±0.92c	22.05±0.78a	27.39±1.12a	14.36±0.38a
T2	0.52±0.04d	7.41±0.41d	16.87±1.25c	20.88±1.52a	21.34±0.60b	26.87±1.38a	6.11±0.27b
T3	4.76±0.28c	11.69±1.42c	17.80±0.86c	18.83±0.68b	19.32±1.02c	21.76±1.20b	5.84±0.20c
T4	7.87±0.46b	17.53±0.96b	23.87±0.77b	18.43±0.84b	14.12±0.92d	13.76±0.84c	4.42±0.18d
T5	10.77±0.38a	19.85±1.22a	36.98±1.38a	13.15±0.58d	7.91±0.41e	8.28±0.52d	3.06±0.22d

(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=5)).

for a plant growth medium. In addition, T2 and T3 treatments increased the particle sizes in the range of 2.00 -3.35 mm and 3.35-5.60 mm compared with the peat because of mixing comparatively larger particles of SA and smaller sized particles of peat.

Bulk density, particle density, air space, total porosity and water holding capacity of the growth substrates are given in Table 5.4. The bulk density values of all substrates were significantly different ($P<0.05$). Abad et al. (2001) defined the bulk density requirement of an ideal substrate should be <0.40 gcm^{-3}. With the exception of T4 and T5 all other substrates were within the established ideal substrate range. The lowest bulk density reported in peat (T1) substrate followed by T2 and T3. High bulk density values have the disadvantage of increasing the transportation cost and reducing porosity (Corti et al.1998). Mixing of peat and SA in treatments of T2, T3 and T4 decrease the bulk density values by 58.62, 50 and 22.41%, respectively in comparison with the SA (T5). Particle density values of T1, T2 and T3 were within the established particle density limit (1.4-2.0 gcm^{-3}) described by Abad et al. (2001), but the T4 and T5 were not in the ideal range. Moreover, air space values of T1 and T5 were not within the ideal range (20—30%) explained by De Boodt and Verdonck (1972). Peat gave the lowest air space value among all substrates. De Boodt and Verdonck (1972) revealed that low percentages of air space in peat based substrates may cause problems for plant growth. SA gave the highest air space value and greater air space means that water should be applied more frequently, and in small amounts to avoid leaching (Benito et al.2006). Addition of SA to substitute peat at the rates of 25 % (T2), 50 % (T3) and 75 % (T4) enhanced air space into the ideal substrate range compared with SA and peat. Total porosity of an ideal substrate should be greater than 85% according to De Boodt and Verdonck (1972). T1, T2 and T3 exceeded 85% of porosity whereas T4 and T5 were well below with the established ideal range (Table 4). Water holding capacities of all substrates were significantly differed. The ideal water holding capacity of an ideal substrate should be in the range of 600-1000 mLL^{-1} according to De Boodt and Verdonck (1972). The highest water holding capacity was reported from T1 substrate where as the lowest given by T5 substrate. Water holding capacities of the T1, T2 and T3 were in the ideal established range while T4 and T5 gave water holding capacities below the ideal range. Therefore, SA addition at the rates of 25% (T2) and 50% (T3) to substitute peat in the growth substrates showed bulk density, particle density, air space, total porosity and water holding capacity in the establish ideal range. Moreover, physical properties of SA substituted substrates were generally within the recommended ranges for production of ornamental plants (Poole et al., 1981; Bunt, 1988; Rynk et al., 1992).

Table 5.4. Bulk density, particle density, air space, total porosity and the water holding capacity of the substrates

Substrates	Bulk density (gcm^{-3})	Particle density (gcm^{-3})	Air Space (%)	Total Porosity (%V/V)	Water Holding Capacity(mLL^{-1})
T1	0.18±0.03e	1.70±0.03e	17.71±0.17c	89.41±1.74a	717±7.34a
T2	0.24±0.04d	1.75±0.04d	20.29±0.30b	86.29±1.60b	660±5.30b
T3	0.29±0.05c	1.97±0.05c	20.18±0.28b	85.28±1.84c	651±5.26c
T4	0.45±0.06b	2.25±0.06b	20.21±0.18b	77.61±1.65d	574±4.35d
T5	0.58e±0.03a	2.61e±0.03a	31.97±0.38a	77.77a±1.28d	458a±8.70e
IS	<0.40	1.4-2.0	20-30	>85	600-1000

(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 ±Standard Deviation (n=5)).

5.1.4.2. Chemical properties of the growth media

The main chemical characteristics of substrates are listed in Table 5.5. The pH values of substrates were significantly differed ($P<0.05$). pH values of substrates varied from 4.64 to 6.40. The established pH range for an ideal substrate is 5.3-6.5 (Raviv et al. 1986: Abad et al. 2001). Originally pH (4.64) of peat was not within the established ideal range. Acidic pH of peat was increased by addition of lime to the ideal range (pH=6.40). Electrical conductivity (EC) of the all media was varied between 0.28-0.76 (dSm^{-1}). The established EC levels for an ideal substrate should be less than 0.50 dSm^{-1} (Raviv et al. 1986, Abad et al. 2001). There is no one single ideal substrate for nursery produced horticultural crops (Poole et al. 1981, Raviv et al.1986, Bugbee & Frink 1996). However, most of the parameters of T2 and T3 were reported in established ideal range compared with peat. The C contents of all substrates were significantly differed where the highest and lowest C contents were given by peat and SA, respectively. Original C content of red soil used to form SA was 1.73 gkg^{-1} increased to 85.40 gkg^{-1} due to incorporation of paper and starch waste. Paper waste is a rich source of C and improves soil organic matter content, soil structure and bulk density (Simard et al. 1998; Rasp & Koch 1992; Zhang et al. 1993). N and P contents of substrates were varied in the range of 0.40-6.71 and 0.05-0.08 gkg^{-1}, respectively. Na, K and Mg contents of substrates did not show any significant differences but Ca contents of substrates were significantly differed. Highest Ca content was obtained from T5. This may be due to addition of lime to produce SA. Substrates of T2, T3 and T4 having mixtures of SA and peat showed suitable chemical properties as growth substrates, which can be considered as substitutions for expensive peat.

Heavy metal concentrations of different substrates are given in Table 5.6. As, Cd and Se were not detected in all substrates. Moreover, most of the Cr, Cu, Mn, Zn and Pb concentrations in all substrates were not significantly differed with each other. Heavy metal concentrations of all substrates were generally well below the maximum pollutant concentration of individual metals for land application suggested by the US Environmental Protection Agency (USEPA 1999). Moreover, the heavy metal concentrations of PW and red soil used were also low compared with the USEPA levels (Table 5.1).The average concentrations of heavy metals reported in uncontaminated soils are (all in $mg\ kg^{-1}$): As 6 , Cr 70, Cu 30, Se 0.4, Mn 1000, Cd 0.35, Zn 90, Pb 35, respectively (Adriano 2001). The heavy metal concentrations in all substrates in this experiment were generally below the heavy metal concentrations reported in uncontaminated soils. According to Abad et al. (1993), maximum levels of Cu, Zn, Cd, Cr and Pb concentrations in a growth substrate should be less than (all in $mg\ kg^{-1}$): Cu 500,Zn 1500, Cd 5, Cr 200 and Pb 1000, respectively. It is evident that heavy metal contents in all growth substrates were below that limits (Table 5.6).

5.1.4.3. Growth and Yield parameters of the French marigold plants

The effect of the different growth substrates formulated with SA and peat on the growth and yield parameters of French marigold after 3 months of growing period are given in the Table 5.7. Different treatemnts used in the experiment are shown in Figure 5.1. There were significant differences ($P<0.05$) in growth and yield parameters of French marigold grown in different growth substrates. The lowest growth parameters were given by T5 and the highest growth parameters given by T2 where peat was substituted by 25% of SA. Plant height, number of flowers per plant, fresh shoot weight, dry shoot weight, root length, fresh root weight and dry root weight of T2 increased by 13.28, 23.07, 28.51, 27.41, 6.66, 68.33 and 7.40 %, respectively compared with peat (T1). This may be due to the improved physical and chemical properties of T2 treatment that can be classified as an ideal substrate according to Abad et al. (2001). Moreover, T2 substrate gave the maximum particle percentage between 0.25 and 2.00 mm, which is classified as the optimal range for a plant growth medium as it allows retention of enough readily available water together with adequate air content (Abad et al. 1993; Benito et al. 2006). Plant height, number of flowers per plant, fresh shoot weight, dry shoot weight, root length, fresh root weight and dry root weight of T5 decreased by 19.35, 38.46, 8.72, 29.28, 22.20, 38.80 and 38.88 %,respectively compared with the peat (T1). The lowest growth of French marigold in T5 may be due to the physical and chemical factors such as high percentage of larger particles, higher bulk density, higher air space, lower water holding capacity and higher EC etc. When bulk density increases, the number of larger pores is reduced, and the forces of the roots necessary for deformation and displacement of substrate particles readily become limiting, and root elongation rates decrease (Taylor & Ratliff, 1969). The lowest root length was observed in the T5 substrate. In addition, high values of EC are detrimental to most of the crops (Bresler et al. 1982). More over, T3 treatment which was having 50% of peat substitution did not show any significant difference ($P<0.05$) compared with the peat substrate (T1). Recent researches have sought to identify alternatives to traditional peat, focusing on recyclable materials not derived from non-renewable sources such as peat bogs (Handar et al. 1985; Raviv et al.1986; Verdock, 1988). Therefore, SA produced by recyclable materials such as low productive red soil, paper waste and starch waste can be suggested as an alternative substitution for expensive peat. In addition, SA substitution rates of 25 and 50% for French marigold cultivation can be regarded as effective alternative growth substrates to expensive peat.

Figure 5.1. Different treatments used in the study

5.1.4.4. Nutrient status of the Marigold plants grown in different growth substrates

The mineral element concentrations in French marigold shoots are given in Table 5.8. It is evident that shoot concentrations of N was significantly ($P<0.05$) differed in all treatments. The shoot concentration of N in T2 was the highest and T5 gave the lowest content. This may be due to efficient nutrient uptake because of improved physical and chemical properties of the T2 after mixing with SA as a peat substitution. Moreover, N content of T1 and T3 did not show any significant difference. The N content of all substrates were above the deficiency level of 15 gkg^{-1} according to Chapman (1966). K and Mg concentrations of T1, T2 and T3 did not show any significant difference among them but significantly differed with T5. Ca content of the plants grown in different substrates did not show any significant difference. Fe, Mn, Cu and Zn concentrations of all treatments did not show any significant difference. Both shoot K, Ca and

Table 5.5. Selected chemical properties of the substrates utilized in the study

Substrates	pH	EC (dSm^{-1})	C (gkg^{-1})	N (gkg^{-1})	P (gkg^{-1})	Na(gkg^{-1})	K(gkg^{-1})	Mg(gkg^{-1})	Ca(gkg^{-1})
T1	6.40±0.12a	0.28±0.05ab	276.59±2.30a	6.71±0.32a	0.05±0.01a	0.18±0.05a	0.24±0.05a	0.40±0.08a	0.46±0.07e
T2	5.76±0.03c	0.30±0.02ab	232.88±2.65b	6.32±0.20a	0.07±0.00a	0.19±0.02a	0.22±0.06a	0.38±0.05a	1.82±0.14d
T3	6.10±0.07b	0.38c±0.04a	192.26±2.42c	5.79±0.18b	0.06±0.01a	0.20±0.03a	0.23±0.03a	0.37±0.07a	3.68±0.10c
T4	6.25±0.05a	0.48±0.03a	146.38±3.18d	5.40±0.08c	0.07±0.02a	0.21±0.04a	0.19±0.04a	0.35±0.06a	6.16±0.16b
T5	6.40±0.09a	0.76±0.04a	85.40±1.80e	0.40±0.06d	0.08±0.01a	0.24±0.09a	0.18±0.01a	0.38±0.07a	9.85±0.12a

(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 ±Standard Deviation (n=5)).

Table 5.6: Heavy metal concentration in the substrates.

Substrates	As (mgkg^{-1})	Cr (mgkg^{-1})	Cu (mgkg^{-1})	Se (mgkg^{-1})	Mn (mgkg^{-1})	Cd (mgkg^{-1})	Zn (mgkg^{-1})	Pb (mgkg^{-1})
T1	ND	1.21±0.14a	13.21±0.16a	ND	20.28±0.18a	ND	21.35±1.10b	3.01±0.01b
T2	ND	1.20±0.08a	12.92±0.18a	ND	19.27±1.20ab	ND	22.78±1.24b	3.42±0.10b
T3	ND	1.24±0.10a	12.75±0.24ab	ND	18.78±1.24b	ND	23.72±1.35ab	3.67±0.14ab
T4	ND	1.27±0.12a	12.71±0.20b	ND	18.50±0.98b	ND	24.12±1.62a	3.88±0.08a
T5	ND	1.30±0.10a	12.70±0.30b	ND	18.37±1.26b	ND	24.52±1.79a	4.02±0.12a
USEPA^{x}	41	1200	1500	36	-	39	2800	300
Uncontaminated soil^{y}	6	70	30	0.4	1000	0.35	90	35

(Means followed by the different superscript letter in the same column differed significantly according to Duncan's multiple range test (P=0.05).Mean±standard deviation (n=5).USEPA^{x} =US Environmental Protection Agency standards (1993). Uncontaminated soil ^{y} (Adriano, 2001).

Table 5.7. Effects of different substrates on the growth of French marigold

Treatments	Plant height (cm)	Number of flowers per plant	Fresh shoot weight (gplant^{-1})	Shoot dry weight (gplant^{-1})	Root length (mm)	Root fresh weight (gplant^{-1})	Root dry weight (gplant^{-1})
T1	19.12±1.18b	13.00±1.25b	24.48±0.88b	9.12±0.16b	240.33±1.14b	8.43c±0.30b	3.24±0.04b
T2	21.66±1.22a	16.00±1.20a	31.46±1.02a	11.62±0.45a	256.33±1.34a	10.19±0.38a	3.48±0.05a
T3	19.00±1.12b	13.00±0.92b	26.78±1.24b	9.98±0.54b	245.00±1.25b	8.45±0.32b	3.35±0.03b
T4	18.66±0.98c	10.00±0.88c	19.67±0.94c	8.65±0.38c	201.33±1.46c	6.56±0.22c	2.57±0.05c
T5	15.42±1.00d	8.00±0.62d	15.76±0.88d	6.45±0.33d	187.00±1.38d	5.16±0.32d	1.98±0.06d

(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 ±Standard Deviation (n=5)).

Table 5.8. Element concentrations in plant shoots

Substrates	N (gkg^{-1})	K (gkg^{-1})	Mg (gkg^{-1})	Ca (gkg^{-1})	Fe (mgkg^{-1})	Cu (mgkg^{-1})	Mn (mgkg^{-1})	Zn (mgkg^{-1})	Pb (mgkg^{-1})
T1	26.34±0.33b	32.32±0.20a	12.98±0.27a	41.57±0.18a	47.03±0.30a	3.54±0.22a	58.09±0.84a	33.02±0.48a	0.33±0.08a
T2	32.18±0.41a	32.65±0.16a	13.21±0.20a	42.21±0.15a	46.76±0.19a	3.32±0.25a	58.12±0.78a	33.74±0.58a	0.36±0.11a
T3	26.97±0.28b	31.24±0.22a	12.10±0.15a	44.98±0.28a	47.12±0.32a	3.18±0.20a	55.76±0.98a	32.30±0.60a	0.34±0.07a
T4	25.88±0.20c	25.67±0.15b	11.76±0.18b	43.76±0.32a	46.67±0.28a	3.62±0.26a	54.17±1.13a	31.65±0.63a	0.35±0.10a
T5	22.71±0.30d	20.16±0.32c	10.37±0.22c	43.21±0.22a	47.36±0.32a	3.74±0.18a	58.26±1.30a	32.41±0.55a	0.40±0.06a

(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 ±Standard Deviation (n=5)).

Mg contents were all above the deficiency limit of 7-15 gkg^{-1} (Chapman 1966), 1.4 gkg^{-1} (Loneragen and Snowball 1969) and 0.6 gkg^{-1} (Chapman 1966), respectively.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 500-1500mg kg^{-1}, respectively (Romheld and Marschner 1991). Therefore, 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. Substitution of peat by 25% (T2) showed the most suitable physical and chemical parameters leads to give the best growth parameters of French marigold production compared with peat only substrate. More over substitution of peat by 50% (T3) can also considered as an alternative substrate to peat, which gave more or less similar growth parameters to French marigold grown in peat substrate.

The average aggregate strength of SA before the pot experiment was 3.58 $kgcm^{-2}$. 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, 2006a, 2008). The average aggregate strength obtained from T2, T3, T4 and T5 treatments after pot experiment were varied between 2.87-3.44 $kgcm^{-2}$. It is evident that aggregates were remaining after the pot experiment, but their strengths were decreased. This may be due to the microbial activities on the organic materials in the aggregates. Further experiments should be conducted to understand the microbial activities on the aggregates in future studies.

5.1.5. Conclusions

This study investigates 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. Peat 75%: SA 25% enhanced substrate physical and chemical properties into the established ideal substrate range. 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. Cu, Fe, Mn and Zn concentrations in all plant shoots were in the normal range and well below the phytotoxic range. 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.

5.2. Evaluation of the use of synthetic red soil aggregates (SRA) and zeolite as substrate for ornamental plant production

5.2.1. Introduction

Accumulation of pests and diseases in soil has always been a problem in crop production. One of the alternatives is substrate culture (Burrage, 1999; Van Os, 2000).On the other hand substrate culture is gaining more importance year by year. Substrates used differ according to the countries, for example rock wool is common in northwest Europe, whereas perlite and locally mined pumice are used a lot in southern Europe (Van Os, 2000).Due to the limited arable land, most of the ornamental plant cultivation in Japan is being carried out in the green house by utilizing various substrates. Growers prefer to use substrates such as zeolite, perlite, pumice sand, peat, and coir dust, where most of them have been imported, which would increased the production cost. Zeolite has attractive physical and chemical properties for agriculture (Yucel, 1987) as a crop growth substrate. Zeolites are hydrated aluminum-silicate minerals, which Al and Si tetrahedral are connected by shared oxygen atoms to form a three dimensional frame work structure. They are characterized by high ability to lose and gain water and to exchange cations without a major change of structure (Mumpton, 1999; Kithome et al., 1999). The structure of zeolites generates particular properties of adsorption and ion exchange, which makes them potentially useful in the field of hydroponics crop production (Harland et al., 1999). The global consumption of zeolites in 2004 was estimated at over 4 million metric Mg (Lauriente and Inoguchi, 2005).

Widely spread red soil (“Kunigami Mahji”) in sub-tropical Okinawa, Japan, which is classified as an ultisol, is not suitable for crop production due to its poor physical (Tokashiki et al., 1994) and chemical properties, such as its highly acidic nature, low organic matter content, and poor nutrient availability (Kobayashi and Shinagawa, 1966; Hamazaki, 1979).This acidic red soil accounts for about 55% of the total land area in subtropical Okinawa Japan (Onaga and Yoshinaga, 1988). Due to the low productivity and the acidity this huge amount of red soil is not properly utilized. This prompted for the development of an effective method of converting under utilized red soil into fertile, arable synthetic aggregates (SRA) by incorporating paper waste and starch waste in order to improve its physical and chemical properties. During last two decades due to improved popularity for the protected agriculture, the evolution of plant growth techniques has increased demand for container substrates such as peat, zeolite, perlite etc, but the supply of these materials has been decreasing (Inbar et al., 1990). Depletion of a non-renewable resources and environmental deterioration together with the high prices of those substrates have favoured the utilization of alternative materials as growth substrates (Abad et al., 2001). Attempts have therefore been made to produce SRA as a substrate for ornamental plant production by using hugely available under-utilized low productive red soil, paper waste and starch waste.

5.2.2. Objective of the study

The objectives of the present study were to examine physical and chemical properties of developed container substrates with SRA and zeolite and to determine their possible utilization as a container substrate for the French marigold (*Tagetes patula*), which is a popular ornamental in Japan.

5.2.3. Materials and methods

5.2.3.1. Collection of sampled materials

Red soil samples were collected from Miyagi-Sajibaru, Higashi-Son, Kunigami-Gun, Okinawa, Japan. The soil texture was heavy clay and was classified as an Ultisol. Collected soil samples were air dried and then sieved through a 10-mm mesh screen and utilized for SRA production. A portion of this soil was used to analyze the particle size distribution by using the dry sieving method (Yoder, 1936). A portion of this soil sample was sieved through a 2-mm mesh sieve, and used for chemical analysis. The paper waste was collected from Ojiryokka Company, Tokyo, Japan. Waste starch and Zeolite samples were obtained form Okinawa Seifun, Corporation ltd. Okinawa, Japan. The physical and chemical properties of the red soil and the paper waste are given in the Table 5.9.

Table 5.9. Selected physical and chemical properties of red soil and paper waste used in the experiment.

Particulars	Red soil	PW
Bulk density (gcm^{-3})	1.26±0.03	-
Particle density (gcm^{-3})	2.65±0.06	-
pH	4.98±0.04	5.70±0.32
EC (mSm^{-1})	4.18±0.08	10.28±0.52
C (gkg^{-1})	1.73±0.04	374.8±2.76
N (gkg^{-1})	0.40±0.04	0.38±0.10
P (gkg^{-1})	0.03±0.01	0.06±0.01
Na (gkg^{-1})	0.06±0.01	0.24±0.09
K (gkg^{-1})	0.05±0.01	0.32±0.05
Mg (gkg^{-1})	0.02±0.00	0.47±0.11
Ca (gkg^{-1})	0.07±0.01	0.63±0.17
As ($mgkg^{-1}$)	ND	ND
Cr ($mgkg^{-1}$)	1.20±0.10	3.70±0.34
Cu ($mgkg^{-1}$)	13.81±0.22	8.5±0.49
Se ($mgkg^{-1}$)	ND	ND
Mn ($mgkg^{-1}$)	20.65±1.95	6.52±1.26
Cd ($mgkg^{-1}$)	ND	ND
Zn ($mgkg^{-1}$)	27.31±2.98	10.1±0.42
Pb ($mgkg^{-1}$)	4.70±0.06	0.63±0.16

PW: paper waste; EC: electrical conductivity; ND: Not Detected; Values are mean ±Standard Deviation (n=5).

5.2.3.2. Production of synthetic red soil aggregates (SRA)

SRA were produced by combining red soil and paper waste using an Eirich mixer (R-02M / C27121) with starch waste as a binder according to Jayasinghe et al., (2005, 2008, 2009b, c, d,e, f,g). 1000 g of red soil and 100 g of waste paper was mixed in the Eirich mixer by adding 225 ml of starch paste which was produced adding 25g of starch to 200 ml hot water until the production of desired SRA.

5.2.3.3. Analytical methods

The pH was measured in water extracts by using a glass electrode (Sample: distilled water ratio of 1:25), and electrical conductivity (EC) was measured using an EC meter (D-54, Horiba) (Sample: distilled water ratio of 1:5). One gram of each dried substrate sample was taken for determination of C and nitrogen (N) contents by using CN coder (Micro coder JM 10). C and N contents in the dried substrate samples were burnt into CO_2, NOx and N_2 during the analysis and the C and N contents in the samples were automatically detected with the assistance of a standard calibration curve. The concentrations of Na, K, Mg and Ca of the air dried substrate samples were extracted by using 1 M ammonium acetate adjusted to pH 7.0. Then the extracts were used to analyze the cation concentration using atomic absorption spectrophotometer (Solaar 969, Thermo Corporation, Tokyo, Japan).The physical properties of each substrate materials were determined using the procedures described by Spomer (1990) and Pill et al., (1995). Each moistened substrate was placed in 12.5 cm diameter standard plastic pots.

Each pot was irrigated for two weeks. After two weeks of irrigation the container's drainage holes were sealed with duct tape and water was added to each substrate until saturated. After determining the weight of the saturated substrate, the drainage holes were unsealed and the substrates were allowed to drain 24 h. Then the amount of water loss was determined as a result of drainage. Then the substrates were oven dried at 65^{0}C for 48h and weighed to determine the amount of water retained by the substrates after draining. The weight of the water needed to saturate each substrate was divided by the medium bulk volume to determine the total pore space percentage. Substrate bulk density was determined by dividing the oven dried weight of each substrate by the substrate bulk volume. All analyses were done in triplicates. Samples of air dried substrates were passed through a series of sieves, from 5.60 mm to 0.25mm, to determine their particle size distribution.

5.2.3.4. Utilization of SRA and zeolite mixtures as a growth substrate for French marigold cultivation

A greenhouse pot experiment was conducted to study the influence of different substrates containing different ratio of SRA and zeolite on the ornamental plant growth. French marigold (*Tagetes patula*) was utilized as the ornamental plant under this study. The container volume was 1.5 L. Table 5.10 shows the volumetric formulations of the different substrates utilized under this study.

Table 5.10. Composition of growth substrates used in the experiment

Substrate	Formulation
T1	SRA (100%)
T2	SRA 3 : Zeolite 1(V/V)
T3	SRA 1 : Zeolite 1 (V/V)
T4	SRA 1 :Zeolite 3 (V/V)
T5	Zeolite (100%)

SRA: Synthetic red soil aggregates, V/V: Volume basis

The experimental design of the pot experiment was a completely randomized design (CRD) with 5 treatments and five replicates. Prepared air dried substrate samples were filled into each pot leaving a distance of 1 cm from the top of the pot and without unnecessary compaction. All pots were arranged in a greenhouse and saturated and kept for 48 h to attain their respective field capacities. Two weeks old French marigold plants obtained from a prepared nursery were planted in each pot. One plant was planted in each pot. Water and nutrient requirements of the plants were supplied equally to all treatments through a complete nutrient solution. The chemical composition of the nutrient solution was as follows (mgL^{-1}): N:210, P:80, K:270, Mg:40,Ca:164, Fe:1.8, Mn:1, Cu:0.02, Zn:0.05 (Otsuka house commercial formulation, Japan). 200 mL of nutrient solution was added to each pot once in two days. Temperature ranged from 20^{0}C to 31^{0}C during the growth season. The volume and the concentration of P, K, Ca and Na in drained solution taken at 3 weeks intervals were determined calorimetrically for P and spectrophotometrically for K, Ca and Na using atomic absorption spectrophotometer (Solaar 969, Thermo Corporation, Tokyo, Japan). Experiments were terminated after 3 months of planting. Plant height, shoot fresh weight, shoot dry weight, root fresh weight, root dry weight and number of flowers were determined. The dried substrates were digested in nitric acid and its mineral element concentrations were analyzed by using atomic absorption spectrophotometer (Solaar 969, Thermo Corporation, Tokyo, Japan).

5.2.3.5. Statistical analysis

Obtained data were subjected to analysis of variance (ANOVA) for determination of the treatment effects. Duncan's multiple comparison range test procedure was employed to denote significant differences among the treatments using the SAS package (SAS Institute, 1990).

5.2.4. Results and discussions

5.2.4.1. Physical properties of the substrates

5.2.4.1.1. Particle size distribution

The particle size distribution of different substrates utilized in this study is given by the Table 5.11. The 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 distribution showed that the fraction between 5.6 mm and 3.35 mm was the most abundant fraction in zeolite substrate. While the dominant fraction of the SRA was in between 3.35mm and 2.00 mm. Dominance of larger particles in a substrate increase aeration and decrease water retention (Benito et al., 2006),while dominance of fine particles clogs pores, increase non-plant available water holding capacity and decrease air filled porosity (Spiers and Fietje, 2000). The best substrate is one that has a medium to coarse texture, equivalent to a particle size distribution between 0.25 and 2.00 mm, as this is optimal range for a plant growth medium that allows retention of enough readily available water together with adequate air content (Abad et al., 1992; Benito et al., 2006). The lowest percentage of particles (19.90%) between 0.25 and 2.00 mm was given by the T5 (Zeolite only) substrate. While that percentage in the T1, T2, T3 and T4 were 33.34%, 34.85%, 33.11% and 24.92%, respectively. It is revealed that mixing of SRA with Zeolite increased the particle percentages between 0.25 and 2.00 mm which is called as the optimal range for the plant growth.

5.2.4.1.2. Bulk density, Particle density, total porosity and the water holding capacity of the substrates

Table 5.12 shows the bulk density, particle density, total porosity and the water holding capacity of the substrates used in the study. Bulk density values of different substrates were significantly different ($P<0.05$). SRA showed the lowest bulk density and the particle density. Similar low bulk density values were found in the synthetic aggregates composed of mine clay with paper waste and coal fly ash by Jayasinghe and Tokashiki (2006ab) and Jayasinghe et al., (2005, 2007, 2008, 2009a, c).This may be due to incorporation of the paper waste to produce SRA. Paper waste is a rich source of C and improves soil organic matter, and bulk density (Simard et al., 1998). Mixing SRA with the Zeolite in T2, T3 and T4 treatments decreased the bulk density by 15.12%, 10.47% and 5.81%, respectively compared with the T5 (Zeolite only). Particle density values of the substrates were varied between 2.48 and 2.62 g cm^{-3}. Total porosity of the treatments significantly ($P<0.05$) increased with increase in SRA addition (Table 4). The highest porosity was given by the T1. This may be because of the low bulk density due to the paper waste incorporation to produce SRA. The porosity values were increased by mixing of SRA with Zeolite. The increased porosity is especially important to crop development since it may have a direct effect on aeration and can enhance root growth (Sugiyanto et al., 1986). In addition, the water holding capacity of the substrates with SRA showed a significant increase ($P<0.05$) in comparison with the zeolite media. The highest water holding capacity was given by the T1. The water holding capacity of the T2, T3 and T4 were increased by 14.31%, 10.59% and 4.31%, respectively compared with the zeolite. These water holding capacity increases are due the improved microspores because of the SRA addition, which are responsible for the holding of water within the substrate. Moreover, paper waste in the SRA can improve water holding capacity of the substrate. Paper waste can improves water holding capacity and soil structure (Simard et al., 1998) and plant growth and yield (Bellamy et al., 1995).

Table 5.11. Particle size analysis of the container substrates used in the experiment

Substrate	>5.60mm (Weight %)	5.6-3.35mm	3.35-2.00mm	2.00-1.00mm	1.00-0.50mm	0.50-0.25mm	<0.25mm
T1	9.77±2.17d	20.85±1.07e	31.98±1.25a	18.15±0.16a	8.91±0.13c	6.28±0.01c	4.06±0.02b
T2	10.12±0.14c	24.56±1.21d	25.76±0.43b	17.84±0.19b	9.96±0.59a	7.05±0.51b	4.71±0.24a
T3	11.01±0.62b	29.42±0.99c	25.18±0.69c	15.57±0.83c	9.35±0.58b	7.19±1.15a	2.28±0.21d
T4	11.55±0.54b	36.98±0.54b	23.77±0.38d	14.84±0.44c	5.76±0.65e	4.32±1.56d	2.78±0.43c
T5	12.29±0.78a	52.06±0.52a	14.38±0.50e	10.55±0.42d	6.34±0.02d	3.01±0.16e	1.37±0.43e

(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 ±Standard Deviation (n=5)).

Table 5.12. Bulk density, particle density, total porosity and the water holding capacity of the substrates

Substrates	Bulk density ($g\ cm^{-3}$)	Particle density ($g\ cm^{-3}$)	Total Porosity (%V/V)	Water Holding Capacity (mLL^{-1})
T1	0.70±0.03e	2.48±0.03e	71.77±1.28a	610±8.70a
T2	0.73±0.05d	2.50±0.04d	70.08±0.16b	583±4.76b
T3	0.77±0.03c	2.55±0.02c	69.80±0.68c	564±5.88c
T4	0.81±0.03b	2.58±0.03b	68.61±0.94d	532±6.25d
T5	0.86±0.03a	2.62±0.03a	67.18±0.94e	510±7.32e

(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 ±Standard Deviation (n=5)).

Table 5.13. Selected chemical properties of the substrates utilized in the study

Substrates	pH	EC (mS m^{-1})	C (g kg^{-1})	N (g kg^{-1})	P (g kg^{-1})	Na (g kg^{-1})	K (g kg^{-1})	Mg (g kg^{-1})	Ca (g kg^{-1})
T1	4.98±0.09e	16.82±0.88e	42.45±2.80a	0.40±0.10a	0.08±0.01a	0.21±0.09e	0.18±0.00e	0.56±0.08e	0.85±0.06e
T2	5.64±0.03d	39.81±0.65d	33.88±1.62b	0.36±0.10a	0.07±0.00a	2.84±0.65d	2.24±0.34d	0.76±0.11d	1.82±0.24d
T3	6.12±0.07c	47.64±0.74c	27.12±2.32c	0.35±0.08a	0.06±0.01a	5.22±0.41c	4.08±0.59c	0.94±0.20c	2.76±0.30c
T4	6.71±0.05b	85.50±0.96b	20.29±3.10d	0.35±0.05a	0.07±0.02a	7.34±0.54b	5.68±0.30b	1.14±0.32b	3.56±0.20b
T5	7.01±0.05a	92.73±0.81a	15.33±1.27e	0.34±0.12a	0.06±0.01a	9.45±0.04a	7.34±1.45a	1.34±0.15a	4.58±0.26a

(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 ±standard deviation (n=5))

Table 5.14. Effects of different substrates on the growth of French marigold

Substrates	Plant height (cm)	Number of flowers per plant	Shoot fresh weight (g $plant^{-1}$)	Shoot dry weight (g $plant^{-1}$)	Root length (mm)	Root fresh weight (g $plant^{-1}$)	Root dry weight (g $plant^{-1}$)
T1	16.12±1.18d	10.00±1.25d	9.76±0.88d	1.12±0.16d	168.33±1.14c	1.16±0.30c	0.13±0.04d
T2	18.76±1.73c	14.66±1.00c	15.32±1.22c	2.78±0.08c	173.33±1.20b	1.68±0.24b	0.24±0.06c
T3	22.46±1.78a	20.00±0.78a	22.68±1.41a	4.10±0.20a	181.33±1.62a	2.02±0.28a	0.31±0.05a
T4	20.32±0.98b	18.66±0.60b	20.76±1.10b	3.35±0.18b	179.26±1.16a	1.94±0.19a	0.27±0.03b
T5	20.18±1.12b	18.00±0.90b	20.58±0.90b	3.20±0.12b	179.00±1.08a	1.90±0.24a	0.26±0.01b

(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 ±standard deviation (n=5)).

5.2.4.2. Chemical properties of the container substrates

Selected chemical properties of the substrates utilized under the study are given in the Table 5.13. The pH showed significant differences ($P<0.05$) among all substrates. The SRA gave a pH value of 4.98 due to the acidic red soil. Established pH range for an ideal substrate is 5.3-6.5 (Abad et al., 2001; Bunt, 1988; De Boodt and Verdonck, 1972; Raviv et al.,1986). It is revealed that T2 and T3 were within this ideal substrate range. The EC values showed significant differences ($P<0.05$) among all substrates. Established EC upper limits for an ideal substrate is 50 mSm^{-1} (Abad et al., 2001; Bunt, 1988; De Boodt and Verdonck, 1972; Raviv et al., 1986). The T1, T2, andT3 substrates were in the established ideal EC range while not for T4 and T5. The EC increased with the increased volume of the Zeolite. The higher EC values of zeolite may be due to the higher concentrations of cations (Table 5.13) compared to SRA.The cation concentrations of the substrates were significantly different among substrates. The highest Na, K, Mg and Ca concentrations were given by the T5 substrate. The structure of the zeolites generates particular properties of adsorption and ion exchange, which makes them potentially useful in the field of hydroponics crop production (Harland et al., 1999). Zeolites are characterized with the ability to exchange cations without major change in the structure (Mumpton, 1999; Kithome et al., 1999). The C content of the substrates were varied between 15.33 and 42.45 gkg^{-1}.The highest C content was given by the SRA only (T1) while the lowest given by the zeolite only (T1). The highest C content in the SRA may be due to the paper waste. Paper waste in the SRA is also a rich source of C (Rasp & Koch, 1992; Zhang et al., 1993). The N and P contents did not show any significant differences among the treated substrates which were varied 0.34-0.40 and 0.06-0.08 gkg^{-1}, respectively.

5.2.4.3. Utilization of SRA and zeolite mixtures as a growth substrate for French marigold cultivation

The plant height, number of flowers per plant, shoot fresh weight, shoot dry weight, root length, root fresh weight and root dry weight grown in different substrates after 3 months of growing period are shown in Table 5.14. Different treatments utilized in the study are shown in Figure 5.2. There were significant differences ($P<0.05$) in growth parameters of French marigold grown in different growth substrates. The trial showed that zeolite only (T5) gave higher growth parameters compared with the SRA only (T1) substrate. There are several studies on possibilities of using zeolite as a substrate, and it is reported that zeolite led to increase in yield (Baikova and Semekhina, 1996; Loboda, 1999). Furthermore; zeolite has a relatively high ion exchange capacity with a preference for large size cations such as NH^{+4} and K^{+} (Harland *et al.* 1999). The lowest plant parameters 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 may be due to the low substrate pH (4.98) and its related nutrient bioavailability. Additionally, low pH was reported to directly affect the permeability of root cell membranes and leakage of various ions from the roots (Yan et al., 1992). The highest plant parameters were given by French marigold grown in T3 substrate, where the SRA and zeolite were mixed at 1:1 ratio. The plant height, number of flowers, shoot fresh weight, shoot dry weight, root length, root fresh weight and root dry weight in T3 substrate were increased by 11.30%, 11.11%, 10.21%, 28.13%,1.30%,6.32% and 19.23%, respectively compared to the zeolite only. This may be due to enhanced particle size distribution, bulk density, porosity, water holding capacity and pH of the T3 substrate compared to the zeolite. It is evident that mixing SRA with zeolite is a better practice as a growth substrate for French marigold cultivation compared with the zeolite only.

Table 5.15. Element concentrations in plant shoots

Substrates	N (g kg^{-1})	K (g kg^{-1})	Mg (g kg^{-1})	Ca (g kg^{-1})	Fe (mg kg^{-1})	Cu (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})
T1	22.71±0.23b	20.16±0.11b	7.37±0.20b	6.21±0.16b	77.36±0.13a	3.14±0.13c	103.26±1.20a	32.41±0.58c
T2	34.47±0.18a	31.77±0.16a	13.22±0.18a	41.12±0.22a	42.12±0.24c	3.48±0.16b	62.77±0.64b	32.88±0.61b
T3	34.66±0.26a	33.26±0.14a	14.16±0.26a	43.23±0.25a	43.72±0.15b	4.18±0.10a	61.87±0.70b	36.18±0.46a
T4	34.12±0.21a	34.18±0.12a	14.66±0.21a	44.10±0.30a	43.24±0.27b	4.27±0.14a	63.96±0.90b	36.01±0.58a
T5	34.60±0.20a	34.07±0.17a	14.75±0.19a	43.22±0.27a	44.32±0.22b	4.21±0.12a	64.25±0.82b	36.37±0.48a

(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 ±standard deviation (n=5)).

Figure 5.2. Different treatments used in the study

Plant nutrient contents of the French marigold are given in Table 5.15. It is evident that the lowest N content was given by the T1 while all other substrates did not significantly differ. The N content of all substrates were above the deficiency level of 15 gkg^{-1} according to Chapman (1966). Mixing zeolite into the SRA significantly increased the K content compared to SRA only. These results support the previous findings reported by Harland et al., (1999) submitting that zeolite acts as a reservoir holding elements in its structure for slow release to the substrate solution or directly to the plant roots. Challinor et al., (1995) reported that zeolite is highly selective for K and ammonium nitrogen. Plant concentrations of Ca and Mg were lower but Mn and Fe concentrations were higher in plants grown T1 than those grown in other substrates. This result is likely that the low pH (4.98) and its related nutrient bioavailability accounted for the reduced growth of French marigold produced from the SRA only. Moreover, the Mg and Ca concentrations of plant tissues in the SRA and zeolite mixtures significantly increased because of zeolite were enriched with these elements (Table 5.13). Both shoot K, Ca and Mg contents were all above the deficiency limit of 7-15 gkg^{-1} (Chapman, 1966), 1.4 gkg^{-1} (Loneragen & Snowball, 1969) and 0.6 gkg^{-1} (Chapman, 1966), respectively. Nevertheless, the Mn concentrations were much higher than Chapman's diagnostic deficiency level of 20 mgkg^{-1} (Chapman 1966). Zn concentration in the shoots from all the substrates was well below the toxicity limit of 150 mgkg^{-1} (Elseewi et al., 1980).

Table 5.16. Elemental composition of drained solution (mgL^{-1})

Substrate	P	K	Ca	Na
T1	17.01±0.96ab	106.20±1.16a	135.71±1.38b	35.20±0.77c
T2	17.32±0.80a	56.72±0.98b	161.82±1.41a	54.72±0.48b
T3	12.50±0.68bc	50.31±0.75b	162.66±1.46a	60.65±0.65b
T4	11.24±0.76c	40.63±0.68c	157.53±1.54a	58.71±0.59b
T5	14.02±0.84abc	34.80±0.80d	168.67±1.31a	64.62±0.64a

(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 ±Standard Deviation (n=5)).

Elemental compositions of the drained solution are given in Table 5.16. It is revealed that there are significant differences with respect to P, K, Ca and Na in the drained solution. It is evident that increase in the zeolite volume decreased leaching K, where as it increased Ca and Na concentration in drained water. These results are in accordance with the findings of previous studies reporting that zeolite or zeolite containing media decreased K concentration (Pivert et al., 1997; Oztan, 2002) and increased Na concentration (Pivert et al., 1997; Harland et al., 1999) in drain solution. Our results showed that addition of SRA to zeolite has an advantage as a substrate compared to zeolite only, as it can be substituted the expensive zeolite, while increasing the growth parameters of the French marigold. Also this effect may be attributed to increase in uptake of some nutrients since zeolite has high cation exchange properties and acts as a reservoir, holding elements in its structure for slow release to the rhizosphere. Moreover, production of the SRA with the low productive red soil is an alternative avenue for the utilization of the underutilized red soil. In addition, SRA production with paper waste can be regarded as a waste management practice for the paper waste.

5.2.5. Conclusions

Production of SRA using acidic red soil and paper waste can be suggested as an unconventional method of utilizing the under utilized red soil. Substrates formed with mixing SRA with zeolite enhanced the physical and chemical characteristics of the substrates compared to zeolite only substrate. The 1:1 of SRA to zeolite mixture gave the best maximum growth and yield parameters of the French marigold compared to the other substrates utilized under this study. Plant height, number of flowers, shoot fresh weight, shoot dry weight, root length, root fresh weight and root dry weight were increased by 11.30%, 11.11%, 10.21%, 28.13%, 1.30%,6.32% and 19.23%, respectively compared to the zeolite substrate. Moreover, the zeolite only and SRA-zeolite mixtures increased N, K, Mg, and Ca concentrations in the leaf tissues compared with the SRA only. Plant tissues obtained from the SRA only substrate gave higher Mn and Fe concentrations compared to the other substrates. It is revealed that the use of zeolite led to reduce K leaching from the substrate compared to the SRA. Further research should be under taken by using different types of plant species to study the interaction between SRA-zeolite substrates and the nutrient status.

Chapter 6

Synthetic aggregates and different types of composts as an alternative containerized media

6.1. Sewage sludge-sugarcane trash based compost and synthetic aggregates as peat substitutes

6.1.1. Introduction

In recent years there has been increasing environmental and ecological concerns against use of peat as a growth substrate because its harvest is destroying endangered wetland ecosystems worldwide (Zaller, 2007: Grigatti et al., 2007). Moreover, increasing demand and rising costs for peat as a growing substrate in horticulture have led to search for high quality and low cost substrates as an alternative. A number of studies have shown that organic residues such as urban solid wastes, sewage sludge, paper waste, pruning waste, spent mushroom and even green wastes, after proper composting, can be used with very good results as growth media instead of peat (Ostos et al, 2008: Bustamante et al., 2008: Moral et al., 2009: Garcia-Gopmez et al., 2002: Benito et al., 2005). The increasing interest in waste recycling is another cause to advocate the recycling and use of organic wastes and composts as soil or potting amendments; it could be one of the most attractive methods of solving the problem of waste disposal. The combination of peat and compost in growing media is synergistic; peat often enhances aeration and water retention and compost improves the fertilizing capacity of a substrate (Ostos et al., 2008). In addition, organic by-products and composts tend to have porosity and aeration properties comparable to those bark and peat and as such are ideal substitutes in propagating media (Chong, 2005)

About 2.44 × 10^8 and 4.14 × 10^8 m^3 of sewage sludge were reportedly produced in Japan in 1990 and 2004, respectively (Japan Sewage Work Association, 1990, 2004) corresponding to an increase of 170% in sewage sludge over just 14 years. Sludge processing generally consists of thickening, dewatering and several different alternative main treatments, such as anaerobic digestion, composting, incineration and melting (Hong et al., 2009). Composting is a stabilization process of aerobic decomposition and leads to the development of microbial populations which causes numerous physico-chemical changes in the waste mixture (Cai et al., 2007). Composting can reduce the mixture volume by 40-50%, effectively destroy the pathogens by the metabolic heat generated by the thermophilic phase, degraded a big number of hazardous organic pollutants and provide a final product that can be used as a soil amendment or fertilizer (Cai et al., 2007). Land application of composted sewage sludge represents one of the most cost effective methods for treatment and final disposal of sewage sludge, because the high levels of valuable components (N, P, K,organic matter and other necessary nutrients for plant growth) in stable sludge can be recycled and the properties of soil can be improved (Wang et al., 2008: Wong et al., 2003: Jamali et al., 2009:He et al., 2009). The use of sewage sludge mixed with different organic waste materials such as rice straw, green waste is now usual in composting experiments (Mupondi et al., 2006: Suthar, 2009) . Sugarcane trash is generating approximately at the rate of 300000 tons annually in southern Japan (Matsuoka et al., 2006) and it has been suggested as a potential soil conditioner due to having efficient plant nutritive values. In order to minimize the environmental impact and to recycle these sugarcane residues, several alternatives have been proposed, composting being a feasible method from both technical and economical points of view. Moreover, mixing of sugarcane trash with sewage sludge in compost mixture not only enhances the nutritive value of the by-product but, at the same time also suppresses the toxicity by metals through supplying a considerable amount of organic matter (Suthar, 2009). Sewage sludge and sugarcane trash were used to produce sewage sludge sugarcane trash based compost (SSC).

Composts may have physical, physico-chemical and chemical properties similar to peat that make them suitable as peat substitutes (sanchez-Monedero et al., 2004). However, several studies (Chong, 2005: Hong et al., 2009: Wang et al., 2008: Jamali et al., 2009: He et al., 2009: Sanchez-Monedero et al.,2004: Egiarte et al.,2008: smith, 2009) have reported that sewage sludge composts can also show features considered as limiting factors for their horticultural use, such as the presence of hazardous components (i.e. heavy metals), poor physical properties, phytotoxicity or an excess of salts or nutrients that originate media with high electrical conductivity. However, the combination of peat with composts can reduce the potential poor properties of single materials according to Raviv et al., (1986) indicated in a study using mixtures of peat with sewage sludge and other residual materials. Thus, the proportion of compost in the growing media is essential to reduce potential hazards, especially salinity. Perez-Murcia et al., (2006) reported that addition of compost to peat increased plant nutrient and heavy metal concentrations of plants and substrates. On the other hand, other researchers (eklind et al., 2001: Pinamonti et al., 1997: Perez-Murcia et al.,2005) have reported that the presence of compost in the growing media tends to reduce concentrations of heavy metals in plants, due to the higher pH values that usually result.

Widely spread red soil (“Kunigami Mahji”) in sub-tropical Okinawa, Japan, which is classified as an ultisol, is not suitable for crop production due to its poor physical (Tokashiki et al., 1994) and chemical properties (Hamazaki, 1979). This prompted for the development of an effective method of converting under utilized red soil into fertile, arable synthetic aggregates (SA) by incorporating paper waste and starch waste in order to improve its physical and chemical properties. Several our previous studies were conducted by using SA developed from different waste materials. SA formed from coal fly ash, paper waste and starch waste addition to the low productive problematic soil as a soil ameliorant improved the physical and chemical properties of the low productive soil and subsequently increased the crop production (Jayasinghe et al., 2009a, c). A potting media developed from coal fly ash based SA and oil palm waste 1:10 gave improved ornamental plant production (Jayasinghe et al., 2009d). SA developed from acidic soil, coal fly ash and starch waste as a crop growth media increased the growth and yield of Soybean (*Gycine max*) and Komatsuna（*Brassica rapa*）(Jayasinghe et al., 2008). Addition of 30% – 40% of SA formed by acidic red soil and paper waste to problematic grey soil in Okinawa, Japan improved the properties of the grey soil and subsequently improved the ornamental plant production (Jayasinghe et al., 2009e). Moreover, SA developed by paper waste and acidic soil can be used as a partial substitution for peat in the growth medium for cultivation of ornamental *Tagetes patula* (Jayasinghe et al., 2009b). In this present study SA developed from red soil, paper waste and starch waste along with SSC were used as a growth medium for lettuce cultivation.

6.1.2. Objective of the study

The main objective of the present work was to ascertain the suitability of these SSC–SA based media as peat substitutions for lettuce production by studying their effects on vegetative and nutritional aspects to determine if there is any limitation to their use.

6.1.3. Materials and Methods

6.1.3.1. Growing media preparation

SSC was produced by composting a mixture of sewage sludge and sugarcane trash. Before composting, sugarcane trash was ground to fragments between 2 and 15 cm. Turned windrow aerated-pile method was applied for SSC, using triangular windrows of 5.5 m width and 2.5 m height. SA were produced by combining red soil and paper waste using an Eirich mixer (R-02M / C27121) with starch waste as a binder. One thousand grams of red soil and 100 g of waste paper were mixed in the Eirich mixer by adding 225 ml of starch paste. Physical and chemical properties of SSC and SA are given in Table 6.1. Six growing media were tested. Peat, which is a commercial growing media used as the control. The treatments assayed were: SSC (40%) + Peat (60%), SA (40%) + Peat (60%), SSC (60%) + SA (40%), SSC (40%) + SA (20%) + Peat (40%) and SSC (40%) + SA (40%) + Peat (20%). Ratios of each component in each substrate are shown in Table 6.2.

Table 6.1.Physical and chemical properties of growing media components, SSC and SA

Parameter	SSC	SA
Bulk density (g cm^{-3})	0.31	0.56
pH	7.15	5.50
EC (dSm^{-1})	2.06	0.51
OM (g kg^{-1})	561	142
N(g kg^{-1})	16.41	0.40
C / N	20.23	213.5
P (g kg^{-1})	28.12	0.08
K (g kg^{-1})	4.21	0.31
Mg (g kg^{-1})	0.96	0.62
Ca (g kg^{-1})	1.12	0.91
Cu (mg kg^{-1})	116	13.20
Zn (mg kg^{-1})	232.27	26.48
Cd (mg kg^{-1})	ND	ND
Cr (mg kg^{-1})	15.6	1.81
Mn (mg kg^{-1})	88.21	20.48
Pb (mg kg^{-1})	46.24	4.48

SSC, sewage sludge sugarcane trash based compost, SA, synthetic aggregates, EC: electrical conductivity, ND, not detected. (n=5)

6.1.3.2. Physical and chemical properties of the growing media

Physical properties of each growth substrates (Table 6.2) were determined using procedures described by Spomer (1990) and Pill et al., (1995). Each moistened pre-plant substrate was placed in 12.5 cm diameter standard plastic pots. Each pot was irrigated for two weeks in the same manner. After two weeks of irrigation, containers drainage holes were sealed with duct tape. Water was then added to each substrate until saturated. After determining the weight of saturated substrate, the drainage holes were unsealed and substrates were allowed to drain 24 h. Then the amount of water loss was determined as a result of drainage. Then substrates were oven dried at 65ºC for 48h and the amounts of water retained by substrates after draining were determined. The weight of water needed to saturate each substrate was divided by the medium bulk volume to determine total pore space percentage. Substrate bulk density was determined by dividing oven dried weight of each substrate by substrate bulk volume. Coarseness index, expressed as weight percentage of particles with ∅>1mm was determined according to Richards et al., (1986). All measurements were carried out 5 times.

6.1.3.3. Pot experiment

Table 6.2. Composition of the growing media

Treatments	Formulation
T1	100% Peat (commercial substrate)
T2	40% SSC+60% peat
T3	40% SA+ 60% peat
T4	60% SSC +40% SA
T5	40% SSC +20% SA +40% peat
T6	40% SSC +40% SA +20% peat

SSC: sewage sludge sugarcane trash based compost, SA: synthetic aggregates

The pH was measured in water extracts of all substrate samples using a glass electrode (Sample: distilled water ratio of 1:5), and electrical conductivity (EC) was measured using an EC meter (D-54, Horiba) (Sample: distilled water ratio of 1:5). Carbon (C) and nitrogen (N) contents in substrate samples were determined by using CN analyzer (Micro coder JM 10; G-Science Laboratory, Tokyo, Japan). Plant samples and substrates were mineralized by microwave acid-digestion (USEPA, 1996) and the total concentrations of K, Ca, Mg, Mn, Cu, Zn, Pb, Cd and Cr were determined by atomic absorption spectrophotometer (Solaar 969, Thermo Corporation, Tokyo, Japan). Extractable metals of the growth media were analyzed by atomic absorption using the method described by Lindsay and Norvell,(1978). Exchangeable K,Mg and Ca of growth media were determined using atomic absorption spectrophotometer (Solaar 969,Thermo Corporation, Tokyo, Japan) after extracting with 1N NH_4CH_3COO(at pH 7.0).Total P of growth substrate samples were determined by using spectrophotometer (JSSSPN,1997). Available P of growth media was determined based on extraction using $NaHCO_3$. (Oslen et al.,1954). Organic matter (OM) of the substrate samples were determined by loss on ignition at 430 ºC for 24 h (Navaro et al., 1993).

A green house pot experiment was conducted to study the influence of different substrates containing different ratios of SSC, SA and peat on lettuce (*Lectuca sativa* L.) plant growth. Container volume was 1.5 L. Table 6.2 shows the volumetric formulations of different container substrates utilized in this study. The acidic pH of the peat (4.34) was adjusted to 5.50 by adding lime. T1 and T3 were enriched with 2 g of slow release fertilizer N: P: K: 15%-15%-15% to supply the minimum fertilizer requirements. Experimental design of the pot experiment was a completely randomized design (CRD) with 6 treatments and 5 replicates. Prepared air dried substrate samples were filled into each pot leaving a distance of 1 cm from the top of the pot and without unnecessary compaction. All pots were arranged in a green house and saturated and kept for 48 h to attain their respective field capacities. Two weeks old lettuce plants obtained from a prepared nursery were planted in each pot. Two plants were initially planted and thinned out to one plant in each pot. 200 mL water was added to each pot once in two days. Temperature ranged from 20-31°C during the growth season. Experiments were terminated after 7 weeks of planting. Plant shoot fresh weight, shoot dry weight, root fresh weight and root dry weight were determined. Plants were oven dried at 70°C for 48 h to determine the dry weight. Plant materials were ground and passed through 2-mm mesh sieve and digested with nitric acid for the mineral element analysis by atomic absorption spectrophotometer (Solaar 969, Thermo Corporation, Tokyo, Japan).

6.1.3.4. Statistical Analysis

Obtained data were subjected to analysis of variance to determine the treatment effects. Duncan's multiple comparison range test was used to determine significant differences between the means using SAS package (SAS, 1990).

6.1.4.Results and Discussion

6.1.4.1. Physical and chemical properties of the growing media

Physical properties of growth substrates are given in Table 6.3. Bulk density of the media increased significantly with the presence of SSC and SA in the growing mixture. Similar results were reported by a previous study conducted using compost based media for bedding plants by Grigatti et al., (2007). In all the media, bulk density values were within the limits (<0.4 g cm^{-3}) established for an ideal substrate (Abad et al., 2001). Initial particle density of peat (1.70 g cm^{-3}) was increased in all treatments with the addition of SA and SSC. Particle density of T1, T2 and T5 were within the ideal limit (1.4-2.0 g cm^{-3}) according to Abad et al., (2001). Particle densities increased with the addition of sludge, as found in previous studies (Guerrero et al., 2002: Chen et al., 2002).T3, T4 and T6 were not within the ideal limit and it exceeded the ideal limit. This may be mainly due to the addition of SA. Potting media containing different ratios of synthetic soil-paper waste aggregates and peat gave increased particle density compared to peat control. This may be due to addition of synthetic aggregates having higher particle density (Jayasinghe et al 2009 b). Air spaces of all substrates were within the established ideal limits except for peat (T1). Moreover, air spaces of SSC and SA based media were significantly higher than the peat. This may be probably due to the great proportion of particles with size >1 mm, because of SSC and SA addition. Low percentages of air space in peat based substrates may cause problems for plant growth (De Boodt and Verdonck, 1972). T1 and T2 gave established ideal porosity values. Water holding capacity of all substrates were within the ideal limit but decreased significantly with the addition of SSC and SA. Similar results were found by a previous study conducted using compost based media for bedding plants by Grigatti et al., (2007). In a study conducted on the physical properties of different coconut coir dust samples reported that water holding capacity diminished proportionally with increasing coarseness index (Abad et al., 2005). Coarseness index of the growth media was increased with addition of SSC and SA as media component compared with peat only substrate. Although there is no single ideal growth medium for plant production (Herrera et al., 2008), physical properties of the substrates formed by substitution of peat with SSC and SA were generally within the recommended ranges for plant production (Bunt, 1988: Noguera et al., 2003: Rynk et al.,1992). Chemical properties of the media are given in Table 6.4. In general, all the substrates, including peat, showed pH values within the established optimal range (5.2–6.5) suggested by different authors (Sanchez-Monedero et al., 2004: Herrera et al., 2008: Bunt, 1988: Noguera et al., 2003: Rynk et al., 1992).

Table 6.3. Physical properties of the growing media

Treatments	Bulk density (g cm^{-3})	Particle density (g cm^{-3})	Air space (%)	Total Porosity (%)	Water holding capacity (mL L^{-1})	CI (%)
T1	0.18d	1.70d	17.71c	89.41a	717a	28d
T2	0.23c	1.76d	22.13b	86.93b	648b	39c
T3	0.33b	2.02b	23.56a	83.66c	601c	48b
T4	0.38a	2.15a	21.73b	82.33c	606c	69a
T5	0.31b	1.94c	23.02ab	84.02c	610c	45b
T6	0.38a	2.12a	21.98b	82.08c	601c	65a
ID	<0.40	1.4–2.0	20–30	>85	600–1000	30–45

CI: coarseness index, ID: Ideal Substrate according to Abad et al., (2001). (Values are means (n=5). Within each column values followed by different letters are significantly different based on Duncan`s test ($p<0.05$).

Table 6.4. Chemical properties of the growing media

	T1	T2	T3	T4	T5	T6	Optimal ranges^{x} and limit values^{y}
pH	5.50d	6.15c	5.50d	6.40a	6.12c	6.28b	5.3–6.5^{x}
EC (dSm^{-1})	0.28d	0.72b	0.39c	1.02a	0.76b	0.72b	<0.5^{x}
OM (gkg^{-1})	704a	618b	324e	335d	441c	330e	>800^{x}
C / N	54.78b	29.84d	71.84a	26.25e	30.71c	31.14c	20–40^{x}
C	412.02a	365.25b	189.66e	195.86d	258.63c	194.32d	–
N(g kg^{-1})	7.52c	12.24a	2.64e	7.46c	8.42b	6.24d	–
P (g kg^{-1})	0.50(0.08)d	14.23(4.01)a	0.21(0.06)e	8.42(2.16)c	11.24(4.12)b	8.86(2.85)c	–
K (g kg^{-1})	0.98(0.30)e	2.56(0.87)a	0.43(0.19)f	1.25(0.48)d	1.86(0. 83)b	1.48(0.67)c	–
Mg (g kg^{-1})	0.44(0.07)c	0.68(0.29)a	0.46(0.05)c	0.54(0.18)b	0.64(0.27)a	0.62(0.28)a	–
Ca (g kg^{-1})	0.51(0.20)d	0.77(0.23)c	0.71(0.24)c	0.80(0.26)b	0.82(0.27)b	0.89(0.29)a	–
Cu (mg kg^{-1})	14.32(7.08)d	60.36(26.21)a	13.18(6.86)d	41.12(19.68)c	52.42(24.73)b	42.94(22.25)c	500^{y}
Zn (mg kg^{-1})	20.32(8.94)d	131.42(37.66)a	22.48(9.13)d	81.24(29.78)c	104.04(38.30)b	86.96(34.76)e	1500^{y}
Cd (mg kg^{-1})	ND	ND	ND	ND	ND	ND	5^{y}
Cr (mg kg^{-1})	1.16(0.59)d	8.24(1.42)a	1.24(0.62)d	5.26(1.14)c	6.98(1.37)b	5.87(1.28)c	200^{y}
Mn (mg kg^{-1})	19.41(9.31)e	54.12(14.36)a	18.54(9.22)f	34.23(11.97)d	45.23(13.22)b	40.68(12.74)c	–
Pb (mg kg^{-1})	1.26(0.50)f	24.32(4.15)a	2.97(0.68)e	15.17(3.48)d	19.47(3.96)b	17.27(3.75)c	1000^{y}

(Values are means (n=5). Within each line values followed by different letters are significantly different based on Duncan`s test ($p<0.05$). EC: electrical conductivity, OM: organic matter. x and y:optimal ranges and limit values in growing media according to Abad et al.,1993. Values within the parenthesis are exchangeable content for K, Mg and Ca, available or extractable content for other elements.

Although there is no single, ideal growth medium for nursery-produced horticultural crops (Raviv et al., 1996: Perez-Murcia et al., 2006), most greenhouse-grown species display better growth at slight acid pH values (5.2– 7.0) (Herrera et al., 2008: Poole et al., 1981: Bugbee, 1996); mixtures with SSC, SA and peat approach these values. The electrical conductivity (EC) values of the growth media were strongly affected by the addition of SSC. Our results were supported by a previous study conducted by Grigatti et al., (2007). The EC values of the mixtures with SSC exceeded the limit for an ideal substrate (<0.5 dSm^{-1}) suggested by Abad et al.,(2001). Moreover, high EC of SSC can be reduced by adding SA and peat. Abad et al.,(2001) stated that a value for total organic matter above 800 gkg^{-1} is adequate for potting media. OM content in all media was lower than the minimum recommended value. The highest OM content of the peat media was significantly decreased with the addition of SA and the SSC. This may be due to the low amount of OM in the SA and the SSC compared to the peat media. Addition of sewage sludge based compost to the peat media decreased the OM content in the growth media compared to peat (Ostos et al., 2008: Herrera et al., 2008). The N content of the growth media ranged between 2.64 and 12.24 g kg^{-1}. The highest N content was given by T2 media having SSC and peat while the lowest given by T3 where peat and SA in the media. The original N content of the SSC, peat and SA were 16.41, 7.52 and 0.4 g kg^{-1}, respectively. T1 and T4 did not show any significant difference in N content. N content of the T5 was significantly higher than the peat control while T6 is significantly lower than the peat control. Mixing SSC with comparatively low N containing peat and SA resulted low N in the growth media compared to the SSC.The C/N ratio varied between 26.25 and 71.84. The ideal established C/N ratio for a potting media is 20-40 (Abad et al., 1993) . C/N ratio of T2, T4, T5 and T6 were in the established ideal range. It is evident that SSC addition declined the C/N ratio compared to peat control. Wilson et al. (2001) found that an increased proportion of compost in crop substrates prompted a decline in the C/N ratio compared to peats, although this will depend on the proportion of each ingredient in the mixture. Total and available P concentrations in SSC based media were higher than that of peat control. This is due to the high P concentration in the SSC (Table 6.1). The presence of SSC in the media mixture increased the total and exchangeable concentrations of K,Mg and Ca compared to peat control. Many authors have shown the use of sewage sludge generally increases the heavy metal contents in compost (Grigatti et al., 2007: Perez-Murcia et al., 2006). The presence of high levels of micronutrients or potentially toxic elements in sewage sludge would be a serious constraint for propagating media preparation. In the present study, total and extractable content Cu, Zn, Cr, Mn and Pb in the SSC based media were increased significantly compared to peat control but they always remained below the limits reported by Abad et al.,1993 (Table 6.4) and those recommended by the United States Environmental Protection Agency (USEPA, 1999). Cd was not detected in any media. Nevertheless, the total contents of Cd, Cr, Cu, Pb and Zn in SSC and SSC-SA based media did not exceed the limits (USEPA, 1999) for land application of sewage sludge recommended by the United States Environmental Protection Agency (Table 6.1 and 6.4). Therefore, the SSC and SSC-SA based media used in this research did not pose a regulated heavy metals toxicity problem. The horticultural compost would be assigned to category `A` following the compost standards in Canada, which stipulated values lower than (mg kg^{-1} of air-dried mass): Cd, 3; Cr, 210; Cu, 100; Pb, 150; Zn, 500 (http://www.compost.org/standard.html).

6.1.4.2. Plant growth and production

In general, significant increases in the dry and fresh weight of shoot and root parts of lettuce plant in SSC-peat (T2) and SSC–SA based media (T4, T5 and T6) compared to peat control were observed (Table 6.5). Different treatments utilized in the study are shown in the Figure 6.1. Similar effects of composts addition to growth media have been referred to by other researchers (Grigatti et al., 2007: Carcia-Gomez et al., 2002: Perez-Murcia et al., 2006: Stabnikova

Figure 6.1. Different treatemnts used in the study

et al., 2005: Warman and Temeer, 2005), which were mainly due to the great contribution of nutrients, especially N and P by composts. Sanchez-Monedero et al., (1997), in experiments using substrates obtained by mixing composts from different origins with peat to grow horticultural plants (broccoli, tomato and onion), found that compost could be used at up to 66.7% by volume with no negative effects on plant growth. The highest increases of yield parameters were obtained in T5, where SSC, SA and peat were present as 40%, 20% and 40% of the total volume, respectively. The shoot fresh weight, shoot dry weight, root fresh weight and root dry weight obtained from the T5 were increased by 44.42 %, 29.53 %, 9.28% and 21.43 %, respectively compared to peat control (Figure 6.1). The second highest yield parameters were given by T6, which showed increased shoot fresh weight, shoot dry weight, root fresh weight and root dry weight by 22.56 %, 15.79 %, 6.13 % and 12.50 %, respectively compared to peat control. Plant growth and yield parameters of T1 and T3 did not show any significant difference. These increased biomass results may be due to the increased concentrations of plant macro and micro nutrients such as P, K, Mg, Ca, Mn, Cu and Zn in the growing media compared to the T1 and T3 media. T2, T4,T5 and T6 reported increased amount of exchangeable cations and extractable trace elements in the mixture compared to T1 (Table 6.4). Moreover, T2 and T5 gave higher N content compared to peat control. The lowest growth and yield parameters of the T1 and T3 may be due to the low concentrations of available nutrients compared to SSC based media. The reduced growth and yield parameters of the T4 compared to other SSC based media may be due to the high EC of the media. The increases in biomass production with the use of sewage sludge based composts as substrate components have been also reported by other authors [Garcia-Gomez et al., 2002:Perez-Murcia et al., 2006]; this could be due to the fertilizing capacity of this compost. Furthermore it is possible that other growth enhancing factors resulting from mixing SSC with peat may have indirectly involved in the improvement of plant growth. Such factors could include humic substances, enzymatic activities, microbial activities, which produce growth stimulating plant hormones, or increased number of beneficial microorganisms (Arancon et al., 2004). Such kind of investigations on humic substances, enzymatic activities and microbial assays should be conducted in future studies. On the other hand, the inclusion of SA in the substrates T3, T4, T5 and T6 at the rates of 20 % or 40%, did not pose any constraint for plant growth compared to peat control. In summary, lettuce grew better in the assayed SSA-peat and SSC-SA media than in the peat control substrate. These results seem to indicate that these SSC-peat and SSC-SA based media may be a viable alternative to peat for containerized production of lettuce.

6.1.4.3. Element concentrations in plant shoots.

Table 6.5. Effects of different substrates on the growth of lettuce

Treatments	Shoot fresh weight (g)	Shoot dry weight (g)	Root fresh weight (g)	Root dry weight (g)
T1	91.16e	3.42d	11.42d	1.12d
T2	100.22c	3.71c	11.83c	1.21c
T3	90.65e	3.36d	11.37d	1.09d
T4	94.54d	3.68c	11.75c	1.20c
T5	131.65a	4.43a	12.48a	1.36a
T6	111.73b	3.96b	12.12b	1.26b

(Values are means (n=5). Within each column values followed by different letters are significantly different based on Duncan`s test ($p<0.05$).

Element concentrations in plant tissues are given in Table 6.6. It is evident that N,P,K,Mg and Ca concentrations of the plants obtained from SSC-peat and SSC-SA based media were increased compared to plants grown in peat control. Increased amounts of N, P, K, Mg and Ca in broccoli plants grown in a media containing 50% of composted sewage sludge and 50% peat were reported in an experiment conducted by Perez-Murcia et al., (2006). These increased element concentrations in the lettuce tissues could be attributed to the higher concentration of this elements observed in the SSC. N content of all substrates were above the deficiency level of 15 gkg^{-1} according to Chapman (1966). Poole et al., (1981) reported that the optimal range of P for potting is 1.5–3.0 gkg^{-1}. Comparing our findings P contents of the plants grown in T2, T4, T5 and T6 substrates were observed that they were within the optimal values. The P values of plants grown in T1 and T3 substrates were below the optimal range. Shoot K, Ca and Mg contents were all above the deficiency limit of 7-15 gkg^{-1} (Chapman, 1966), 1.4 gkg^{-1} (Loneragan and Snowball, 1969) and 0.6 gkg^{-1} (Chapman, 1966), respectively. Positive effects on plant nutrition derived from using composted sewage sludge in growing media have been reported in literature (Raviv et al., 1986: Pinamonti et al., 1997). Therefore, a combination of peat with composts and other residual products (e.g., fresh pine bark, pruning waste, green waste, paper waste) can minimize the negative properties of a single material, thus obtaining sound and cheap substrates (Raviv et al., 1986: Bures, 1997). Cu, Cr and Pb concentrations in the plant tissues obtained from assayed media did not show any significant difference with the plant tissues obtained from the peat control. Pb concentrations in broccoli plant tissues obtained from a media containing composted sewage sludge and peat did not show any significant difference compared to broccoli plants obtained from peat control (Perez-Murcia et al., 2006). Zn concentration of the lettuce plant tissues obtained from assayed media showed significant increase compared to peat control. Similar results were reported in a previous study conducted by Perez-Murcia et al., (2006). In general, none of the trace elements studied reached phytotoxic levels in plants (the growth was not affected). In general, Cu, Mn, Zn,

Table 6.6. Element concentrations in plant shoots

Elements	T1	T2	T3	T4	T5	T6	Normal Range	Phytotoxic range
N (g kg^{-1})	22.44b	24.32a	21.21b	23.46a	24.28a	23.17a		
P(g kg^{-1})	0.61c	1.56b	0.68c	1.68a	1.66a	1.58b		
K (g kg^{-1})	12.24b	18.43a	11.88c	18.12a	18.21a	18.09a		
Mg (g kg^{-1})	3.88c	4.89a	3.74c	4.12b	4.83a	4.24b		
Ca (g kg^{-1})	10.21b	11.23a	9.88c	11.12a	11.45a	11.20a		
Cu (mg kg^{-1})	3.88a	3.82a	3.91a	3.77a	3.70a	3.76a	3–20 ^{y}	25–40 ^{x}
Mn (mg kg^{-1})	101.24a	88.12b	100.36a	89.32b	86.12b	84.25b	15–150 ^{y}	400–2000^{x}
Zn (mg kg^{-1})	20.37b	22.15a	19.23b	23.12a	24.29a	23.21a	15–150 ^{y}	500–1500 ^{x}
Cd (mg kg^{-1})	ND	ND	ND	ND	ND	ND	0.1–1 ^{y}	5–700 ^{x}
Cr (mg kg^{-1})	0.44a	0.51a	0.40a	0.47a	0.46a	0.44a	0.02–14^{y}	-
Pb (mg kg^{-1})	0.51a	0.54a	0.47a	0.45a	0.48a	0.46a	2–5 ^{y}	-

(Values are means (n=5). Within each row values followed by different letters are significantly different based on Duncan`s test ($p<0.05$). x and y:phytotoxic and normal range values according to Romheld and Marschner,1991 and Adriano, 2001, respectively.

Cd, Cr and Pb concentrations in plants tissues obtained from all media were far lower than the phytotoxic ranges (Romheld and Marschner, 1991), and in some cases even lower than the ranges considered normal for plants (Adriano, 2001). Organic amendments such as sludge composts or peat, which contain high proportion of humified organic matter, can decrease the bioavailability of heavy metals by adsorption and by forming stable complexes with humic substances (shuman,1999: Liu et al., 2009). The highest Mn content was reported in T1 and T3. This fact could be due to a decrease in the availability of Mn with the increase in the pH of the media after the addition of the composts (Raviv et al., 1986). For Mn, a concentration decrease derived from the composts applications have been reported by other authors (Murillo et al., 1995: Madejon et al., 2006: Gigliotti et al., 1996). A possible dilution effect derived from the greater biomass reached by the plants grown in the SSC based substrates could also cause these comparatively low concentrations of Mn in relation to T1 and T3 substrates as described by Perez-Murcia et al.,(2006). The evaluation of heavy metals in the plant tissues is important in order to avoid food chain hazards. The permitted values for consumption of Cd and Pb, in horticultural crops are 0.2 and 0.3 mg kg^{-1}, respectively, on a fresh weight basis (EEC, 2001). In the present experiment, Cd were not detected and Pb level was below these values, considering the water content of lettuce.

Table 6.7. Comparative effects of the different growing media studied on trace elements (Cu, Zn, Cr and Pb) extraction ratios (Total trace elements taken up by the plant vs extractable trace elements in growth media before planting).

Treatment	Cu	Zn	Cr	Pb
T1	0.55a	2.28a	0.75a	1.02a
T2	0.15b	0.59c	0.36b	0.13c
T3	0.57a	2.11a	0.65a	0.69b
T4	0.19b	0.78b	0.41b	0.13c
T5	0.15b	0.63c	0.34b	0.12c
T6	0.17b	0.67c	0.34b	0.12c

(Values are means (n=5). Within each column values followed by different letters are significantly different based on Duncan`s test ($p<0.05$).

The extraction ratios of trace elements into plant tissues expressed as trace elements concentrations in plant versus extractable trace elements in the growth media were given in Table 6.7. Highest extraction ratios for Cu, Zn, Cr and Pb were in the plant tissues were obtained from the plants grown in peat control (T1) and Peat – SA (T3) media. Similar results were reported by Perez-Murcia et al., (2006).Pitchel and Anderson (1996) observed an insignificant effect on concentrations of Cr and Pb in oat grown on soils amended with composted municipal solid waste or composted sewage sludge. Concentrations of Pb, Ni, Cu, and Cd in roots and leaves of *Dactylis glomerata* were unrelated to the total or DTPA-extractable concentrations in the sludge-amended soil (Ortiz and Alcaniz, 2006). Therefore, it can be concluded that increased concentrations of total and extractable trace elements in SSC based growth media did not increase the trace element concentrations in plant tissues compared to peat control.

6.1.5. Conclusions

It can be concluded that, in general, the substrates elaborated with SSC and SA showed suitable physical and chemical properties, absence of phytotoxicity and important nutrient contents. Although, these substrates showed pH and EC values higher than pure peat, which can constitute the main limiting factor for their use as growing media, they did not induce any reduction in plant growth. Increased biomass production of lettuce was reported from the SSC-peat and SSC-SA assayed media compared to peat media. Moreover, due to physical and chemical characteristics of the media developed by SSC and SA, SSC-SA based media can be considered as valuable partial peat substitutes for lettuce, especially at the rates of 40% of SSC, 20% of SA and 40% of peat, which gave the maximum growth parameters and the highest biomass yield of the lettuce when compared to peat. Therefore, the SSC and SA 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.

6.2. Evaluation of containerized media developed by cattle manure compost and synthetic aggregates for ornamental plant production as a peat alternative

6.2.1. Introduction

Increasing demand and rising costs for peat as a growing substrate in horticulture have led to search for high quality and low cost substrates as an alternative (Chong, 2005; Wilson et al., 2006; Ostos et al., 2008;Gil et al., 2008 ab;Moral et al., 2009). A number of studies have shown that organic residues such as urban solid wastes, sewage sludge, animal manure and dung, paper waste, pruning waste, spent mushroom and even green wastes, after proper composting, can be used with very good results as container growth media instead of peat (Zaller, 2007; Ostos et al., 2008; Bustamante e al., 2008; Moral et al., 2009; Wright et al., 2008; Miaomiao et al., 2009; Tumuhairme et al., 2009). The increasing interest in waste recycling is another cause to advocate the recycling and use of organic wastes and composts as soil or potting amendments; it could be one of the most attractive methods of solving the problem of waste disposal (Banegas et al., 2007; Kanat et al., 2006; Liu et al., 2009). The combination of peat and compost in growing media is synergistic; peat often enhances aeration and water retention and compost improves the fertilizing capacity of a substrate (Zaller, 2007). In addition, organic by-products and composts tend to have porosity and aeration properties comparable to those bark and peat and as such are ideal substitutes in propagating media (Chong, 2005). Moreover, composts tend to improve the organic matter content of the media (Qazi et al., 2009)

In recent years, the intensive and industrial livestock production system has resulted in high density of animals in relatively small areas and producing large quantities of manure (Ko et al., 2008; Gil et al., 2008a). Thus, livestock production has become separated from its land base and has difficulty in treating the manures within internal management (Richard and Choi, 1999). This has led to environmental problems for people, including water contamination (Elwell et al., 2001; Gay et al., 2003; Gil et al., 2008a; Ko et al., 2008; Giusti, 2009). Therefore, the need for more environmentally friendly methods for the treatment and utilization of animal manure has become imperative. There are several kinds of animal waste treatment methods, such as composting, lagoon, evaporation, and water purification. Composting cattle manure produces a stabilized product that leads to the development of microbial populations, which causes numerous physico-chemical changes in the waste mixture (Cai et al 2007) and improves the handling characteristics of manure by reducing volume and weight (Eghball and Power, 1999, Adamtey et al., 2009). Cattle manure compost (CMC) are considered as a valuable product that can be used as a source of soil amendment and organic matter in agriculture which improves the quality of the crop and the environment (Hoitink, 2000; Ko et al., 2008,).CMC did not cause any heavy metal pollution and there were no phytotoxicity symptoms found in maize plants treated with CMC (Gil et al., 2008a). Composts may have physical, physico-chemical and chemical properties similar to peat that make them suitable as peat substitutes (Sanchez-Monedero et al., 2004). Moreover, CMC addition to soil improve the soil quality, soil organic matter, soil aggregate stability, water holding capacity, water infiltration, hydraulic conductivity and nutrient content (specially N, P and K)(Sager, 2007; Bartl et al., 2002; Castrillion et al., 2009; Indraratne et al., 2009).However, the combination of peat with composts can reduce the potential poor properties of single materials, such as high salinity, heterogeneity or high content of contaminants (Raviv et al., 1986).

Widely spread red soil (“Kunigami Mahji”) in sub-tropical Okinawa, Japan, which is classified as an ultisol, is not suitable for crop production due to its poor physical (Tokashiki et al., 1994) and chemical properties (Hamazaki, 1979; Onaga and Yoshinaga, 1988). This prompted for the development of an effective method of converting under utilized red soil into fertile, arable SA by incorporating paper waste and starch waste in order to improve its physical and chemical properties. The starch waste coming out as waste materials from Okinawa Seifun

Corporation Okinawa, Japan was used as the SA binder as described in our previous studies (Jayasinghe et al., 2005, 2008, 2009b,c,d,e,f,g). Moreover, SA developed by coal fly ash with paper waste and acidic red soil was utilized as plant growth media in our previous studies (Jayasinghe et al., 2007, 2008, 2009a,c). The ornamental plant production industry is one of the fastest growing major segment of Japan agriculture, accounted for 13% from the global production, has a production value of 3147 million Euros per annum (Wijnands, 2005). The total area for ornamental plant production in Japan in 2004 was 22382 ha, out of which 51% was from protected houses (Wijnands, 2005). During last two decades due to improved popularity for protected agriculture, evolution of plant growth techniques has increased demand for container substrates such as peat, zeolite, perlite etc, but the supply have been decreasing (Inbar et al., 1990). Depletion of non-renewable resources and environmental deterioration together with high prices of those substrates have favored the utilization of alternative materials as growth substrates (Abad et al., 2001). In this present study CMC along with SA were used to improve the properties of the growth substrates for crop production.

6.2.2. Objective of the study

The aims of the present work were: (1) to evaluate the main physical and chemical properties of the containerized media developed from CMC and SA, and (2) to ascertain the potential utilization of these CMC-SA based media as an alternative to widely using peat media for ornamental French marigold cultivation by studying their effects on vegetative and nutritional aspects to determine if there is any limitation to their use.

6.2.3. Materials and methods

6.2.3.1. Collection of samples

CMC was collected from a local industrial composter (Takathomi Bussan,Pvt.ltd, Kagoshima,Japan). The compost was produced from cattle manure and wood chips. Compost was fully matured (Compost which undergoes adequate decomposition). Red soil samples were collected from Miyagi-Sajibaru, Higashi-Son, Kunigami-Gun, Okinawa, Japan. The soil texture used to produce SA was clay and is classified as an Ultisol. Collected soil samples were air-dried and then sieved through a 10-mm mesh screen and utilized for SA production. A portion of this soil sample was sieved through a 2-mm mesh sieve, and used for chemical analysis. Paper waste was collected from Ojiryokka Company, Tokyo, Japan. Starch waste and peat samples were obtained from Okinawa Seifun, Corporation ltd, Okinawa, Japan. Physical and chemical properties of the paper waste and soil are given in Table 6.8.

6.2.3.1.2. Production of synthetic soil aggregates (SA)

SA was produced by combining red soil and paper waste using an Eirich mixer (R-02M/C27121) with starch waste as a binder according to Jayasinghe et al.,(2005, 2008, 2009a,b). 1000 g of red soil, 100 g of waste paper and 25 g of lime were mixed in Eirich mixer by adding 225 ml of starch paste (starch paste was produced adding 25g of starch to 200 ml hot water) for the production of SA.

6.2.3.1..3. CMC and SA mixtures utilized under the study

Table 6.9 shows volumetric formulations of different SA and CMC mixtures used in the study.

Table 6.8. Selected physical and chemical properties of paper waste and red soil used in the experiment.

Particulars	Paper waste	Red soil
Bulk density (gcm^{-3})	-	1.26±0.03
Particle density (gcm^{-3})	-	2.65±0.06
pH	5.70±0.32	4.96±0.14
EC (dSm^{-1})	0.10±0.001	0.04±0.001
C (gkg^{-1})	374.8±2.76	1.73±0.04
N (gkg^{-1})	0.38±0.10	0.40±0.04
P (gkg^{-1})	0.06±0.01	0.03±0.01
Na (gkg^{-1})	0.24±0.09	0.06±0.01
K(gkg^{-1})	0.32±0.05	0.05±0.01
Mg(gkg^{-1})	0.47±0.11	0.02±0.00
Ca (gkg^{-1})	0.63±0.17	0.07±0.01
As (mgkg^{-1})	ND	ND
Cr (mgkg^{-1})	3.70±0.34	1.20±0.10
Cu (mgkg^{-1})	8.50±0.49	13.81±0.22
Se (mgkg^{-1})	ND	ND
Mn (mgkg^{-1})	6.52±1.26	20.65±1.95
Cd (mgkg^{-1})	ND	ND
Zn (mgkg^{-1})	10.10±0.42	27.31±2.98
Pb (mgkg^{-1})	0.63±0.16	4.70±0.06

EC: electrical conductivity, ND = Not Detected; Values are mean ±Standard Deviation (n=5)

6.2.3.1.4. Analytical methods

The pH was measured in water extracts of all substrate samples using a glass electrode (Sample: distilled water ratio of 1:5), and electrical conductivity (EC) was measured using an EC meter (D-54, Horiba) (Sample: distilled water ratio of 1:5). Carbon (C) and nitrogen (N) contents in substrate samples were determined by using CN analyzer (Micro coder JM 10; G-Science Laboratory, Tokyo, Japan). Organic matter (OM) contents of the substrate samples were determined by loss on ignition at 430 ◦C for 24 h (Navarro et al., 1993). Concentrations of Na, K, Mg and Ca of substrate samples were extracted by using 1 M ammonium acetate and the extracts were used to analyze the cation concentration using atomic absorption spectrophotometer (Solaar 969, Thermo Corporation, Tokyo, Japan). Substrate samples were digested in nitric acid in pressurized microwave (USEPA, 1996) and analyzed for heavy metals (As, Cr, Cu, Se, Mn, Cd, Zn and Pb) by using atomic absorption spectrophotometer (Solaar 969, Thermo Corporation, Tokyo, Japan). Total P of substrate samples were determined by using spectrophotometer after digestion in nitric acid in a pressurized microwave (Hafner et al., 1993).

Physical properties of each substrate materials were determined using procedures described by Spomer (1990) and Pill et al., (1995). Each moistened pre-plant media was placed in 12.5 cm diameter standard plastic pots. Each pot was irrigated for two weeks in the same manner. After two weeks of irrigation, container’s drainage hole was sealed with a duct tape. Water was then added to each substrate until saturated. After determining the weight of saturated substrate, the drainage holes were unsealed and substrates were allowed to drain 24 h. Then the amount of water loss was determined as a result of drainage. Then substrates were oven dried at 65^{0}C for 48h and the amounts of water retained by substrates after draining were determined. The weight of water needed to saturate each substrate was divided by the medium bulk volume to determine total pore space percentage. Substrate bulk density was determined by dividing oven dried weight of each substrate by substrate bulk volume. Samples of air dried substrates were passed through a series of sieves, from 5.6 mm to 0.10mm, to determine their particle size distribution. Coarseness index, expressed as weight percentage of particles with Ø>1mm (Richards et al., 1986) was determined. All measurements were carried out 5 times.

6.2.3.1.5. Utilization of CMC and SA mixtures as a containerized growth media for French marigold cultivation

Table 6.9. Composition of containerized media used in the experiment

Media	Formulation
T1	Peat only (commercial media)
T2	SA only
T3	CMC20% :SA 80% (V/V)
T4	CMC 40% :SA 60% (V/V)
T5	CMC 60%: SA 40% (V/V)
T6	CMC only

SA: Synthetic aggregates, CMC: cattle manure compost, V/V: Volume basis

A green house pot experiment was conducted to study the influence of different growth media containing different ratios of CMC and SA on ornamental plant growth. French marigold (*Tagetes patula*) was utilized as the ornamental plant in this study. Container volume was 1.5 L. Table 2 shows the volumetric formulations of different container substrates utilized in this study. The acidic pH of the peat (4.60) and SA (5.00) were adjusted to 5.50 by adding lime. T1 and T2 were also enriched with slow release fertilizer 15-15-15. Experimental design of the pot experiment was a completely randomized design (CRD) with 6 treatments and 5 replicates. Prepared substrate samples were filled into each pot leaving a distance of 1 cm from the top of the pot and without unnecessary compaction. All pots were arranged in a green house and saturated and kept for 48 h to attain their respective field capacities. Two weeks old French marigold plants obtained from a prepared nursery were planted in each pot. One plant was planted in each pot. 200 mL water was added to each pot once in two days. Temperature ranged from 20-31^{0}C during the growth season. Experiments were terminated after 3 months after planting. Plant height, shoot fresh weight, shoot dry weight, root length, root fresh weight, root dry weight and number of flowers per plant were determined. Plants were oven dried at 70^{0}C for 48 h to determine the dry weight. Plant materials were ground and passed through 2-mm mesh sieve and digested with nitric acid for the mineral element analysis by atomic absorption spectrophotometer (Solaar 969, Thermo Corporation, Tokyo, Japan).

6.2.3.1.6. Statistical Analysis

Obtained data were subjected to analysis of variance to determine the treatment effects. Duncan's multiple comparison range test was used to determine significant differences between the means using SAS package (SAS Institute 1990).

6.2.4. Results and Discussion

6.2.4.1. Physical and chemical properties of the containerized media

6.2.4.1.1. Physical properties

The particle size distribution (Table 6.10) of a substrate is important because it determines pore space, bulk density, air and water holding capacities. An excess of fines (less than 0.1 mm) clogs pores, increases non-plant-available water holding capacity and decreases air filled porosity (Spiers and Fietje, 2000). Handreck (1983) also underlined the importance of the fraction with size between 0.1 and 0.5 mm and its relation to the available water holding capacity. With the exception of mixes T2 and T3 with less than 20% particles within this range the rest of the substrates were between 20% and 35% (wt). The mean distribution shows that the

Table 6.10. Particle size analysis of the containerized media used in the experiment

Media	>5.6mm (weight %)	5.6-3.35mm	3.35-2.00mm	2.00-1.00mm	1.00-0.50mm	0.50-0.25mm	0.25-0.10 mm	<0.10mm	CI (%)
T1	0.54±0.30f	6.60±0.46f	9.90±0.78e	16.75±0.88c	25.05±0.66a	24.36±1.08a	10.70±0.38°	6.10±0.28a	33.79±0.62f
T2	11.08±0.34a	18.16±1.02a	22.48±1.12a	12.54±0.30f	17.76±0.52f	9.38±0.44f	6.30±0.32e	2.30±0.41e	64.26±0.78a
T3	8.76±0.22b	15.64±0.87b	19.76±1.23b	14.83±0.55e	18.40±0.48e	10.58±0.30e	8.70±0.18d	3.33±0.34d	58.99±0.60b
T4	7.36±0.31c	13.64±0.72c	17.42±0.98c	15.62±0.46d	20.83±0.41d	12.02±0.42d	9.07±0.27c	4.04±0.47c	54.04±1.02c
T5	6.20±0.26d	12.10±0.60d	15.12±0.86d	17.60±0.80b	22.23±0.68c	13.51±0.52c	9.62±0.35b	3.92±0.32c	50.72±0.82d
T6	4.12±0.42e	8.26±0.90e	15.00±0.86d	20.18±0.84a	23.22±0.96b	14.36±0.77b	10.68±0.32a	4.18±0.51b	47.56±0.48e

CI, coarseness index, (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=5)).

Table 6.11. Physical properties of the media

media	Bulk density (gcm^{-3})	Particle density (gcm^{-3})	Air Space (%)	Total Porosity (%V/V)	Total water Holding Capacity(mLL^{-1})
T1	0.18±0.03f	1.70±0.03f	17.71±0.17d	89.41±1.74a	717±7.34a
T2	0.52±0.03a	2.57±0.03a	33.97±0.38a	79.77±1.28d	458±8.70f
T3	0.45±0.05b	2.35±0.05b	31.95±1.12b	80.85±1.81d	489±6.30e
T4	0.39±0.06c	2.06±0.06c	28.37±1.24c	81.07±1.64c	527±5.24d
T5	0.35±0.03d	1.91±0.03d	28.28±0.45c	81.68±2.28c	534±8.70c
T6	0.28±0.07e	1.80±0.08e	28.84±0.4c	84.44±1.62b	556±7.40b
IS	<0.40	1.4-2.0	20-30	>85	600-1000

(Means followed by the different letter in the same column differed significantly according to Duncan’s multiple range test (P=0.05). (n=5)).

Table 6.12. Chemical properties of the media

Particulars	T1	T2	T3	T4	T5	T6	Optimal ranges^{x} and limit values^{y}
pH	5.50±0.12e	5.50±0.09e	6.12±0.16d	6.43±0.08c	6.92±0.23b	8.02±0.20a	5.3-6.5^{x}
EC (dSm^{-1})	0.28±0.06e	0.05±0.01f	0.42±0.07d	0.69±0.10c	1.21±0.09b	2.32±0.12a	<0.5^{x}
OM (gkg^{-1})	704.03±4.31a	142.21±2.82f	207.10±4.24e	288.13±3.36d	364.28±2.88c	522.18±3.74b	>800^{x}
C / N	54.78±3.21b	213.50±5.66a	38.02±1.20c	23.10±0.78d	17.98±0.44e	13.84±0.36f	20-40^{x}
C	412.02±9.34a	85.40±8.25f	122.05±6.12e	169.56±7.34d	209.54±6.12c	308.69±4.26b	-
N(gkg^{-1})	7.52±0.66c	0.40±0.08e	3.21±0.21d	7.34±0.54c	11.65±0.76b	22.30±0.88a	-
P (gkg^{-1})	0.50±0.04e	0.08±0.02f	0.88±0.07d	3.12±0.16c	5.32±0.21b	10.18±0.24a	
K (gkg^{-1})	0.98±0.19e	0.31±0.08f	2.64±0.24d	7.46±0.35c	12.45±0.37b	22.36±0.42a	-
Mg (gkg^{-1})	0.44±0.10f	0.62±0.13e	1.02±0.16d	2.43±0.12c	3.24±0.24b	6.23±0.31a	-
Ca (gkg^{-1})	0.51±0.12f	0.91±0.18e	3.42±0.15d	6.83±0.23c	11.02±0.42b	20.34±0.38a	-
Cu ($mgkg^{-1}$)	14.32±0.24e	13.40±0.36f	18.59±0.41d	25.66±0.32c	30.28±0.47b	49.36±0.51a	500^{y}
Zn ($mgkg^{-1}$)	20.32±1.12f	27.30±1.32e	34.65±1.54d	42.87±1.38c	58.27±1.42b	86.37±1.45a	1500^{y}
Cd ($mgkg^{-1}$)	ND	ND	ND	ND	ND	ND	5^{y}
Cr ($mgkg^{-1}$)	1.16±0.17e	1.18±0.21e	1.39±0.24d	1.77±0.12c	2.08±0.20b	2.76±0.28a	200^{y}
Mn ($mgkg^{-1}$)	19.41±1.23f	20.48±1.30e	39.15±1.44d	59.84±1.52c	88.37±1.73b	143.87±1.49a	-
Pb ($mgkg^{-1}$)	1.26±0.21f	4.48±0.18e	4.72±0.26d	5.20±0.20c	5.90±0.31b	6.87±0.34a	1000^{y}

Optimal ranges (x) and limit values (y) for heavy metals in raw materials are shown (mean values, N=5). For each variable, values followed by the same letter do not differ significantly ($p<0.05$). EC: electrical conductivity, OM: organic matter;^{x,y} According to Abad etal.,(1993,2001) fraction between 1 and 0.50 mm was the most abundant, followed by the fraction between 2 and 1 mm and 3.35 and 2 mm. T2 and T3 showed higher particle percentages > 1mm which was rather coarse. Richards et al. (1986) defined a ‘‘coarseness index’’ as the cumulative volume percentage of particles larger than 1 mm. The average ‘‘coarseness index’’ (CI) expressed as weight percent in the samples studied was varied between 33.79 % to 64.26 %. According to Abad et al., (2001) an established CI for an ideal substrate should be 30-45%. Peat substrate (T1) was in the ideal range. Highest and lowest CI was given by SA and the peat media, respectively. Physical properties that must be considered in preparing containerized media include total porosity, air space, water holding capacity, bulk density and particle density. Some physical properties of the growing media are given in Table 6.11. The bulk density of a containerized media gives a good indication of porosity, which determines the rate at which air and oxygen can move through the substrate. The bulk density values of all substrates were significantly different ($P<0.05$). Abad et al., (2001) defined the bulk density requirement of an ideal substrate should be <0.40 gcm^{-3}. With the exception of T2 and T3 all other substrates were within the established ideal substrate range. The lowest bulk density reported in peat (T1) and highest was given by SA only (T2). High bulk density values have the disadvantage of increasing the transportation cost and reducing porosity (Corti et al.,1998). Particle density values of T1, T5 and T6 were within the established ideal particle density limit (1.4-2.0 gcm^{-3}) described by Abad et al., (2001), but the T2, T3 and T4 were not in the ideal range. Moreover, air space values of T1,T2 and T3 were not within the ideal range (20−30%） explained by De Boodt and Verdonck, (1972). Peat gave the lowest air space value among all substrates. De Boodt and Verdonck, (1972) revealed that low percentages of air space in peat based substrates may cause problems for plant growth. SA gave the highest air space value and greater air space means that water should be applied more frequently, and in small amounts to avoid leaching (Benito et al., 2006; Garcia-Gomez et al., 2002). Mixing of CMC and SA in treatments T4 and T5 enhanced air space into the ideal substrate range compared with SA and peat. Total porosity of an ideal substrate should be greater than 85% according to De Boodt and Verdonck, (1972). Peat (T1) only exceeded 85% of porosity whereas all other media were below the established ideal range (Table 6.11). The ideal water holding capacity of an ideal substrate should be in the range of 600-1000 mLL^{-1} according to De Boodt and Verdonck, (1972). The highest water holding capacity was reported from T1 substrate whereas the lowest given by T2 substrate. Except peat water holding capacities of other media were not in the ideal established range. Abad et al., (2005) reported in a study on the physical properties of different coconut coir dust samples that both easily available water and total water holding capacity diminished proportionally with increasing coarseness index, while the air content was positively correlated. CMC-SA based media showed higher coarseness index compared to peat control and their water holding capacities were low compared to peat control. Although there is no single, ideal growth medium for nursery-produced horticultural crops (Poole et al., 1981; Raviv et al., 1986; Bugbee, 1996), physical properties of CMC-SA based substrates were generally within the recommended ranges for production of ornamental plants (Poole et al., 1981; Bunt, 1988; Rynk et al., 1992).

6.2.4.1.2. Chemical properties

The main chemical characteristics of media are listed in Table 6.12. Values for pH in the media ranged from 5.50 to 8.02, peat pH being the lowest. Except for T5 and T6 media, pH (1:5 v/v) of the substrates were within the acceptable limit for an ideal substrate suggested by different authors (Abad etal.,1993;Bunt, 1988; Noguera et al., 2003; Sanchez- Monedero et al., 2004). The basic condition of CMC (pH = 8.2) could be limiting to some plants. Mixing alkaline CMC with acidic SA gave favorable pH values for plant growth and these pH values can be used for plants sensitive to alkaline conditions. Soluble salt level can be estimated by measuring the EC of a saturated paste. The components contributing most to salinity are Na, K, Cl^{-1}, ammonia, nitrate and sulfate. Low soluble salt levels (EC < 3.5 dSm^{-1}) are preferable for potting compost (Noguera et al., 2003). Low values indicate a lack of available salts, while high values indicate a large amount of soluble salts that may inhibit biological activity or may be unsuitable for land application if large quantities of the material are used. Nevertheless, Sanchez-Monedero et al., (2004) tested two composts with high salt content (8.5–13.2 dSm^{-1}) as a potential component of growing media for vegetable transplant production, observing that media prepared with either of the composts and mixed with commercial substrate or peat at a rate of up to 67% did not have any detrimental effect on plant growth. The EC was higher in the CMC-based substrates compared to peat due to the higher EC of the compost (Table 6.12). Gil et al., 2008b reported that CMC was characterized by higher EC. T4, T5 and T6 exceeded the suggested acceptable limit for an ideal substrate according to Abad et al., (1993). High salinity of CMC compost can be attenuated by mixing it with acidic SA, which acts as diluents in potting mixtures. The organic matter contents were lower than the level suggested by Abad et al., (1993) for an 'ideal' substrate (800 kg g^{-1}) in all media. The N content in CMC based media were higher compared with the peat control. The highest N content was given by CMC only (T6). The C/N ratio is widely used as an indicator of the maturity and stability of organic matter. The C/N ratio varied between 13.84 and 213.50. The established ideal range of C/N ratio for a growth substrate is between 20 and 40. SA gave the highest value and CMC gave the lowest value. Davidson et al., (1994) report that composts with a *C/N* ratio of less than 20 are ideal for nursery plant production. Ratios above 30 may be toxic; causing plant death (Zucconi et al., 1981).Mixing of CMC with SA lowered C/N ratio ratios. Wilson et al., (2001) found that an increased proportion of compost in crop substrates prompted a decline in the *C/N* ratio compared to peats, although this will depend on the proportion of each ingredient in the mixture. However, Inbar et al., (1990) cautioned that the C/N ratio of compost is only one parameter by which maturity should be gauged and specific chemical analyses are equally important. P concentrations in CMC based media were higher than that of peat control. This is due to the high P concentration in the CMC (T6). The presence of CMC in the media mixture increased the concentrations of K, Mg and Ca. Moreover, Cu, Zn, Cr, Mn and Pb in the CMC based media were increased significantly compared to peat control but were below the stated limits (Abad et al., 1993). Cd was not detected in any media. It is evident that CMC addition increased the nutrient availability in the growing media. The contents of Cd, Cr, Cu, Pb and Zn in CMC and CMC-SA based media were several times lower than regulation limits prescribed by the USEPA for exceptional quality compost. These limits, in terms of $mgkg^{-1}$of dry weight, are as follows: Cd, 39; Cr, 1200; Cu, 1500; Pb, 300; Zn, 2800 (USEPA, 1999).Therefore, the CMC and CMC-SA based media used in this research did not pose a regulated heavy metals toxicity problem.

6.2.4.2. Utilization of CMC and SA mixtures as a containerized growth media for French marigold cultivation

Plant growth and yield parameters of the French marigold cultivated in different containerized media showed significant differences compared to peat control (Table 6.13). Different treatments used in the study are shown in the Figure 6.2. Highest growth and yield parameters were given by French marigold grown in T4, where CMC and SA were mixed at 40% and 60%, respectively, followed by T3 and T5. 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 T4 treatment were increased by 27.01%, 42.86%, 37.09%, 67.29%, 5.14%,45.58% and 34.26% ,respectively compared to peat control. The increases in biomass production with the use of composts as substrate components have been also reported by other authors (Chiu et al., 2006; Gil et al.,2008ab; Perez-Murcia et al.,2006; Bustamante et al., 2008); this situation could be attributed to the great input of nutrients provided by composts, especially N and P. Higher concentrations of K, P, Ca and Na were found after CMC application than chemical fertilizer application for maize (*Zea maize*) cultivation, which showed that the CMC contributed more of these than the chemical fertilizer (Gil et al., 2008a). In a previous study conducted by Grigatti et al., (2007) reported that French marigold grown in the media having 25-50% composts gave better or comparable biomass production and ornamental value with respect to the control peat. Sanchez-Monedero et al., (1997), in experiments using substrates obtained by mixing composts from different origins with peat to grow horticultural plants (broccoli, tomato and onion), found that compost could be used at up to 66.7% by volume with no negative effects on plant growth. Lowest growth and yield parameters were given by T2 (SA only) and T6 (compost) only media. Plant height, number of flowers per plant, fresh shoot weight, shoot dry weight, root length, root fresh weight and root dry weight obtained from SA only (T2) treatment were decreased by 20.88%, 28.57%, 28.88%, 9.40%, 0.83%,16.38% and 21.91%, respectively compared to peat control. This could be due to high air space, low water holding capacity and low percentage of finer particles in the growth media (Table 3 and 4). Moreover, plant height, number of flowers per plant, fresh shoot weight, shoot dry weight, root length, root fresh weight and root dry weight obtained from compost only (T6) treatment were decreased by 23.70%, 35.71%,42.99%, 18.12%,20.69%, 39.76% and 39.81%, respectively compared to peat control. It is likely that the high pH (8.20), high EC (2.32 dSm^{-1}) and its related nutrient bioavailability accounted for the reduced growth and yield parameters of French marigold in the T6 treatment compared with other treatments. High pH of substrate can sharply decrease availabilities of P, iron (Fe) and Mn (Peterson, 1982).In addition, the increasing rate of compost in the media induced a decrease in the dry and fresh weights despite the increase in the nutrient concentration of the media probably due to the increase in salinity (Bustamante et al.,2008). On the other hand, the inclusion of CMC in the substrates T3, T4 and T5 at the rates of 20 %, 40% or 60%, did not pose any constraint for plant growth and showed significant increase of biomass compared to peat control. In summary, French marigold grew better in the assayed CMC-SA media than in the control substrate. These results seem to indicate that these CMC-SA based media may be a viable alternative to peat for containerized production of French marigold.

Figure 6.2. Different treatments used in the study

Table 6.13. Effects of different substrates on the growth of French marigold

Media	Plant height (cm)	Number of flowers per plant	Fresh shoot weight (gplant^{-1})	Shoot dry weight (gplant^{-1})	Root length (mm)	Root fresh weight (gplant^{-1})	Root dry weight (gplant^{-1})
T1	20.25±1.12d	14.00±1.20d	26.80±0.72d	10.21±0.12d	240.00±1.02c	9.28±0.45c	3.24±0.14d
T2	16.02±0.86e	10.00±0.66e	19.06±0.63e	9.25±0.43e	238.00±1.30c	7.76±0.44d	2.53±0.12e
T3	24.16±1.02b	18.00±1.09b	32.61±1.22b	14.56±0.34b	259.33±1.51a	13.85±0.41a	4.28±0.12b
T4	25.72±1.14a	20.00±0.77a	36.74±1.31a	17.08±0.42a	252.33±1.42b	13.51±0.56a	4.35±0.09a
T5	23.12±0.87c	16.00±0.69c	30.71±0.89c	13.62±0.28c	248.33±1.16b	11.88±0.37b	3.44±0.11c
T6	15.45±0.85f	9.00±0.54f	15.28±0.73f	8.36±0.30f	190.35±0.80d	5.59±0.21e	1.95±0.16f

(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 ±Standard Deviation (n=5)).

Table 6.14. Element concentrations in plant shoots

Elements	T1	T2	T3	T4	T5	T6	Normal Range	Phytotoxic range
N (gkg^{-1})	25.28±0.42d	22.86±0.36e	28.28±0.41b	30.56±0.30a	27.21±0.28c	27.82±0.32c		
P(gkg^{-1})	0.52±0.07e	0.47±0.04f	0.72±0.10d	1.54±0.12c	1.84±0.10b	1.92±0.14a		
K (gkg^{-1})	18.46±1.20e	16.77±1.26f	20.34±1.42d	22.45±1.02c	26.34±0.78b	29.25±0.98a		
Mg (gkg^{-1})	7.96±0.33e	6.91±0.28f	14.12±0.54d	16.22±0.68c	19.34±0.72b	21.24±0.65a		
Ca (gkg^{-1})	8.36±0.16e	7.76±0.22f	14.39±0.24d	18.89±0.45c	22.18±0.38b	24.16±0.56a		
Cu (mgkg^{-1})	4.46±0.18a	4.35±0.14a	4.51±0.22a	4.48±0.24a	4.57±0.18a	4.60±0.20a	3-20[y]	25-40[x]
Mn (mgkg^{-1})	112.36±1.23a	108.12±1.36b	92.12±0.89c	89.44±1.34d	83.24±0.87e	81.36±0.94f	15-150[y]	400-2000[x]
Zn (mgkg^{-1})	25.68±0.51f	25.15±0.36e	33.78±0.61d	40.48±0.46c	46.65±0.28b	50.68±0.58a	15-150[y]	500-1500[x]
Cd (mgkg^{-1})	ND	ND	ND	ND	ND	ND	0.1-1[y]	5-700[x]
Cr (mgkg^{-1})	0.64±0.12a	0.59±0.08a	0.66±0.14a	0.62±0.12a	0.67±0.14a	0.69±0.16a	0.02-14[y]	-
Pb (mgkg^{-1})	0.56±0.14a	0.53±0.08a	0.58±0.10a	0.57±0.12a	0.54±0.10a	0.60±0.14a	2-5[y]	-

For each row values followed by the same letter do not differ significantly according to Duncan multiple range test ($P<0.05$).[x]Critical toxicity concentration (Romheld and marschner, 1991): from [y]Adiano, (2001).

6.2.4..3. Nutritional status of the French marigold plants

The use of the CMC and SA in the growing media elaborated influenced significantly the nutritional status of the plants (Table 6.14). N, K, Mg, Ca and P concentrations of the CMC-SA based media were increased compared to peat control, which could be attributed to the higher concentration of this element observed in the CMC. Especially, K, Mg, K and P contents of plants grown in 100% CMC medium were found higher than in those growing in other mixtures. Poole et al. (1981) reported that the optimal ranges for potting plants with regard to N, P, K and Ca are 15-45 gkg^{-1}, 1.5-3.0 gkg^{-1}, 15-50 gkg^{-1} and 6-15 gkg^{-1}, respectively. Comparing our findings for N and K contents of the plants grown in different mixtures it was observed that they were generally within the optimal values. The P values of T1, T2 and T3 were below the optimal range and T4, T5 and T6 were within the range. Ca values of T4, T5 and T6 were higher than the optimal levels. Positive effects on plant nutrition derived from composts in growing media have been reported in literature (Raviv et al., 1986; Pinamonti et al., 1997). The presence of high levels of micronutrients or potentially toxic elements in composts could be a serious constraint for propagating media preparation. In general, none of the trace elements studied reached phytotoxic levels in plants (the growth was not affected). In general, Cu, Mn, Zn, Cd, Cr and Pb concentrations in plants under our study were far lower than the phytotoxic ranges given by Romheld and Marschner, (1991), and in some cases even lower than the ranges considered normal for plants (Adriano,2001). Our results were supported by a previous study conducted by Gil et al.,(2008b); stating that CMC can be recommended as a good substitution for conventionally used chemical fertilizers for Maize and there were no heavy metal pollution and phytotoxicity symptoms were found in maize plants. Accumulation of heavy metals is a much less serious problem in container culture of ornamentals than where composts are used in field crops for human or animal consumption (Chaney, 1990). Organic amendments such as composts, animal manure or peat, which contain high proportion of humified organic matter, can decrease the bioavailability of heavy metals by adsorption and by forming stable complexes with humic substances (Shuman, 1999; Liu et al., 2009).Highest Mn content was reported in T1 and T2. This fact could be due to a decrease in the availability of Mn with the increase in the pH of the media after the addition of the composts (Perez-Murcia et al.,2006).For Mn, a concentration decrease derived from the composts application have been reported by other authors (Murillo et al.,1995; Madejon et al., 2006).

6.2.5. Conclusions

From experiment results, it can be concluded that, in general, the proposed CMC-SA based containerized growing media had adequate physical and chemical parameters and notable contents of plant nutrients, mainly N,P, Ca and Mg. Moreover, Plants growth in CMC-SA based containerized substrates gave higher growth parameters than the ones growth in peat substrate. The use of CMC-SA media in the preparation of substrates was adequate for French marigold cultivation, since it showed statistically significant effect on the French marigold growth parameters even using CMC and SA at 60% and 40%, respectively. Mixture of CMC and SA at 40% to 60, which gave the highest growth and yield parameters by increasing plant height, number of flowers per plant, fresh shoot weight, shoot dry weight, root length, root fresh weight and root dry weight by 27.01%, 42.86%, 37.09%, 67.29%, 5.14%, 45.58% and 34.26%, respectively compared to peat control, can be recommended as the most suitable containerized media for French marigold cultivation. Moreover, due to physical and chemical parameters of the media developed by CMC-SA, it can be concluded that peat can be substituted by CMC-SA based media for ornamental plant production. Future studies should be conducted to evaluate the influences of CMC-SA based media for different types of crop varieties.

Chapter 7
General conclusions

Based on the above all investigations following conclusions can be made.

a) Heterogeneous synthetic aggregates produced from coal fly ash, paper waste, starch binder or inorganic binders (calcium sulfate and calcium hydroxide) showed low bulk density, high saturated permeability, high water holding capacity, alkaline pH values, high cation concentrations, high aggregate strengths, high water stable aggregate percentages and high percentage of larger particles. The trace element concentrations of the developed aggregates were below the maximum pollutant concentration of individual metals for land application of sewage sludge given by the US Environmental Protection Agency. Scanning electron microscopic (SEM) study showed higher structural surface area of synthetic aggregates, where round shape coal fly ash particles were embedded into the fibrous paper waste matrix. Incorporation of these synthetic aggregates as a soil ameliorant and a fertilizer source to the low productive acidic red soil ("Kunigami Mahji") in Okinawa, Japan can improve the soil fertility and soil physical and chemical properties such as neutralizing soil pH, increasing electrical conductivity, decreasing bulk density, enhancing hydraulic conductivity, increasing water holding capacity and increasing soil C content. Synthetic aggregates addition to red soil improved the growth and yield parameters of *Brassica rapa Var.Pervidis* compared to red soil with no aggregates addition.

b) "Kunigami mahji" soil, coal fly ash, paper waste and starch can efficiently be used to produce heterogeneous synthetic soil aggregates. The produced aggregates had low particle density, low bulk density, high saturated hydraulic conductivity, high water holding capacity, high organic matter content, and high cation exchange capacity in comparison with the original "Kunigami Mahji" soil. Coal fly ash addition between 20% and 60% gave the highest aggregate strengths. It can be suggested that aggregates produced by adding 20% of coal fly ash to "Kunigami Mahji" soil, along with paper waste and starch as a binder, can be successfully used as a growth medium for komatsuna (*Brassica rapa Var.Pervidis*) and soybean (*Glycine max*) cultivation.

c) Homogenous pellet aggregates developed from coal fly ash, paper waste, ammonium sulfate and starch binder addition to the problematic grey soil ("Jahgaru") as a soil amendment improved the soil physical and chemical properties such as bulk density, hydraulic conductivity, water holding capacity, electrical conductivity, nutrient concentration (K, Mg, Ca, Zn, Cu). The heavy metal concentrations in the PA added media were well below the permissible levels. Pellet aggregate addition to grey soil improved the growth and yield parameters of *Brassica campestris* compared to grey soil with no aggregates addition. Moreover, the heavy metal content of the plant tissues were well below the permissible level and no phytotoxic symptoms were shown. Further researches should be undertaken for wide variety of plant species to check out the suitability of the aggregates as a fertilizer and a soil amendment for grey soils

d) Synthetic aggregates formed from low productive acidic red soil, paper waste and starch waste can be effectively utilized as a soil ameliorant to the problematic grey soil in Okinawa, Japan to enhance the crop production. Synthetic aggregates addition as a soil ameliorant improved the particle size distribution, bulk density, water holding capacity, porosity, hydraulic conductivity, pH, organic matter and soil C compared to original grey soil. The highest growth parameters of French marigold were given by the treatments of 30% and 40% synthetic aggregates additions. The plant height, number of flowers per plant, shoot fresh weight, shoot dry weight, root length, root fresh weight and root dry weight in

30% of SA addition were increased by 1.5, 2.9, 3.5, 4.7, 3.4, 4.3 and 9 times, respectively compared to grey soil. It can be suggested that the aggregates developed by red soil and paper waste and starch waste can be utilized as a soil amendment to improve the physical and chemical properties of the grey soil. SA addition to grey soil at 30% and 40% as a soil amendment gave the best maximum growth parameters of French marigold, which is a popular ornamental in Japan.

e) Synthetic aggregates developed from coal fly ash, paper waste and starch waste can be used as a containerized media component with the oil palm waste. Synthetic aggregates with oil palm waste at the ratio of 1:10 gave enhanced physical and chemical properties such as bulk density (0.25 gcm^{-3}), particle density (1.76 gcm^{-3}), air space (20.59%), total pore space (85.79%), total water holding capacity (652 mLL^{-1}), pH (6.18) and electrical conductivity (42.4mSm^{-1}),which were in the established ideal substrate range. The growth of French marigold (*Tagetes patula*), which is a popular ornamental plant in Japan was assessed using these newly developed substrates. The mixing ratio of synthetic aggregates and oil palm wastes at 1:10 ratio reported the best maximum growth and yield parameters of French marigold, with increase in shoot fresh weight, shoot dry weight, root fresh weight, root dry weight, plant height and number of flowers per plant by 51%, 93%, 54%, 150%, 19%, and 61%, respectively compared to the zeolite media. It can be suggested that a mixture of CSA and oil palm waste at the ratio of 1:10 can be successfully utilized as an alternative container substrate for French marigold production.

f) Synthetic soil aggregates (SA) formed by low productive acidic soil with paper and starch waste can be utilized as a partial peat substitution in growing substrate for production of French marigold (*Tagetes patula*). Peat 75%: SA 25% enhanced substrate physical and chemical properties into the established ideal substrate range. 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. Cu, Fe, Mn and Zn concentrations in all plant shoots were in the normal range and well below the phytotoxic range. 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.

g) Synthetic aggregates (SA) developed from acidic red soil and paper waste can be used as a plant growth substrate together with natural zeolite. Substrates formed with mixing SA with zeolite enhanced the physical and chemical characteristics of the substrates compared to zeolite only substrate. The 1:1 of SA to zeolite mixture gave the best maximum growth and yield parameters of the French marigold compared to the other substrates utilized under this study. Plant height, number of flowers, shoot fresh weight, shoot dry weight, root length, root fresh weight and root dry weight were increased by 11.30%, 11.11%, 10.21%, 28.13%, 1.30%,6.32% and 19.23%, respectively compared to the zeolite substrate. Moreover, the zeolite only and SA-zeolite mixtures increased N, K, Mg, and Ca concentrations in the leaf tissues compared with the SA only.

h) Growth substrates developed from sewage sludge sugarcane trash based compost (SSC) and synthetic soil aggregates (SA) can be utilized as an alternative containerized media for lettuce cultivation. Te substrates elaborated with SSC and SA showed suitable physical and chemical properties, absence of phytotoxicity and important nutrient contents. Although, these substrates showed pH and EC values higher than pure peat, which can constitute the main limiting factor for their use as growing media, they did not induce any reduction in plant growth. Increased biomass production of lettuce was reported from the SSC-peat and SSC-SA assayed media compared to peat media. Moreover, due to physical and chemical characteristics of the media developed by SSC and SA, SSC-SA based media can be considered as valuable partial peat substitutes for lettuce, especially at the rates of 40% of SSC, 20% of SA and 40% of peat, which gave the maximum growth parameters and the highest biomass yield of the lettuce when compared to peat. Therefore, the SSC and SA 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.

i) Cattle manure compost (CMC) and synthetic soil aggregates (SA) based containerized growing media showed adequate physical and chemical parameters and notable contents of plant nutrients, mainly N, P, Ca and Mg. Moreover, plants growth in CMC-SA based containerized substrates gave higher growth parameters than the ones growth in peat substrate. The use of CMC-SA media in the preparation of substrates was adequate for French marigold cultivation, since it showed statistically significant effect on the French marigold growth parameters even using CMC and SA at 60% and 40%, respectively. Mixture of CMC and SA at 40% to 60, which gave the highest growth and yield parameters by increasing plant height, number of flowers per plant, fresh shoot weight, shoot dry weight, root length, root fresh weight and root dry weight by 27.01%, 42.86%, 37.09%, 67.29%, 5.14%, 45.58% and 34.26%, respectively compared to peat control, can be recommended as the most suitable containerized media for French marigold cultivation. Moreover, due to physical and chemical parameters of the media developed by CMC-SA, it can be concluded that peat can be substituted by CMC-SA based media for ornamental plant production.

j) Further researchs should be undertaken for a wide variety of plant species to checkout the suitability of synthetic aggregates as a fertilizer, a soil amendment and a potting media component. The longterm effects of synthetic aggregates addition on soil carbon content, soil organic matter, soil macro and micro nutrient content should be further researched in future investigations.

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