HEAVY METAL STABILIZED SEWAGE SLUDGE COMPOST AS A GROWTH MEDIUM FOR ORNAMENTALS

by

REHANA M. R.

(2017-11-035)

THESIS

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN AGRICULTURE

Faculty of Agriculture
Kerala Agricultural University

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
COLLEGE OF AGRICULTURE
VELLAYANI, THIRUVANANTHAPURAM - 695 522
KERALA, INDIA

2019

DECLARATION

I, hereby declare that this thesis entitled **"HEAVY METAL STABILIZED SEWAGE SLUDGE COMPOST AS A GROWTH MEDIUM FOR ORNAMENTALS"** is a bonafide record of research work done by me during the course of research and the thesis has not previously formed the basis for the award to me of any degree, diploma, associateship, fellowship or other similar title, of any other University or Society.

Rehana

Vellayani **Rehana M. R.**

Date: 5/9/2019 (2017-11-035)

CERTIFICATE

Certified that this thesis entitled **"HEAVY METAL STABILIZED SEWAGE SLUDGE COMPOST AS A GROWTH MEDIUM FOR ORNAMENTALS"** is a record of research work done independently by Ms. Rehana M. R. (2017-11-035) under my guidance and supervision and that it has not previously formed the basis for the award of any degree, fellowship or associateship to her.

5/9/19

Vellayani

Dr. Biju Joseph
(Major advisor, Advisory committee)
Assistant Professor
Department of Soil science &
Agricultural Chemistry
Instructional Farm
College of Agriculture, Vellayani

CERTIFICATE

We, the undersigned members of the advisory committee of Ms. Rehana. M. R, a candidate for the degree of **Master of Science in Agriculture** with major in Soil Science and Agricultural Chemistry, agree that the thesis entitled **"HEAVY METAL STABILIZED SEWAGE SLUDGE COMPOST AS A GROWTH MEDIUM FOR ORNAMETALS"** may be submitted by Ms. Rehana. M. R in partial fulfillment of the requirement for the degree.

5/9/19

Dr. Biju Joseph
(Major advisor, Advisory committee)
Assistant Professor
Department of Soil science &
Agricultural Chemistry
Instructional Farm
College of Agriculture, Vellayani

Dr. K. Ushakumari
(Member, Advisory committee)
Professor& Head
Department of Soil science &
Agricultural Chemistry
College of Agriculture, Vellayani

Dr. K. N. Anith
(Member, Advisory committee)
Assistant Professor
Department of Agricultural Microbiology
College of Agriculture, Vellayani
Thiruvananthapuram- 695 522

Dr. Aparna. B
(Member, Advisory committee)
Assistant Professor
Department of Soil Science &
Agricultural chemistry
College of Agriculture, Vellayani
Thiruvananthapuram- 695 522

ACKNOWLEDGEMENT

And so comes the time to look back on the path traveled during the endeavor and to remember the faces and spirits behind the action with a sense of gratitude.

I have been amazingly fortunate to have such an advisor who gave me the freedom to explore on my own and at the same time the guidance to recover when my steps faltered. The words may fall in short to express my sincere and profound gratitude to my chairman Dr. Biju Joseph , Assistant Professor, Department of Soil Science and Agricultural Chemistry for his valuable guidance, critical comments, well-timed support, warm encouragement and worthy advices that I have experienced for the last two years. Thank you sir for your care and special love

I express my sincere and heartfelt gratitude to Dr. K Ushakumari, Professor and Head, Department of Soil Science and Agricultural Chemistry, for the timely advice, careful instructions, valuable suggestions and support provided during the course of work. I was very fortunate to get suggestions and advice from you.

I extend my sincere gratefulness to Dr. K.N Anith, Professor, Department of Agricultural Microbiology for the valuable suggestions, facilities provided, technical advices and incessant motivation throughout the research work.. I am extremely thankful to Dr. B. Aparna, Assistant Professor, Department of Plant Physiology and member of my Advisory Committee for her outright categorical comments, suggestions and affectionate approach at all the stages of research work.

I express my grattitude to Soumya chechi, Anilettan, Aneeshettan, Arya chechi, Asha chechi rchana chechi , Susheela chechi, Shyni chechi , Biju chettan, Vijayakumar chettan, Santhosh chettan and Sreekumar chettan for the timely support, care and love rendered during all stages of my research work. I also thank Geetha chechi and Baby chechi for their support and help in these two years.

I avail this opportunity to thank my dear seniors Nibin chettan, Geethu chechi, Amrithechi, Nihalatha and dear juniors for their support, help, care, love and encouragement during my research work.

I express my heartfelt thanks to my dearest batchmates Kavya, Navya, Anagha, Aswathy, Greeshma, Reshma, Adithya, Chethan and Rameshan for the care, support and inspiration throughout these two years and also for the great times we relished together.

I do not have words to express my love, affection and gratitude to my beloved friends Tinu, Arathy, Monisha, Subbu, Archana, Nivyachechi, Amalachechi, Aura and Akhila for their company, constant help, support and inspiration. It's my duty to express my sincere gratitude to Ratheesh chettan, Rajesh chettan, Vijeesh chettan, Vineesh chettan, Anuja chechi and Tinu for their love, affection and support throughout my life.

I am thankful to the KAU for providing all the facilities during my study. I would like to thank all teaching and non teaching staff of CoA, Vellayani for their direct or indirect help renderd during the course work I do acknowledge the help and support rendered by all seniors, juniors of CoA Vellayani.

I can enjoy this happiness only because of you - Amma and Pappa. My gratitude towards you never ends. Thank you for being so supportive. I bow to the lotus feet of the Almighty, whose grace had endowed me the inner strength and patience and blessed me with will power to complete this endeavour successfully.

Rehana M.R

CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

LIST OF ABREVIATIONS AND SYMBOLS USED

$^{\circ}$C	Degree celsius
%	Per cent
As	Arsenic
B	Boron
Ca	Calcium
Cd	Cadmium
CD	Critical Difference
CEC	Cation exchange capacity
Cr	Chromium
Cu	Copper
cm	Centimeter
DAT	Days after transplanting
dS m^{-1}	deci Siemens per metre
EC	Electrical conductivity
et al	Co- authors/ co- workers
Fe	Iron
Fig.	Figure
FYM	Farmyard manure
i.e.	That is
K	Potassium
KAU	Kerala Agricultural University
kg ha^{-1}	kilogram per hectare
m^{-2}	per square metre
ME	Morin Equivalent
Mg	Magnesium
mg g^{-1}	milligram per gram
mg kg^{-1}	milligram per kilogram
Mn	Manganese

N	Nitrogen
ND	Not Detected
NS	Non significant
P	Phosphorus
Pb	Lead
pH	Negative logarithm of H^+ ion concentration
S	Sulphur
WHC	Water holding capacity
Zn	Zinc

Introduction

1. INTRODUCTION

Extensive urbanization, industrialization and population growth has necessitated the installation of a large number of wastewater treatment plants and there by resulting in the production of huge amounts of municipal sewage sludge. Proper handling and disposal of this sewage sludge is a major problem. To avoid the negative impacts of sewage sludge on the environment, it is better to decrease the volume of this waste and to effectively use this as a rich source of organic matter and nutrients.

Sewage sludge is the residual material which is semisolid in consistency produced from the sedimentation of the suspended solid during the treatment processes of waste water. Handling of huge quantities of sludge causes a significant proportion of the overall operating costs of water treatment works. So appropriate reuse strategies that are sustainable from an environmental and economic point of view are needed. The main disposal routes of sludge are incineration, sanitary landfill, or for land application. Treated sludge application as amendment to soil causes the structural improvement of soil, acts as soil buffer and as soil amendment. Moreover it provides a major part of the N and P requirements for crops. Use of sludge principally in agriculture involves lower costs when compared to incineration and sanitary landfill.

The properties of sludge are determined by the characteristics of waste water from which it is originated and also by the methods by which waste water is treated. Normally it contains organic matter, a wide range of macro and micro nutrients, heavy metals, microorganisms and organic pollutants.

Thiruvananthapuram Corporation is the largest city corporation in the Kerala state by area and population. This Municipal Corporation comprises an area of 141.74 sq. km. However, only 30 % of it is covered by a piped sewerage system. Quantum of solid waste and liquid waste generated is 300 MT and 100 Ml d respectively. Earlier sewage generated from the city, was pumped into open ground and was used for cultivation of fodder for cattle and was known as sewage fodder farm. The sewage farm was initially Designed for a capacity of 8 ml d and was commissioned in 1945 at Valiyathura in Thiruvananthapuram. Due to prolonged load of sewage and lack of maintenance, now the farm is overloaded with higher quantity of sewage. As a result of this raw sludge remains stagnated within the farm resulting in a worse condition. Rainy season aggravates the condition when there is spillage of sewage to the adjacent Parvathy puthanar. Ground water contamination, nuisance of mosquito and health hazards are the major environmental issues.

To solve this problem a sewage treatment plant was installed at Muttathara, Thiruvananthapuram. The plant was inaugurated on 30th October 2013. Activated sludge process with extended aeration is used for the treatment of sewage. Lack of proper mechanism to dispose the sludge generated at the sewage treatment plant at Muttathara has become a problem. The daily generation is 9 to 10 m^3 of sludge has been accumulating in the plant site. If this continues, it will affect the functioning of the treatment plant. So the sewage sludge has to be utilized. The best option is to use this sludge for crop production.

The sludge is rich in organic carbon and plant nutrients. The presence of heavy metals and pathogens are limiting its use for crop production. *E.coli* detected in initial raw sewage sludge was eliminated on sun drying and was not found in the growing medium prepared from sewage sludge. However, it contains heavy metals like Cd, Ni, Pb, As, Cr above the permissible limit. There is a considerable bio accumulation of heavy metals when the sludge was used in the growing medium for ornamentals. The sludge can be used for growing food crops only if the heavy metal is stabilized and its bioavailability is reduced.

This can be achieved by modifying the pH of the material and by the addition of heavy metal adsorbents and bulking agents. By properly stabilizing heavy metals present in the sludge by composting process it can be effectively utilized for crop production. However the use of this compost for the production of food crops need necessary studies so, detailed studies are necessary in this direction. But there is a possibility for its use for growing flowering plants.

With this background the present study on “Heavy metal stabilized sewage sludge compost as a growth medium for ornamentals” was undertaken with the following objectives

(1) Characterization of different sewage sludge composts

(2) Performance evaluation of sewage sludge compost as growing medium for ornamentals.

Review of Literature

2. REVIEW OF LITERATURE

The study entitled "Heavy metal stabilized sewage sludge compost as a growth medium for ornamentals" was conducted at the department of Soil Science and Agricultural Chemistry, College of Agriculture Vellayani, with the objective to prepare and characterize heavy metal stabilized sewage sludge compost and to evaluate its suitability as a growth medium for marigold. A brief reviews of the research work related to the present study has been reviewed and presented under suitable headings.

2.1 Characteristics of Sewage Sludge

Sewage sludge is the residue generated during the waste water treatment process. The increase in urbanization and industrialization causes the drastic increase in the volume of waste water and sewage sludge (Marchioretto, 2003). Organic waste or compost application to the soil for crop production is of great importance due to the nutritional input and low cost (Mantovi *et al.*, 2005).

Chitdeshwari *et al.* (2002) did the chemical characterization of biosolids from sewage farm of Ukkadam, Coimbatore and the result revealed that it has a pH of 6.70 and contain 15.9 per cent organic carbon. Fanny *et al.* (2015) reported that pH of sewage sludge generated from India as well as other countries varies from slightly acidic to neutral range. The acidic nature of sludge may be ascribed to the decomposition of organic matter present in the sludge which may lower the pH. Asokan (2017) characterized the sewage sludge from Muttathara sewage treatment plant Thiruvananthapuram and reported that pH of sewage sludge was strongly acidic and it was characterized by high organic carbon content.

Liu and Sun (2013) analysed the nutrient content of sewage sludge produced from waste water treatment plant of Guangzhou, China. They reported that sewage sludge contain 28.1 to 60.6% organic C, 1.25 to 3.83% total N, 1.19 to 3.62% total P and 0.67 to 1.91% total K. Asokan (2017) reported that sewage sludge was rich in plant nutrients such as N, P, K, Ca, Mg, Fe, S, Mn, Zn, Cu and B. Physical properties such as water holding capacity and porosity were high and bulk density was very low.

Singh and Agrawal (2010) analysed the nutrient status of sewage sludge collected from Dinapur sewage treatment plant Varanasi and reported that sewage sludge had 785.3 mg kg^{-1} Zn, 317.7 mg kg^{-1} Cu, 60.0 mg kg^{-1} Pb, 154.5 mg kg^{-1} Cd and 47.17 mg kg^{-1} Ni. Saha *et al.* (2017) evaluated the suitability of sludges produced in Kolkata for agricultural usage by and analyzing the plant nutrients availability, heavy metals loads, and their mobility. Results indicated that the sludge produced at different sewage treatment plants of Kolkata were rich in organic C (9.75-15.88%) and major nutrients mainly N (2.05-3.87%) and P (1.62-2.47%), but the K content (0.98-1.96%) was much lower.

Economic and environmental costs of incineration and land filling is very high. The best option is to use this sludge for crop production as it provides an opportunity to recycle the organic matter (OC), N, P, and other plant nutrients (Dubey *et al.,* 2006; Liu and Sun, 2013). Use of municipal sewage sludge in agriculture as an organic fertilizer proved beneficial for a variety of field crops (Outhman and Firdous 2016; Saha *et al.,* 2017)

Asokan (2017) concluded that Sewage sludge from Sewage treatment plant Muttathara is highly acidic and contains heavy metals like Cd, Ni, Pb, As and Cr. Cr is above the permissible limit. There is a considerable bio accumulation of heavy metals when the sludge was used as growing medium for ornamentals.

23

2.2 Effect of Sewage Sludge on Soil Properties

Sewage sludge is a rich source of organic matter, it often improves the soil's physical and chemical properties and enhances its biological activities (Silva *et al.,* 2016).

2.2.1 Physical Properties

Epstein (1975) reported that application of 0.5% sewage sludge to soil improved the water retention, hydraulic conductivity and aggregate stability. According to Roberts *et al.* (1998), sewage sludge is a rich source of organic matter and organic matter content of sewage sludge is usually more than 50% of dry matter. Addition of organic matter in the form of sewage sludge improved the soil physical properties such as water retention capacity, bulk density, porosity, soil aeration and pore size distribution. It also have a positive soil conditioning effect on most of the soils.

The application of sludge to the soil improve the soil physical properties by increasing water content, increasing water retention capacity, enhanced aggregation, increased soil aeration, increased permeability, increased water infiltration and decreased surface crusting (Albiac *et al.*, 2001).

Mumptom (1978) reported that sewage sludge compost improved the soil properties such as bulk density, porosity and water holding capacity. Improvement in soil physical properties will result in increased soil filtration rate, reduction in surface run off and water erosion. Bahremand, *et al.* (2003) suggested that sewage sludge application significantly increased mean weight diameter, hydraulic conductivity, final infiltration rate, moisture percentage at 1/3 and 15 bars and significantly decreased soil bulk density. Cogger (2005) reported that agricultural use of sewage sludge as amendments consistently showed decrease in the bulk density and penetration resistance with increasing rates of amendment. Decrease in bulk density is mainly due to increase in aggregate stability and total porosity. According to Wortmann (2005), due to the stability of organic compounds in bio-solids, sewage sludge improve the soil physical properties such as increased soil aggregate formation and stability.

According to Bai *et al.* (2017), sewage sludge combined with green manuring decreased bulk density, pH, salinity, and exchangeable sodium percentage of the topsoil (0–20 cm soil layer) and increased aggregate stability, cation exchange capacity, and N and P concentration of the topsoil.

A field experiment conducted by Mondal *et al.* (2015) revealed the positive effects of sewage sludge on different parameters and reported that application of sewage sludge decreased the the bulk density by 21%, increased mean weight diameter and porosity of the soil. The application of sewage sludge cause a reduction in the bulk density which was lowest at sewage sludge applied at the rate of 15 t ha^{-1} followed by 10 t ha^{-1} and 5 t ha^{-1}.

Municipal solid waste compost had a high water holding capacity because of its organic matter content, which in turn improved the water holding capacity of the soil (Hernando *et al.*, 1989). They conducted a study to determine the effect of municipal solid waste compost application to soil on aggregate stability. The result indicated that application of municipal solid waste compost improves the soil structure by improving aggregate stability through the formation of cationic bridges. Annabi *et al.* (2007) also reported that application of mature municipal solid waste compost to a silt loam soil increased aggregate stability.

25

2.2.2 Chemical Properties

2.2.2.1 pH, electrical conductivity and organic carbon

Land application of sewage sludge may be a more preferred option, as it provides an opportunity to recycle the organic matter (OC), N, P, and other plant nutrients (Liu and Sun, 2013).

Belhaj *et al.* (2016) conducted a study to find the usefulness of sewage sludge amendment for *Helianthus annuus*. They conducted a pot experiment by mixing sewage sludge at 2.5, 5, and 7.5 % (w/w) amendment ratios to the agricultural soil. Report showed that sewage sludge amendment decreased soil pH and increased electrical conductivity, organic matter and other nutrients.

Sewage sludge application to the soil improved the cation exchange capacity of soil. This is due to the fact that it helps in retaining essential plant nutrients within the effective root zone of higher plants due to additional cation binding sites. Presence of high content of nitrogen which are bound by humic substances in sewage sludge is the main criteria of usefulness of sludge for agricultural purposes (Veekan *et al.* 2000).

Jamil *et al.* (2006) suggested that application of sewage sludge to soil increase the organic matter content of the soil. The application of sewage sludge to soil increases the total organic carbon content in the soil.

Singh and Agrawal (2010) opinioned that sewage sludge decreases the soil pH as a result of the production of humic acid during the degradation of organic matter. Mushali *et al.* (2014) reported that sewage sludge application to low pH soil decreased the pH further. Outhman and Bharose (2014) reported that pH of the post harvest soil decreases with increase in sludge amendment rates.

Mushali *et al*. (2014) found an increase in electrical conductivity of soil due to sewage sludge application. The increase in electrical conductivity is mainly due to the salts present in sewage sludge

Sewage sludge is a rich source of organic carbon and other nutrients and can be used as an organic amendment to soil (Caravaca *et al*., 2002). Selivanoskaya *et al*. (2007) observed that application of sewage sludge compost to soil increase the organic carbon content from 1.4 to 1.5 %. Ashokan (2017) reported that sewage sludge generated from sewage treatment plant Muttathara had a high organic carbon status of 12.2 % and its application to soil as an amendment increases the organic carbon status of soil.

2.2.2.2 Status of macro and micronutrients

Sewage sludge improves the plant growth and yield by providing a number of essential plant nutrients and organic matter. Thus its application to soil enables recycling of the major nutrients N and P which may partially substitute the need for costly commercial fertilizers (Placek *et al.,* 2016).

Sewage sludge application to soil increased the organic matter content, available P, exchangeable K, Fe, Mn, Zn and Cu (Huma, 1997). Albiach *et al.* (2001) reported that sludge is a rich source of organic matter, nitrogen, phosphorus and other nutrients. If properly managed it can be used to improve the soil fertility in intensively cropped degraded soils and thus can reduce the need of synthetic fertilizers. It also improves the soil physical, chemical and biological properties of soil.

Lakhdar *et al* (2010) reported that the application of municipal solid waste compost (13.3 g Kg^{-1}) and sewage sludge (26.6 g Kg^{-1}) significantly improved soil physical-chemical properties specially carbon and nitrogen contents. Yousefi *et al.*

(2013) reported that application of sewage sludge and sewage sludge compost improved organic carbon by 2.5 fold, phosphorus by 1.4 fold and nitrogen by 1.6 fold as compared to the inorganically fertilized plots. Outhman and Bharose (2014) reported that there was an increase in the nitrogen content in the soil with the increasing level of sewage sludge application.

Jamil *et al.* (2006) observed that application of sewage sludge to soil increased the soil organic matter, EC, NPK, Ca, Mg and trace elements such as Fe, Mn, Zn, Cu with the increasing levels of sewage sludge.

Kabirinejad and Hoodaji (2012) studied the impact of biosolid application on soil chemical properties and found that the availability of potassium, iron and manganese in the soils increased significantly by the application of sludge compost at the rate of 50 t ha $^{-1}$.

Morris and Lathwell (2004) reported that the sludge amendment enhanced the available nitrogen content in alkaline soils than acidic soils. Study conducted by Outhman and Bharose (2014) revealed that there was a significant increase in the nitrogen content in the soil with the increasing level of sewage sludge amendment.

Parat *et al.* (2005) studied the long-term effect of sewage sludge application on soil organic matter and reported that the microbial biomass as well as OC content was higher than that in the unamended soil. Mendoza *et al.* (2006) reported that soil pH decreased due to the application of sludge and it increased the organic matter and extractable Cu, Zn, Ni, Pb, Mn and Fe in the soil.

Bai *et al.* (2017) observed that sewage sludge application combined with green manuring decreased bulk density, pH, salinity, and exchangeable sodium percentage of the topsoil and increased aggregate stability, cation exchange capacity, N and P concentration of the topsoil.

2.2.3 Microbial Population

Application of sludge having very low concentration of heavy metals improved soil microbial activity, their population and microbial biomass (Powlson, 2002). Application of sewage sludge to soil not only promotes crop yields and improving soil physical and chemical properties but also promotes soil biological activity. Application of sewage sludge significantly increases the microbial biomass-C, basal respiration, N-mineralisation, and some soil enzyme activities such as urease, BAA-protease, dehydrogenase, alkaline phosphatase and β-glucosidase, which promotes the recycling of nutrients for crop (Angin and Yaganoglu, 2011)

Banarjee (1997) studied the effect of sewage sludge application on biological and biochemical properties of soil. Sludge application increased the amount of microbial biomass present in the soils and enhanced the N mineralization potential of the soil. Potential activities of three soil enzymes such as arylsulfatase, acid phosphatase and alkaline phosphatase were increased by sewage sludge application.

Kizilkaya and Bayrakli (2005) studied the effect of different doses of sewage sludge on activities of soil enzymes and reported that there was a significant increase in the activity of β-glucosidase, alkaline phosphatase, arylsulphatase and urease.

2.3 Effect of Sewage Sludge and Compost on Heavy Metal Accumulation in Soil and Plant

Sewage sludge and MSW compost contain important plant nutrients and organic matter that can improve soil fertility. But the presence of toxic heavy metals in sewage sludge and MSW compost often causes soil contamination, phytotoxicity and undesirable residues in plant and animal products (Alloway and Jackson, 1991). There is a chance for pollution problems if theses toxic metals are mobilized into the soil solution and are either taken up by plants or transported in drainage waters. In case of humans and animals the health may be adversely affected by the consumption of such crops or intake of contaminated waters. Long term application of sewage sludge and MSW compost can also cause a significant accumulation of Zn, Cu, Pb, Ni and Cd in the soil and plants (Mulchi *et al.,* 1991).

Effect of long-term application of treated sewage water on heavy metal accumulation in vegetables was studied by Ghosh *et al.* (2011) and the results showed that treated sewage water is a rich source of essential plant nutrients but contained Cd, Cr and Ni in amounts well above the permissible limits for its use as irrigation water. Long term application of treated sewage water resulted in significant build-up of total and DTPA extractable Cd, Cr, Ni and Pb than the ground water irrigated sites. Eid *et al.* (2017) reported that incorrect use of sewage sludge adversely affect the agro ecosystem productivity.

A significant increase in concentrations of Pb, Ni, Cu, Cr, and Zn was recorded in the sewage sludge amended soil as compared to unamended control soil (Belhaj, 2016). Results indicated that metal concentrations were higher in the plant tissues grown in sewage sludge amended soils than in control soil. Concentrations of metal increased with the increasing rates of sludge application. Metal accumulation was higher in shoots than in the roots and was found in the order of Cr > Ni > Cu >Zn.

Pot culture experiment conducted by Asokan (2017) reported that growth and yield of marigold was higher in the treatment receiving sewage sludge and soil in 1:9 ratio. The content of heavy metals (Cd, Cr, Ni, Pb) in shoot and root of marigold was above the permissible limit in treatment receiving sludge alone.

The sewage sludge amendment significantly altered the soil properties such as the salinity, pH, organic matter and Cr, Fe, Ni and Zn concentrations in comparison to the control soil. Salinity, organic matter and Cr, Fe, Ni and Zn concentrations increased, but the soil pH decreased in response to the sewage sludge applications.

Gupta *et al.* (2010) conducted an experiment to find the effect of waste water irrigation on heavy metal accumulation in soil and edible parts of plants such as *Colocasia esculentum*, *Brassica nigra*, and *Raphanus sativus*. Eventhough the wastewater contains low levels of the heavy metals like Fe, Mn, Pb, Cd, and Cr, the soil and plant samples show higher values due to accumulation. The metal accumulation trend of wastewater-irrigated soil is in the order: Fe > Pb > Mn > Cr > Cd.

Sewage sludge application above 4.5 kg m^{-2} increased the yield of rice, but caused risk of food chain contamination as concentrations of Ni and Cd in rice grains were found to be above the Indian safe limits of human consumption and in case of Pb concentration was above the Indian safe limits of human consumption when the sludge application was above 6.0 kg m^{-2} (Singh and Agrawal, 2010).

Tiwari *et al.* (2011) evaluated the metal concentrations in selected vegetables grown in mixed industrial effluent irrigated agricultural field near Vadodara. Concentration of heavy metal accumulation in soil showed the trend of Fe > Mn > Zn > Cd > Cu > Pb > Cr> As. Among the studied ten vegetable species five vegetable species such as Spinach, Radish, Tomato, Chili and Cabbage showed high accumulation and translocation of toxic metals like As, Cd, Cr, Pb and Ni in their edible parts. They concluded that vegetable crops restricting toxic metal in their non-edible part may be recommended for cultivation in such metal contaminated agricultural field.

The impact of sewage sludge on growth, development and quality of *Zoysia japonica* and *Poa annua* grass species was studied by Wang *et al.* (2008). They concluded that sewage sludge applied in various doses increased the heavy metal content in soil and observed that contamination of Cd exceeded the safe limit whereas concentration of Zn, Pb and Cu were within the permissible limit.

A pot experiment was conducted by Singh and Agrawal (2007) to study the usefulness of sewage sludge amendment for palak and consequent heavy metal contamination, by mixing sewage sludge at 20% and 40% (w/w) amendment ratios to the agricultural soil. They concluded that Cd, Cu, Mn and Zn concentrations in soil were higher at 40% soil sludge amendment, whereas Ni, Pb and Cr concentrations were higher at 20% sewage sludge amendment. Concentrations of heavy metals in shoots and roots of plants grown in sewage sludge-amended soils were significantly higher as compared to those in unamended soil.

Singh and Agrawal (2006) observed that increased heavy metal content in soil due to sewage sludge application led to the increased uptake of Ni, Cd, Cu, Cr, Pb and Zn in plants. The accumulation was more in roots than shoot for most of the heavy metals.

Heavy metal content was found higher in seeds of cowpea plants grown in sewage sludge amended soil (Singh and Agarwal 2010). Effect of sewage sludge water and canal irrigation water was compared for their physico chemical properties and heavy metal accumulation by Swapnanil *et al.* (2011) and reported that concentration of Cd was above Indian standard limits.

2.4 Sewage Sludge Compost as a Nutrient Source

The sludge acts as an important reservoir of nitrogen, phosphorus, micronutrients and OC. Therefore the use of sewage sludge results in significant improvement in soil OC content and increased the availability of plant essential nutrients in the soil, particularly nitrogen, thereby causing an increase in the biomass yield of plants. Sometimes this increment will be more than those grown on recommended NPK treated soils. However, an increase in heavy metal concentration in edible portion of the plant may occur, which should be taken into consideration before recommending sludge application. Therefore, prior to application in the soil, the dose of sewage sludge should be standardised for a particular crop based on heavy metal and other pollutant concentrations.

Composting of sewage sludge can be done to minimize the availability of heavy metals by adding various additives (Fang and Wong, 1999). The reduction in the bioavailabilty of heavy metals might be due to the transformation of insoluble carbonates, adsorption of heavy by the bulking agents or by the formation of organo-metallic compounds during the composting process. Composting of sewage sludge can be done by using various additives such as zeolite, coal flyash, coirpith, sawdust, lime etc.

Composting is a biological process that uses naturally occurring microorganisms to convert biodegradable organic matter into a humus-like product and it is a suitable method for recycling waste water treatment sludge. Composting of municipal solid waste is a method of diverting organic waste materials from landfills and creating a product, which is available at relatively low-cost and it is suitable for agricultural purposes (Kaur *et al*., 2012).

2.4.1 Effect of lime on Sewage sludge composting

The addition of liming material is very effective for reducing the plant availability of metals probably due to the transformation of less soluble metal carbonates and hydroxides at higher pH (Wong and Selvam, 2006).

Humification of organic matter occurs during composting and this will have a significant effect on the physicochemical form of heavy metals. Wong and Selvam, (2006) conducted a study to investigate the effect of co-composting of sewage sludge with lime on heavy metal speciation and the changes in DTPA extractable metals. They reported that addition of lime in composting process lowered the DTPA extractable metal contents.

Fang and Wong (1999) conducted an experiment to find the effect of lime amendment on exchangeable and acid extractable fractions of heavy metals and reported that there was a significant reduction in the exchangeable and acid extractable fractions of Cu, Mn, Pb and Zn of lime-sludge compost. During lime sludge composting there was a reduction in DTPA extractable metal contents.

According to Kung *et al.* (2007), the higher ion exchange capacity and alkalinity of lime and zeolite contributes to significant reduction in DTPA extractable Pb, Cu and Zn in matured sewage sludge compost. Zeolite and lime would contribute to inhibit the mobility of metals during sewage sludge composting process.

2.4.2 Effect of fly ash on sewage sludge composting

Coal fly ash is a byproduct from coal fired power plants and its chemical composition and pH varies depending upon the coal source. Coal fly ash contain higher amount of MgO and CaO. These compounds have the ability to precipitate the heavy metals in sewage sludge compost and thus decrease the toxicity of heavy metals to plants which are grown in sewage sludge compost with coal fly ash (Wong *et al.*, 1997).

Beaver *et al.* (1995) reported that coal fly ash didn't inhibit the biological activity in composting and it improved the nutrient status of sewage sludge compost. Fang *et al.* (1999) conducted an experiment to evaluate the effect of coal fly ash on nutrient transformation during sewage sludge composting. The result revealed that coal fly ash raised the pH of sewage sludge compost during the composting period.

Coal fly ash does not inhibit the carbon cycle and it inhibited the nitrification process and phosphorus transformation.

2.4.3 Effect of Zeolite on Sewage Sludge Composting

Due to the presence of heavy metals the management of sewage sludge is very difficult. Natural zeolite have the ability to remove cations from aqueous solution as well as solid phase by the property of ion exchange (Zorpas *et al.,* 1999).

Zorpas *et al.* (2000) conducted a study to find the effect of application of natural zeolite for immobilization of heavy metals in the water hyacinth compost and reported that it improved the physical and chemical properties of the compost. Zeolite can be used as a bulking material in composting process and it improves the composting process and the biodegradability of the organic matter due to its ability to increase the porosity of the substrate.

An experiment conducted by Zorpas *et al.* (2008) revealed that with an increasing level of zeolite the concentrations of all the heavy metal in the sewage sludge compost sample decrease. Natural zeolite can be effectively used for reducing mobility and bioavailability heavy metals in sewage sludge composting due to its sorption and exchangeable properties towards the heavy metals. Natural zeolite have the ability to uptake easily available fractions and exchangeable fractions of heavy metals (Singh and Kalamdhad, 2012).

2.4.4 Effect of Coirpith and Sawdust on Sewage Sludge Composting

Sewage biosolid compost prepared with coirpith compost was found to be effective in restricting the availability of heavy metal and 60 days of composting was found to be sufficient for land application (Chitdeshwari and Savithri, 2004).

The decreased extractability of metals from coirpith compost might be due to the low availability of organic compounds from the ligniferous coirpith. This was in line with the results reported by Petruzzelli *et al.* (1985).

Bazrafshan *et al.* (2006) conducted an experiment to find the optimum conditions of co-composting of sewage sludge with sawdust and reported that the concentration of cadmium and other heavy metals in final compost is less than maximum contaminant level in sewage sludge compost.

According to Zorpas and Loizidou (2008), composting of sewage sludge with different ratios of sawdust and zeolite decreased the heavy metal content in sewage sludge than the initial value. Humic substances in the final product increased with the increased addition of sawdust.

2.5 Effect of Composting of Sewage Sludge on Heavy Metal Speciation

Heavy metals are defined as elements in the periodic table having atomic number greater than 20 or densities more than 5 g cm^{-3} generally excluding alkali metals and alkaline earth metals (Sherene, 2010).

Land application of sewage sludge after composting is considered as one of the most economical ways for the treatment and final disposal of sewage sludge because it combines material recycling with sludge disposal at the same time (Fang and Wong, 1999).

The total concentrations of heavy metals indicate the extent of contamination. But total concentration of heavy metal provide only little information about the forms in which heavy metals are present, or about their potential for mobility and bioavailability in the environment (Lake, 1987). On dry weight basis the total heavy metal content in sewage sludge is about 0.5–2.0% but in some cases may rise up to 4%, especially for metals such as Cu and Zn (Karvelas *et al.*, 2003).

Chemical speciation can be defined as the process for identifying and quantifying different forms or phases present in a substance (Zheng *et al.*, 2007).

Heavy metals are non-biodegradable and occur in different forms in sewage sludge and its compost. In order to assess their environmental impact their mobility and bioavailability in a given medium are very important. This can be achieved through but also their chemical speciation in sludge and compost (Nomeda *et al.*, 2008)

During composting process, organic matter mineralization and the metal solubilization occurs by the decrease of pH. Metal biosorption by the microbial biomass or metal complexation with the newly formed humic substances may occurs. (Zorpas et al., 2008).

According to Tessier *et al.* (1979) heavy metals are associated with five fractions. Exchangeable fraction, which is affected by sorption - desorption process. Carbonate fraction affected by changes in pH, reducible fraction which consist of iron and manganese oxides and is thermodynamically stable under anoxic conditions, organic fraction that undergo degradation and leading to the release of soluble metals under oxidizing conditions. Residual fraction that contains primary and secondary minerals that may hold metals within their crystal structure.

Doelsch, *et al.* (2006) reported that available fraction of heavy metals mainly decides their mobility, bioavailability or phytotoxicity in soils. Assessment of concentrations and chemical speciation of heavy metals in sewage sludge composts helps to evaluate their bioavailability and suitability for land application.

Zorpas *et al.* (2008) reported that sequential extraction procedure of sewage sludge compost with zeolite took up metal bound in the exchangeable and carbonate fractions into residual fraction which is in an inert form.

Yuan *et al.* (2011) conducted an experiment to evaluate the effect of bulking agents on reducing the mobility and bioavailability of Zn, Cu, Pb and Cr during the sewage sludge composting process. They reported that the composting processes shows an increase in the stable fractions of Zn, Cu, Pb and Cr over time by composting.

2.6 Effect of Sewage Sludge and Compost on Growth and Yield of Crops

Fanny *et al.* (2015) reported that sewage sludge application to rice and wheat increases the grain yield and test weight by increasing the number of tillers. But higher dose of sludge application to rice increased the heavy metal content in rice grain. Application of higher doses of sludge (30 and 40 t ha^{-1}) increased N, K, S and Zn contents in soil even after the harvest of wheat. They concluded that sewage sludge has a potential to supply the nutrients to crops for prolonged time.

Solanki *et al.* (2017) reported that application of sewage sludge significantly increased the plant height of marigold at all growth stages of crop (30, 45 and 60 DAT). The plant height was linearly increased with increase in sewage sludge application rates up to 100% sewage sludge.

A pot culture experiment was conducted by Kharub (2012) to investigate the effect of sewage sludge on the emergence and growth quality of ladies finger. Results pointed out that 30:50 soil: sewage sludge had a better positive result on the emergence and growth of ladies finger.

. Antolin *et al.* (2005) reported that there is an increase in barley grain yield through the application of sewage sludge. The increase in grain yield yield is mainly due to the improvement in soil microbiological properties which promoted the recycling of nutrients for the crop.

Plant dry matter, fruit yield and mineral content including N, P, K, Ca and Mg increased in tomato fruit by the application of increasing rates of sewage sludge (Silva. 2016).

Hussein (1991) reported that sludge application increased the Ca, Mg, K, N, Fe, Mn, Cu and Zn content in corn, sugar beet and cotton plants and their yield of the three crops increased by application of sewage sludge.

Asokan (2017) conducted an experiment to find out the performance evaluation of sewage sludge as a growth medium for ornamentals. Results revealed that plant growth parameters such as plant height and secondary branches was maximum in the treatment receiving potting mixture and sewage sludge in 9:1 ratio.

Flower pot experiment conducted by Belhaj *et al.* (2016) revealed that sewage sludge amendment increased root and shoot length, number of leaves, biomass and antioxidant activities of sunflower. The increase in anti-oxidant enzyme activity (glutathione, proline) and soluble sugar content may be the defense mechanisms induced in response to heavy metal stress.

Jamil *et al.* (2006) suggested that different treatments of sewage sludge application increased the yield and yield attributes of wheat crop as compared to untreated soil. Maximum height (107 cm), no of tillers (433 m^{-2}), and straw yield (9.82 t ha^{-1}) was observed in the treatment plant receiving 80 t ha^{-1} of sewage sludge. But in the case of number of productive tillers, 1000 grain weight, grain yield, number of grain spike^{-1} was observed in treatment amended with 40 t ha^{-1} of sewage sludge.

Sewage sludge can be successfully used for fertilization of forest lands and urban landscapes. Application of sludge in forestry is an ideal utilization option for this type of waste along with its ability to improve the structure and fertility of forest soils. Plants of *E. camaldulensis* fertilized soil/sludge mixture that contained 60% of sludge showed 20% better growth and 40% high leaf numbers. Sludge addition to soil improved plants growth and development (Leila *et al.*, 2017).

Materials and Methods

3. MATERIALS AND METHODS

A scientific study entitled “Heavy metal stabilized sewage sludge compost as a growth medium for ornamentals” was conducted at College of Agriculture Vellayani during the period 2017-19. Sewage sludge generated from sewage treatment plant Muttathara, Trivandrum was used for the study. The materials and techniques employed for the study are described under the following headings.

Study comprises of two phases

1. Composting experiment – preparation of heavy metal stabilized sewage sludge compost.
2. Pot culture experiment to evaluate the suitability of sewage sludge compost as a growth medium for ornamentals with marigold as test crop.

3.1 COMPOSTING EXPERIMENT

For conducting the experiment sewage sludge collected from Muttathara sewage treatment plant was utilized.

3.1.1 Collection of Sewage Sludge Samples

Representative samples were collected from different zones of sewage sludge yard. Five samples were collected from each zone and composite samples was prepared by using quartering technique.

3.1.2 Preparation of Composts

Heavy metal stabilized sewage sludge compost was prepared as per the treatments using sewage sludge, liming material, heavy metal adsorbent and bulking agents. Composting period was 60 days. The sewage sludge, coirpith, zeolite and sawdust used in the experiment was characterized for chemical properties like pH, EC, organic carbon, C: N ratio, total N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu and B. The neutralizing value of fly ash and lime were determined.

3.1.2.1 Experimental Details

Design : CRD

Treatments : 8

Replication : 3

Liming material : 2 (lime and fly ash). Liming materials were added to bring the pH of the sewage sludge to 7 (250 g of lime and 2.5 kg of flyash)

Heavy metal adsorbent : 1 (Zeolite)

Bulking agent : 2 (Sawdust and coirpith)

Table 1. Treatment details of composting experiment

T_1	Sewage sludge + coir pith (50:50) + lime	Compost 1
T_2	Sewage sludge + coir pith + zeolite (50:30:20) + lime	Compost 2
T_3	Sewage sludge + sawdust + (50:50) + lime	Compost 3
T_4	Sewage sludge + sawdust + zeolite (50:30:20) + lime	Compost 4
T_5	Sewage sludge + coir pith (50:50) + fly ash	Compost 5
T_6	Sewage sludge + coir pith+ zeolite (50:30:20) + flyash	Compost 6
T_7	Sewage sludge + sawdust (50:50) +flyash	Compost 7
T_8	Sewage sludge + sawdust + zeolite (50:30:20) + flyash	Compost 8

3.1.2.2 Characterization of Composts

Compost samples were drawn from different treatments on 0th, 30th and 60th days of composting. The compost samples were analysed for physical, chemical and biological properties such as moisture content, bulk density, pH, EC, organic carbon, C:N ratio, total N, P, K, Ca, Mg, S, micronutrients (Fe, Mn, Zn, Cu, B), heavy metal content (Pb, Cd, As, Cr, Ni), heavy metal fractions (Exchangeable,

Table 2. Analytical procedures followed for compost analysis

Sl. No	Parameter	Method	Reference
1	pH	pH meter (compost and water taken in 1:5 ratio w/v)	FAI (2017)
2	EC	Conductivity meter (compost and water taken in 1:5 ratio w/v)	FAI (2017)
3	Organic carbon	Weight loss on ignition	FAI (2017)
4	Total N	Microkjeldahl distillation after digestion with H_2SO_4	Jackson (1973)
5	Total P	Nitric-perchloric (9:4) acid digestion and spectrophotometry using vanado-molybdo yellow colour method	Greenberg *et al.* (1992)
6	Total K	Nitric-perchloric (9:4) acid digestion and flame photometry	FAI (2017)
7	Total S	Nitric-perchloric (9:4) acid digestion and estimation using turbidimetry.	Massoumi and Cornfield (1963)
8	Total B	Nitric-perchloric (9:4) acid digestion and spectrophotometry - Azomethine-H method	Roig *et al.* (1996)
9	Total metals (Ca, Mg, Fe, Mn, Cu, Zn, Pb, Cd, Ni, Cr, As)	Nitric-perchloric (9:4) acid digestion and atomic absorption spectrometry	FAI (2017)
10	Fractionation of heavy metal (Pb, Cd, Ni, Cr, As)	Exchangeable, Carbonate, Reducible Organic matter bound and Residual fraction	Tessier *et al.* (1979)
11	Bulk density	Tap volume	Saha *et al.*(2017)
12	Moisture content	Oven dry method	FAI (2017)
13	Coliforms	Serial dilution and spread plating	Goldman and Green (2008)

Carbonate, Reducible, Organic, Residual) and for enumeration of *E. coli* as per standard procedures given in Table 2.

3.2 Pot Culture Experiment

Pot culture experiment was conducted to evaluate the performance of sewage sludge compost as a growth medium for ornamentals with marigold as test crop.

3.2.1 Experimental Details

Design : CRD

Number of treatments : 9

Replication : 3

Test Crop : Marigold

Variety : Pusa Narangi Gainda

Treatment details

T_1: Soil + sewage sludge (1:1) [control]

T_2: Soil + compost 1 (1:1)

T_3: Soil + compost 2 (1:1)

T_4: Soil + compost 3 (1:1)

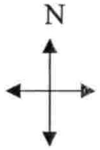
T_5: Soil + compost 4 (1:1)

T_6: Soil + compost 5 (1:1)

T_7: Soil + compost 6 (1:1)

T_8: Soil + compost 7 (1:1)

T_9: Soil + compost 8 (1:1)



T_9R_2	T_3R_2	T_5R_1
T_1R_2	T_7R_1	T_8R_3
T_7R_2	T_6R_1	T_2R_3
T_3R_2	T_4R_2	T_4R_1
T_5R_3	T_1R_1	T_9R_1
T_2R_2	T_6R_3	T_7R_3
T_6R_2	T_2R_1	T_1R_3
T_4R_3	T_3R_3	T_8R_1
T_9R_3	T_8R_2	T_5R_2

Fig.1.Layout of pot culture experiment

3.2.2 Growing Media

The growing medium used in this study were prepared with potting mixture (sand: soil: FYM @ 1:1:1) and dried sewage sludge compost. Sufficient grow bags having a capacity of 10 kg were procured and filled with the growing media and different composts as per the treatments.

3.2.3 Planting

Seedlings were raised in portrays filled with cocopeat, vermiculite and perlite in the ratio 1:1:1. The seedlings were transplanted one month after sowing. Plants were given uniform irrigation. Necessary shade was also provided for first few days after transplanting.

The recommended rate of fertilizers were applied as per package of practices recommendation of KAU (2016). Pinching was done to increase the total yield by removing the terminal bud portion of the plant 30 days after transplanting. Top dressing of the crop with urea was done at the time of pinching. Crop was irrigated depending upon the moisture and weather conditions. Weeding was carried out. Crop was ready for first harvest 30 days after transplanting and subsequent harvest were made at regular intervals.

3.2.4 Analysis of Growing Medium

Samples of growing media was collected from each treatment unit. Samples were air dried, ground and sieved through 2 mm sieve and stored in air tight container. Samples were drawn before and after planting the crop. They were analyzed for physical, chemical and biological properties as per the standard procedures given in Table 3.

Plate 1. General view of the experimental field

Plate 2. Effect of treatment on number of flowers

Table 3. Analytical procedures for growing media analysis

	Parameter	Method	Reference
1	pH	Potentiometry	FAI (2017)
2	EC	Conductometry	FAI (2017)
3	Organic carbon	Chromic acid wet digestion	Walkley and Black (1934)
4	Available N	Alkaline potassium permanganate method	Subbiah and Asija (1956)
5	Available P	Bray No. 1 extraction and spectrophotometry	Jackson (1973)
6	Available K	Neutral 1N ammonium acetate extraction and flamephotometry	Jackson (1973)
7	Available Ca, Mg	Neutral 1N ammonium acetate extraction and Atomic Absorption spectrophotometry	Hesse (1971)
8	Available S	0.15 % $CaCl_2$ extraction and turbidimetry	Massoumi and Cornfield (1963)
9	Available Fe, Mn, Zn, Cu, Pb, Cd, Cr, Ni, As	0.1 M HCl extraction and Atomic Absorption Spectrophotometry	Osiname *et al*. (1973)
10	Available B	Hot water extraction and spectrophotometry	Gupta (1967)
11	Dehydrogenase activity	Spectrophotometric method	Casida *et al.*(1964)
12	Coliforms	Serial dilution method	Goldman and Green (2008)

3.2.5 Collection of Plant Samples for Analysis

After the final harvest of the crop, plants were uprooted and shoots and roots were separated. To remove the adhering soil particles roots were washed in running water. Shoots and roots were air dried and oven dried at 60 ^{0}C. Oven dried weight was recorded. The dried samples were chopped, powdered and stored for further analysis.

3.2.6 Analysis of Plant Samples

Shoots and roots were analysed separately for N, P, K, Ca, Mg, S, Fe, Mn, Cu, Zn , B and heavy metals like Cd, Ni, Cr, Pb and As. Analytical procedures followed in plant analysis are given the Table 4.

Table 4. Analytical procedures for plant sample analysis

Sl. No	Parameter	Method	Reference
1	Total N	Microkjeldahl distillation after digestion with H_2SO_4	Jackson (1973)
2	Total P	Nitric-perchloric (9:4) acid digestion and spectrophotometry using vanado-molybdo yellow colour method	Greenberg *et al.* (1992)
3	Total K	Nitric-perchloric (9:4) acid digestion and flame photometry	FAI (2017)
4	Total S	Nitric-perchloric (9:4) acid digestion and estimation using turbidimetry.	Massoumi and Cornfield (1963)
5	Total B	Nitric-perchloric (9:4) acid digestion and spectrophotometry - Azomethine-H method.	Roig *et al.* (1996)
6	Total metals (Ca, Mg, Fe, Cu, Mn, Zn, Pb, Cd, Ni, Cr, As)	Nitric-perchloric (9:4) acid digestion and atomic absorption spectrometry	FAI (2017)

3.2.7 Plant Growth Parameters

Plant growth parameters were recorded from three tagged plants from each replication and the average was worked out.

3.2.7.1 Plant Height

Height of the plants were measured from the base of the plant to the terminal leaf bud at 30 days after planting and expressed in centimeter.

3.2.7.2 Number of Primary Branches per Plant

The number of primary branches were counted from tagged plants from each treatment units and the average was worked out.

3.2.7.3 Number of Secondary Branches per Plant

The number of secondary branches from tagged plants from each treatment units were counted when the growth of the plant had stopped and the average was worked out.

3.2.8 Floral Parameters

3.2.8.1 Days to First Flowering

Number of days from the date of transplanting to the first flowering of observational plants were recorded and the average was worked out.

3.2.8.2 Flower Diameter

The maximum diameter of fully opened flowers were measured with a scale and the value expressed in centimeters.

3.2.8.3 Flower Length

The length of the flower was measured from the point of emergence to the tip of the flower with a scale and expressed in centimeters.

3.2.8.4 Flower Weight

The individual fresh weight of flowers during harvest were taken and the average weight was calculated and expressed in grams.

3.2.8.5 Number of Flowers per Plant

The total number of flowers produced per plant during the entire flowering season was counted and recorded as no of flowers per plant.

3.2.9 Biochemical Analysis

The biochemical analysis such as chlorophyll content of leaves, xanthophyll and flavonoid content of flowers were done using standard procedures.

3.2.9.1 Chlorophyll Content in Leaves

The chlorophyll content of the leaves at flowering was analysed by dimethyl sulphoxide (DMSO) extract method. It was measured from the leaf extract by spectrophotometer and expressed in mg g^{-1} (Sadasivam and Manickam, 1992).

3.2.9.2 Xanthophyll Content in Flower

The xanthophyll content of flowers from initial harvests was extracted using acetone and hexane extract method (Bolanos *et al.*, 2004). Xanthophyll content was measured from flower extract by spectrophotometer and expressed in mg g^{-1}.

3.2.9.3 Flavonoid Content in Flowers

Total flavonoid content was measured by aluminium chloride colorimetric assay (Har *et al.*, 2012). Total flavonoid content was measured from the flower extract by spectrophotometer at 510 nm and expressed as mg of ME g^{-1}.

3.2.10 Yield

3.2.10.1 Flower Yield

The total fresh weight of flowers from each plant was recorded and expressed in grams.

3.2.10.2 Dry matter Yield of Shoot and Root

Dry matter yield of shoot and root at harvest was determined from the fresh weight and oven dry weight of shoot and root. For getting oven dry weight the fresh shoots and roots were shade dried and then oven dried at 60 ^{0}C to a constant weight and expressed in gram per plant.

3.3 Statistical Analysis

The data obtained from the experiment were subjected to analysis of variance as per design, CRD and their significance was tested using F test. All statistical analysis were carried out by using standard procedures described by Panse and Sukhatme (1978).

Result

4. RESULTS

The investigation entitled "Heavy metal stabilized sewage sludge compost as a growth medium for ornamentals" was conducted in the department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani during 2017-2019 with the objective to prepare and characterize heavy metal stabilized sewage sludge compost and to evaluate its suitability as a growth medium for marigold. Sewage sludge for the study was obtained from sewage treatment plant, Muttathara Thiruvananthapuram. The results of the study are presented in this chapter.

4.1 COMPOSTING EXPERIMENT

Sewage sludge composts were prepared using different bulking agents, liming materials and heavy metal adsorbents. Compost samples were taken during 0th, 30th and 60th day of composting and were analysed for various physical, chemical and biological characters.

4.1.1 Characterization of Composting Materials used for the Preparation of Sewage Sludge Compost

Materials used for the preparation of sewage sludge compost such as sewage sludge, coirpith, sawdust and zeolite were subjected to various physical, chemical and biological analysis to understand their properties. The results obtained are presented in Table 5.

4.1.1.1 Sewage Sludge

The results obtained indicated that sewage sludge generated from sewage treatment plant Muttathara had a pH of 5.36, an electrical conductivity of 8.08 dS m^{-1}. The organic carbon content was high (17.03%) with a C:N ratio of 10.14. It was rich in plant nutrients N (1.68 %), P (7.73 %), K (1.20 %), Ca (12.00 %), Mg (4.80 %), S (616.00 mg kg^{-1}), Fe (4500 mg kg^{-1}), Mn (1028.80 mg kg^{-1}), Zn (220.00 mg kg^{-1}), Cu (250.00 mg kg^{-1}) and B (23.06 mg kg^{-1}).The sludge contained heavy metals Pb (73.20

55

mg kg^{-1}), Cr (113.20 mg kg^{-1}), Ni (122 mg kg^{1}) and Cd (10.8 mg kg^{-1}) of which Cr, Ni and Cd were above the critical limit. As was not detected. *E.coli* was not detected in these sludge samples.

4.1.1.2 Coirpith

Coirpith used in this study had a pH of of 5.84 with an electrical conductivity of 0.72 dS m^{-1} and an organic carbon content of 58 %. N, P and K contents were 1.01 %, 0.02 % and 0.04 % respectively. The secondary nutrients content in coirpith were found to be Ca (0.16 %), Mg (0.19 %) and S (0.06 %). The content of Fe, Mn, Cu and Zn were 3165.20 mg kg^{-1}, 11.60 mg kg^{-1}, 24.40 mg kg^{-1} and 70 mg kg^{-1} respectively. Boron and heavy metals like cadmium, chromium, lead, nickel and arsenic were not detected.

4.1.1.3 Zeolite

The results revealed that zeolite used in this study had a pH of of 7.41 with an electrical conductivity of 0.17 dS m^{-1} and an organic carbon content of 2.32 %. N, P and K contents were 0.22 %, 0.05 % and 0.12 % respectively. The secondary nutrients such as Ca, Mg and S content in zeolite were found to be 0.03%, 0.19 % and 0.01 % respectively. The content of Fe, Mn, Cu and Zn were 38.89 mg kg^{-1}, 2.93 mg kg^{-1}, 0.17 mg kg^{-1} and 0.15 mg kg^{-1} respectively. Boron and heavy metals like cadmium, chromium, lead, nickel and arsenic were not detected.

4.1.1.4 Sawdust

The results revealed that sawdust used in this study had a pH of of 5.66 with an electrical conductivity of 1.80 dS m^{-1} and an organic carbon content of 52.20 %. N, P and K contents were 0.78 %, 0.01 % and 0.12 % respectively. The secondary nutrients such as Ca, Mg and S content in sawdust were found to be 0.08%, 0.48 % and 0.06%. The content of Fe, Mn and Zn were 682 mg kg^{-1}, 19.60 mg kg^{-1} and 51.20

Table 5. Characterization of composting materials

Parameters	Sewage sludge	Coirpith	Zeolite	Sawdust
pH	5.36	5.84	7.41	5.66
EC (dS m^{-1})	8.08	0.72	0.17	1.80
OC (%)	17.03	58.00	2.32	52.20
C:N	10.14	57.43	10.54	66.92
N (%)	1.68	1.01	0.22	0.78
P (%)	7.73	0.02	0.05	0.01
K (%)	1.20	0.04	0.12	0.12
Ca (%)	12.00	0.16	0.03	0.08
Mg (%)	4.80	0.19	0.19	0.48
S (mg kg^{-1})	616.00	0.06	0.01	0.06
Fe (mg kg^{-1})	4500.00	3165.20	39.89	682.00
Mn (mg kg^{-1})	1028.80	11.60	2.93	51.20
Zn (mg kg^{-1})	220.00	70.00	0.15	19.60
Cu (mg kg^{-1})	250.00	24.40	0.17	ND
B (mg kg^{-1})	23.06	ND	ND	ND
Pb (mg kg^{-1})	73.20	ND	ND	ND
Cd (mg kg^{-1})	10.80	ND	ND	ND
Cr (mg kg^{-1})	113.20	ND	ND	ND
Ni (mg kg^{-1})	122.00	ND	ND	ND
As (mg kg^{-1})	ND	ND	ND	ND

mg kg^{-1} respectively. Boron, copper and heavy metals like cadmium, chromium, lead, nickel and arsenic were not detected.

4.1.2 Physical Chemical and Biological Properties of Sewage Sludge Composts

The physico-chemical characteristics of sewage sludge composts prepared as per the treatments are presented below.

4.1.2.1 Moisture Content

The results of moisture content of different sewage sludge compost prepared as per the treatments are presented in Table 6.

The moisture content of different sewage sludge compost was significantly influenced by different treatments. Moisture content had an increasing trend on 30th day but on 60th day a drop was observed. T_5 recorded the highest value on 0th (51.09 %) and 30th day (54.93 %) and was significantly higher from all other treatments. On 60th T_5 recorded the highest value (49.78 %), which was on par with T_1 (47.41 %).

4.1.2.2 Bulk Density

Bulk density of compost at different composting periods were significantly influenced by the treatments and were within the limit prescribed by FCO and the data is presented in Table 7. On all the sampling intervals T_3 recorded the highest bulk density. On 0th day T_3 had a highest bulk density of 0.66 g cc^{-1} followed by T_4 (0.62 g cc^{-1}) which was found to be on par. On 30th day T_3 had a value of 0.68 g cc^{-1} which was on par with T_7 (0.66 g cc^{-1}) and T_4 (0.67 g cc^{-1}) were found to be on par. On 60th day T_3 had a value of (0.71 g cc^{-1}) which was on par with T_7 (0.69 g cc^{-1}) and T_4 (0.70 g cc^{-1}).

4.1.2.3 pH

The data pertaining to the influence of treatments on pH of the compost is presented in the Table 8.

Table 6. Effect of treatments on moisture content during composting, %

Treatments	0 D	30 D	60 D
T_1 SS + CP (50:50) + lime	41.72	51.29	47.41
T_2 SS + CP + Z (50:30:20) + lime	40.82	47.04	42.83
T_3 SS + SD (50:50) + lime	35.10	34.93	37.45
T_4 SS + SD + Z (50:30:20) + lime	35.03	44.91	39.52
T_5 SS + CP (50:50) + flyash	51.09	54.93	49.78
T_6 SS + CP + Z (50:30:20) + flyash	43.77	47.00	43.42
T_7 SS + SD (50:50) + flyash	29.19	32.68	39.53
T_8 SS + SD + Z (50:30:20) + flyash	38.71	43.48	41.14
SE (m±)	0.68	0.81	1.76
C.D. (0.05)	2.08	2.45	3.66

D: Days of composting; SS: Sewage sludge; CP: Coirpith; Z: Zeolite; SD: Sawdust

Table 7. Effect of treatments on bulk density during composting, g cc^{-1}

Treatments	0 D	30 D	60 D
T_1 SS + CP (50:50) + lime	0.40	0.42	0.44
T_2 SS + CP + Z (50:30:20) + lime	0.38	0.4	0.41
T_3 SS + SD (50:50) + lime	0.66	0.68	0.71
T_4 SS + SD + Z (50:30:20) + lime	0.62	0.67	0.70
T_5 SS + CP (50:50) + flyash	0.44	0.45	0.47
T_6 SS + CP + Z (50:30:20) + flyash	0.36	0.4	0.49
T_7 SS + SD (50:50) + flyash	0.57	0.66	0.69
T_8 SS + SD + Z (50:30:20) + flyash	0.55	0.61	0.64
SE (m±)	0.02	0.02	0.01
C.D. (0.05)	0.08	0.06	0.04

D: Days of composting; SS: Sewage sludge; CP: Coirpith; Z: Zeolite; SD: Sawdust

59

The pH had a decreasing trend on 30th day and after that the pH increased. On 0th day T_8 had the highest value (6.65) followed by T_4 (6.55) and T_3 (6.42) which were found to be on par. On 30th day T_8 recorded the highest value (5.950) and T_6 (5.84), T_7 (5.740) and T_4 (5.64) were found to be on par. On 60th day T_8 had the highest value (7.07) and was found to be statistically different from all other treatments. T_2 recorded the lowest value during 0th (5.59) and 30th (5.29) day.

4.1.2.4 Electrical Conductivity

The electrical conductivity of the compost had an increasing trend throughout the composting period and is outlined in Table 9 .On 0th day T_1 recorded the highest value (5.50 dS m^{-1}) and followed by T_4 (4.74 dS m^{-1}). On 30th day T_2 recorded the highest value (6.27 dS m^{-1}), which was on par with T_1 (6.11 dS m^{-1}). T_7 recorded the lowest value of 4.10 dS m^{-1} on 0th day and 4.71 dS m^{-1} on 30th day. On 60th day T_2 (6.52 dS m^{-1}) recorded highest value which was on par with, T_1 (6.35 dS m^{-1}) and T_7 (6.05 dS m^{-1}).

4.1.2.5 Organic Carbon

The total organic carbon content of the compost was not significantly influenced by the treatment during 0th and 30th day of composting (Table 10). Organic carbon content of the compost decreased during the composting period. On 0th day T_5 recorded the highest value (25.65 %) and on 30th day it was by T_1 (20.51 %). On 60 th day T_7 recorded the highest value (14.45 %) and treatments T_1 (14.23 %), T_8 (13.54 %), T_6 (13.51 %) and T_5 (13.32 %) were found to be on par.

4.1.2.6 C:N ratio

The effect of treatments on C:N ratio was presented in Table 11. On 0th and 30th day the treatments have no influence on C:N ratio. There was a significant reduction in the C:N ratio during composting. The highest C:N ratio of final compost

Table 8. Effect of treatments on pH during composting

Treatments	0 D	30 D	60 D
T_1 SS + CP (50:50) + lime	5.840	5.370	6.230
T_2 SS + CP + Z (50:30:20) + lime	5.590	5.290	6.570
T_3 SS + SD (50:50) + lime	6.420	5.340	6.240
T_4 SS + SD + Z (50:30:20) + lime	6.550	5.640	6.740
T_5 SS + CP (50:50) + flyash	5.900	5.570	6.280
T_6 SS + CP + Z (50:30:20) + flyash	6.150	5.840	6.610
T_7 SS + SD (50:50) + flyash	5.910	5.740	6.750
T_8 SS + SD + Z (50:30:20) + flyash	6.650	5.950	7.070
SE (m±)	0.104	0.102	0.093
C.D. (0.05)	0.339	0.334	0.271

D: Days of composting; SS: Sewage sludge; CP: Coirpith; Z: Zeolite; SD: Sawdust

Table 9. Effect of treatments on EC during composting, dS m^{-1}

Treatments	0 D	30 D	60 D
T_1 SS + CP (50:50) + lime	5.50	6.11	6.35
T_2 SS + CP + Z (50:30:20) + lime	4.23	6.27	6.52
T_3 SS + SD (50:50) + lime	4.52	5.54	5.68
T_4 SS + SD + Z (50:30:20) + lime	4.74	5.25	5.33
T_5 SS + CP (50:50) + flyash	4.30	4.80	5.30
T_6 SS + CP + Z (50:30:20) + flyash	4.20	5.35	5.45
T_7 SS + SD (50:50) + flyash	4.10	4.71	6.05
T_8 SS + SD + Z (50:30:20) + flyash	4.53	4.78	5.30
SE (m±)	0.19	0.15	0.20
C.D. (0.05)	0.60	0.48	0.65

D: Days of composting; SS: Sewage sludge; CP: Coirpith; Z: Zeolite; SD: Sawdust

Table 10. Effect of treatments on organic carbon during composting, %

Treatments	0 D	30 D	60 D
T_1 SS + CP (50:50) + lime	25.22	20.51	14.23
T_2 SS + CP + Z (50:30:20) + lime	22.90	16.38	11.31
T_3 SS + SD (50:50) + lime	24.53	19.55	12.70
T_4 SS + SD + Z (50:30:20) + lime	21.50	16.95	11.47
T_5 SS + CP (50:50) + flyash	25.65	20.20	13.32
T_6 SS + CP + Z (50:30:20) + flyash	24.50	20.49	13.51
T_7 SS + SD (50:50) + flyash	23.50	12.27	14.45
T_8 SS + SD + Z (50:30:20) + flyash	21.10	18.98	13.54
SE (m±)	-	-	0.54
C.D. (0.05)	NS	NS	1.62

D: Days of composting; SS: Sewage sludge; CP: Coirpith; Z: Zeolite; SD: Sawdust

Table 11. Effect of treatments on C:N ratio during composting

Treatments	0 D	30 D	60 D
T_1 SS + CP (50:50) + lime	16.93	12.58	8.27
T_2 SS + CP + Z (50:30:20) + lime	20.09	12.23	7.03
T_3 SS + SD (50:50) + lime	20.79	14.27	7.90
T_4 SS + SD + Z (50:30:20) + lime	18.06	14.12	7.45
T_5 SS + CP (50:50) + flyash	23.75	12.32	8.01
T_6 SS + CP + Z (50:30:20) + flyash	22.27	13.66	8.55
T_7 SS + SD (50:50) + flyash	17.40	8.29	9.20
T_8 SS + SD + Z (50:30:20) + flyash	13.79	12:32	8.48
SE (m±)	-	-	0.52
C.D. (0.05)	NS	NS	1.56

D: Days of composting; SS: Sewage sludge ; CP: Coirpith ; Z: Zeolite ; SD: Sawdust was observed in T_7 (9.20) which was on par with T_1, T_3, T_5, T_6 and T_8. The lowest value was obtained in T_2 (7.03) which was on par with T_4 (7.45).

4.1.2.7 Total Nitrogen

Mean values of total nitrogen during composting experiment are presented in Table 12. There was significant difference in total nitrogen content between treatments during 0th day and 60th day. On 0th day T_8 recorded the highest value (1.53 %) which was on par with T_1 (1.49 %) and T_7 (1.35 %). On 60th day T_1 recorded the highest value (1.72 %) which was on par with T_5 (1.66 %). On 30th day there was no significant effect of treatment on total nitrogen and T_5 recorded the highest value (1.64 %) followed by T_1 (1.63 %).

4.1.2.8 Total Phosphorus

There was a significant increase in the total phosphorus content during composting period (Table 13). On 0th day and 30th day T_1 recorded the highest value and was on par with T_5. On 60th day there was no significant influence of treatments on total phosphorus content during composting.

4.1.2.9 Total Potassium

There was a significant difference between the treatments with respect to total potassium (Table 14). Treatment T_8 recorded highest value for potassium during the entire composting period. On 0th day it was 0.170 % which was on par with T_6 (0.160 %). On 30th day T_8 recorded the highest value of 0.210 % and was significantly different from all other treatments. T_2 recorded the lowest value for total potassium during the entire composting experiment. (0.080, 0.090, 0.120 % during 0th, 30th and 60th day of composting)

Table 12. Effect of treatments on total nitrogen during composting, %

Treatments	0 D	30 D	60 D
T_1 SS + CP (50:50) + lime	1.49	1.63	1.72
T_2 SS + CP + Z (50:30:20) + lime	1.14	1.34	1.61
T_3 SS + SD (50:50) + lime	1.18	1.37	1.61
T_4 SS + SD + Z (50:30:20) + lime	1.19	1.20	1.54
T_5 SS + CP (50:50) + flyash	1.08	1.64	1.66
T_6 SS + CP + Z (50:30:20) + flyash	1.10	1.50	1.58
T_7 SS + SD (50:50) + flyash	1.35	1.48	1.57
T_8 SS + SD + Z (50:30:20) + flyash	1.53	1.54	1.60
SE (m±)	0.06	-	0.03
C.D. (0.05)	0.18	NS	0.09

D: Days of composting; SS: Sewage sludge; CP: Coirpith; Z: Zeolite; SD: Sawdust

Table 13. Effect of treatments on total phosphorus during composting, %

Treatments	0 D	30 D	60 D
T_1 SS + CP (50:50) + lime	0.800	1.040	1.150
T_2 SS + CP + Z (50:30:20) + lime	0.620	0.830	1.070
T_3 SS + SD (50:50) + lime	0.490	0.770	1.170
T_4 SS + SD + Z (50:30:20) + lime	0.410	0.680	1.040
T_5 SS + CP (50:50) + flyash	0.780	0.990	1.200
T_6 SS + CP + Z (50:30:20) + flyash	0.700	0.840	1.080
T_7 SS + SD (50:50) + flyash	0.450	0.720	1.120
T_8 SS + SD + Z (50:30:20) + flyash	0.410	0.700	1.240
SE (m±)	0.017	0.060	-
C.D. (0.05)	0.057	0.198	NS

D: Days of composting; SS: Sewage sludge; CP: Coirpith; Z: Zeolite; SD: Sawdust

4.1.2.10 Total Calcium

There was a significant influence of treatments on total calcium during composting (Table 15). On 0th day T_5 recorded the highest value (10.63 %) followed by T_2 (9.40 %). On 30th day T_5 recorded the highest value (12.20 %) which was on par with T_6 (12.00 %), T_7 (12.00 %), T_8 (12.00 %), T_2 (12.00 %) and T_1 (11.80 %). The highest value on the 60th day was observed in T_8 (19.06 %) followed by T_7 (17.94 %).

4.1.2.11 Total Magnesium

The treatments significantly influenced the magnesium content during composting as evident from Table 16. On 0th day the highest value was observed in T_6 (7.07 mg kg^{-1}), which was on par with T_7 (7.00 %). On 30th day T_7 registered the highest value (9.80 %) followed by T_6 (9.10 %). The highest value for magnesium during the 60th day was observed in T_7 (12.72 %) which was followed by T_3 (10.59 %). The least value was observed in T_1 (9.53 %).

4.2.1.12 Total Sulphur

There was a significant influence of treatments on total sulphur during composting experiment (Table 17). On 0th day T_8 recorded the highest value (0.250 mg kg^{-1}) and was significantly different from all other treatments. On 30th day the highest total S was associated with T_4 (0.430 %) which was significantly higher than all other treatments. On 60th day highest value for sulphur was recorded by T_8 (0.492 %) which was on par with T_7 (0.480 %).

4.2.1.13. Total Micronutrient Content

4.2.1.13.1. Iron

The values for iron content differed significantly on 0th, 30th and 60th days of composting (Table 18). T_1 recorded the highest iron content at 0th, 30th and 60th days

Table 14. Effect of treatments on total potassium during composting, %

Treatments	0 D	30 D	60 D
T_1 SS + CP (50:50) + lime	0.103	0.180	0.233
T_2 SS + CP + Z (50:30:20) + lime	0.080	0.090	0.120
T_3 SS + SD (50:50) + lime	0.120	0.151	0.169
T_4 SS + SD + Z (50:30:20) + lime	0.107	0.090	0.121
T_5 SS + CP (50:50) + flyash	0.140	0.191	0.270
T_6 SS + CP + Z (50:30:20) + flyash	0.160	0.190	0.250
T_7 SS + SD (50:50) + flyash	0.130	0.180	0.220
T_8 SS + SD + Z (50:30:20) + flyash	0.170	0.210	0.290
SE (m±)	0.009	0.003	0.007
C.D. (0.05)	0.028	0.010	0.021

D: Days of composting; SS: Sewage sludge; CP: Coirpith; Z: Zeolite; SD: Sawdust

Table 15. Effect of treatments on total calcium during composting, %

Treatments	0 D	30 D	60 D
T_1 SS + CP (50:50) + lime	9.37	11.80	13.44
T_2 SS + CP + Z (50:30:20) + lime	9.40	12.00	14.94
T_3 SS + SD (50:50) + lime	6.67	10.50	14.63
T_4 SS + SD + Z (50:30:20) + lime	6.67	10.70	17.24
T_5 SS + CP (50:50) + flyash	10.63	12.20	16.55
T_6 SS + CP + Z (50:30:20) + flyash	6.60	12.00	16.31
T_7 SS + SD (50:50) + flyash	8.00	12.00	17.94
T_8 SS + SD + Z (50:30:20) + flyash	6.80	12.00	19.06
SE (m±)	0.09	0.25	0.336
C.D. (0.05)	0.33	0.51	1.015

Table 16. Effect of treatments on total magnesium during composting, %

Treatments	0 D	30 D	60 D
T_1SS + CP (50:50) + lime	5.67	7.00	9.53
T_2 SS + CP + Z (50:30:20) + lime	5.70	7.27	9.67
T_3 SS + SD (50:50) + lime	5.73	7.60	10.59
T_4 SS + SD + Z (50:30:20) + lime	5.93	7.30	9.90
T_5 SS + CP (50:50) + flyash	6.20	8.23	10.44
T_6 SS + CP + Z (50:30:20)+ flyash	7.07	9.10	10.42
T_7 SS + SD (50:50) + flyash	7.00	9.80	12.72
T_8 SS + SD + Z (50:30:20)+ flyash	6.20	8.83	9.90
SE (m±)	0.14	0.18	0.47
CD (0.05)	0.30	0.29	1.42

D: Days of composting; SS: Sewage sludge; CP: Coirpith; Z: Zeolite; SD: Sawdust

Table 17. Effect of treatments on total sulphur during composting, %

Treatments	0 D	30 D	60 D
T_1SS + CP (50:50) + lime	0.103	0.212	0.370
T_2 SS + CP + Z (50:30:20) + lime	0.190	0.263	0.450
T_3 SS + SD (50:50) + lime	0.190	0.260	0.360
T_4 SS + SD + Z (50:30:20) + lime	0.200	0.430	0.470
T_5 SS + CP (50:50) + flyash	0.120	0.181	0.240
T_6 SS + CP + Z (50:30:20)+ flyash	0.113	0.210	0.240
T_7 SS + SD (50:50) + flyash	0.160	0.240	0.480
T_8 SS + SD + Z (50:30:20)+ flyash	0.250	0.290	0.492
SE (m±)	0.011	0.011	0.011
CD (0.05)	0.033	0.034	0.032

D: Days of composting; SS: Sewage sludge; CP: Coirpith; Z: Zeolite; SD: Sawdust

of composting with 782.13 mg kg^{-1}, 724.64 mg kg^{-1} and 835.27 mg kg^{-1} respectively. T_4 recorded the lowest iron content at 0th, 30th and 60th day of composting with 594.12 mg kg^{-1}, 585.27 mg kg^{-1} and 604.04 mg kg^{-1} respectively.

4.2.1.13.2 Manganese

The manganese content of composts was significantly influenced by treatments and is presented in Table 19. T_7 recorded the highest value on 0th (671.89 mg kg^{-1}) and 30th day (650.44 mg kg^{-1}). On 30th day it was on par with T_5 (643.18 mg kg^{-1}) . On 60th day T_1 had the maximum Mn content (734.25 mg kg^{-1}) which was significantly different from all the treatments.

4.2.1.13.3 Copper

The values of copper content during composting was significantly influenced by the treatments (Table 20). On 0th day T_3 recorded the highest value (174.39 mg kg^{-1}) followed by T_8 (171.27 mg kg^{-1}) and T_1 (171.00 mg kg^{-1}) which were found to be on par. On 30th day T_5 recorded the highest value (165.28 mg kg^{-1}), followed by T_8 (162.34 mg kg^{-1}), T_3 (161.41 mg kg^{-1}) and T_1 (160.95 mg kg^{-1}) which were on par with T_5. Highest value for Copper on 60th day was recorded by T_8 (176.95 mg kg^{-1}), followed by T_1 (173.98) and T_3 (172.24 mg kg^{-1}) which were on par. Least value for copper was observed in T_5 during 0th (150.82 mg kg^{-1}) and 60th day (152.98 mg kg^{-1}). On 30th day the lowest values for copper was observed in T_6 (150.76 mg kg^{-1}).

4.2.1.13.4 Zinc

Treatment T_5 had the highest Zn content at 0th, 30th and 60th day of composting (Table 21) with 174.26 mg kg^{-1}, 146.49 mg kg^{-1} and 175.83 mg kg^{-1} respectively. On 0th day it was par with T_1 (165.35 mg kg^{-1}) and on 30th day it was found to be on par with T_1 (140.24 mg kg^{-1}) while on 60th day T_1 (172.52 mg kg^{-1}) and T_3 (168.31 mg kg^{-1}) were found to be on par with T_5.

Table 18. Effect of treatments on total iron during composting, mg kg^{-1}

Treatments	0 D	30 D	60 D
T_1 SS + CP (50:50) + lime	782.13	724.64	835.27
T_2 SS + CP + Z (50:30:20) + lime	706.00	682.67	728.57
T_3 SS + SD (50:50) + lime	604.00	592.14	629.13
T_4 SS + SD + Z (50:30:20) + lime	594.12	585.27	604.04
T_5 SS + CP (50:50) + flyash	756.12	704.32	772.58
T_6 SS + CP + Z (50:30:20) + flyash	694.01	636.87	742.81
T_7 SS + SD (50:50) + flyash	702.67	644.36	715.41
T_8 SS + SD + Z (50:30:20) + flyash	743.61	701.05	795.79
SE (m±)	3.20	5.01	5.08
C.D. (0.05)	9.66	15.14	15.37

D: Days of composting; SS: Sewage sludge; CP: Coirpith; Z: Zeolite; SD: Sawdust

Table 19 .Effect of treatment on total manganese during composting, mg kg^{-1}

Treatments	0 D	30 D	60 D
T_1 SS + CP (50:50) + lime	580.33	558.99	734.25
T_2 SS + CP + Z (50:30:20) + lime	570.30	550.32	670.33
T_3 SS + SD (50:50) + lime	583.05	553.44	648.17
T_4 SS + SD + Z (50:30:20) + lime	561.87	520.03	630.19
T_5 SS + CP (50:50) + flyash	642.20	643.18	652.67
T_6 SS + CP + Z (50:30:20) + flyash	604.20	544.62	649.02
T_7 SS + SD (50:50) + flyash	671.89	650.44	698.26
T_8 SS + SD + Z (50:30:20) + flyash	555.17	532.04	650.00
SE (m±)	7.59	6.74	8.43
C.D. (0.05)	22.97	20.37	25.50

D: Days of composting; SS: Sewage sludge; CP: Coirpith; Z: Zeolite; SD: Sawdust

Table 20. Effect of treatment on total copper during composting, mg kg^{-1}

Treatments	0 D	30 D	60 D
T_1 SS + CP (50:50) + lime	171.00	160.95	173.98
T_2 SS + CP + Z (50:30:20) + lime	168.33	156.22	167.24
T_3 SS + SD (50:50) + lime	174.39	161.41	172.24
T_4 SS + SD + Z (50:30:20) + lime	165.48	153.27	164.33
T_5 SS + CP (50:50) + flyash	150.82	165.28	152.98
T_6 SS + CP + Z (50:30:20) + flyash	155.31	150.76	156.11
T_7 SS + SD (50:50) + flyash	164.62	154.02	163.68
T_8 SS + SD + Z (50:30:20) + flyash	171.27	162.34	176.95
SE (m±)	1.68	1.80	1.71
C.D. (0.05)	5.09	5.43	5.18

D: Days of composting; SS: Sewage sludge; CP: Coirpith; Z: Zeolite; SD: Sawdust

Table 21. Effect of treatments on total zinc during composting, mg kg^{-1}

Treatments	0 D	30 D	60 D
T_1 SS + CP (50:50) + lime	165.35	140.24	172.52
T_2 SS + CP + Z (50:30:20) + lime	160.72	135.56	164.25
T_3 SS + SD (50:50) + lime	159.46	130.21	168.31
T_4 SS + SD + Z (50:30:20) + lime	157.50	136.00	162.31
T_5 SS + CP (50:50) + flyash	174.26	146.49	175.83
T_6 SS + CP + Z (50:30:20) + flyash	152.04	132.74	154.47
T_7 SS + SD (50:50) + flyash	159.83	134.17	156.82
T_8 SS + SD + Z (50:30:20) + flyash	147.93	130.43	140.82
SE (m±)	3.15	3.14	3.39
C.D. (0.05)	9.53	9.50	10.26

D: Days of composting; SS: Sewage sludge; CP: Coirpith; Z: Zeolite; SD: Sawdust

4.2.1.13.5 Boron

The boron content of composts were significantly influenced by different treatments during 30th and 60th day of composting (Table 22). Highest value for boron (8.447 mg kg^{-1}) was recorded for T_8 treatment during 30th day and was significantly higher than other treatments. On 60th day T_8 recorded the highest value of 9.76 mg kg^{-1} which was on par with T_1 (9.65 mg kg^{-1}).

4.2.1.14 Total Heavy Metal Content

The data on the influence of treatments on the contents of total heavy metals during composting is represented in the Table 23-26.

4.2.1.14.1 Total Lead

Table 23 shows a significant influence of treatments on total lead concentration during composting. A general increase in total lead content was observed in all treatments with time. On 0th day highest value was observed for T_1 (37.47 mg kg^{-1}), followed by T_7 (35.53 mg kg^{-1}) which were found to be on par. Highest lead content on 30th day was observed in T_1 treatment (38.55 mg kg^{-1}) and was on par with T_5 (36.35 mg kg^{-1}), T_7 (36.32 mg kg^{-1}) and T_3 (35.87 mg kg^{-1}). At 60th day T_1 (40.32 mg kg^{-1}) recorded the highest value and T_6 (37.49 mg kg^{-1}), T_7 (38.00 mg kg^{-1}), T_5 (38.62 mg kg^{-1}) and T_2 (39.33 mg kg^{-1}) were found to be on par with T_1. T_8 recorded the lowest value of lead during the the entire composting period (31.71 mg kg^{-1} on 0th day, 32.72 mg kg^{-1} on 30th day, 33.06 mg kg^{-1} on 60th day) .

4.2.1.14.2 Total Cadmium

The data on total cadmium content as influenced by various treatments is given in Table 24.

There was a significant difference between the treatments with respect to total cadmium content. The cadmium content in initial composts ranged between 5.17 –

71

Table 22. Effect of treatment on total boron during composting, mg kg^{-1}

Treatments	0 D	30 D	60 D
T_1 SS + CP (50:50) + lime	5.40	7.52	9.65
T_2 SS + CP + Z (50:30:20) + lime	5.17	6.55	8.19
T_3 SS + SD (50:50) + lime	5.33	6.44	8.61
T_4 SS + SD + Z (50:30:20) + lime	5.33	5.43	7.67
T_5 SS + CP (50:50) + flyash	5.67	6.28	7.98
T_6 SS + CP + Z (50:30:20) + flyash	5.10	7.93	8.44
T_7 SS + SD (50:50) + flyash	5.40	7.41	9.18
T_8 SS + SD + Z (50:30:20) + flyash	5.93	8.45	9.76
SE (m±)	-	0.16	0.20
C.D. (0.05)	-	0.48	0.60

D: Days of composting; SS: Sewage sludge; CP: Coirpith; Z: Zeolite; SD: Sawdust

Table 23. Effect of treatment on total lead during composting, mg kg^{-1}

Treatments	0 D	30 D	60 D
T_1 SS + CP (50:50) + lime	37.47	38.55	40.32
T_2 SS + CP + Z (50:30:20) + lime	33.64	34.46	39.33
T_3 SS + SD (50:50) + lime	34.66	35.87	36.64
T_4 SS + SD + Z (50:30:20) + lime	32.50	34.05	37.01
T_5 SS + CP (50:50) + flyash	35.00	36.35	38.62
T_6 SS + CP + Z (50:30:20) + flyash	33.26	34.62	37.49
T_7 SS + SD (50:50) + flyash	35.53	36.32	38.00
T_8 SS + SD + Z (50:30:20) + flyash	31.71	32.72	33.06
SE (m±)	0.62	1.04	0.99
C.D. (0.05)	1.88	3.16	2.98

D: Days of composting; SS: Sewage sludge; CP: Coirpith; Z: Zeolite; SD: Sawdust

5.6 mg kg^{-1}. There was an increasing trend of cadmium at the end of composting. On 0th day T_3 recorded the highest value (5.60 mg kg^{-1}) which was on par with T_1 (5.50 mg kg^{-1}) and T_7 (5.50 mg kg^{-1}). T_3 and T_7 obtained the highest cadmium content (5.70 mg kg^{-1}) on 30th day which was on par with all treatments except T_8 and T_5. The treatments T_3 and T_6 recorded the highest value during 60th day and was on par with T_1 (5.83 mg kg^{-1}) and T_7 (5.81 mg kg^{-1}). T_8 recorded the least value for total cadmium content during the entire composting period (5.17 mg kg^{-1} on 0th day, 5.30 mg kg^{-1} on 30th day and 5.41 mg kg^{-1} on 60th day).

4.2.1.14.3 Total Nickel

The total nickel in compost was influenced significantly by composting treatments as presented in Table 25. T_1 recorded the highest value during 0th day (107.34 mg kg^{-1}), 30th day 108.55 mg kg^{-1} and 60th day 110.60 mg kg^{-1}. On 0th day T_1 was on par with T_3 (104.74 mg kg^{-1}) and T_5 (103.01 mg kg^{-1}). On 30th day T1 was on par with T_3 (105.63 mg kg^{-1}), T_5 (104.49 mg kg^{-1}) and T_7 (103.59 mg kg^{-1}). On 60th day T_1 was significantly different from all other treatments.

4.2.1.14.4 Total Chromium

A gradual increase of total Cr was observed during composting (Table 26). The treatment T_1 recorded the highest Cr on 0th day (51.33 mg kg^{-1}) followed by T_3 (51.17 mg kg^{-1}) which were on par. On 30th and 60th day T_3 had the highest value (53.60 and 55.43 mg kg^{-1} respectively). T_4 (50.80 mg kg^{-1}) and T_5 (52.00 mg kg^{-1}) were on par with T_3 on 30th day and on 60th day it was on par with T_5 (53.80 mg kg^{-1}). Treatment T_8 recorded the least value during all the sampling intervals.

4.2.1.15 Fractions of Heavy Metal

4.2.1.15.1 Exchangeable Fraction

The content of exchangeable fractions of heavy metal is very important as it is mobile.

Table 24. Effect of treatment on total cadmium during composting, mg kg^{-1}

Treatments	0 D	30 D	60 D
T_1 SS + CP (50:50) + lime	5.50	5.60	5.83
T_2 SS + CP + Z (50:30:20) + lime	5.25	5.50	5.70
T_3 SS + SD (50:50) + lime	5.60	5.70	5.90
T_4 SS + SD + Z (50:30:20) + lime	5.55	5.68	5.70
T_5 SS + CP (50:50) + flyash	5.40	5.50	5.62
T_6 SS + CP + Z (50:30:20) + flyash	5.2	5.57	5.90
T_7 SS + SD (50:50) + flyash	5.5	5.70	5.81
T_8 SS + SD + Z (50:30:20) + flyash	5.17	5.30	5.41
SE (m±)	0.08	0.08	0.04
C.D. (0.05)	0.25	0.25	0.13

D: Days of composting; SS: Sewage sludge; CP: Coirpith; Z: Zeolite; SD: Sawdust

Table 25. Effect of treatment on total nickel during composting, mg kg^{-1}

Treatments	0 D	30 D	60 D
T_1 SS + CP (50:50) + lime	107.34	108.55	110.60
T_2 SS + CP + Z (50:30:20) + lime	98.23	100.54	103.49
T_3 SS + SD (50:50) + lime	104.74	105.63	106.26
T_4 SS + SD + Z (50:30:20) + lime	96.24	98.18	100.42
T_5 SS + CP (50:50) + flyash	103.01	104.49	105.41
T_6 SS + CP + Z (50:30:20) + flyash	96.70	97.00	99.19
T_7 SS + SD (50:50) + flyash	101.03	103.59	101.95
T_8 SS + SD + Z (50:30:20) + flyash	96.23	96.79	97.62
SE (m±)	1.88	1.92	1.02
C.D. (0.05)	5.67	5.81	3.08

D: Days of composting; SS: Sewage sludge; CP: Coirpith; Z: Zeolite; SD: Sawdust

Table 26. Effect of treatment on total chromium during composting, mg kg^{-1}

Treatments	0 D	30 D	60 D
T_1 SS + CP (50:50) + lime	48.00	49.42	51.00
T_2 SS + CP + Z (50:30:20) + lime	46.00	48.00	50.30
T_3 SS + SD (50:50) + lime	51.17	53.60	55.43
T_4 SS + SD + Z (50:30:20) + lime	49.24	50.80	52.04
T_5 SS + CP (50:50) + flyash	51.33	52.00	53.80
T_6 SS + CP + Z (50:30:20) + flyash	48.57	49.70	51.00
T_7 SS + SD (50:50) + flyash	45.84	47.00	48.40
T_8 SS + SD + Z (50:30:20) + flyash	43.44	45.25	47.00
SE (m±)	0.64	0.99	0.73
C.D. (0.05)	1.94	2.99	2.21

D: Days of composting; SS: Sewage sludge; CP: Coirpith; Z: Zeolite; SD: Sawdust

The effect of treatments on exchangeable fractions of heavy metals are given in Table 27. A general decrease in exchangeable fractions of heavy metal compared to the initial level was observed in all treatments.

4.2.1.15.1.1 Lead

On 0th day the highest value was observed in T_3 treatment (0.82 mg kg^{-1}), followed by T_1 (0.720 mg kg^{-1}) which were found to be on par. The least content of exchangeable fraction of lead was recorded by T_8 (0.470 mg kg^{-1}) which was on par with T_2 (0.550 mg kg^{-1}), T_5 (0.490 mg kg^{-1}), T_6 (0.530 mg kg^{-1}) and T_7 (0.480 mg kg^{-1}). On 30th day T_3 recorded the highest value (0.809 mg kg^{-1}). T_2 recorded the least value (0.40 mg kg^{-1}) during 30th day which was on par with T_5 (0.450 mg kg^{-1}), T_7 (0.469 mg kg^{-1}) and T_8 (0.450 mg kg^{-1}). T_3 had the highest value during 60th day (0.760 mg kg^{-1}) followed by T_1 (0.670 mg kg^{-1}). Least exchangeable Pb content during 60th day was for T_2 (0.360 mg kg^{-1}) and T_8 (0.360 mg kg^{-1}), T_7 was found to be on par (0.400 mg kg^{-1}).

4.2.1.15.1.2 Cadmium

Exchangeable fraction of Cd also decreased during composting. T_3 obtained the highest value for exchangeable fraction during all the sampling intervals. On 0th day the least value was recorded for T_8 (0.053 mg kg^{-1}) treatment, and was significantly different from all other treatments. T_8 recorded the least (0.013 mg kg^{-1}) during 30th day, T_1 (0.016 mg kg^{-1}) and T_2 (0.016 mg kg^{-1}) were on par with T_8. During the final sampling T_1 (0.013 mg kg^{-1}) and T_2 (0.013 mg kg^{-1}) were on par with T_8 (0.010 mg kg^{-1}), which had the least exchangeable cadmium.

4.2.1.15.1.3 Nickel

A general decrease in exchangeable Ni was obtained during the entire composting period. T_2 obtained the highest value during 0th day (2.076 mg kg^{-1}) and was found to on par with T_4 (2.000 mg kg^{-1}). During the second sampling T_4 recorded

Table. 27. Effect of treatments on exchangeable fractions of heavy metals, mg kg $^{-1}$

Treatments	0 D				30 D				60 D			
	Pb	Cd	Ni	Cr	Pb	Cd	Ni	Cr	Pb	Cd	Ni	Cr
T_1	0.720	0.057	1.480	0.672	0.700	0.016	1.206	0.263	0.670	0.013	1.153	0.052
T_2	0.550	0.055	2.076	0.977	0.401	0.016	1.666	0.380	0.360	0.013	1.395	0.074
T_3	0.820	0.088	1.920	0.752	0.809	0.085	1.763	0.285	0.760	0.051	1.647	0.056
T_4	0.670	0.084	2.000	0.701	0.640	0.023	1.813	0.265	0.650	0.016	1.583	0.052
T_5	0.490	0.077	1.470	0.717	0.450	0.026	1.136	0.270	0.450	0.015	1.096	0.054
T_6	0.530	0.073	1.000	0.882	0.510	0.024	1.010	0.336	0.440	0.014	0.094	0.065
T_7	0.480	0.086	1.900	0.640	0.469	0.028	1.736	0.244	0.400	0.016	1.710	0.048
T_8	0.470	0.053	1.423	0.702	0.450	0.013	1.323	0.267	0.360	0.010	1.253	0.053
SE (m±)	0.036	0.002	0.050	0.006	0.041	0.003	0.030	0.003	0.023	0.001	0.028	0.001
CD	0.118	0.008	0.150	0.018	0.075	0.009	0.095	0.010	0.069	0.003	0.085	0.003

T1 - SS + CP (50:50) + lime, T2 - SS + CP + Z (50:30:20) + lime, T3 - SS + SD (50:50) + lime, T4 - SS + SD + Z (50:30:20) + lime, T5 - SS + CP (50:50) + flyash, T6 - SS + CP + Z (50:30:20) + flyash, T7 - SS + SD (50:50) + flyash, T8 - SS + SD + Z (50:30:20) + flyash

D: Days of composting; SS: Sewage sludge; CP: Coirpith; Z: Zeolite; SD: Sawdust

the highest value (1.813 mg kg^{-1}), T_3 (1.763 mg kg^{-1}) and T_7 (1.736 mg kg^{-1}) were found to be on par. On 60th day T_3 (1.647 mg kg^{-1}) was found to be on par with T_7, which obtained the highest value (1.710 mg kg^{-1}). The least value was observed in T_6 (1.00, 1.010 and 0.094 mg kg^{-1} respectively on 0th, 30th and 60th day) and the treatment was significantly different from all the treatments.

4.2.1.15.1.4 Chromium

The value of exchangeable chromium ranged from 0.640 mg kg^{-1} (T_7) – 0.977 mg kg^{-1} (T_2) during the 0th day of composting. A general decrease in the content of exchangeable Cr was observed during the entire period of composting. T_2 recorded the highest value of 0.977 mg kg^{-1} on 0th day, 0.380 mg kg^{-1} on 30th day and 0.074 mg kg^{-1} 60th day which was significantly different from all other treatments. T_7 recorded the lowest value during all the sampling periods and the treatment effect was significantly different from all other treatments.

4.2.1.15.2 Carbonate fraction

The variation in carbonate fraction of heavy metals are presented in Table 28.

4.2.1.15.2.1 Lead

The carbonate fraction of sewage sludge compost was influenced by the treatments and a decrease in the content of the fraction was observed during the composting period. On 0th, 30th and 60th day T_3 recorded the highest value and was significantly different from all other treatments. On 0th day the least value was obtained for treatment T_7 (0.400 mg kg^{-1}), treatment T_8 (0.410 mg kg^{-1}) and T_5 (0.430 mg kg^{-1}) were on par. On 30th day T_8 recorded the least value (0.360 mg kg^{-1}) which was on par with T_5 (0.410 mg kg^{-1}), T_6 (0.400 mg kg^{-1}) and T_7 (0.370 mg kg^{-1}). Treatment T_2 and T_8 (0.310 mg kg^{-1}) obtained the least value during 60th day of composting and were significantly different from all other treatments.

4.2.1.15.2.2 Cadmium

Carbonate fraction of cadmium ranged from 0.376-0.200 mg kg^{-1} during the initial sampling. On 0th, 30th and 60th day T_3 recorded the highest value (0.376 mg kg^{-1}, 0.139 mg kg^{-1} and 0.031 mg kg^{-1} respectively). T_8 recorded the least value of 0.200 mg kg^{-1}, 0.070 mg kg^{-1} and 0.013 mg kg^{-1} on 0th, 30th and 60th day respectively. T_1 and T_2 was found to be on par with T_8 during all the sampling period.

4.2.1.15.2.3 Nickel

The carbonate fraction of nickel was significantly influenced by the treatments. The values showed that was a gradual decrease of carbonate fraction during composting. On 0th day T_1 recorded the highest value (2.400 mg kg^{-1}) followed by T_6 (2.207 mg kg^{-1}). The least value was observed in T_8 treatment (1.190 mg kg^{-1}). On 30th and 60th day the highest value was recorded by T_6 (2.100 mg kg^{-1} and 2.055 mg kg^{-1} respectively). On 30th day T_1 (2.003 mg kg^{-1}) was on par with T_6. On 0th, 30th and 60th day the carbonate fraction of Ni was lowest in T_8 treatment with values of 1.190 mg kg^{-1}, 1.064 mg kg^{-1} and 1.039 mg kg^{-1} respectively.

4.2.1.15.2.4 Chromium

Carbonate fraction of chromium also showed a decreasing trend at the end of composting period. Treatment T_2 recorded the highest value during all the sampling stages. On 0th day T_2 recorded the highest value (0.568 mg kg^{-1}) which was followed by T_6 (0.504 mg kg^{-1}). The least value was shown by T_7 (0.365 mg kg^{-1}) and the treatment was significantly different from all other treatments during the initial sampling. On 30th day T_6 (0.246 mg kg^{-1}) was on par with T_2 and the least value for carbonate fraction was observed in T_7 treatment (0.159 mg kg^{-1}). T_1 (0.172 mg kg^{-1}), T_4 (0.173 mg kg^{-1}) and T_5 (0.176 mg kg^{-1}) were on par with T_7 on the 30th day of sampling. On the 60th day of composting T_2 attained the highest value (0.073 mg kg^{-1}) which was on par with T_3 (0.057 mg kg^{-1}), T_5 (0.053 mg kg^{-1})) T_6 (0.061 mg kg^{-1}).

Table 28. Effect of treatments on carbonate fractions of heavy metals, mg kg $^{-1}$

	0 D				30 D				60 D			
	Pb	Cd	Ni	Cr	Pb	Cd	Ni	Cr	Pb	Cd	Ni	Cr
T_1	0.620	0.208	2.400	0.384	0.600	0.074	2.003	0.172	0.570	0.017	1.567	0.049
T_2	0.470	0.206	1.280	0.568	0.460	0.077	1.140	0.248	0.310	0.017	1.040	0.073
T_3	0.710	0.376	1.513	0.429	0.680	0.139	1.377	0.186	0.650	0.031	1.270	0.057
T_4	0.580	0.303	1.592	0.403	0.560	0.113	1.498	0.173	0.540	0.025	1.414	0.052
T_5	0.430	0.286	1.649	0.412	0.410	0.103	1.613	0.176	0.380	0.026	1.543	0.053
T_6	0.460	0.258	2.207	0.504	0.400	0.096	2.100	0.246	0.380	0.021	2.055	0.061
T_7	0.400	0.300	1.500	0.365	0.370	0.116	1.490	0.159	0.340	0.023	1.280	0.047
T_8	0.410	0.200	1.190	0.401	0.360	0.070	1.064	0.174	0.310	0.013	1.039	0.051
SE(m±)	0.017	0.006	0.057	0.001	0.018	0.003	0.054	0.008	0.012	0.002	0.034	0.006
CD	0.056	0.020	0.172	0.003	0.061	0.009	0.163	0.025	0.041	0.006	0.103	0.020

T1 - SS + CP (50:50) + lime, T2 - SS + CP + Z (50:30:20) + lime, T3 - SS + SD (50:50) + lime, T4 - SS + SD + Z (50:30:20) + lime, T5 - SS + CP (50:50) + flyash, T6 - SS + CP + Z (50:30:20) + flyash, T7 - SS + SD (50:50) + flyash, T8 - SS + SD + Z (50:30:20) + flyash D: Days of composting; SS: Sewage sludge; CP: Coirpith; Z: Zeolite; SD: Sawdust

The least value during 60th day was obtained by T_7 treatment (0.047 mg kg^{-1}) and the treatment was significantly different from all other treatments.

4.2.1.15.3 Reducible Fractions

The variation among treatments in reducible fractions of heavy metal was found to be significant as evident from Table 29.

4.2.1.15.3.1 Lead and Cadmium

Reducible fractions of Pd and Cd were not detected in any treatments during the composting period.

4.2.1.15.3.2 Nickel

On 0th, 30th and 60th day T_6 recorded the highest value of 25.313, 23.395 and 20.450 mg kg^{-1} respectively. On 0th day the least value for reducible fraction of Ni was recorded by T_3 (13.502 mg kg^{-1}), T_8 was found to be on par (13.576 mg kg^{-1}). On 30th day T_1 (23.13 mg kg^{-1}) was on par with T_6 and the least value on 30th day was recorded by T_8 (11.471 mg kg^{-1}). On 60th day T_6 recorded the highest value (20.450 mg kg^{-1}) and the lowest value was recorded by T_3 (10.594 mg kg^{-1}).

4.2.1.15.3.3 Chromium

On 0th, 30th and 60th day T_2 obtained the highest value among all treatments. On 0th day T_2 had a value of 0.472 mg kg^{-1} which was followed by T_6 (0.422 mg kg^{-1}). Lowest value on the 0th day was recorded by T_7 (0.306 mg kg^{-1}) which was on par with T_1 (0.324 mg kg^{-1}). T_7 recorded the least value (0.327 mg kg^{-1}) on 30th day which was on par with T_1 (0.347 mg kg^{-1}), T_3 (0.385 mg kg^{-1}), T_4 (0.356 (mg kg^{-1}), T_5 (0.366 mg kg^{-1}) and T_8 (0.357 mg kg^{-1}). On 60th day T_7 recorded the least value (0.336 mg kg^{-1}) and it was significantly different from all other treatments.

Table.29. Effect of treatments on reducible fractions of heavy metals, mg kg $^{-1}$

	0 D				30 D				60 D			
	Pb	Cd	Ni	Cr	Pb	Cd	Ni	Cr	Pb	Cd	Ni	Cr
T_1	ND	ND	24.519	0.324	ND	ND	23.130	0.347	ND	ND	19.433	0.364
T_2	ND	ND	23.146	0.472	ND	ND	21.576	0.510	ND	ND	17.407	0.521
T_3	ND	ND	13.502	0.359	ND	ND	12.672	0.385	ND	ND	10.594	0.392
T_4	ND	ND	17.545	0.335	ND	ND	15.571	0.356	ND	ND	13.383	0.364
T_5	ND	ND	18.342	0.343	ND	ND	17.610	0.366	ND	ND	14.560	0.377
T_6	ND	ND	25.313	0.422	ND	ND	23.395	0.451	ND	ND	20.450	0.455
T_7	ND	ND	16.413	0.306	ND	ND	15.336	0.327	ND	ND	12.553	0.336
T_8	ND	ND	13.576	0.335	ND	ND	11.471	0.357	ND	ND	11.253	0.372
SE	-	-	0.197	0.007	-	-	0.202	0.018	-	-	0.296	0.005
CD	-	-	0.591	0.018	-	-	0.607	0.056	-	-	0.889	0.017

T1 - SS + CP (50:50) + lime, T2 - SS + CP + Z (50:30:20) + lime, T3 - SS + SD (50:50) + lime, T4 - SS + SD + Z (50:30:20) + lime, T5 - SS + CP (50:50) + flyash, T6 - SS + CP + Z (50:30:20) + flyash, T7 - SS + SD (50:50) + flyash, T8 - SS + SD + Z (50:30:20) + flyash

D: Days of composting; SS: Sewage sludge; CP: Coirpith; Z: Zeolite; SD: Sawdust

4.2.1.15.4 Organic Fractions

The effect of treatments on organic fractions of heavy metals are depicted in the Table 30. A general increase of organic fractions of heavy metals with time during composting was observed.

4.2.1.15.4.1 Lead and Cadmium

Organic fractions of Pb and Cd were not dectected in any one of the treatment during composting.

4.2.1.15.4.2 Nickel

On 0th day of composting the highest value of organic fraction of Ni was observed in T_1 treatment (28.530 mg kg^{-1}) which was on par with T_5 (28.33 mg kg^{-1}). Least value was observed for T_6 (19.317 mg kg^{-1}). T_1 recorded the highest value during 30th day (29.340 mg kg^{-1}) which was on par with T_2 (29.163 mg kg^{-1}) and T_5 (29.260 mg kg^{-1}). The least value was observed in T_3 treatment (21.09 mg kg^{-1}). On 60th day T_5 recorded the highest value (31.90 mg kg^{-1}) and was on par with T_1 (31.067 mg kg^{-1}). The lowest value was associated with T_3 (22.030 mg kg^{-1}).

4.2.1.15.4.3 Chromium

The treatments were greatly influenced the organic fraction content of Cr. The treatment T_2 had the highest organic fraction content of Cr at every sampling stages (1.412 mg kg^{-1}, 1.460 mg kg^{-1}, 2.977 mg kg^{-1} respectively). The lowest value for these fraction was attained by T_7 during the entire composting period (0.917 mg kg^{-1}, 0.940 mg kg^{-1}, 1.920 mg kg^{-1} respectively).

4.2.1.15.5 Residual Fractions

Residual fraction of heavy metals are very important since this fraction is the most stable fraction. The effect of various treatments on the residual fractions of heavy metals are depicted in the Table 31.

Table 30. Effect of treatments on organic fractions of heavy metals, mg kg $^{-1}$

	O D				30 D				60 D			
	Pb	Cd	Ni	Cr	Pb	Cd	Ni	Cr	Pb	Cd	Ni	Cr
T_1	ND	ND	28.530	0.988	ND	ND	29.340	1.010	ND	ND	31.067	2.016
T_2	ND	ND	26.900	1.412	ND	ND	29.163	1.460	ND	ND	29.513	2.977
T_3	ND	ND	19.330	1.071	ND	ND	21.093	1.089	ND	ND	22.030	2.282
T_4	ND	ND	23.700	0.987	ND	ND	23.033	1.026	ND	ND	25.467	2.098
T_5	ND	ND	28.333	1.025	ND	ND	29.260	1.040	ND	ND	31.900	2.150
T_6	ND	ND	19.317	1.232	ND	ND	22.940	1.290	ND	ND	26.740	2.642
T_7	ND	ND	25.850	0.917	ND	ND	27.970	0.940	ND	ND	29.940	1.920
T_8	ND	ND	20.277	1.007	ND	ND	26.770	1.029	ND	ND	28.300	2.135
SE	-	-	0.190	0.008	-	-	0.200	0.009	-	-	0.290	0.031
CD	-	-	0.590	0.024	-	-	0.610	0.027	-	-	0.850	0.093

T1 - SS + CP (50:50) + lime, T2 - SS + CP + Z (50:30:20) + lime, T3 - SS + SD (50:50) + lime, T4 - SS + SD + Z (50:30:20) + lime, T5 - SS + CP (50:50) + flyash, T6 - SS + CP + Z (50:30:20) + flyash, T7 - SS + SD (50:50) + flyash, T8 - SS + SD + Z (50:30:20) + flyash

D: Days of composting; SS: Sewage sludge; CP: Coirpith; Z: Zeolite; SD: Sawdust

4.2.1.15.5.1 Lead

On 0th day the residual fraction of lead was not significantly affected by the treatments. The highest value was attained by T_1 (35.13 mg kg^{-1}) and the lowest value was for T_8 treatment (29.00 mg kg^{-1}). Similar trend was observed on 30th day where T_1 recorded the highest value (36.80 mg kg^{-1}) which was on par with T_7 (34.50 mg kg^{-1}). The lowest value was obtained for T_8 (30.88 mg kg^{-1}). On 60th day the highest value was associated with T_1 (38.80 mg kg^{-1}) which was on par with T_2 (38.00 mg kg^{-1}), T_5 (37.02 mg kg^{-1}) and T_7 (36.90 mg kg^{-1}). The lowest value was observed in T_8 treatment (32.00 mg kg^{-1}).

4.2.1.15.5.2 Cadmium

During the initial sampling T_1 recorded the highest value (5.20 mg kg^{-1}) and the least value was observed in T_6 treatment (4.79 mg kg^{-1}). On 30th day there was no significant difference between the treatments. The highest value was observed in T_7 (5.49 mg kg^{-1}) and the lowest was observed in T_8 (5.09 mg kg^{-1}). On 60th day the highest value was observed in T_1 (5.74 mg kg^{-1}) which was on par with T_4 (5.63 mg kg^{-1}), T_6 (5.67 mg kg^{-1}) and T_7 (5.65 mg kg^{-1}). The lowest value was observed in T_8 treatment (5.25 mg kg^{-1}).

4.2.1.15.5.3 Nickel

An increasing trend of residual fraction with time was observed. T_3 had the highest value on 0th day (65.96 mg kg^{-1}), 30th day (67.79 mg $kg^{-}1$) and 60th day (68.94 mg kg^{-1}). On 0th day and 30th day the lowest value was recorded in T_2 treatment (42.04 mg kg^{-1} and 44.45 mg kg^{-1} respectively). The lowest value on 60th day was observed in T_6 treatment (48.76 mg kg^{-1}).

4.1.2.15.5.4 Chromium

T_3 recorded the highest value during 0th, 30th and 60th day of composting. On 0th day the highest value of 47.09 mg kg^{-1} which was on par with T_1 (43.97 mg kg^{-1}),

Table 31. Effect of treatments on residual fractions of heavy metals, mg kg $^{-1}$

	0 D				30 D				60 D			
	Pb	Cd	Ni	Cr	Pb	Cd	Ni	Cr	Pb	Cd	Ni	Cr
T_1	35.13	5.20	48.82	43.97	36.80	5.42	50.55	45.60	38.80	5.74	55.48	48.19
T_2	31.00	4.87	42.04	39.19	32.09	5.28	44.45	43.47	38.00	5.58	50.26	46.03
T_3	30.13	5.02	65.96	47.09	32.32	5.40	67.79	50.16	34.25	5.61	68.94	52.00
T_4	29.01	5.07	49.15	43.96	31.77	5.47	54.95	46.39	34.90	5.63	58.00	48.99
T_5	32.02	5.00	50.35	45.64	34.29	5.27	53.04	49.13	37.02	5.42	56.03	51.02
T_6	30.03	4.79	45.00	42.59	32.82	5.33	46.95	45.63	36.00	5.67	48.76	47.02
T_7	33.62	5.09	53.78	40.44	34.50	5.49	56.04	44.01	36.90	5.65	56.00	45.99
T_8	29.00	4.87	55.00	38.82	30.88	5.09	56.16	41.50	32.00	5.25	56.79	44.90
SE		-	1.11	1.21	0.92	-	1.27	1.08	0.64	0.04	1.33	1.28
CD	NS	NS	3.68	3.99	3.06	NS	4.30	3.56	2.10	0.12	4.40	4.23

T1 - SS + CP (50:50) + lime, T2 - SS + CP + Z (50:30:20) + lime, T3 - SS + SD (50:50) + lime, T4 - SS + SD + Z (50:30:20) + lime, T5 - SS + CP (50:50) + flyash, T6 - SS + CP + Z (50:30:20) + flyash, T7 - SS + SD (50:50) + flyash, T8 - SS + SD + Z (50:30:20) + flyash

D: Days of composting; SS: Sewage sludge; CP: Coirpith; Z: Zeolite; SD: Sawdust

T_4 (43.96 mg kg^{-1}) and T_5 (45.64 mg kg^{-1}) were found to be on par with T_3. The lowest value was recorded by T_8 (38.82 mg kg^{-1}). The highest value during the 30th day was 50.16 mg kg^{-1} and the lowest was observed in T_8 treatment (41.50 mg kg^{-1}). On 60th day also a similar trend was seen.

From the results it can be concluded that the compost T_8 (sewage sludge + sawdust + coirpith (50:30:20) + flyash) was superior with respect to stabilization of heavy metals.

4.2. POT CULTURE EXPERIMENT

A pot culture experiment was conducted to evaluate the suitability of sewage sludge compost as a growth medium for ornamentals.

4.2.1 Physical, Chemical and Biological Properties of Growing Media Before and After the Experiment.

4.2.1.1 pH, EC and Organic Carbon

The data on pH, EC and organic carbon content of growing media as influenced by various treatments at the initial and at the end of the experiment are given in the Table 32.

pH of the initial growing media ranged from 4.36 to 5.76. Soil + compost 8, 1:1 (T_9) recorded the highest pH and was followed by treatment T_8 (5.26). The lowest mean value was recorded by the treatment T_1 (4.36).

Soil + compost 8, 1:1 (T_9) registered the highest pH of 4.89 in final growing media which was on par with T_5 (4.79). The lowest pH was observed in treatment T_6 (3.35) followed by T_7 (3.96).

The effects of treatments on EC of initial and final growing media is presented in Table. 32. The results revealed that the treatments significantly influenced the EC content. The treatment T_1 recorded the highest E C of 3.60 dS m^{-1} initially, which was followed by T_7 (2.10 dS m^{-1}).

After the experiment EC content of the growing media reduced and the treatment T_1 recorded the highest value of 1.87 dS m^{-1} and was followed by treatment T_3 (1.32 dS m^{-1}). The treatment T_8 (Soil + Compost 7, 1:1) registered lowest value of (1.00 dS m^{-1}).

There was a reduction in organic carbon content of final growing media as depicted in Table 32. Organic carbon content of initial and final growing media also varied significantly with the treatments. T_1 (Soil + sewage sludge 1:1) recorded the highest organic carbon content (6.89 %) and was followed by treatment T_6 (6.70 %) which were on par. The lowest mean value was recorded in the treatment T_7 (4.10 %) and was on par with T_3 (4.55 %).

Soil + compost 7, 1:1 (T_8) registered the highest organic carbon content of 4.86 % in final growing media which was significantly superior to other treatments. The lowest content was observed in treatment T_7 (2.46 %) and was on par with treatment T_3 (2.51 %).

4.2.1.2 Effect of Treatments onPprimary Nutrient Content of Growing Media

The primary nutrient content of growing media before and after the experiment is represented in the Table. 33 Perusal of the data indicated that available nitrogen content of the growing media varied significantly with the treatments before and after the experiment.

4.2.1.2.1 Available Nitrogen

In the initial growing media, the highest available nitrogen content of 626.24 g kg^{-1} was observed in treatment T_1 (soil + sewage sludge, 1:1) which was significantly higher than all other treatments and the lowest of 311.64 g kg^{-1} was recorded by the treatment T_6 (soil + compost 5, 1:1).

Table 32. Effect of treatments on physico- chemical properties of growth media

Treatments	pH		EC (dS m^{-1})		OC (%)	
	Initial	Final	Initial	Final	Initial	Final
T_1 soil + sewage sludge (1:1)	4.36	4.06	3.60	1.87	6.89	3.54
T_2 soil + compost 1 (1:1)	4.75	4.50	1.30	1.10	5.98	4.26
T_3 soil + compost 2 (1:1)	4.91	4.76	1.40	1.32	4.55	2.51
T_4 soil + compost 3 (1:1)	4.75	4.60	1.15	1.05	6.05	3.92
T_5 soil + compost 4 (1:1)	5.06	4.79	1.27	1.05	5.79	4.30
T_6 soil + compost 5 (1:1)	4.76	3.35	1.50	1.15	6.70	3.87
T_7 soil + compost 6 (1:1)	4.75	3.96	2.10	1.27	4.10	2.46
T_8 soil + compost 7 (1:1)	5.26	4.35	1.30	1.00	7.15	4.86
T_9 soil + compost 8 (1:1)	5.76	4.89	1.60	1.07	6.11	4.52
SE (m±)	0.04	0.03	0.06	0.04	0.25	0.07
CD (0.05)	0.12	0.11	0.19	0.12	0.76	0.22

Soil + sewage sludge (1:1) registered the highest available nitrogen content in final growing media 420.33 g kg^{-1} which was significantly superior to other treatments. The lowest content was observed in treatment T_4 (198.5 g kg^{-1})

4.2.2.2 Available phosphorus

Available Phosphorus content of initial and final growing media (Table 33) also varied significantly with the treatments. Soil + sewage sludge (1:1) recorded the highest available phosphorus content (112 g kg^{-1}) followed by treatment T_6 (88.25 g kg^{-1}). The lowest mean value was recorded in the treatment T_2 (67.33 kg ha^{-1}) and was on par with T_4 (72.08 g kg^{-1}) and T_5 (68.39 g kg^{-1}).

Soil + sewage sludge (1:1) registered the highest available phosphorus content in final growing media (79.54 g kg^{-1}) which was significantly superior to other treatments. The lowest content was observed in treatment T_8 (46.50 g kg^{-1}) and was on par with treatment T_9 (50.54 g kg^{-1}).

4.2.2.3 Available Potassium

The effects of treatments in available potassium content of initial and final growing media is presented in Table. 33. The results revealed that the treatments significantly influenced the available potassium content. The treatment T_1 and T_5 recorded the highest available potassium content of 356.04 g kg^{-1} initially, whereas the lowest content was observed by the treatment T_2 (163.83 g kg^{-1})

After the experiment the available potassium content of the growing media reduced and the treatment T_3 recorded the highest value of 230.8 g kg^{-1} and was followed by treatment T_1 (224.94 g kg^{-1}). The treatment T_4 (Soil + Compost 3 (1:1)) registered lowest value of 121.31 g kg^{-1}.

Table 33. Effect of treatments on primary nutrient status of growing media

Treatments	N (g kg $^{-1}$)		P (g kg $^{-1}$)		K (g kg $^{-1}$)	
	Initial	Final	Initial	Final	Initial	Final
T_1 soil + sewage sludge (1:1)	626.24	420.33	112.00	79.54	356.04	224.94
T_2 soil + compost 1 (1:1)	448.29	253.10	67.33	56.83	163.83	131.34
T_3 soil + compost 2 (1:1)	403.54	210.38	74.65	62.51	243.23	230.80
T_4 soil + compost 3 (1:1)	360.69	198.50	72.08	53.38	190.39	121.31
T_5 soil + compost 4 (1:1)	503.45	223.70	68.39	55.69	356.04	126.38
T_6 soil + compost 5 (1:1)	311.64	237.15	88.25	57.56	215.37	128.60
T_7 soil + compost 6 (1:1)	426.88	212.56	77.29	70.64	243.39	177.67
T_8 soil + compost 7 (1:1)	350.24	210.33	80.30	46.50	255.14	183.27
T_9 soil + compost 8 (1:1)	463.22	248.20	73.54	50.54	223.66	181.22
SE (m±)	2.06	2.87	1.87	1.83	2.69	1.44
CD (0.05)	6.129	8.538	5.562	5.445	7.986	4.280

4.2.3 Secondary Nutrient Content of Growing Media

The data on secondary nutrients like calcium, magnesium and sulphur in growing media as influenced by the treatments are presented in Table. 34

4.2.3.1 Exchangeable Calcium

The treatments had significant influence on the exchangeable calcium content (Table 34). Highest initial exchangeable calcium content was observed in the treatment T_1 (971.60 mg kg^{-1}) and was followed by treatment T_5 (606.44 mg kg^{-1}). Treatment T_8 recorded the lowest value of 409.55 mg kg^{-1}.

The mean values of exchangeable Ca ranged from 311.64 mg kg^{-1} to 626.24 mg kg^{-1} after the experiment. T_1 registered the highest mean (626.24 mg kg^{-1}) which was significantly higher than other treatments. The lowest mean value of 311.64 mg kg^{-1} was associated with treatment T_6 (soil + compost 5, 1:1).

4.2.3.2 Exchangeable Magnesium

It is inferred from the Table 34 that exchangeable Mg content was significantly influenced by different treatments in both initial and final growing media. The initial exchangeable Mg content was highest for the treatment T_1 (330.11 mg kg^{-1}) and was followed by treatment T_4 (300.36 mg kg^{-1}). The treatment soil + compost 4 (1:1) was inferior to all other treatments with an exchangeable Mg content of 160.53 mg kg^{-1}.

The exchangeable Mg content of final growing media also varied significantly with the treatments and the highest mean value was observed in the treatment T_1 (230.39 mg kg^{-1}) and was on par with T_4 (228.40 mg kg^{-1}) and T_9 (228.19 mg kg^{-1}) whereas the lowest was observed in the treatment T_5 (104.25 mg kg^{-1}).

4.2.3.3 Available Sulphur

The data pertaining to available Sulphur content of initial and final growing media is given in Table. 34 Soil + Sewage sludge (1:1) resulted in the highest available Sulphur content (349.80 mg kg^{-1}) and was found to be significantly superior to all other treatments and the lowest mean value of 116.39 mg kg^{-1} was recorded in the treatment T_4 (soil + compost 3, 1:1).

The treatment T_7 (soil + compost 6, 1:1) resulted in the highest available Sulphur content (278.69 mg kg^{-1}) of final growing media and was followed by treatment T_1 (248.30 mg kg^{-1}). Lowest mean value of 100.47 mg kg^{-1} was registered by treatment T_4 which was statistically on par with T_6 (102.26 mg kg^{-1}).

4.2.4. Micronutrient Content of Growing Media

The results with respect to micronutrients (iron, manganese, copper, zinc and boron) content in growing media as influenced by the treatments are presented in Table. 35 and 36.

4.2.4. 1 Available Iron

The Fe content of growing media varied significantly with the treatments. In the initial growing media the highest value of 146.07 mg kg^{-1} was recorded by the treatment T_1 and was followed by T_7 (135.42 mg kg^{-1}) in initial growing media. The lowest value of 81.40 mg kg^{-1} was recorded in the treatment T_2 which was on par with T_6 (84.69 mg kg^{-1}) and T_4 (84.35 mg kg^{-1}).

The available iron content in final growing media also varied significantly and the highest value was recorded in treatment T_1 (88.12 mg kg^{-1}) and the lowest was observed in treatment T_4 (31.60 mg kg^{-1}) which was on par with T_6 (34.52 mg kg^{-1}).

Table 34. Effect of treatments on secondary nutrient content of growing media

Treatments	Ca (mg kg^{-1})		Mg (mg kg^{-1})		S (mg kg^{-1})	
	Initial	Final	Initial	Final	Initial	Final
T_1 soil + sewage sludge (1:1)	971.60	626.24	330.11	230.39	349.80	248.30
T_2 soil + compost 1 (1:1)	516.17	448.29	190.22	176.83	181.48	119.00
T_3 soil + compost 2 (1:1)	460.47	403.54	258.78	186.28	217.34	121.37
T_4 soil + compost 3 (1:1)	432.69	360.69	300.36	228.40	116.39	100.47
T_5 soil + compost 4 (1:1)	606.44	503.45	160.53	104.25	299.08	204.39
T_6 soil + compost 5 (1:1)	413.14	311.64	226.45	182.07	192.54	102.26
T_7 soil + compost 6 (1:1)	480.39	426.88	190.03	128.14	314.02	278.69
T_8 soil + compost 7 (1:1)	409.55	350.24	246.21	206.18	196.36	139.14
T_9 soil + compost 8 (1:1)	523.15	463.22	286.40	228.19	305.28	191.28
SE(m±)	3.39	2.06	3.35	2.25	1.96	1.94
CD (0.05)	10.07	6.129	9.950	6.678	5.876	5.753

4.2.4.2 Available Manganese

Available Mn content was significantly influenced by the treatments. The treatment with soil + sewage sludge (T_1) recorded the highest available Mn content (126.39 mg kg^{-1}) and the lowest was observed in treatment T_8 (61.13 mg kg^{-1}). The treatment T_1 registered significantly higher available Mn content of 53.24 mg kg^{-1} in final growing media also. The treatments T_4, T_2, T_8 and T_9 exhibited the lowest on par values of 23.24 mg kg^{-1}, 22.19 mg kg^{-1}, 21.31 mg kg^{-1} and 20.33 mg kg^{-1} respectively.

4.2.4.3 Available Zinc

The treatment T_1 recorded the highest available Zn content of 141.08 mg kg^{-1} and 46.10 mg kg^{-1} in initial and final growing media respectively. The lowest value for available Zn content in initial growing media was observed by T_4 (19.52 mg kg^{-1}) and was on par with T_6 (21.46 mg kg^{-1}) and T_8 (21.06 mg kg^{-1}) whereas the treatment T_7 registered the lowest Zn content (18.32 mg kg^{-1}) in final growing media which was found to be on par with T_9 (22.24 mg kg^{-1}), T_3 (21.38 mg kg^{-1}), T_8 (20.54 mg kg^{-1}), T_6 (20.34 mg kg^{-1}) and T_4 (18.40 mg kg^{-1}).

4.2.4.4 Available Copper

The treatments had a significant influence on the available Cu content. The treatment T_1 registered the highest available Cu content in both initial and final growing media with mean values of 26.20 mg kg^{-1} and 10.38 mg kg^{-1} respectively. The treatment T_4 recorded the lowest value (8.33 mg kg^{-1}) in initial growing media and was on par with T_5 (11.52 mg kg^{-1}), T_2 (9.16 mg kg^{-1}), T_8 (8.42 mg kg^{-1}), T_9 (8.40 mg kg^{-1}) and T_6 (8.38 mg kg^{-1}). In final growing media the treatment T_6 resulted in the lowest available Cu content (2.32 mg kg^{-1}) and was found to be on par with T_4 (3.21 mg kg^{-1}), T_2 (3.17 mg kg^{-1}), T_9 (3.14 mg kg^{-1}) and T_8 (3.10 mg kg^{-1}).

4.2.4. 5 Available Boron

The influence of treatments on B content of growing media was found to be significant and the highest B content of 1.116 mg kg^{-1} was recorded by treatment T_3 (soil + compost 2 (1:1) in initial growing media and was significantly superior to other treatments. In final growing media the treatment T_3 recorded the highest mean value of 0.650 mg kg^{-1} and was found to be on par with treatment T_7 (0.610 mg kg^{-1}). The lowest available B content in initial growing media was observed in treatment T_4 (0.203 mg kg^{-1}) and was on par with T_5 (0.223 mg kg^{-1}) and T_2 (0.266 mg kg^{-1}). Treatment T_5 resulted in the lowest available B content (0.103 mg kg^{-1}) in final growing media and was found to be on par with T_4 (0.126 mg kg^{-1}).

4.2.5 Heavy Metal Content of Growing Media

The results with respect to heavy metals (cadmium, nickel, arsenic, chromium and lead) in growing media as influenced by the treatments are presented in Table. 37 and 38

4.2.5.1 Available Cadmium

Available Cd content was significantly influenced by the treatments. The treatment with soil + sewage sludge (T_1) recorded the highest available Cd content (2.22 mg kg^{-1}) and the lowest was observed in treatment T_8 (1.04 mg kg^{-1}). The treatments T_5, T_3 and T_8 exhibited the lowest on par values of 1.07 mg kg^{-1}, 1.10 mg kg^{-1}, and 1.23 mg kg^{-1} respectively.

The treatment T_1 registered highest available Cd content of 1.33 mg kg^{-1} in final growing media also. It was on par with T_3 (0.34 mg kg^{-1}).

4.2.5.2 Available Nickel

In the initial growing media, soil + sewage sludge 1:1 (T1) resulted in the highest available Nickel content (10.40 mg kg^{-1}) and was found to be significantly

Table 35: Effect of treatments on micronutrient content of growing media

Treatments	Boron (mg kg $^{-1}$)		Iron (mg kg $^{-1}$)		Manganese (mg kg $^{-1}$)	
	Initial	Final	Initial	Final	Initial	Final
T_1 soil + sewage sludge, (1:1)	0.986	0.620	146.07	88.12	126.39	53.24
T_2 soil + compost 1 (1:1)	0.266	0.226	81.40	38.25	75.08	22.19
T_3 soil + compost 2 (1:1)	1.116	0.650	110.310	56.06	106.42	33.12
T_4 soil + compost 3 (1:1)	0.203	0.126	84.35	31.60	79.170	23.24
T_5 soil + compost 4 (1:1)	0.223	0.103	101.58	68.24	72.40	24.16
T_6 soil + compost 5 (1:1)	0.460	0.340	84.69	34.52	67.97	28.28
T_7 soil + compost 6 (1:1)	0.960	0.610	135.42	56.23	95.78	31.55
T_8 soil + compost 7 (1:1)	0.686	0.486	98.05	47.22	61.13	21.31
T_9 soil + compost 8 (1:1)	0.596	0.410	104.44	49.19	70.97	20.33
SE (m±)	0.030	0.020	1.730	2.080	1.710	1.630
CD (0.05)	0.087	0.054	5.146	6.183	5.061	4.829

Table 36: Effect of treatments on micronutrient content of growing media

Treatments	Zinc (mg kg $^{-1}$)		Copper (mg kg^{-1})	
	Initial	Final	Initial	Final
T_1 soil + sewage sludge (1:1)	141.08	46.10	26.20	10.38
T_2 soil + compost 1 (1:1)	24.21	24.79	9.16	3.17
T_3 soil + compost 2 (1:1)	38.50	21.38	15.45	8.42
T_4 soil + compost 3 (1:1)	19.52	18.40	8.33	3.21
T_5 soil + compost 4 (1:1)	43.62	32.02	11.52	7.58
T_6 soil + compost 5 (1:1)	21.46	20.34	8.38	2.32
T_7 soil + compost 6 (1:1)	29.72	18.32	12.40	6.42
T_8 soil + compost 7 (1:1)	21.06	20.54	8.42	3.10
T_9 soil + compost 8 (1:1)	29.37	22.24	8.40	3.14
SE (m±)	1.54	1.60	1.27	0.61
CD (0.05)	4.578	4.751	3.785	1.815

superior to all other treatments and the lowest mean value of 1.26 mg kg^{-1} was recorded by the treatment T_9 (soil + compost 8, 1:1).

The treatment T_1 (soil + sewage sludge, 1:1) resulted in the highest available Nickel content (7.60 mg kg^{-1}) of final growing media and was followed by treatment T_7 (2.01 mg kg^{-1}). This was on par with T_2 (1.90 mg kg^{-1}) and T_3 (1.82 mg kg^{-1}). The lowest mean value of 1.03 mg kg^{-1} was registered by treatment T_9 which was statistically on par with T_4 (1.08 mg kg^{-1}) and T_5 (1.25 mg kg^{-1}).

4.2.5.3 Available Arsenic

Arsenic was not detected in any of the treatments in initial and final growing media.

4.2.5.4 Available Chromium

The results revealed that the treatments significantly influenced the available chromium content. The treatment T_1 recorded the highest available chromium content of 23.64 mg kg^{-1} which was followed by T_7 (18.20 mg kg^{-1}). The treatment T_9 recorded the least value of 14.27 mg kg^{-1} which was on par with T_8 (14.39 mg kg^{-1}) and T_3 (14.55 mg kg^{-1}).

After the experiment the available chromium content of the growing media reduced and the treatment T_1 recorded the highest value of 18.32 mg kg^{-1} and was followed by treatment T_7 (12.06 mg kg^{-1}) which was on par with T_2 (11.94 mg kg^{-1}). The treatment T_9 (soil + compost 8, 1:1) registered lowest value of 10.18 mg kg^{-1} which was on par with T_5 (10.48 mg kg^{-1}).

4.2.5.5 Available Lead

The lead content of growing media varied significantly with the treatments. In the initial growing media the highest value of 14.19 mg kg^{-1} was recorded in the treatment T_1 and was followed by T_4 (6.91 mg kg^{-1}) in initial growing media. This

Table 37. Effect of treatments on heavy metal content of growing media

Treatments	Cadmium (mg kg^{-1})		Nickel (mg kg^{-1})		Arsenic (mg kg^{-1})	
	Initial	Final	Initial	Final	Initial	Final
T_1 soil + sewage sludge, 1:1	2.22	1.33	10.40	7.60	ND	ND
T_2 soil + compost 1, 1:1	1.38	0.41	2.29	1.90	ND	ND
T_3 soil + compost 2, 1:1	1.10	0.34	2.12	1.82	ND	ND
T_4 soil + compost 3, 1:1	1.56	0.76	1.27	1.08	ND	ND
T_5 soil + compost 4, 1:1	1.07	0.62	1.45	1.25	ND	ND
T_6 soil + compost 5, 1:1	1.59	0.48	1.67	1.47	ND	ND
T_7 soil + compost 6, 1:1	1.35	0.40	2.32	2.01	ND	ND
T_8 soil + compost 7, 1:1	1.23	0.62	1.56	1.38	ND	ND
T_9 soil + compost 8, 1:1	1.04	0.30	1.26	1.03	ND	ND
SE (m±)	0.07	0.03	0.09	0.09	-	-
CD (0.05)	0.24	0.09	0.30	0.27	-	-

Table 38. Effect of treatments on heavy metal content of growing media

Treatment details	Chromium (mg kg^{-1})		Lead (mg kg^{-1})	
	Initial	Final	Initial	Final
T_1 soil + sewage sludge (1:1)	23.64	18.32	14.19	10.71
T_2 soil + compost 1 (1:1)	16.40	11.94	6.72	5.94
T_3 soil + compost 2 (1:1)	14.55	10.60	4.23	3.67
T_4 soil + compost 3 (1:1)	17.30	11.57	6.91	4.91
T_5 soil + compost 4 (1:1)	15.68	10.48	5.00	4.44
T_6 soil + compost 5 (1:1)	16.28	11.02	5.00	4.42
T_7 soil + compost 6 (1:1)	18.20	12.06	4.00	3.59
T_8 soil + compost 7 (1:1)	14.39	10.31	4.62	4.07
T_9 soil + compost 8 (1:1)	14.27	10.18	3.32	2.97
SE (m±)	0.29	0.13	0.07	0.10
CD (0.05)	0.94	0.40	0.23	0.33

Table: 39. Effect of treatments on enumeration of *E. coli*

Treatments	Initial	Final
T_1 soil + sewage sludge (1:1)	ND	ND
T_2 soil + compost 1 (1:1)	ND	ND
T_3 soil + compost 2 (1:1)	ND	ND
T_4 soil + compost 3 (1:1)	ND	ND
T_5 soil + compost 4 (1:1)	ND	ND
T_6 soil + compost 5 (1:1)	ND	ND
T_7 soil + compost 6 (1:1)	ND	ND
T_8 soil + compost 7 (1:1)	ND	ND
T_9 soil + compost 8 (1:1)	ND	ND

was on par with T_2 (6.72 mg kg^{-1}). The lowest value of 3.32 mg kg^{-1} was recorded for the treatment T_9 which was followed by T_7 (4.00 mg kg^{-1}).

The available lead content in final growing media also varied significantly and the highest value was recorded by the treatment T_1 (10.71 mg kg^{-1}) and the lowest was observed by the treatment T_9 (2.97 mg kg^{-1}).

4.2.6 Enumeration of E. coli

E. coli was not detected in the initial and final growth media.

4.2.7 Dehydrogenase Activity

The effects of treatments on dehydrogenase activity of initial and final growing media is presented in Table 40. The results revealed that the treatments significantly influenced the dehydrogenase activity. The treatment T_9 recorded the highest dehydrogenase activity of 16.317 μg TPF/gram soil/24 hr which was followed by T_3 (14.013 μg TPF/gram soil/24 hr). The treatment T_5 recorded the least value of 5.95 μg TPF/gram soil/24 hr which was on par with T_7 (6.717 μg TPF/gram soil/24 hr), T6 (7.103 μg TPF/gram soil/24 hr) and T_8 (7.637 μg TPF/gram soil/24 hr).

After the experiment the dehydrogenase activity increased and the treatment T_9 recorded the highest value of 66.603 μg TPF/gram soil/24 hr and was followed by treatment T_8 (44.617 μg TPF/gram soil/24 hr) and T_3 (40.307 μg TPF/gram soil/24 hr). The treatment T_1 (soil + sewage sludge, 1:1) registered lowest value of 18.750 μg TPF/gram soil/24 hr which was on par with T_2 (20.987 μg TPF/gram soil/24 hr) and T_4 (20.347 μg TPF/gram soil/24 hr).

4..3 Plant Growth Parameters

The treatments significantly influenced the plant growth parameters of marigold and the results are shown in Table 41.

Table 40. Dehydrogenase activity of initial and final growth media

Treatments	Dehydrogenase activity (µg TPF/gram soil/24 hr)	
	Initial	Final
T_1 soil + sewage sludge (1:1)	11.900	18.750
T_2 soil + compost 1 (1:1)	8.830	20.987
T_3 soil + compost 2 (1:1)	14.013	40.307
T_4 soil + compost 3 (1:1)	5.950	20.347
T_5 soil + compost 4 (1:1)	9.600	38.517
T_6 soil + compost 5 (1:1)	7.103	24.183
T_7 soil + compost 6 (1:1)	6.717	40.180
T_8 soil + compost 7 (1:1)	7.637	44.617
T_9 soil + compost 8 (1:1)	16.317	66.603
SE(m±)	0.765	0.855
CD (0.05)	2.289	2.561

4..3.1 Plant Height

The height of the plant was significantly influenced by the treatments. Treatment receiving soil + compost 8 (T_9) recorded the highest value (131.67 cm) and was significantly superior to all other treatments. It was followed by T_4 (117.00 cm) which was on par with T_8 (116.17 cm) and T_7 (115.50 cm) were found to be on par. The lowest value was observed in treatment T_1 (70.67 cm) which received soil and sewage sludge in 1:1 ratio.

4..3.2 Number of Primary Branches

There was a significant influence of treatment on the number of primary branches of marigold. The maximum no of primary branches (15.10) was observed in T_9 which was on par with T_8 (14.67) and T_7 (14.00). The lowest number of primary branches (7.67 Nos) was observed in the treatment receiving soil and sewage sludge in 1:1 ratio (T_1) which was on par with T_3 (9.00).

4..3.3 Number of Secondary Branches

The number of secondary branches ranged from 23.33 to 41.55. The maximum number of secondary branches was observed in T_7 (soil + compost compost 6, 1:1) which was on par with T_5 (39.00), T_9 (39.00) and T_6 (38.00). The minimum number of secondary branches (23.33) was associated with T_1 (soil+ sewage sludge, 1:1) which was on par with T_3 (23.66) and T_2 (25.33).

4.3.4 Floral Parameters

Table. 42 shows the floral parameters of marigold as influenced by different treatments.

4.3.4.1 Days to First Flowering

There was a significant influence of treatments on the number of days to first flowering in marigold. The days required for first flowering was lowest in T_9 (31.33).

Table: 41 Effect of treatments on vegetative parameters of marigold

Treatments	Height (cm)	Primary branches	Secondary branches
T_1 soil + sewage sludge (1:1)	70.67	7.67	23.33
T_2 Soil + compost 1(1:1)	92.67	12.67	25.33
T_3 Soil + compost 2 (1:1)	83.83	9.00	23.66
T_4 soil + compost 3 (1:1)	117.00	12.67	36.66
T_5 soil + compost 4 (1:1)	107.83	12.00	39.00
T_6 soil + compost 5 (1:1)	91.00	11.33	38.00
T_7 soil + compost 6 (1:1)	115.50	14.00	41.55
T_8 soil + compost 7 (1:1)	116.17	14.67	33.66
T_9 soil + compost 8 (1:1)	131.67	15.10	39.00
SE (m±)	1.99	0.78	1.47
CD (0.05)	5.96	2.35	4.42

This was on par with T_6 (33.67), T_7 (34.33) and T_5 (34.67). T_1 (soil + sewage sludge, 1:1) took the maximum number of days (42.67) followed by T_3 and T_4 (37.33).

4.3.4.2 Flower Length

The flower length of marigold was significantly influenced by the treatments. The highest flower length of 11.70 cm was associated with T_9 which was on par with T_7 (11.58 cm). T_1 recorded the lowest value of 10.39 cm which was on par with T_2 (10.51 cm), T_6 (10.66 cm) and T_8 (10.56 cm).

4.3.4.3 Flower Diameter

The values of flower diameter varied from 2.79 to 4.35 cm. Flower diameter was highest in T_9 (soil + compost 8, 1:1) which was on par with T_7 (3.96 cm) and T_6 (3.94 cm). The smallest flower diameter was noticed in T_1 (2.79 cm).

4.3.4.4 Flower Weight

The flower weight of marigold was significantly influenced by the treatments. Highest flower weight (2.54 g) was noticed in T_9 which was on par with T_4 (2.52 g), T_7 (2.47 g), T_5 (2.39 g), T_3 (2.31 g) and T_2 (2.29 g). The treatment T_1 recorded the lowest flower weight (1.79 g).

4.3.4.5 Number of Flowers per plant

The number of flowers per plant was significantly influenced by the treatments. Maximum number of flowers per plant was recorded in T_9 (232.02) which was on par with T_8 (231.31) followed by T_5 (212.98). This was on par with T_7 (204.84). The lowest number of flower was associated with T_1 (111.03).

4.3.5 Biochemical Properties

The data on the biochemical properties of marigold such as chlorophyll content in leaves, xanthophyll and flavonoid content in flowers are shown in Table 43.

Table 42. Effect of treatments on floral parameters of marigold

Treatments	Days to first flowering	Flower length (cm)	Flower diameter (cm)	Flower weight (g)	Flower number
T_1 soil + sewage sludge 1:1	42.67	10.39	2.79	1.79	111.03
T_2 soil + compost 1, 1:1	37.00	10.51	3.51	2.29	159.54
T_3 soil + compost 2, 1:1	37.33	11.40	3.45	2.31	140.15
T_4 soil + compost 3, 1:1	37.33	11.23	3.45	2.52	172.37
T_5 soil + compost 4, 1:1	34.67	11.31	3.58	2.39	212.98
T_6 soil + compost 5, 1:1	33.67	10.66	3.94	2.26	144.60
T_7 soil + compost 6, 1:1	34.33	11.58	3.96	2.47	204.84
T_8 soil + compost 7, 1:1	36.33	10.56	3.66	2.18	231.31
T_9 soil + compost 8, 1:1	31.33	11.70	4.35	2.54	232.02
SE (m±)	1.16	0.09	0.18	0.09	3.09
CD (0.05)	3.50	0.28	0.54	0.28	9.88

4.3.5.1 Chlorophyll content in leaves

There was no significant difference between treatments with respect to chlorophyll content of leaves.

4.3.5.2 Xanthophyll content in flower

Xanthophyll content in flower was not significantly influenced by the treatments. The highest value of 22.15 mg g^{-1} was in T_4 (soil +compost 3,1:1) and the lowest value of 10.16 mg g^{-1} was in T_1 (soil + sewage sludge, 1:1).

4.3.5.3 Flavonoid content in flower

The treatment was not significantly influenced by the treatments. The flavonoid content in flower varied from 176.00 to 186.00 mg of ME/g.

4.3.6 Yield and Yield Attributes

The treatments significantly influenced the yield and yield attributes of marigold as given in Table 44. .

4.3.6.1 Dry matter yield of shoot

The highest dry matter production of the shoot was associated with T_9 (43.5 g) followed by T_6 (41.087 g) which was on par with T_8 (40.177 g). The lowest dry matter production was in T_1 (19.747 g) which was on par with T_3 (20.320 g).

4.3.6.2 Dry matter yield of root

The treatments significantly influenced the dry matter production of root also. The maximum dry matter yield of root (2.32 g) was observed in T_9. This was followed by T_5 (1.92 g) which was on par with T_3 (1.89 g), T_4 (1.83 g), T_8 (1.8 g) and T_2 (1.65 g). The least value was observed in T_1 (0.98 g) which was on par with T_6 (1.3 g).

108

Table. 43 Effect of treatments on biochemical properties of marigold

Treatments	Chlorophyll in leaves (%)	Xanthophyll in flower (mg g^{-1})	Flavanoid in flower (mg of ME g^{-1})
T_1 soil + sewage sludge 1:1	3.67	10.16	176.00
T_2 soil + compost 1, 1:1	3.54	20.79	184.00
T_3 soil + compost 2, 1:1	3.62	18.65	186.00
T_4 soil + compost 3, 1:1	3.75	22.15	178.33
T_5 soil + compost 4, 1:1	3.48	19.54	178.00
T_6 soil + compost 5, 1:1	3.46	18.65	181.00
T_7 soil + compost 6, 1:1	3.27	19.66	183.33
T_8 soil + compost 7, 1:1	3.58	18.87	179.00
T_9 soil + compost 8, 1:1	3.66	14.36	176.00
SE (m±)	-	-	-
CD	NS	NS	NS

4.3.6.3 Flower yield

Flower yield of marigold was greatly influenced by the treatments. Significantly higher flower yield of 589.330 g was observed in T_9 (soil + compost 8 1:1). This was followed by T_5 (507 g) which was on par with T_7 (503.960 g) and T_8 (502.260 g). The lowest flower yield was associated with T_1 (198.530 g).

4.3.7 Primary Nutrient Content in Shoot, %

The results of primary nutrient content of marigold shoot is presented in Table 45.

4.3.7.1 Plant Nitrogen

The value of total nitrogen in shoot varied between 2.00 to 3.901 %. The highest value for shoot nitrogen was registered by the treatment soil + sewage sludge in 1:1 ratio (T_1) which was on par with T_3 (3.789 %). The least value was observed in T_7 treatment followed by T_9 (2.744 %).

4.3.7.2 Plant Phosphorus

The phosphorus content in shoot ranged from 0.397 % to 0.7 %. The highest value was observed in T_3 treatment followed by T_8 (0.575 %) and T_5 (0.518 %). The lowest value was shown by T_6 treatment followed by T_9 (0.447 %) and T_1 (0.496 %).

4.3.7.3 Plant Potassium

The treatment T_6 had the highest K content (3.760 %) in shoot as presented in the Table 45. The least concentration of K was found in T_1 treatment (2.213 %) followed by T_4 (2.493 %) and T_9 (2.707 %).

4.3.8 Secondary Nutrient Content

The secondary nutrient content in shoot is depicted in the Table 46.

Table: 44 Effect of treatments on yield and yield attributes of marigold

Mean	Dry matter yield of shoot (g)	Dry matter yield of root (g)	Flower yield g plant-^{1}
T_1 soil + sewage sludge 1:1	19.747	0.980	198.530
T_2 soil + compost 1, 1:1	23.780	1.650	364.350
T_3 soil + compost 2, 1:1	20.320	1.890	322.750
T_4 soil + compost 3, 1:1	33.800	1.830	431.350
T_5 soil + compost 4, 1:1	36.630	1.920	507.010
T_6 soil + compost 5, 1:1	41.087	1.300	325.700
T_7 soil + compost 6, 1:1	28.353	1.390	503.960
T_8 soil + compost 7, 1:1	40.177	1.800	502.260
T_9 soil + compost 8, 1:1	43.500	2.320	589.330
SE (m±)	0.733	0.111	3.225
CD (0.05)	2.195	0.359	10.317

4.3.8.1 Plant Calcium

The content of calcium in shoot ranged from 0.99 to 1.95 %. The treatment receiving sewage sludge and soil in 1:1 (T_1) recorded the highest calcium percentage in shoot followed by T_3, which was found to be on par (1.84 %). The least calcium content was observed in T_9 treatment (0.99 %) which was on par with T_5 (1.04 %), T_6 (1.17%) and T_7 (1.17 %).

4.3.8.2 Plant Magnesium

The treatments significantly influenced the content of magnesium in shoots of marigold. The value ranged from to 0.31 to 1.53 %. The highest value was recorded in T_1 treatment followed by T_5 (0.92 %) and T_6 (0.73 %). The least value was registered in T_3 (soil + compost 2, 1:1) followed by T_9 (0.41 %) and T_7 (0.43 %).

4.3.8.3 Plant Sulphur

The content in shoot ranged from 0.50 to 1.87 %. The highest value for sulphur was associated with T_1 treatment which was followed by T_7 (1.50 %) and T_3 (0.88 %). The least value was observed in T_6 (soil + compost 5, 1:1), which was followed by T_2 (0.56 %).

4.2.9 Micronutrient Content in Shoot

The effect of treatments on micronutrient content in shoot is presented in the Table 47.

4.2.9.1 Iron

The content of iron in root varies from 0.21 to 1.26 %. The highest value of iron was associated with T_5 treatment followed by T_3 (1.24 %) which were on par. The lowest value was obtained for T_9 followed by T_1 (0.60 %).

Table 45. Effect of treatments on primary nutrient content in shoot, %

Treatments	N	P	K
T_1 soil + sewage sludge (1:1)	3.901	0.496	2.213
T_2 soil + compost 1 (1:1)	3.211	0.553	3.093
T_3 soil + compost 2 (1:1)	3.789	0.700	3.293
T_4 soil + compost 3 (1:1)	2.987	0.511	2.493
T_5 soil + compost 4 (1:1)	3.136	0.518	2.867
T_6 soil + compost 5 (1:1)	3.435	0.397	3.760
T_7 soil + compost 6 (1:1)	2.000	0.530	2.920
T_8 soil + compost 7 (1:1)	3.173	0.575	3.120
T_9 soil + compost 8 (1:1)	2.744	0.447	2.707
SE (m±)	0.059	0.013	0.044
CD (0.05)	0.177	0.038	0.132

Table 46. Effect of treatments on secondary nutrient content in shoot, %

Treatments	Ca	Mg	S
T_1 soil + sewage sludge (1:1)	1.95	1.53	1.87
T_2 soil + compost 1 (1:1)	1.41	0.44	0.56
T_3 soil + compost 2 (1:1)	1.84	0.31	0.88
T_4 soil + compost 3 (1:1)	1.49	0.76	0.81
T_5 soil + compost 4 (1:1)	1.04	0.92	0.69
T_6 soil + compost 5 (1:1)	1.17	0.73	0.50
T_7 soil + compost 6 (1:1)	1.17	0.43	1.50
T_8 soil + compost 7 (1:1)	1.28	0.50	0.82
T_9 soil + compost 8 (1:1)	0.99	0.41	0.57
SE (m±)	0.08	0.11	0.01
CD (0.05)	0.24	0.34	0.03

4.2.9.2 Manganese

The treatment significantly influenced the Mn content in shoot. The values ranges from 0.01 to 0.09 mg kg^{-1}. The highest value was recorded by T_3 which was followed by T_7 (0.08 mg kg^{-1}) which were on par. The lowest value was obtained for T_5 followed by T_4 (0.02 mg kg^{-1}) and T_6 (0.02 mg kg^{-1}) which were on par.

4.2.9.3 Copper

The treatments influenced the copper content in shoot. The content in shoot ranged from 4.01 to 9.80 mg kg^{-1}. The highest value for Cu content in shoot was recorded in T_4 followed by T_1 (6.41 mg kg^{-1}). The least value was recorded in T_9 which was followed by T_3 (4.10 mg kg^{-1}) and T5 (4.52 mg kg^{-1}) which were on par.

4.2.9.4 Zinc

The content of zinc in shoot varied from 0.01 to 0.06 mg kg^{-1}. It was highest in treatment receiving soil and sewage sludge in 1:1 ratio (T_1) which was on par with T3 (0.05 mg kg^{-1}). The treatment T_s had the lowest zinc content and was on par with T_9 (0.02 mg kg^{-1}).

4.2.9.5 Boron

The treatment significantly influenced the boron content in shoot. The values ranged from 1.33 to 5.23 mg kg^{-1}. The highest value was recorded by T_2 which was followed by T_6 (2.85 mg kg^{-1}). The lowest value was obtained for T_7 followed by T_5 (1.35 mg kg^{-1}) and T_4 (1.53 mg kg^{-1}) which were on par.

4.2.10 Heavy Metal Content in Shoot

The influence of different treatments on heavy metal content in shoots of marigold are presented in Table 48.

Table : 47 Effect of treatments on micronutrient nutrient content in shoot, %

Treatments	B (mg kg^{-1})	Fe (%)	Zn (%)	Cu (mg kg^{-1})	Mn (mg kg^{-1})
T_1 soil + ss (1:1)	2.32	0.60	0.06	6.41	0.06
T_2 soil + compost 1 (1:1)	5.23	0.21	0.04	5.01	0.06
T_3 soil + compost 2 (1:1)	2.34	1.24	0.05	4.10	0.09
T_4 soil + compost 3 (1:1)	1.53	1.03	0.03	9.80	0.02
T_5 soil + compost 4 (1:1)	1.35	1.26	0.01	4.52	0.01
T_6 soil + compost 5 (1:1)	2.85	0.97	0.03	4.71	0.02
T_7 soil + compost 6 (1:1)	1.33	0.49	0.04	4.92	0.08
T_8 soil + compost 7 (1:1)	2.43	0.65	0.03	6.22	0.07
T_9 soil + compost 8 (1:1)	1.95	0.50	0.02	4.01	0.06
SE (m ±)	0.10	0.02	0.003	0.52	0.003
CD (0.05)	0.31	0.06	0.01	0.16	0.01

4.2.10.1 Cadmium

The content of cadmium in shoot varied from 0.010 to 0.042 mg kg^{-1}. It was highest in treatment receiving soil and sewage sludge in 1:1 ratio (T_1) which was significantly higher than all other treatments. This was followed by T_8 (0.017 mg kg^{-1}) which was on par with T_6 (0.016 mg kg^{-1}), T_4 (0.015 mg kg^{-1}), T_7 (0.014 mg kg^{-1}) and T_2 (0.013 mg kg^{-1}). The treatment T_3 had the lowest cadmium content which was on par with T_9 (0.011 mg kg^{-1}), T_5 (0.012 mg kg^{-1}), T_2 (0.013 mg kg^{-1}), T_7 (0.014 mg kg^{-1}), and T_4 (0.015 mg kg^{-1}).

4.2.10.2 Chromium

The value of chromium content in shoot ranges from 1.003 to 5.334 mg kg^{-1}. The highest value was observed in T_1. Least value was observed in T_7 which was on par with T_2 (1.209 mg kg^{-1}), T_3 (1.145 mg kg^{-1}) T_4 (1.141 mg kg^{-1}), T_5 (1.101 mg kg^{-1}) and T_9 (1.173 mg kg^{-1}).

4.2.10.3 Nickel

In shoot the content of nickel ranges from 0.063 to 2.729 mg kg^{-1}. The treatment receiving sewage sludge and soil in 1:1 ratio recorded the highest value for nickel which was followed by T_2 (0.122 mg kg^{-1}). The lowest value was observed in T_9 which was on par with T_5 (0.066 mg kg^{-1}).

4.2.10.4 Lead

The content of lead in shoot ranged from 0.411 to 2.375 mg kg^{-1}. The highest value was observed in T_1 treatment followed by T_4 (1.191 mg kg^{-1}) which was on par with T_2 (1.172 mg kg^{-1}) and T_6 (1.13 mg kg^{-1}). Least value was observed in T_9 which was on par with T_8 (0.500 mg kg^{-1}).

4.2.11 Primary Nutrient content in root

The data on content of primary nutrients in root is presented in Table 49.

116

Table 48. Effect of treatments on heavy metal content in shoot, %

Treatments	Cd	Cr	Ni	Pb
T_1 soil + sewage sludge 1:1	0.042	5.334	2.729	2.375
T_2 soil + compost 1 (1:1)	0.013	1.209	0.122	1.172
T_3 soil + compost 2 (1:1)	0.010	1.145	0.115	0.855
T_4 soil + compost 3 (1:1)	0.015	1.141	0.076	1.191
T_5 soil + compost 4 (1:1)	0.012	1.101	0.066	0.973
T_6 soil + compost 5 (1:1)	0.016	1.210	0.116	1.130
T_7 soil + compost 6 (1:1)	0.014	1.003	0.083	0.920
T_8 soil + compost 7 (1:1)	0.017	1.245	0.073	0.500
T_9 soil + compost 8 (1:1)	0.011	1.173	0.063	0.411
SE (m±)	0.002	0.070	0.017	0.048
CD (0.05)	0.005	0.224	0.055	0.154

Table 49. Effect of treatments on primary nutrient content in root, %

Treatments	N	P	K
T_1 soil + sewage sludge (1:1)	1.96	0.48	2.07
T_2 soil + compost 1 (1:1)	1.71	0.41	3.63
T_3 soil + compost 2 (1:1)	1.62	0.48	3.41
T_4 soil + compost 3 (1:1)	1.70	0.36	1.67
T_5 soil + compost 4 (1:1)	1.51	0.43	2.35
T_6 soil + compost 5 (1:1)	1.74	0.49	3.47
T_7 soil + compost 6 (1:1)	1.31	0.32	1.59
T_8 soil + compost 7 (1:1)	1.68	0.28	2.36
T_9 soil + compost 8 (1:1)	1.51	0.23	1.28
SE (m±)	0.05	0.01	0.05
CD (0.05)	0.16	0.04	0.15

4.2.11.1 Plant Nitrogen

Significant difference was observed in the case of nutrient content in root. The treatment T_1 registered the highest value (1.96 %) followed by T_6 (1.74 %) and T_2 (1.71 %). The least value was observed in T_7 (1.31 %).

4.2.11.2 Plant Phosphorus

The treatments influenced the phosphorus content in root. Phosphorus content in root ranged from 0.23 to 0.49 %. The highest value for P content in root was recorded by T_6 (0.49 %) followed by T_1 (0.48 %) and T_3 (0.048 %) which were on par. The least value was recorded by T_9 (0.23 %) which was on par with T_8 (0.28 %).

4.2.11.3 Plant Potassium

The value of potassium content in root ranged between 1.28 to 3.63 %. The highest value was registered by T_2 treatment followed by T_6 (3.47 %) and T_3 (3.41 %). The least value was obtained by T_9 which was followed by T_7 (1.59 %).

4.2.12 Secondary nutrients

The effect of treatments on secondary nutrient content in root is represented in the Table 50. The treatments significantly influenced the secondary nutrient content in root.

4.2.12.1 Plant Calcium

Calcium content in root was found to be highest in T_3 and T_4 (0.088 %) which were significantly higher from all other treatments. The lowest value of 0.32 % was observed in T_1 (soil + sewage sludge, 1:1) and T_5 (soil + compost 4, 1:1).

4.2.12.2 Plant Magnesium

The magnesium content of root varied from 0.90 to 2.08 %. The highest value was recorded by T_6 (soil + compost 5, 1:1) which was followed by T_1 (1.82 %). The lowest value was associated with T_9 followed by T_3 (1.15 %) which were on par.

4.2.12.3 Plant Sulphur

The sulphur content in root was also influenced by the treatments. T_1 recorded the highest value (1.19 %) which was followed by T_4 (0.87 %). The least value for the same was recorded by T_7 (0.64 %) followed by T_5 (0.73 %).

4.2.13 Micronutrient content in root

The effect of treatments on micronutrient content in root is presented in the Table 51.

4.2.13.1 Iron

The content of iron in root varied from 0.23 to 0.35 %. The highest value of iron was associated with T_1 treatment followed by T_5 (0.34 %) and T_9 (0.34 %) which were found to be on par. The lowest value for iron was obtained for T_2 and T_8 (0.23 %).

4.2.13.2 Manganese

The treatments significantly influenced the manganese content in root. The values ranges from 111.60 to 724 mg kg^{-1}. The highest value was recorded in T_1 which was followed by T_4 (614.90 mg kg^{-1}). The lowest value was obtained in T_3 followed by T_9 (137.20 mg kg^{-1}) and T_5 (141.20 mg kg^{-1}) which were on par.

4.2.13.3 Copper

The treatment influenced the copper content in root. The content in root ranged from 5.70 to 9.470 mg kg^{-1}. The highest value for copper content in root was recorded by T_4 followed by T_1 (9.440 mg kg^{-1}) and T_8 (9.22 mg kg^{-1}) which were on par. The least value was recorded by T_3 which was followed by T_9 (7.010 mg kg^{-1}).

4.2.13.4 Zinc

The content of zinc in shoot varied from 517.33 to 741.33 mg kg^{-1}. It was highest in treatment receiving soil and sewage sludge in 1:1 ratio (T_1) which was significantly higher than all other treatments. This was followed by T_8 (714.67 mg kg^{-1}). The treatment T_3 and T_7 had the lowest zinc content.

4.2.13.5 Boron

The treatments significantly influenced the boron content in root. The values ranges from 2.10 to 5.28 mg kg^{-1}. The highest value was recorded by T_6. The lowest value was obtained for T_5 (2.10 mg kg^{-1}) followed by T_8 (2.97 mg kg^{-1}) and T_9 (3.09 mg kg^{-1}).

4.2.14 Heavy metal content in roots

The data on heavy metal content in roots as influenced the various treatments are given in Table 51.

4.2.14.1 Cadmium

The treatments significantly influenced the cadmium content in the roots of marigold plants. The treatment receiving soil and sewage sludge in 1:1 ratio (T_1) showed the highest value of 0.323 mg kg^{-1} which was significantly higher than all other treatments. It was followed by T_6 (0.019 mg kg^{-1}). The least value (0.015 mg kg^{-1}) for cadmium in root was observed in T_9 which is received soil and compost 8 in 1:1 ratio.

4.2.14.2 Chromium

The highest chromium content value in roots as observed in T_1 (5.523 mg kg^{-1}) treatment, which was followed by T_2 (1.263 mg kg^{-1}). The lowest chromium

120

Table 50. Effect of treatments on secondary nutrient content in root, %

Treatments	Ca	Mg	S
T_1 soil + sewage sludge (1:1)	0.32	1.82	1.19
T_2 soil + compost 1 (1:1)	0.56	1.28	0.83
T_3 soil + compost 2 (1:1)	0.88	1.15	0.77
T_4 soil + compost 3 (1:1)	0.88	1.28	0.87
T_5 soil + compost 4 (1:1)	0.32	1.63	0.73
T_6 soil + compost 5 (1:1)	0.45	2.08	0.82
T_7 soil + compost 6 (1:1)	0.51	1.25	0.64
T_8 soil + compost 7 (1:1)	0.45	1.31	0.83
T_9 soil + compost 8 (1:1)	0.56	0.90	0.79
SE (m±)	0.06	0.08	0.003
CD (0.05)	0.17	0.25	0.01

Table 51. Effect of treatments on micronutrient content in root

Treatments	Fe (%)	Mn ($mg\ kg^{-1}$)	Cu ($mg\ kg^{-1}$)	Zn ($mg\ kg^{-1}$)	B ($mg\ kg^{-1}$)
T_1 Soil + sewage sludge (1:1)	0.35	724.00	9.440	741.33	3.99
T_2 Soil + compost 1 (1:1)	0.23	608.00	8.270	618.67	2.36
T_3 Soil + compost 2 (1:1)	0.33	111.60	5.700	517.33	2.73
T_4 Soil + compost 3 (1:1)	0.25	614.90	9.470	689.33	4.45
T_5 Soil + compost 4 (1:1)	0.34	141.20	7.820	556.00	2.10
T_6 Soil + compost 5 (1:1)	0.25	438.30	8.200	641.33	5.28
T_7 Soil + compost 6 (1:1)	0.33	160.80	8.500	517.33	3.86
T_8 Soil + compost 7 (1:1)	0.23	524.00	9.220	714.67	2.97
T_9 Soil + compost 8 (1:1)	0.34	137.20	7.010	572.00	3.09
SE (m ±)	0.003	14.34	0.752	3.33	0.34
CD (0.05)	0.01	43.03	0.232	10.01	1.02

content in root was observed in T_5 treatment (1.167 mg kg^{-1}) which receives soil and compost 4 in 1:1 ratio.

4.2.14.3 Nickel

The nickel content in the roots of marigold ranged from 0.154 mg kg^{-1} to 7.453 mg kg^{-1}. Treatments containing sewage sludge and soil in 1:1 ratio attained the highest value of 7.453 which was significantly higher than all treatments. The lowest value was attained for T_7 treatment (soil + compost 6) which was on par with T_5 (0.282 mg kg^{-1}) and T_4 (0.331 mg kg^{-1}).

4.2.14.4 Lead

The presence of lead could not be detected in the roots of marigold plants in any of the treatments.

4.2.14.5 Arsenic

Arsenic content was not detected in the roots of marigold plants in any of the treatments.

Table 52. Effect of treatments on heavy metal content in root, %

Treatments	Cd	Cr	Ni	Pb
T_1 soil + sewage sludge (1:1)	0.323	5.523	7.453	ND
T_2 soil + compost 1 (1:1)	0.018	1.263	0.511	ND
T_3 soil + compost 2 (1:1)	0.017	1.183	0.476	ND
T_4 soil + compost 3 (1:1)	0.018	1.196	0.331	ND
T_5 soil + compost 4 (1:1)	0.017	1.167	0.282	ND
T_6 soil + compost 5 (1:1)	0.019	1.28	0.516	ND
T_7 soil + compost 6 (1:1)	0.017	1.175	0.154	ND
T_8 soil +compost 7 (1:1)	0.018	1.256	0.358	ND
T_9 soil +compost 8 (1:1)	0.015	1.183	0.279	ND
SE (m±)	0.005	0.052	0.055	
CD (0.05)	0.014	0.155	0.179	-

Discussion

5. DISCUSSION

The investigation entitled "Heavy metal stabilized sewage sludge compost as a growth medium for ornamentals" was conducted in the department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani during 2017-2019 with the objective to prepare and characterize heavy metal stabilized sewage sludge compost and to utilize it as a growth medium for marigold. The results obtained from this study were discussed in this chapter.

5.1 COMPOSTING EXPERIMENT

5.1.1 Characterization of Composting Materials used for the preparation of Sewage Sludge Compost

Sewage sludge composts were prepared using different bulking agents, liming materials and heavy metal adsorbents. The materials used in this study namely sewage sludge, coirpith, sawdust (bulking agents) and zeolite (heavy metal adsorbent) were characterised for various chemical properties like p^H, EC, organic carbon, C:N ratio, total N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, B.

5.1.1.1 Sewage sludge

Application of sewage sludge to agricultural soil is increasing now a days. Even though sewage sludge is a rich source of organic carbon and other important nutrients the presence of heavy metals and pathogens is a limiting factor for its use. So the characterization of sewage sludge is important before its application to the soil.

The analysis of sewage sludge revealed that the sewage sludge generated from Muttathara sewage treatment plant had a pH of 5.36 and an electrical conductivity of 8.08 dS m^{-1}. The low can be explained by the fact that sludge samples contain large fraction of organic nitrogen which may be decomposed into amino acids. The ionization of amino acid release hydrogen ion which will contribute to acidity. Similar results were given by El-Nahhal *et al.* (2014). The high values for electrical conductivity may be due to the accumulation and concentration of high levels of soluble salts in sewage sludge. The results are in line with the findings of Novok and Trapp (2005).

Sewage sludge from Muttathara sewage treatment plant have a high organic carbon content of 17.03 %. Presence of high amount of organic matter may be the reason behind this high organic carbon content. Chitdeshwari *et al.* (2002) also reported that sewage sludge from Ukkadam have an organic carbon content of 15.9 %.

Analysis of sewage sludge revealed that it was rich in plant nutrients N (1.68 %), P (7.73 %), K (1.20 %), Ca (12.00 %), Mg (4.80 %), S (616.00 mg kg^{-1}), Fe (4500 mg kg^{-1}), Mn (1028.80 mg kg^{-1}), Zn (220.00 mg kg^{-1}), Cu (250.00 mg kg^{-1}) and B (23.06 mg kg^{-1}). Similar results were given by Asokan (2017) in sewage sludge from Muttathara sewage treatment plant which also had a high concentration of organic carbon, total N, P and K.

Presence of heavy metals metals are the limiting factors for the land application of sewage sludge. Heavy metal analysis of the sludge indicated that the sludge was contaminated with heavy metals. The sludge contained heavy metals Pb (73.20 mg kg^{-1}), Cr (113.20 mg kg^{-1}), Ni (122 mg kg^{1}) and Cd (10.8 mg kg^{-1}). Cr, Ni and Cd were above the critical limit. Arsenic was not detected in the sewage sludge. The main source of heavy metals in sewage sludge are waste water coming from various industries, domestic sewage , storm water run off from roads etc. Concentration of metals in sewage sludge depends upon the sewage origin, sewage treatment process and sludge treatment process (Singh and Agrawal, 2008). In a similar study, Feng *et al.* (2018) reported that heavy metals in sewage sludge were mainly from domestic wastewater.

The sludge had a high C:N ratio of 10.14, this may be due to the limited mobilization of nitrogen by incorporation into cell mass. This makes the availability of nitrogen at later stages of application. (Lloreta *et al.*, 2016)

5.1.1.2 *Coirpith*

Coirpith is the residue generated from coir manufacturing industry, obtained during the extraction of coir fiber from coconut husk. Coir pith is light, fluffy, spongy substance having high water-holding capacity (Meerow, 1995). The results revealed that coir pith used in this study had a pH of of 5.84 with an electrical conductivity of 0.72 dS m^{-1} and an organic carbon content of 58 %. N, P and K contents were 1.01 %, 0.02 % and 0.04 % respectively. The secondary nutrient content in coir pith were found to be Ca (0.16 %), Mg (0.19 %) and S (0.19 %). The content of Fe, Mn, Cu and Zn were 3165.20 mg kg^{-1}, 11.60 mg kg^{-1}, 24.40 mg kg^{-1} and

70 mg kg^{-1} respectively. Boron and heavy metals like cadmium, chromium, lead, nickel and arsenic were not detected. Tripetchkul *et al.* (2012) reported that coirpith had pH of 5.68. Abhiramy and Rose (2012) reported that NPK content of coirpith was found to be 0.68%, 0.27% and 0.04 % respectively. Muthurayar and Dhanarajann (2013) reported that raw coirpith recorded a P and K content of 0.02 % and 0.30 % respectively.

5.1.1.3 Sawdust

Sawdust is a byproduct from wood industry. The sawdust used in this study had a pH of of 5.66 with an electrical conductivity of 1.80 dS m^{-1} and an organic carbon content of 52.20 %. N, P and K content were 0.78 %, 0.01 % and 0.12 % respectively. The secondary nutrients such as Ca, Mg and S content in sawdust were found to be 0.08%, 0.48 % and 0.06%. The content of Fe, Mn and Zn were 682 mg kg^{-1}, 19.60 mg kg^{-1} and 51.20 mg kg^{-1} respectively. Boron, copper and heavy metals like cadmium, chromium, lead, nickel and arsenic were not detected. Nomeda *et al.* (2008) reported that sawdust had a pH of 5.6. Yousefi *et al.* (2013) reported that sawdust had a pH of 6.1 with an electrical conductivity of 1.80 dS m^{-1} and an organic carbon content of 54.08 %.

5.1.1.4 Zeolite

Zeolites are aluminosilicate minerals of alkali or alkaline earth metal which contains crystal water. Zeolites consist of three-dimensional networks of aluminate and silicone dioxide tetrahedral linked by partnership of all oxygen atoms. (Mumpton, 1978). The most important properties of zeolites are ion selectivity and cation exchange capacity (Colella, 1996).

The results revealed that zeolite used in this study had a pH of of 7.41 with an electrical conductivity of 0.17 dS m^{-1} and an organic carbon content of 2.32 %. N, P and K content were 0.22 %, 0.05 % and 0.12 % respectively. The secondary nutrients such as Ca, Mg and S content in zeolite were found to be 0.03%, 0.19 % and 0.01 % respectively. The content of Fe, Mn, Cu and Zn were 38.89 mg kg^{-1}, 2.93 mg kg^{-1}, 0.17 mg kg^{-1} and 0.15 mg kg^{-1} respectively. Boron and heavy metals like cadmium, chromium, lead, nickel and arsenic were not detected. The results are in line with the findings of Zorpas *et al.* (2008) who reported that zeolite had a pH of of 7.85 and EC of 0.155 dS m^{-1}.

5.1.2 Characterisation of Sewage Sludge Composts

The important advantage of composted manure is its maturity and stability. Composted manure have gained wide acceptance as organic manure due to its high level of organic matter and its ability to improve soil physical, chemical and biological properties (Eneji *et al.*, 2001). The prepared compost were analysed for physical, chemical and biological properties.

5.1.2.1 Physical Properties – Moisture Content and Bulk Density

Moisture content is an important parameter in composting process as these influences the activity of micro-organisms. Moisture content of the compost increased upto 30th day and after that there was a slight reduction in moisture content. Compost prepared with the combination of sewage sludge and coir pith attain the highest moisture content than that of sawdust. This may be due to the fact that coir pith have high absorption capacity and moisture retaining capacity than that of sawdust. Similar findings were also given by Jeyaseeli and Raj (2010). Spongy structure of coir pith helps in the retention of water. It absorbs over eight times its weight of water (Manickam and Subramaniyam, 2014). The variation in moisture content of the compost may be probably due to the variation in temperature during composting process. Similar findings were put forwarded by Nomeda *et al.* (2008).

Bulk density is an important parameter that optimises the composting process. Optimum conditions for the microbial development, microbial activity, and organic matter degradation is influenced by bulk density. A gradual increase of bulk density was observed during the composting period. The increase in bulk density might be due to the prominent reduction in volume of compost than that of the mass. Significant increase in bulk density during composting have been reported by Mohee and Mudhoo (2005).

5.1.2.2 Chemical Properties

5.1.2.2.1 pH, Electrical Conductivity and Organic carbon

The treatments had a significant effect on the, electrical conductivity and organic carbon during composting. The compost pH decreased during the 30th day of composting. This might be due to the production of organic acids from manures as suggested by Wakene *et al.* (2005). At

128

the end of composting period the pH value increased. Final increase in the pH of the compost should be due to the activity of proteolytic bacteria and high buffering capacity of bulking agents, which avoids further pH fluctuation (Rich *et al.*, 2018).

Electrical conductivity value increased during the composting period. The increase in EC value might be due to the release of nutrient elements from manure as a result of the mineralisation process. Glaser *et al.* (2015) reported similarly that during composting mineralisation process occurs and this causes the release of cationic and anionic nutrients. Thus electrical conductivity increases. The increase in electrical conductivity might have been due to the loss of weight of organic matter and release of different mineral salts in available forms as reported by Garg *et al.* (2006).

Organic carbon values gradually decreased during the composting period. This may be due the loss of organic matter during composting. This carbon loss may be due the oxidation of C to CO_2 during composting process as suggested by Khwairakpam and Bhargava (2006).

5.1.2.3 C: N ratio

C: N ratio is an important parameter as far as the availability of nutrients is concerned. There is a decrease in C:N ratio during composting. During the composting process the degradable organic matter is converted to volatile CO_2 and was removed from the compost. As compost age increases there is an increase of nitrogen content by the mineralisation of organic matter. Along with the loss of carbon and the increase of nitrogen content a reduction in C:N ratio occurs with time. The result are in line with the findings of Bazrafshan *et al.* (2006).

5.1.2.4 Effect of Treatments on Primary Nutrients

Treatments significantly influenced the nutrient status of composts. With ageing of compost there was an increase in the nutrient status of the compost.

Total nitrogen content increased during composting mainly due to the concentration effect (Bustamante *et al.*, 2008). The maximum value for nitrogen at the end of composting period was observed in T_1 treatment which was on par with T_5 treatment. The highest values for this treatment may be due to the common bulking agent *i.e.*, coir pith. The nitrogen content of

129

coirpith used was higher than that of sawdust. Coirpith also has have the ability of cation adsorption which reduces the loss of nitrogen during composting.

There was a significant increase of phosphorus and potassium content during composting. Due to the mineralisation process the nutrient value increased. In the final compost there was no significant increase in phosphorus content. In the case of final compost total potassium content was highest in T_8 (sewage sludge + sawdust + zeolite + flyash).

5.1.2.5 Effect of Treatment on Secondary Nutrients

Secondary nutrients also have an increasing trend towards the end of composting. There was significant influence of treatments on total calcium during composting. The highest value of calcium on 60th day was observed in T_8 (19.06 %), for magnesium it was in T_7 (12.72 %) and for sulphur it was T_8 (0.492 %) which was on par with T_7 (0.480 %). The gradual increase in this element may be due to the mineralization process as composting process advanced. Flyash is the residue produced from the coal combustion process which contain higher amount of MgO and CaO (Kaur and Sharma, 2017). The presence of flyash in the compost would have contributed to higher calcium and magnesium.

5.1.2.6 Effect of Treatments on Micronutrient Content

An increasing trend of content of micronutrients was observed at the end of the composting period. The increase in the concentration of the metals might be due to the reduction of compost mass. Similar opinion was put forwarded by Singh and Kalamdhad (2014). Similarly Stephens *et al.*, (2001) reported that as the degradation process in compost progress there is chance for the formation of iron oxy hydroxides. These produced hydrous oxide scavenge the metal from the composted mixture.

5.1.2.7 Effect of Treatments on Total Heavy Metal Content

Treatments significantly influenced the heavy metal content during composting. Similarly like all the other nutrients heavy metals like lead, cadmium, nickel and chromium increased at the end of composting period. The increase may be due to the reduction in compost mass at the end of composting. Similar results were reported by Hsu and Lo (2001) who explained that increase in the heavy metal concentration was due to weight loss of materials during organic

130

matter decomposition and mineralisation process. Even though there was an increases in total concentration of heavy metals in the final compost the concentration was less than that in the raw sewage sludge. This may be due to the dilution effect offered by the bulking agents as suggested by (Nomeda *et al*., 2008).

The lowest value for all the heavy metals were associated with T_8 treatment (sewage sludge + sawdust + zeolite (50:30:20) + flyash). This may be due to the characteristic properties of the components used in the compost. Sawdust is a by- product from wood industry. Sawdust contain the organic compounds like cellulose, hemicellulose and lignin along with polyphenolic groups. These polyphenolic group have the ability to bind heavy metal (Kaur and Sharma, 2017). With the addition of zeolite, environmental alkalinity increases, which helps promote the metal adsorption via surface complexation (Zorpas *et al.,* 2008). Researchers reported that natural zeolite used widely for decreasing the bioavailability and mobility of heavy metals in sewage sludge composting due to its sorption and exchangeable properties towards the heavy metals (Zorpas *et al*., 2000). Natural zeolite has the ability to uptake of heavy metals which are in easily available fractions, and exchange of sodium and potassium (Zorpas *et al.,* 2000; Singh and Kalamdhad, 2012). Flyash is a residue produced from the coal combustion process. Also flyash contain higher amount of MgO and CaO. These compounds have the ability to precipitate the heavy metals in sewage sludge compost and thus decrease the toxicity of heavy metals. Along with this fly ash is a pozzolanic material which reduces the availability of heavy metals.

5.1.2.8 Effect of Treatments on the Fractions of Heavy Metals

The determination of total heavy metal content does not give useful information about the bioavailability, remobilization capacity and behavior of metals in the environment (Hsu and Lo, 2001). Metal speciation gives an idea about the metal bioavailability and their bond strength. Usually heavy metals are associated with five fractions, they are exchangeable, carbonate, reducible, organic and residual fraction (Tessier *et al*., 1979). Metal mobility of the sewage sludge compost might be affected by the chemical composition, content of organic matter bounded metal and heavy metal speciation as suggested by Wang *et al.* (2005). Exchangeable and carbonate fractions of heavy metals are the most mobile fraction.

From the results of the fractionation studies it was observed that there was a decrease in mobile fractions namely exchangeable, carbonate and reducible fraction during composting. The

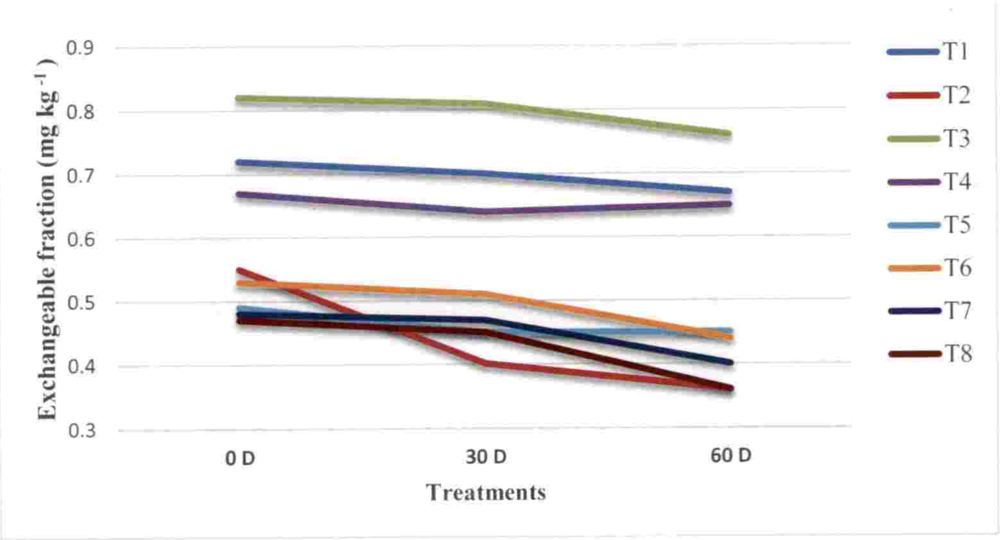


Fig 2: Effect of treatments on exchangeable fraction of Pb

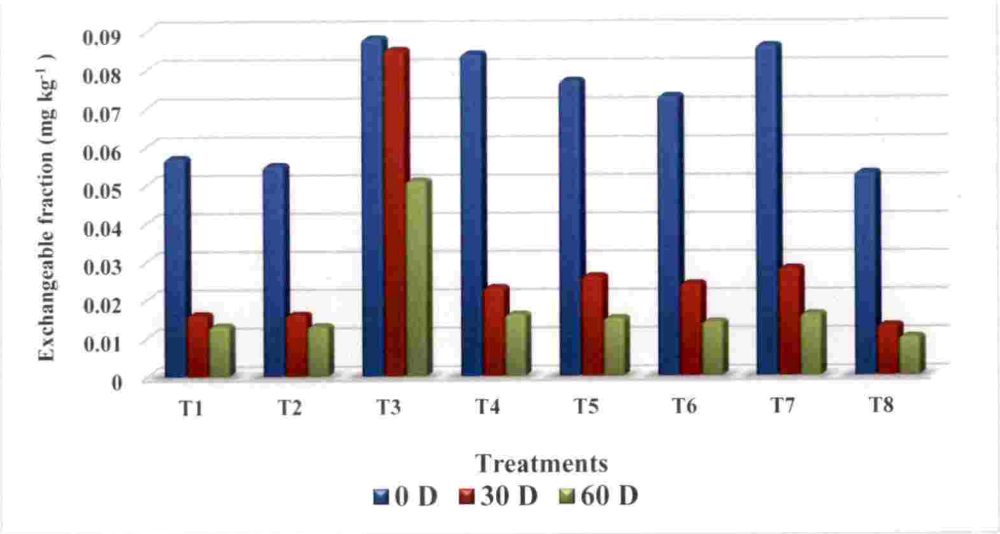


Fig 3: Effect of treatments on exchangeable fraction of Cd

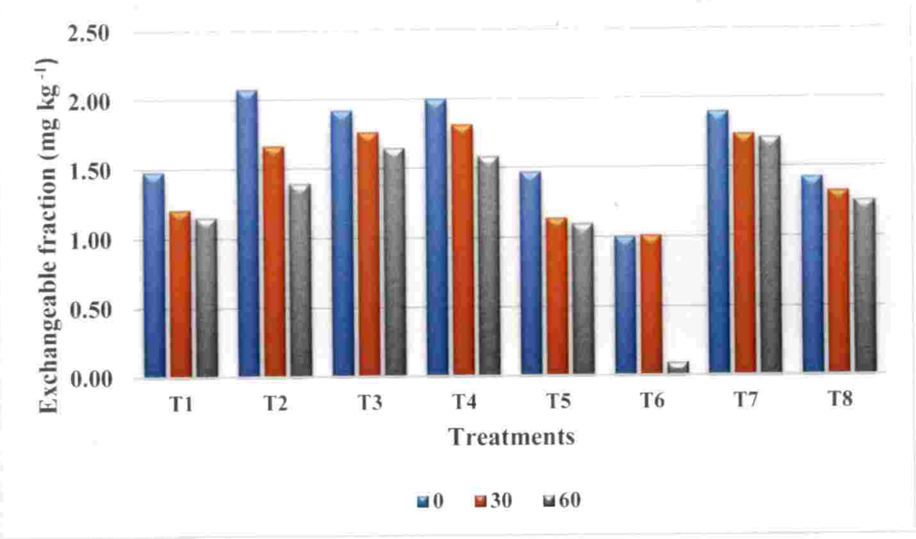


Fig 4: Effect of treatments on exchangeable fraction of Ni

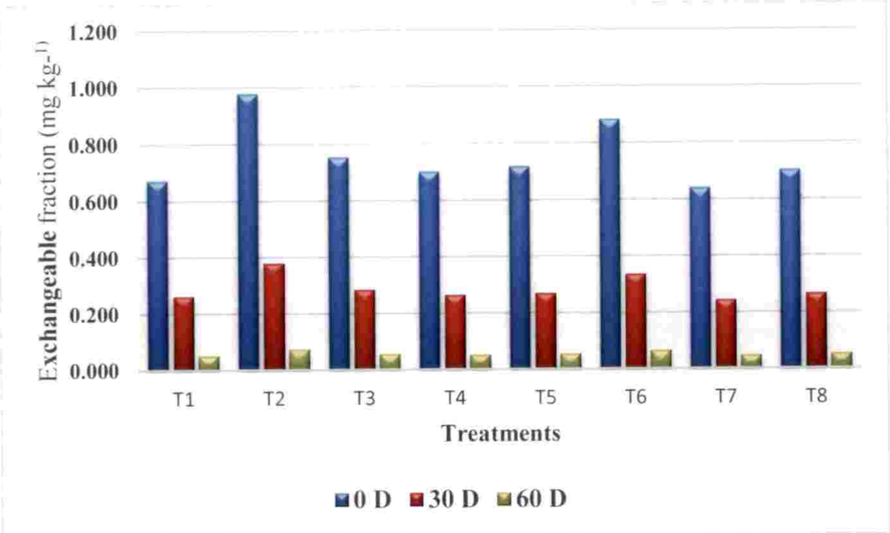


Fig:5 Effect of treatments on exchangeable fraction of Cr reason may be due to the fact that during composting the complexation of heavy metal occurs resulting in a decrease in the bioavailability.

5.1.2.8.1 Exchangeable fraction, Carbonate fraction and Reducible fraction

In all the treatments there was a reduction in exchangeable fraction of heavy metals. This fraction is very important as far as the mobility is concerned. As composting days increases a reduction in this fraction was observed. Exchangeable fraction was found to be low in zeolite amended compost. Similar results have also reported by Zorpas *et al.* (2008).

Like exchangeable fraction there was a reduction in carbonate fraction also. As composting days increase there was a reduction in carbonate fraction also. This might be due to the variation in pH. Zorpas *et al.* (2008) also reported that carbonate fractions changes with the environmental pH. At the end of composting there was an increase in pH of the compost. This may be the reason for the reduction in the availability of carbonate fraction during composting.

Only a slight change in reducible fraction was detected. This fraction is mainly associated with Fe-Mn oxides and are thermodynamically unstable under adverse conditions.

As composting advances a decline in the mobile fractions of lead was observed. This might be due to the changes in pH during composting. The development of slightly alkaline medium decreases the mobility of Pb by forming lead- humus complex. A drop in pH at the middle of composting period increases the mobility of lead and this metal binds with zeolite and gets transferred to the most stable fraction. This findings were in strong accordance with Zorpas *et al.* (2008) and Singh and Kalamdhad (2014).

A significant reduction in the mobile fractions of Nickel was observed during the composting period. This reduction may be due to the alkaline stabilization process. This can be explained with the help of similar findings given by Singh and Kalamdhad (2012). Similarly the mobility of cadmium decreased after composting. This may be due to the formation of strong chemical bond between cadmium and degraded organic matter (Haroun *et al.*, 2007). While considering the mobility of chromium there was a significant reduction in concentration of mobile fractions. The reduction in the concentration of exchangeable and carbonate fraction may be due to the strong bond formation between the various organic functional groups present in

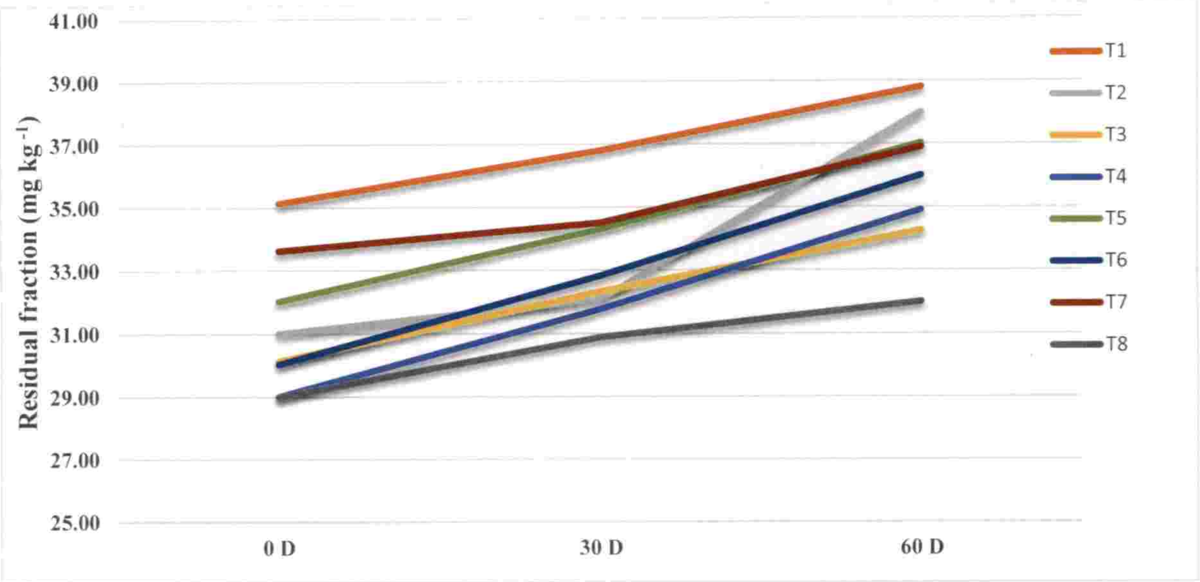


Fig: 6 Effect of treatments on residual fractions of Pb.

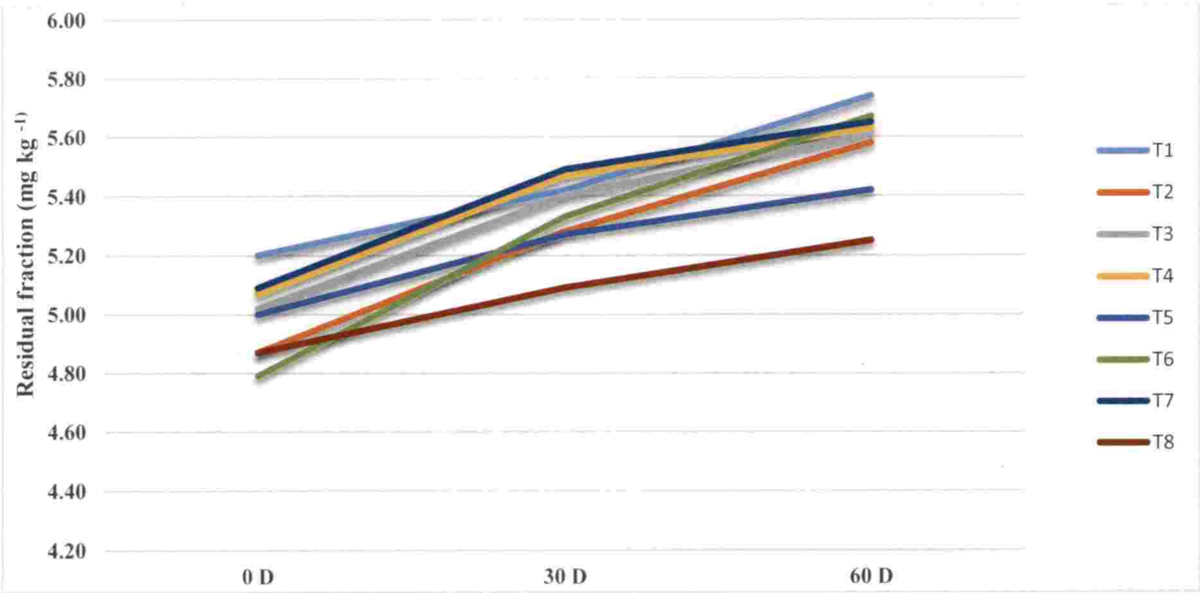
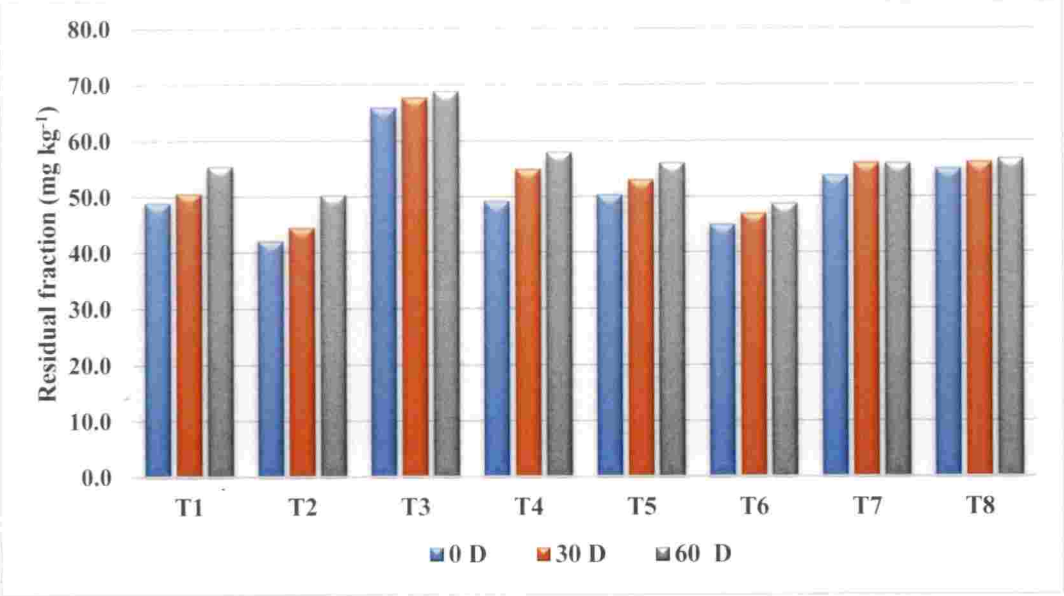


Fig:7 Effect of treatments on residual fractions of Cd.



Fig; 8 Effect of treatments on residual fractions of Ni

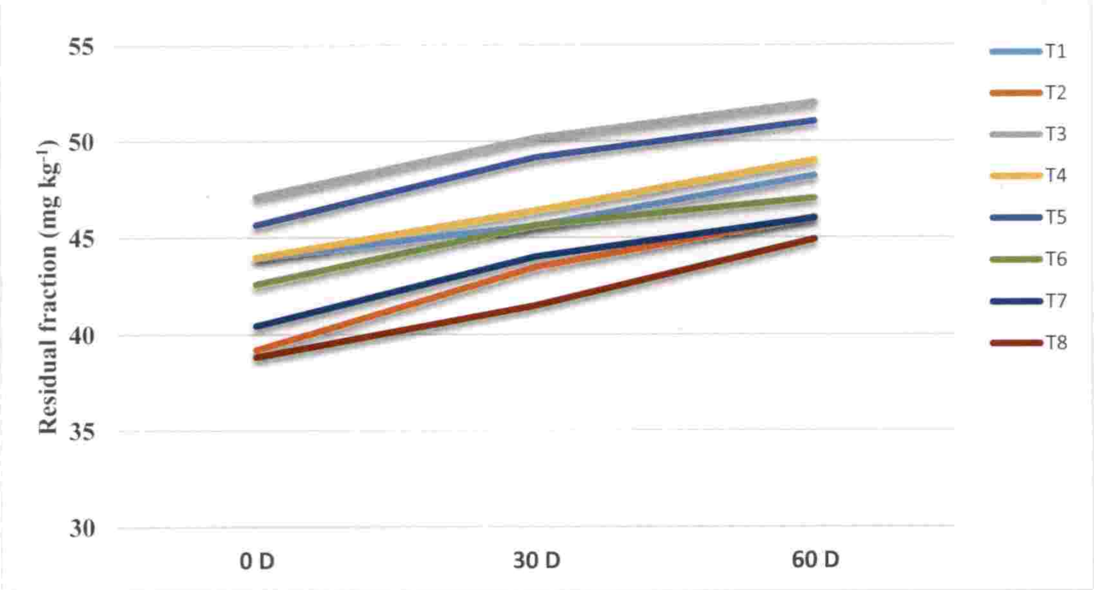


Fig: 9 Effect of treatments on residual fraction of Cr.

136

humic substance and the reduction in reducible fraction may be due to the conversion of this fraction to residual fraction. This results was in agreement with the conclusion of Singh (2008).

5.1.2.8.2 Organic fraction and Residual fraction

Organic fractions are fractions that are generally bound to organic matter. Residual fraction is the most stable fraction of metals and it was found to be relatively immobile. This might be due presence of primary and secondary minerals in them. This minerals have the ability to hold metal within their crystal structure. Similar findings were reported by Zorpas *et al.* (2008). At the end of composting a large proportion of heavy metal was found in the residual fraction. These fractions are more stable forms and they are considered to be unavailable to plant uptake. After composting the bioavailable fraction was found to be less than 2%. Similar results have been reported by Amir *et al.* (2005).

In this study the residual fraction was found to be more in zeolite amended compost. This might be due to the conversion of mobile fractions into residual fraction at the end of composting. This is mainly due to the adsorption and exchange property of zeolite as pointed out by Zorpas *et al.* (2008).

Liming materials have a significant influence on the immobile fractions of heavy metals. Increase in these fractions were observed in all the treatments. This may be due to the formation of clay – humus complex (Tiquia and Tam, 2000) and the conversion of mobile fractions of heavy metals to the most stable fraction of heavy metal.

5.1.2.9 Enumeration of E.coli

E. coli was not detected in any of the treatment during 0th, 30th and 60th day of composting. Dried sewage sludge was used for the preparation of sewage sludge compost which might be the reason for the absence of *E.coli* in any of the treatment. Drying reduce the number of feacal coliforms due to elevated temperature and dessication on exposure to the sunlight. These results are in line with the findings of Ogleni and Ozdemir (2010) and Asokan (2017).

5.2 POT CULTURE EXPERIMENT

A pot culture experiment was conducted to evaluate the suitability of sewage sludge compost as growth medium for ornamentals.

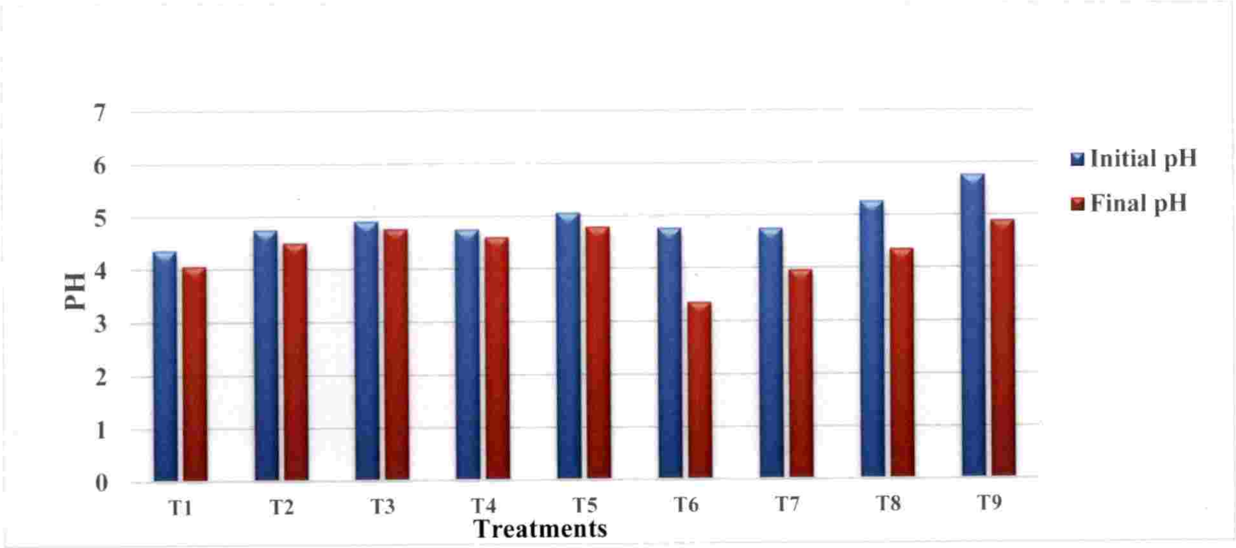


Fig 10: Effect of treatments on P^H of growing medium (before and after the experiment)

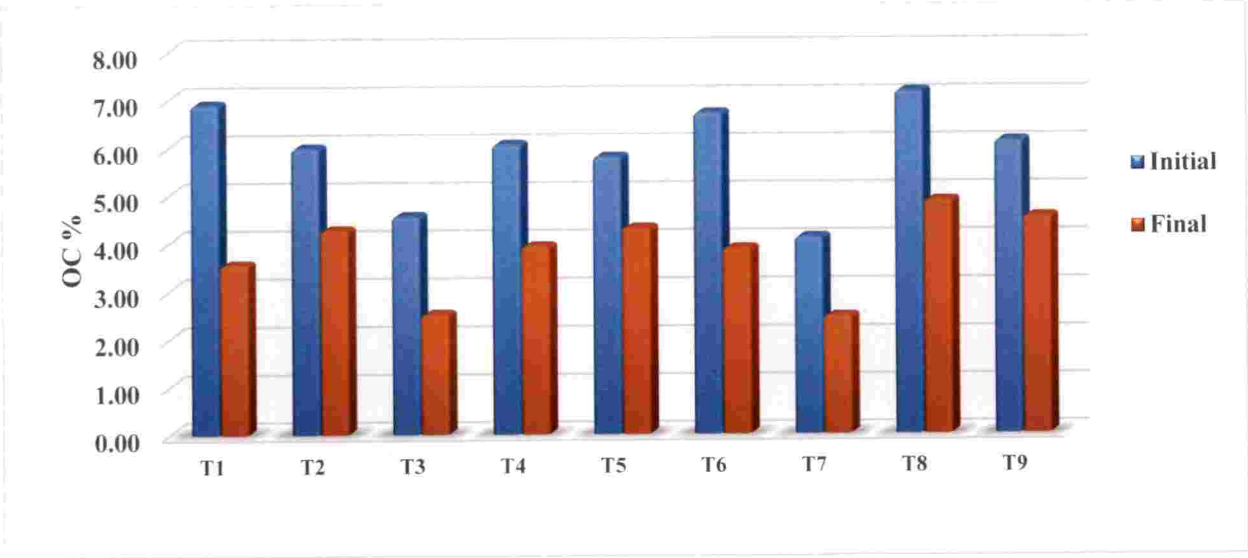


Fig 11 : Effect of treatments on organic carbon content of growing media (initial and after the experiment)

5.2.1 Physical, Chemical and Biological Properties of Growing Medium

The results obtained on physical, chemical and biological properties of the growing media before and after raising the crop are discussed here.

5.2.1.1 pH, Electrical Conductivity and Organic carbon

The treatments influenced the pH of the initial and final media significantly. When comparing the pH of pre and post harvest soil a reduction in pH was observed. This decrease in pH may be due to the release of organic acid during composting as reported by the Wakene *et al.* (2005). Similar findings were given by Leno *et al.* (2017). Similarly as plants grow, root produce organic acids and root exudates which also would have caused a reduction in pH in the final growing media.

A marginal decline in electrical conductivity was observed between the pre and post-harvest soil. This could be due to the utilization of ions in the growing media by the plants (Asokan, 2017).

Organic carbon content also showed the similar trend. In all the treatments organic carbon decreased in the final growing media. This may be due to the mineralization of carbon with time.

5.2.2.2 Primary Nutrients

The primary nutrient content of the initial and final media varied significantly with treatments. The available nitrogen content was found to be maximum in T_1 at the initial and end of the experiment. T_1 was significantly higher than all other treatments. This might be due to the high nitrogen content in the sewage sludge than that of the compost. Similarly highest P and K values were obtained by T_1 treatment (soil + sewage sludge) during the initial and at the end of the experiment. A reduction in the values of the nutrients was observed at the end of the experiment. A decline in this values may be due to the removal of these nutrients by crop for their growth and development. Asokan (2017) also reported that there was a reduction in the final nutrient values compared to the initial value and the reason behind this was due to the crop removal. Even after the crop removal a significant amount of N, P and K was found in the final

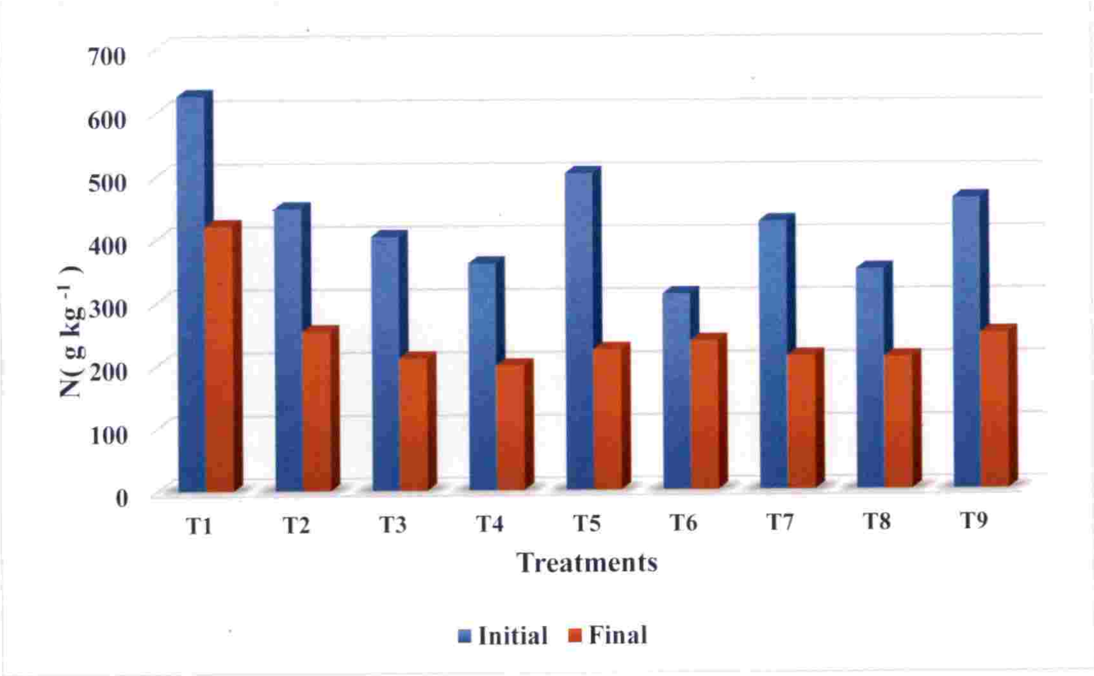


Fig 12 : Effect of treatments on nitrogen content of growing media (initial and after the experiment)

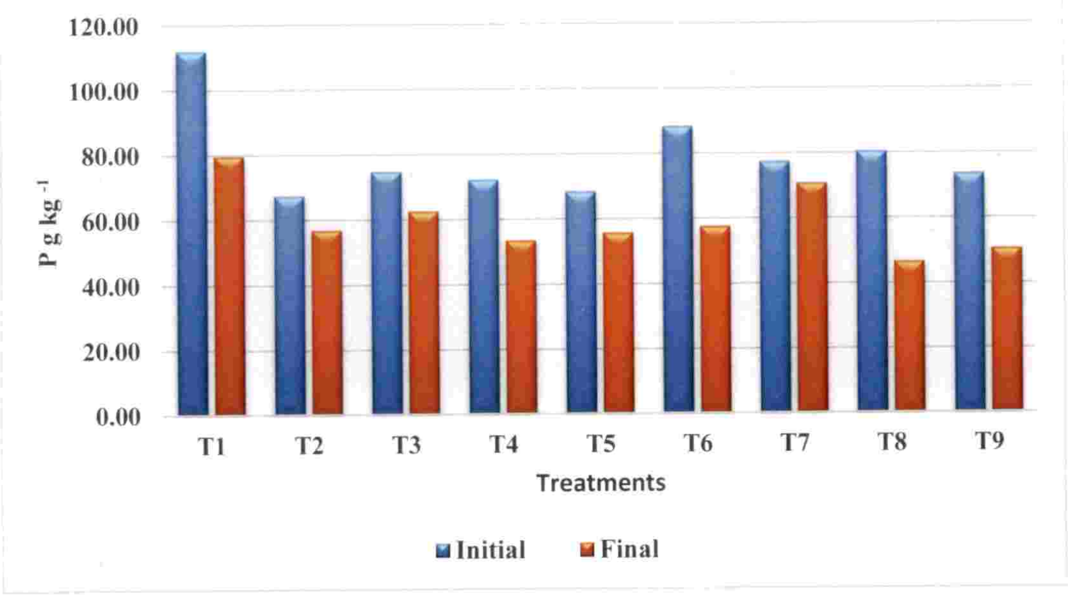


Fig 13 : Effect of treatments on phosphorus content of growing media (initial and after the experiment)

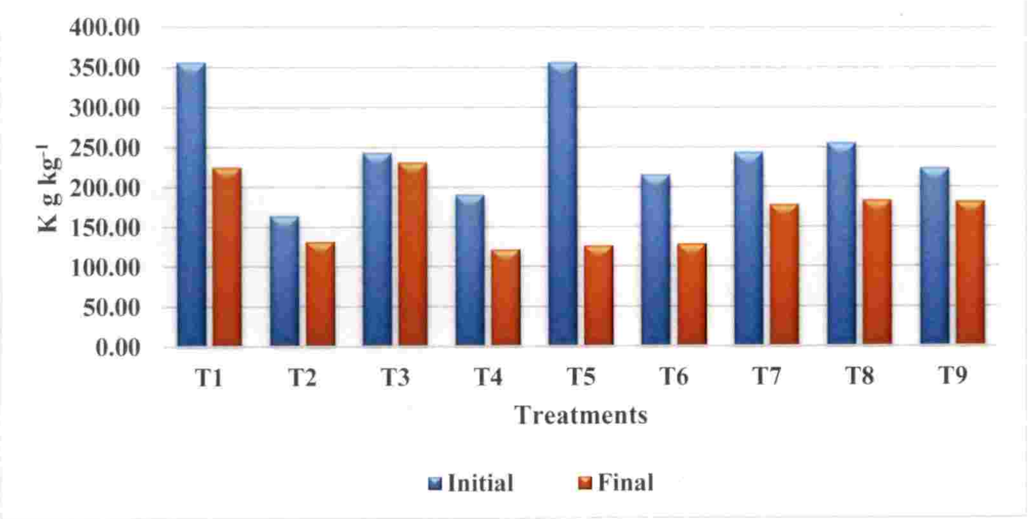


Fig 14 : Effect of treatments on potassium content of growing media (initial and after the experiment) growing media. This may be due to the high nutrient status of sewage sludge used in this experiment.

5.2.2.3 Secondary Nutrients and Micronutrients

The highest value for secondary and micronutrients was associated with T_1 (soil + sewage sludge). A decline in the nutrient content in the final media was observed. This may be due to the uptake by plants.

The present study revealed that the content of available micronutrients like iron, manganese, copper, zinc and boron values declined in the final growth media. The reduction in nutrient content may be due to the crop uptake as suggested by Asokan (2017). Treatment T_1 recorded the highest value for Fe, Mn, Cu and Zn for the initial and final media. This may be due to the higher micronutrient content in the initial sewage sludge.

5.2.2.4 Heavy Metal Content

The treatments influenced the heavy metal content of growing media. The treatment receiving sewage sludge and soil in 1:1 (T_1) obtained the highest value for heavy metals in the initial and final growing media. From T_2 to T_9 sewage sludge compost was used in the growing medium.

Composting of sewage sludge with suitable bulking agents, liming materials and heavy metal adsorbents decreases the availability of heavy metals in growing medium. Treatment T_8 recorded the least value for heavy metals in the initial and final media. This may be due to the combined effect of components used for the preparation of this compost namely sawdust, zeolite and flyash.

Sawdust contains organic compounds like cellulose, hemicellulose and lignin along with polyphenolic groups. They have the ability to bind heavy metal (Kaur and Sharma, 2017). With the addition of zeolite, environmental alkalinity increases, which helps promote the metal adsorption via surface complexation (Zorpas *et al.,* 2008). Coal flyash contain higher amount of MgO and CaO. These compounds have the ability to precipitate the heavy metals in sewage sludge compost and thus decrease the toxicity of heavy metals. Along with this fly ash is a pozzolanic material which reduces the availability of heavy metals.**5.2.3 Enumeration of *E.coli***

142

E.coli was not detected in any of the treatments in the initial and final growing medium as dried sewage sludge was used in the study. Drying reduces the number of feacal coliforms due to elevated temperature and dessication on exposure to the sunlight. These results are in conformity with the findings given by Ogleni and Ozdemir (2010) and Asokan, (2017).

5.2.4 Dehydrogenase Activity

Dehydrogenase activity increased at the end of the experiment. This may be due to the increased activity of micro-organisms at the end of the experiment. Highest dehydrogenase activity was found in T_9 treatment during initial (16.317 μg TPF/gram soil/24 hr) and at the end of the experiment (66.603 μg TPF/gram soil/24 hr). This may be due to root activity as well as low heavy metal content as compared to other treatments (Anushma, 2014).

5.2.5 Plant Growth and Floral Parameters

Compost application to the soil significantly influenced the plant growth parameters such as plant height, number of primary branches and secondary branches. Treatment receiving sewage sludge and soil in 1:1 ratio (T_1) recorded the minimum height of 70.67 cm and the maximum height (131.67 cm) was observed in T_9 treatment (soil + compost 8 in 1:1 ratio). The maximum number of primary branches was observed in T_9 treatment (15.10) and the lowest was observed in T_1 treatment (7.67). Maximum number of secondary branches (41.55) was observed in T_7 (soil + compost 6) and the minimum number (23.33) was observed in T_1 treatment.

Floral parameters such as days to first flowering, flower length, flower diameter, flower weight and flower number were significantly influenced by the treatments. Treatment T_9 (soil+ compost 8, 1:1) took the least number of days to first flowering (31.33) and T_1 (soil + sewage sludge, 1:1) took the maximum number of days (42.67) to first flowering. Similarly for the other floral parameters T_9 recorded the highest value for flower length (11.70 cm), flower diameter (4.35 cm), flower weight (2.54 g) and number of flowers per plant (232.02). T_1 recorded the least values for flower length (10.39 cm), flower diameter (2.79 cm), flower weight (1.79 g) and number of flowers per plant (111.03).

By observing the floral parameters it can be concluded that marigold grown in the soil + sewage sludge in 1:1 ratio recorded the least value for all the parameters. This reduction may be

143

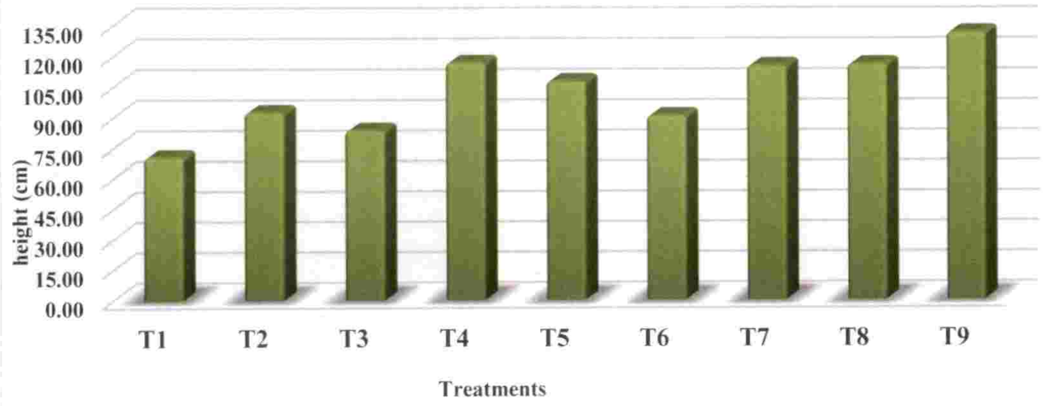


Fig: 15 Effect of treatments on height of marigold plant

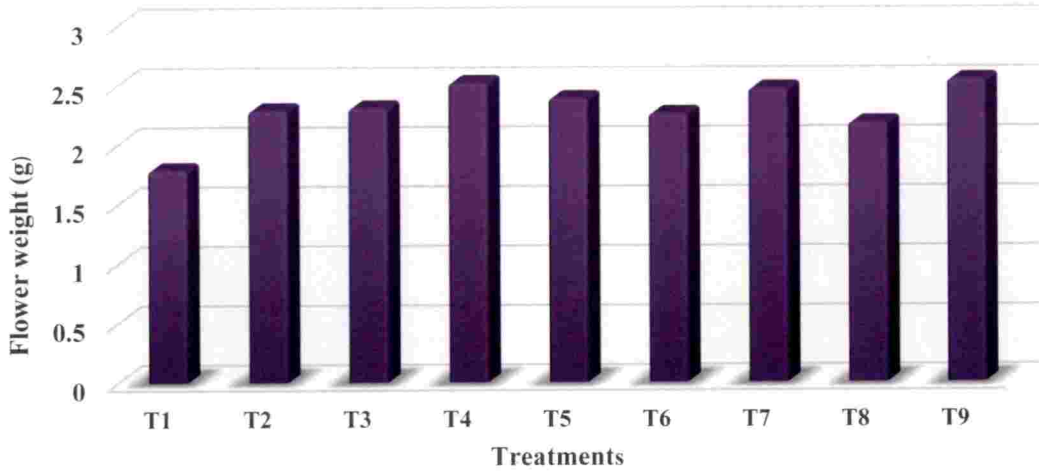


Fig:16 Effect of treatments on flower weight of marigold

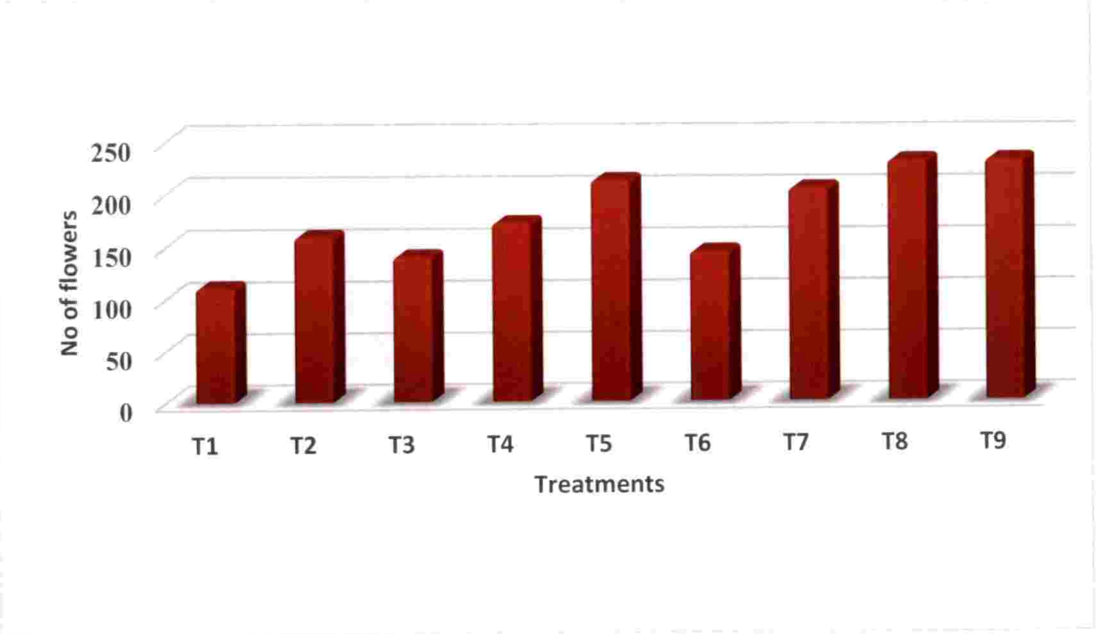


Fig:17 Effect of treatments on flower number of marigold due to the increased availability of heavy metals in T_1 treatment than other treatments. In all other treatments sewage sludge was mixed with the bulking agents such as sawdust and coirpith. The mixing of sewage sludge and bulking agents reduced the heavy metal concentration significantly. Nomeda *et al.* (2008) also reported similarly.

All treatments from T_2 to T_9 sewage sludge compost were used. Composting process also decreased the content of mobile fractions of heavy metals in sewage sludge. The availability of heavy metals and the rate of uptake by plants were depend upon the pH and (Alloway, 1995). Co-composting sewage sludge with alkaline materials such coal fly ash and lime reduce the soluble and exchangeable fractions of heavy metals in sludge compost (Wong *et al.*, 1997; Qiao and Ho, 1997). This may be due to the formation of insoluble carbonates, adsorption of metals onto particles of liming materials or by the formation of organo-metallic compound with organic matter in insoluble fractions (Petruzzelli, 1985; Wong *et al.*, 1997).

Besides this heavy metal adsorbent was added in T_3, T_5, T_7 and T_9 treatment. Due to the cation exchange property and molecular sieving properties it has the ability to take up heavy metals (Zorpas and Loizidou, 2008). Thus composting of sewage sludge with suitable liming material, heavy metal adsorbent and bulking agents decreases the bioavailability of heavy metals.

The treatments have no significant influence on biochemical properties such as chlorophyll content in leaves, flavonoid and xanthophyll content in flowers.

5.2.6 Yield and Yield Attributes

The treatments have significant influence on the yield and yield attributes of marigoid. The dry matter production of shoot and root was found to be minimum in treatment receiving sewage sludge and soil in 1:1 ratio. This may be due to the higher content of heavy metals. Heavy metal toxicity may drastically affect the cell growth and whole plant growth. Metal toxicity may cause reduction in fresh shoot and root weight. Metal toxicity may affect growth and development, various physiological activities like photosynthesis, water relation, essential nutrient uptake and enzyme activities. Similar observations have also been made by Shah and Dubey (2010). Treatment receiving sewage sludge and compost 8 in 1:1(T_9) ratio recorded the maximum dry matter yield of shoot and root. The reason may be due to the

146

decreased availability of heavy metals in this treatment other than T_1. Compost 8 was used in T_9 which was prepared by using sewage sludge, sawdust, zeolite and flyash. Sawdust which is a byproduct from wood industry contain organic compounds such as cellulose, lignin, hemicellulose and other polyphenolic groups. They have the ability to bind heavy metals. Flyash a residue from coal combustion process is a mixture of silica, alumina, ferric oxide, calcium oxide, magnesium oxide and carbon. More over this the alkalinity nature of flyash also helps to act as a neutralizing agent, which reduces the availability of heavy metals. (Kaur and Sharma, 2017). Also zeolite favours the metal sorption. Similar results were also reported by Muhlbachova *et al.* (2005).

5.2.7 Nutrient Content in Shoot and Root

The treatments significantly influenced the nutrient content in shoot and root. Nitrogen is considered as an important element needed for growth and development of plants. Present investigation revealed that N content in plant was significantly influenced by the treatments. T_1 recorded the highest nitrogen content in shoot and root. This may be due to the highest nitrogen content present in the sewage sludge. P is an important element needed for root development. The value ranges from 3.97 % to 7 %. The highest value was observed in T_3 treatment (7 %). The treatment T_6 had the highest K content (3.760 %) in shoot.

The value of calcium in shoot ranges from 0.99 to 1.95 %. The treatment receiving sewage sludge and soil in 1:1 (T_1) recorded the highest calcium percentage in shoot followed by T_3. The treatments influenced the content of magnesium in shoots of marigold. The value of magnesium ranges from to 0.31 to 1.53 %. The highest value was recorded in T_1 treatment (1.53 %) followed by T_5 (0.92 %) and T_6 (0.73 %). The value of sulphur ranges from 0.50 to 1.87 %. The highest value for sulphur was associated with T_1 treatment which was followed by T_7 (1.50 %) and T_3 (0.88 %). The higher nutrient content of sewage sludge would have contributed to there presence in greater amounts in T_1.

The content of iron in shoot varies from 0.21 to 1.26 %. The highest value of iron was associated with T_5 treatment followed by T_3 (1.24 %) which were on par. The treatments significantly influenced the Mn content in shoot. The highest value was recorded by T_3 which was followed by T_7 (0.08 mg kg^{-1}) which were on par. The copper content in shoot ranged from

147

4.01 to 9.80 mg kg^{-1}. The highest value for Cu content in shoot was recorded by T_4 followed by T_1 (6.41 mg kg^{-1}). The least value was recorded by T_9 which was followed by T_3 (4.10 mg kg^{-1}) and T5 (4.52 mg kg^{-1}) which were on par. The content of zinc in shoot varied from 0.01 to 0.06 mg kg^{-1}. It was highest in treatment receiving soil and sewage sludge in 1:1 ratio (T_1) which was on par with T3 (0.05 mg kg^{-1}). The treatment significantly influenced the boron content in shoot. The values ranges from 1.33 to 5.23 mg kg^{-1}. The highest value was recorded by T_2 (5.23 mg kg^{-1}).

Significant difference was observed in the case of nitrogen content in root among the treatments. The treatment T_1 registered the highest value of 1.96 % followed by T_6 (1.74 %) and T_2 (1.71 %). The treatment influenced the phosphorus content in root. Phosphorus content in root ranged from 0.23 to 0.49 %. The highest value for P content in root was recorded by T_6 (0.49 %) followed by T_1 (0.48 %) and T_3 (0.048 %) which were on par. The highest value for potassium value was registered by T_2 treatment followed by T_6 (3.47 %) and T_3 (3.41 %). The least value was obtained by T_9 which was followed by T_7 (1.59 %).

Calcium content in root was found to be highest in T_3 (0.088 %). The magnesium content of root varied from 0.90 to 2.08 %. The highest value was recorded by T_6 (2.08 %). The sulphur content in root was also influenced by the treatments. T_1 recorded the highest value (1.19 %).

The content of iron in root varies from 0.23 to 0.35 %. The highest value of iron was associated with T_1 (0.35 %). The treatment significantly influenced the Mn content in root. The values ranges from 111.60 to 724 mg kg^{-1}. The highest value was recorded by T_1 (724 mg kg^{-1}). The treatment influenced the copper content in root. The content in root ranged from 5.70 to 9.470 mg kg^{-1}. The highest value for Cu content in root was recorded by T_4 (9.47 mg kg^{-1}).The content of zinc in shoot varied from 517.33 to 741.33 mg kg^{-1}. It was highest in treatment receiving soil and sewage sludge in 1:1 ratio (T_1). The treatment significantly influenced the boron content in root. The values ranges from 2.10 to 5.28 mg kg^{-1}. The highest value was recorded by T_6. The higher content of these elements in growing media associated with these treatments would have contributed to their higher uptake and content in shoot and root.

5.2.8 Heavy Metal Content in Shoot and Root

Heavy metal content in shoot and root were significantly influenced by the treatments. The heavy metals such as cadmium, chromium, nickel and lead was found to be maximum in T_1 treatment receiving sewage sludge and soil in 1:1 ratio. T_1 recorded highest value for all the heavy metals in shoot, cadmium (0.042 mg kg^{-1}), chromium (5.334 mg kg^{-1}), nickel (2.729 mg kg^{-1}) and lead (2.375 mg kg^{-1}). In this except nickel all the elements were above the permissible limits.

The content of heavy metal in root was significantly influenced by the treatments. The content of heavy metal in root was significantly influenced by the treatments and was the highest in T_1 for cadmium (0.323 mg kg^{-1}), chromium (5.523 mg kg^{-1}) and nickel (7.453 mg kg^{-1}). All these heavy metals were above the permissible limits Lead was not detected in roots of any treatments. The higher content of heavy metal in shoot and root in T_1 treatment may be a reflection of the presence of these elements in significantly higher amounts in the growing media in $T_{1.}$ Similar results were also reported by Asokan (2107).

Accumulation of heavy metals were found to be higher in roots than in shoot. This may be due to the fact that roots are first target organ to come in contact with the heavy metal. Also whenever the plant tissues come in contact with the heavy metals, resistance strategies were adopted by the plants and the root cap and border cell exudates mucilage which can bind the metallic cations. The complex formation of heavy metal with these root exudates decreases the mobility of heavy metals to above ground parts. This was in accordance with the findings of Singh and Agrawal (2008).

Heavy metal content in shoot and root was found to be minimum in treatment receiving soil and compost 8 in 1:1 ratio (T_9). It should be noted that the availability of heavy metals in the growing media was less in $T_{9.}$ compared to other treatments. This would have resulted in lesser uptake of these elements into the plant and subsequent accumulation in root and shoot.

Summary

6. SUMMARY

The present investigation entitled "Heavy metal stabilized sewage sludge compost as a growth medium for ornamentals" was conducted in the department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani during 2017-2019 with the objective to prepare and characterize heavy metal stabilized sewage sludge compost and to evaluate its suitability as a growth medium for marigold. Sewage sludge for the study was obtained from sewage treatment plant, Muttathara Thiruvananthapuram.

The study comprised of two parts preparation of sewage sludge compost and the evaluation of the suitability of the compost as a component for growing media for ornamentals. The composting experiment was laid out in completely randomized block design with eight treatments and three replications. The treatments consisted of sewage sludge + coir pith (50:50) + lime (T_1 - compost 1), sewage sludge + coir pith + zeolite (50:30:20) + lime (T_2 - compost 2), sewage sludge + sawdust (50:50) + lime (T_3 - compost 3), sewage sludge + sawdust + zeolite (50:30:20) + lime (T_4 - compost 4), sewage sludge + coir pith (50:50) + fly ash (T_5 - compost 5), sewage sludge + coir pith+ zeolite (50:30:20) + flyash (T_6 - compost 6), sewage sludge + sawdust (50:50) + flyash (T_7 - compost 7) and sewage sludge + sawdust + zeolite (50:30:20) + flyash (T_8 - compost 8). The compost samples were drawn during 0th, 30th and 60th days of composting and they were analysed for physical (moisture content and bulk density), chemical (pH, EC, organic carbon, macronutrients, micronutrients, heavy metals and heavy metal fractions) and biological (enumeration of *E.coli*) properties.

In the second phase, growing media prepared using the sewage sludge composts and soil in 1:1 ratio were taken as treatments and evaluated using marigold as test crop. The nine treatments were T_1 - soil + sewage sludge, T_2 - soil + compost 1, T_3 - soil + compost 2, T_4 - soil + compost 3, T_5 - soil + compost 4, T_6 - soil +

compost 5, T_7 - soil + compost 6, T_8 - soil + compost 7 and T_9 - soil + compost 8. The design adopted was CRD with three replications. The physical, chemical and biological properties of growing media were analysed before and after the experiment. Growth parameters of plant such as plant height, number of primary branches, number of secondary branches, yield and yield attributes (dry matter yield of shoot, root and flower yield) were recorded. The content of primary, secondary nutrients and heavy metals were analysed in shoot and root separately.

The results obtained from this study are summarised as below

- The sewage sludge generated from Muttathara sewage treatment had a pH of 5.36 which was acidic and an electrical conductivity of 8.08 ds m^{-1} which was high.
- It had an organic carbon status of 17.03 %.
- It was rich in plant nutrients N (1.68 %), P (7.73 %), K (1.20 %), Ca (12.00 %), Mg (4.80 %), S (616.00 mg kg^{-1}), Fe (4500 mg kg^{-1}), Mn (1028.80 mg kg^{-1}), Zn (220.00 mg kg^{-1}), Cu (250.00 mg kg^{-1}) and B (23.06 mg kg^{-1}).
- It contained the heavy metals Pb (73.20 mg kg^{-1}), Cr (113.20 mg kg^{-1}), Ni (122 mg kg^{1}) and Cd (10.8 mg kg^{-1}). Cr, Ni and Cd were above critical limit. As was not detected.
- *E.coli* was not present in this sludge sample.

  The salient findings of the first phase of the experiment involving the production of composts with different bulking agents, heavy metal adsorbents and liming materials are summarized as follows:
- The highest moisture content was recorded by T_5 (49.78 %) and the highest bulk density was observed in T_3 (0.71 g cc^{-1}) during 60th day of composting.
- In the final compost T_8 recorded the highest pH (7.07) and for EC T_2 recorded highest value (6.52 dS m^{-1}).

- Organic carbon decreased during the composting and all macro, micro and heavy metals increased at the end of composting.
- Fractionation studies of heavy metals revealed that the mobile fractions namely exchangeable, carbonate and reducible fraction decreased at the end of composting and stable organic and residual fraction increased.
- *E.coli* was not observed in any of the treatment during 0th, 30th and 60th days of composting.
- The compost T_8 (Sewage sludge + sawdust + zeolite (50:30:20) + flyash) was superior with respect to stabilization of heavy metals.
- Analysis of the initial and final growing media revealed that pH, EC, organic carbon, N, P, K, Ca, Mg, S, Fe, Mn, Cu, Zn and B decreased in the final growing media than the initial growing media.
- Treatment receiving soil and sewage sludge in 1:1 ratio recorded the highest concentration of heavy metals when compared to the other treatments.
- *E.coli* was not detected in any of the treatment both in initial and final growing media.
- Treatments did not significantly influence the biochemical properties like chlorophyll in leaves, xanthophyll and flavonoid content in flowers.
- Treatments significantly influenced the plant growth parameters. T_9 recorded the highest plant height (131.67 cm) and no of primary branches (15.10). The maximum number of secondary branches (41.55) was observed in T_7 (soil + compost 6).
- Floral parameters such as days to first flowering, flower length, flower diameter, flower weight and flower number were significantly influenced by the treatments. Treatment T_9 (soil+ compost 8, 1:1) took the least number of days to first flowering (31.33). It recorded the highest value for flower length (11.70 cm), flower diameter (4.35 cm), flower weight (2.54 g) and number of flowers per plant (232.02).

- T_1 (soil + sewage sludge, 1:1) took the maximum number of days (42.67) to first flowering. T_1 recorded the least values for flower length (10.39 cm), flower diameter (2.79 cm), flower weight (1.79 g) and number of flowers per plant (111.03).
- The treatments have significant influence on the yield and yield attributes of marigold. The dry matter production of shoot and root was found to be least in treatment receiving sewage sludge and soil in 1:1 ratio. The highest dry matter production of the shoot (43.50 g) and root (2.320 g) was associated with T_9 (soil + compost 8, 1:1).
- Treatments significantly influenced the heavy metal content in plants (shoot and root). The heavy metals such as cadmium, chromium, nickel and lead were found to be maximum in T_1 treatment receiving sewage sludge and soil in 1:1 ratio. T_1 recorded the highest value for all the heavy metals namely cadmium (0.042 mg kg^{-1}), chromium (5.334 mg kg^{-1}), nickel (2.729 mg kg^{-1}) and lead (2.375 mg kg^{-1}). Except nickel the concentration of all the heavy metals elements studied were above the permissible limits.
- The content of heavy metal in root was significantly influenced by the treatments and was the highest in T_1 for cadmium (0.323 mg kg^{-1}), chromium (5.523 mg kg^{-1}) and nickel (7.453 mg kg^{-1}). All these heavy metals were above the permissible limits. Lead was not detected in roots of any treatments.

Based on the present investigation it can be concluded that sewage sludge generated from sewage treatment Muttathara is rich in organic carbon and other plant nutrients and had a pH of 5.36. The sludge contained heavy metals such as Pb, Cr, Ni and Cd of which Cr, Ni and Cd were above the critical limit. Sewage sludge compost prepared as per the treatments were rich in organic carbon and plant nutrients. During composting there was a drastic reduction in the mobile fractions (exchangeable and carbonate) and an increment in stable fractions (residual) which indicated that composting of sewage sludge with heavy metal adsorbent and different bulking agents decreased the mobility and bioavailability of heavy metals.

Results of pot culture experiment indicated that the growth and yield of marigold was higher in the treatment receiving sewage sludge, sawdust, zeolite (50:30:20) and flyash. The heavy metal content in marigold were found to be below the permissible limit in all the treatments were composted sewage sludge was used indicating that composting of sewage sludge with bulking agents like coirpith, sawdust, adsorbents like zeolite and liming materials like lime and flyash decreased the uptake of heavy metals by plants.

Based on the findings it can be concluded that sewage sludge from sewage treatment plant Muttathara after composting with sawdust, zeolite and flyash for 60 days can be used as a component of growing medium for ornamentals (1:1 ratio mixed with potting mixture). However its suitability for growing food crops should be further evaluated before the use.

Future line of work

1. Evaluation of sewage sludge compost for the production of food crops.
2. Screening of crops and varieties suitable for sewage sludge compost treated soil.
3. Production of biochar from sewage sludge.

References

7. REFERENCES

Abhiramy, K. S. and Rose, P. R. 2012. Reutilisation of spent waste of mushroom industry for vermiculture. *Int. J. Res. Biol. Sci.* 2 (3):120-123

Albiach, R., Canet, R., Pomares, F., and Ingelmo, F. 2001. Organic matter components, aggregate stability and biological activity in a horticultural soil fertilized with different rates of two sewage sludges during ten years. *Bioresour. Technol.* 77 (2): 109-114.

Alloway, B. J. and Jackson, A. P. 1991. The behaviour of heavy metals in sewage sludge-amended soils. *Sci. Total Environ.* 100: 151-176.

Alloway, B. J. 1995. *Heavy metals in soils: trace metals and metalloids in soils and their bioavailability*. Springer Science and Business Media, New York, 597p.

Amir, S., Hafidi, M., Merlina, G., and Revel, J. C. 2005 Sequential extraction of heavy metals during composting of sewage sludge. *Chemosphere.* 59: 801–810.

Angin, I. and Yaganoglu, A. V. 2011. Effects of sewage sludge application on some physical and chemical properties of a soil affected by wind erosion. *J. Agric. Sci. Technol.* 13: 757–768.

Annabi, M., Houot, S., Francou, C., Poitrenaud, M., and Bissonnais, Y. L. 2007. Soil aggregate stability improvement with urban composts of different maturities. *Soil Sci. Soc. Am. J.* 71(2): 413-423.

Antolin, M.C., Pascual, I., Garcia, C., Polo, A., and Sanchez-Diaz, M. 2005. Growth, yield and solute content of barley in soils treated with sewage sludge under semiarid Mediterranean conditions. *Field Crops Res.* 94(3): 224-237.

Anushma, S. 2014. Characterization, conversion and evaluation of selected lignocellulosic biomass. M.Sc (Ag) thesis, Kerala Agricultural University, Thrissur, 164p.

Asokan, A. 2017. Evaluation of sewage sludge as a growth medium for ornamentals. M.Sc (Ag) thesis, Kerala Agricultural University, Thrissur, 110p.

Bahremand, M. R. Majid, A., Hajabbassi, M. A., and Rezainejad, Y. 2003. Utilization of sewage sludge for horticultural crops. *J. Sci. Technol. Agric. Nat. Resour.* 121-128.

Bai, R., Wang, J. T., Deng, Y., He, J. Z., Feng, K., and Zhang, L. M. 2017. Microbial community and functional structure significantly varied among distinct types of paddy soils but responded differently along gradients of soil depth layers. *Front. Microbiol.* 8: 945.

Banerjee, M. R., Burtonz, D. L., and Depoe, S. 1997. Impact of Sewage Sludge Application on Soil Biological Characteristics. *Agric. Ecosyst. Environ.* 66(3): 241-249.

Bazrafshan, T., Panwar, N., and Singh, M. V. 2006. An assessment of municipal solid waste compost quality produced in different cities of India in the perspective of developing quality control indices. *Waste Manag.* 30: 192-201.

Beaver, Y., Singh, J., and Kalamdhad, A. S. 1995. Effect of lime on speciation of heavy metals during composting of water hyacinth. *Frontiers Environ. Sci. Eng.* 10 (1): 93-102.

Belhaj, K., Ramamurthy, S., Rajarajan, A., and Savarimuthu, E. 2016. Suitability of Dindigul town's sewage sludge for field application: Nutritional perspective. *Pollut. Res.* 17: 61-63.

Bolanos, N., Jose, L., Hugo, J., Enrique, B., Ramiro, R., and Octavio, P. 2004. An optimization study of solid state fermentation: xanthophylls extraction from marigold flowers. *Appl. Microbiol. Biotech.* 65: 383-390.

Bustamante, M. A., Paredes, C., Marhuenda-Egea, F. C., Perez-Espinosa, A., Bernal, M. P., and Moral, R. 2008. Co-composting of distillery wastes with animal manures: Carbon and nitrogen transformations in the evaluation of compost stability. *Chemosphere*. 72(4): 551-557.

Caravaca, F., Garcia, C., and Hernandez, M. T. 2002. Aggregate stability changes after organic amendment and mycorrhizal inoculation in the afforestation of a semiarid site with *Pinus halepensis*. *Appl. Soil. Ecol.* 19: 199-208.

Casida, L. E., Klein D. A. and Santoro, T. 1964. Soil dehydrogenase activity. *Soil. Sci.* 98: 371-376.

Chitdeshwari, T., Savithri, P., and Raja, S. M. 2002. Effect of sewage biosolids compost on biomass yield of amaranthus and heavy metal availability. *J. Indian Soc. Soil Sci.* 50(4): 480-484.

Chitdeshwari, T. and Savithri, P. 2004. Quality of sewage biosolid composts and their impact on the yield of maize. *Indian J. Res.* 38 (2): 147-150.

Colella, C. 1996. Ion exchange equilibria in zeolite minerals. *Mineralium Deposita.* 31(6): 554-562.

Doelsch, E., Deroche, B., and vandeKerchove, V. 2006. Impact of sewage sludge spreading on heavy metal speciation in tropical soils. *Chemosphere*. 65 (2): 286-293.

Dubey, S. K., Yadav, R. K., Joshi, P. K., Chaturvedi, R. K., Goyel, B., Yadav, R., and Minhas, P. S. 2006. Agricultural uses of sewage sludge and water and their impact on soil water and environmental health in Haryana, India. In *Abstract of 18th World Congress of Soil Science*.

El-Nahhal, I. Y., Al-Najar, H. M., and El-Nahhal, Y. 2014. Physicochemical properties of sewage sludge from Gaza. *Environ. Sci. Technol.* 36: 343–347.

Eid, E. M., Alrumman, S. A., El-Bebany, A. F., Hesham, A. E. L., Taher, M. A., and Fawy, K. F. 2017. The effects of different sewage sludge amendment rates on the heavy metal bioaccumulation, growth and biomass of cucumbers (*Cucumis sativus L.*). *Environ. Sci. Pollut. Res.* 24: 16371-16382.

Eneji, A. E., Yamamoto, S., Honna, T., and Ishiguro, A. 2001. Physicochemical changes in livestock feces during composting. *Common Soil Sci. Plant Anal.* 32: 477-489.

Epstein, E. L., Taylor, J. M., and Chancy, R. L. 1975. Effects of sewage sludge and sludge compost applied to soil on some soil physical and chemical properties. *J. Environ. Qual.* 5 (4): 422-426.

FAI (Fertilizer Association of India). 2017. *The Fertilizer (Control) Order, 1985.* The Fertilizer Associoation of India, New Delhi. Available: http: //www. Astaspice .org/food-safety/astas-analytical-methods-manual.

Fang, M. and Wong, J. W. C. 1999. Effects of lime amendment on availability of heavy metals and maturation in sewage sludge composting. *Environ. Pollut.* 106 (1): 83-89.

Fang, M., Wong, J. W. C., Ma, K. K., and Wong, M. H. 1999. Co-composting of sewage sludge and coal flyash nutrient transformations. *Bioresour. Technol.* 67(1): 19-24.

Fanny, S. R., Jorge, M. E., Mario, U. M., and Cruz, M. Q. 2015. Degradation of sewage sludge from plant wastewater using vermicompost. *Int. J. Modern Biol. Res.* 4: 1-4.

Feng, J. J., Jia, L., Liu, Q. Z., Chen, X. L., and Cheng, J. P. 2018. Source identification of heavy metals in sewage sludge and the effect of influent characteristics: a case study from China. *Urban Water J.* 15(4): 381-387.

Garg, V. K., Kaushik, P. N., and Dilbaghi. 2006. Vermicomposting of different types of waste using *Eisenia fetida*: a comparative study. *Bioresour. Technol.* 97: 391–395.

Glaser, B., Wiedner, K., Seelig, S., Schmidt, H. P., and Gerber, H. 2015. Biochar organic fertilizers from natural resources as substitute for mineral fertilizers. *Agron. Sustain. Dev.* 35: 667-678.

Ghosh, A. K., Bhatt, M. A. and Agrawal, H. P. 2011. Effect of long-term application of treated sewage water on heavy metal accumulation in vegetables grown in Northern India. *Environ. Monit Assess.* 184(2): 1025-1036.

Goldman, E. and Green, L. H. 2008. Practical Handbook of Microbiology, 2nd edition. CRC Press, Boca Baton, Florida. 155p.

Greenberg, A. E., Clesceri, L. S., and Eaton, A. D. 1992. *Standard Methods for the Examination of Water and Waste Water,* 18th (Ed.). American Public Health Association, Washington. 75p.

161

Gupta, S., Satpati, S., Nayek, S., and Garai, D. 2010. Effect of wastewater irrigation on vegetables in relation to bioaccumulation of heavy metals and biochemical changes. *Environ. Monit. Assess.* 165(4): 169-177.

Gupta, U. C. 1967. A simplified method for determining hot water soluble boron in podzol soils. *Soil Sci.* 103(6): 424-428.

Har, W., Safinar, I., and Ismail, S. 2012. Antioxidant activity, total phenolics and total flavonoids of *Syzygium polyanthum. Int. J. Med. Aromat.* 2(2): 219-228.

Haroun, M., Idris, A., and Omar S. S. 2007. A study of heavy metals and their fate in the composting of tannary sludge. *Waste Manag.* 27(11): 1541-1550.

Hernando, S., Lobo, M. C., and Polo, A. 1989. Effect of the application of a municipal refuse compost on the physical and chemical properties of a soil. *Sci. Total Environ.* 81: 589-596.

Hesse, P. R. 1971. *A Textbook of Soil Chemical Analysis.* Jone Murray Ltd, London, 520p.

Hsu, J. H. and Lo, S. L. 2001. Effect of composting on characterization and leaching of copper, manganese, and zinc from swine manure. *Environ. Pollut.* 114(1): 119-127.

Huma, R. 1997. Effect of sewage sludge on grain yield of corn and wheat soil fertility and heavy metals accumulation under rainfed conditions. M.Sc. thesis, University of Arid Agriculture, Rawalpindi, 46p.

Hussein, A. H. 1991. Impact of sewage sludge as organic manure on some soil properties, growth, yield and nutrient contents of Cucumber crop. *Environ. Technol.* 9(8): 1401-1411.

Jackson, M. L. 1973. *Soil Chemical Analysis* (2nd Ed.). Prentice hall of India, New Delhi, 498p.

Jamil, M., Qasim, M., and Umar, M. 2006. Utilization of sewage sludge as organic fertilizer in sustainable agriculture. *J. Appl. Sci.* 6(3): 531-535.

Jeyaseeli, D.M. and Raj, S.P. 2010. Chemical characteristics of coir pith as a function of its particle size to be used as soilless medium. *Ecoscan*. 4(3): 163-169.

Kabirinejad, S. and Hoodaji, M. 2012. The effect of biosolid application on soil chemical properties and Zea mays nutrition. *Int. J. Utilis. Org. Agric.* 1(4): 34-39.

Karvelas, M., Katsoyiannis, A., and Samara, C. 2003. Occurrence and fate of heavy metals in the wastewater treatment process. *Chemosphere*. 53(10):1201-1210.

KAU [Kerala Agricultural University]. 2016. Package of Practices Recommendations: Crops (15th Ed.). Kerala Agricultural University, Thrissur, 393p.

Kaur, A. and Sharma, S. 2017. Removal of heavy metals from waste water by various adsorbents A review. *Indian J. Sci. Technol.* 10(34): 1-14.

Kaur, R., Wani, S. P., Singh, A. K., and Lal, K. 2012. Wastewater production, treatment and use in India. National report presented at the 2nd regional workshop on safe use of wastewater in agriculture, New Delhi, India.

Kharub, M. 2012. Effect of sewage sludge application on growth of *Abelmoschus esculentus* (Ladies finger). *Int. J. Environ. Sci. Technol.* 2 (3): 61-64.

Khwairakpam, M. and Bhargava. 2006. Vermitechnology for sewage sludge recycling. *J. Hazardous Mater*. 161(3): 948-954.

Kizilkaya, R. and Bayrakli, B. 2005. Effects of N-enriched sewage sludge on soil enzyme activities. *Appl. Soil Ecol.* 30 (3): 192-202.

Kung, C., Huang, J. H., and Chang, C. N. 2007. Enhancement of heavy metal stabilization by different amendments during sewage sludge composting process. *J. Environ. Manag*. 17(4): 249-256.

Lake, D. L. 1987. Chemical speciation of heavy metals in sewage sludge and related matrices, heavy metals in wastewater and sludge treatment processes. *Int. J. Environ. Sci. Technol*. 5 (4): 80-84.

Lakhdar, A., Scelza, R., Scotti, R., Rao, M. A., Jedidi, N., Gianfreda, L., and Abdelly, C. 2010. The effect of compost and sewage sludge on soil biologic activities in salt affected soil. *J Soil Sci. Plant Nutr.* 10 (1): 40-47.

Leila, S., Muhamed, M., Hermann, H., Mykola, K., Oliver, W., Christin, M., Elena, O. and Nadia, B., 2017. Fertilization value of municipal sewage sludge for *Eucalyptus camaldulensis* plants. *Biotechnol. Rep.* 13 (2): 8-12.

Leno, N., Sudharmaidevi, C. R., and Mathew, P. B. 2017. Nutrient availability from an organic fertilizer produced by chemical decomposition of solid wastes in relation to dry matter production in banana. *Adv. Res.* 12 (5): 1-9.

Liu, J. and Sun, S. 2013. Total concentrations and different fractions of heavy metals in sewage sludge from Guangzhou, China. *Trans. Nonferrous Met. Soc. China*. 23: 2397-2407.

Lloreta, E., Jose, A. P., Brodieb, E. L., Nicholas, J., Bouskillb, Insamd, H., Juarezd, M. F. D. and Gobernaa, M. 2016. *Appl. Soil Ecol.* 101: 37–46

Manickam, N. I. and Subramanian, P. 2014. Study of physical properties of coir pith. *Int. J. Green Energy* 3(4): 397-406

Mantovi, P., Baldoni, G., and Toderi, G. 2005. Reuse of liquid, dewatered, and composted sewage sludge on agricultural land: effects of long-term application on soil and crop. *Water Res.* 39 (3): 289-296.

Marchioretto, M. M. 2003. Heavy metal removal from anaerobically digested sludge. Ph.D. thesis, Wageningen University, Netherlands, 142p.

Massoumi, A. and Cornfield, A. H. 1963. A rapid method for the determination of sulphate in water extracts of soil. *Analyst.* 88: 321-322.

Meerow, A. W. 1995. Growth of two tropical foliage plants using coir dust as a container medium amendment. *Hort. Technol.* 5 (3): 237-239.

Mendoza, J., Garrido, T., Castillo, G., and Martin, N. 2006. Metal availability and uptake by sorghum plants grown in soils amended with sludge from different treatments. *Chemosphere.* 65 (11): 2304-2312.

Mohee, R. and Mudhoo, A. 2005. Analysis of the physical properties of an in-vessel composting matrix. *Powder Technol.* 155 (1): 92-99.

Mondal. S., Singh, R, D., Patra, A. K., and Dwivedi, B. S. 2015. Changes in soil quality in response to short term application of municipal sewage sludge in a typic haplustept under cowpea-wheat cropping system. *Environ. Nanotechnol. Monitoring Manag.* 4: 37-41.

Morris, D. R. and Lathwell, D. J. 2004. Anaerobically digested dairy manure as fertilizer for maize in acid and alkaline soils. *Commun. Soil. Sci. Plant Anal.* 35(11): 1757-1771.

Mushali, J. S., Tiruneh, A. T., and Fadiran, A. 2014. Characterization of sewage sludge generated from waste water treatment plants in Swaziland in relation to agricultural uses. *Resour. Environ.* 4 (4):190-199.

Mulchi, C. L., Adamu, C. A., Chaney, R. L., and Bell, P. F. 1991. Residual heavy metal concentrations in sludge-amended coastal plain soils. Comparison of extractants. *Commun. Soil Sci. Plant Anal.* 22 (9-10): 919-941.

Mumpton, F. A. 1978. Natural Zeolites, Occurrence, Properties, Use. *Pergamon Press, Oxford New York*, p.385.

Muthurayar, T. and Dhanarajan, M.S. 2013. Biochemical changes during composting of coir pith waste as influenced by different agro industrial wastes. *Agri. Sci.* 4(5): 28-30.

Muhlbachova, G., Simon, T., and Pechova, M. 2005. The availability of Cd, Pb and Zn and their relationships with soil pH and microbial biomass in soils amended by natural clinoptilolite. *Plant Soil Environ.* 51(1): 26-33.

Nomeda, S., Valdas, P., Chen, S.Y., and Lin, J.G. 2008. Variations of metal distribution in sewage sludge composting. *Waste Manag.* 28: 1637-1644.

Novok, J. and Trapp, S. 2005. Growth of Plants on TBT-contaminated harbour sludge and effect on TBT removal. *Environ. Sci. Pollut. Res.* 12 (6): 332-341.

Ogleni, N. and Ozdemir, S. 2010. Pathogen reduction effects of solar drying and soil application in sewage sludge. *Turkian J. Agric.* 34: 509-515.

Osiname, O. A., Schults, B. T., Corey, R. B. 1973. Soil tests for available copper and zinc in soils of Western Nigeria. *J. Sci. Food Agric.* 24: 1341-1349.

Outhman, M. A. and Firdous, F. 2016. The impact of the use of sludge in agriculture on the vegetative growth of cereal crops. *Int. J. Adv. Ind. Eng.* 4: 1-9.

Outhman, M. A. and Bharose, R. 2014. Effect of different levels of sewage sludge on chemical properties of soil grown with cereal crop. *Interlink Continental J. Biol. Sci.* 1(4): 234-272.

Panse, V. G. and Sukhatme, P. V. 1978. Statistical Methods for Agricultural Workers. Indian Council of Agricultural Research, New Delhi, 339p.

Parat, C., Chaussod, R., Leveque, J., and Andreux, F. 2005. Long-term effects of metal-containing farmyard manure and sewage sludge on soil organic matter in a fluvisol. *Soil Biol. Biochem.* 37 (4): 673-679.

Petruzzelli, G. 1985. Recycling wastes in agriculture: heavy metal bioavailability. *Agric. Ecosyst. Environ.* 27 (4): 493-503.

Placek, A., Grobelak, A., and Kacprzak, M. 2016. Improving the phytoremediation of heavy metals contaminated soil by use of sewage sludge. *Int. J. Phytoremediation.* 18: 605-618.

Powlson, D. S. 2002. Impact of Heavy Metals on Soil Quality with Respect to Microbial Activity and Production of Crops. *Soil Science Department IACR, Rothamsted.* 18p.

Qiao, L. and Ho, G. 1997. The effects of clay amendment and composting on metal speciation in digested sludge. *Water Res.* 31(5): 951-964.

Rich, N., Bharti, A., and Kumar, S. 2018. Effect of bulking agents and cow dung as inoculant on vegetable waste compost quality. *Bioresour. Technol.*252: 83-90.

Roig, A., Lax, A., Costa, F., Cegarra, J. and Hernandez, T. 1996. The influence of organic materials on the physical and physico-chemical properties of soil. *Agric. Medit.* 117: 309-318.

Sadasivam, S. and Manickam, A. 1992. *Biochemical Methods for Agricultural Sciences.* Willey Eastern Ltd., New Delhi, 371p.

Saha, S., Saha, B. N., Pati, S., Pal, B., and Hazra, G. C. 2017. Agricultural use of sewage sludge in India: benefits and potential risk of heavy *metals* contamination and possible remediation options A review. *Int. J. Environ. Tech. Manag.* 20: 183-199.

Selivanovskaya, S., Galitskaya, P., Kuritsin, I., and Gumerova, R. 2007. Beneficial utilization of composted sewage sludge: Effects on biomass and activity of microbial community of haplic greyzem. *Waste Manag.* 26: 1253-1258.

Shah, M and Dubey, L. 2010. Natural zeolites as effective adsorbents in water and wastewater treatment. *Chem. Eng. J.* 156(1): 11-24.

Sherene, T. 2010. Mobility and transport of heavy metals in polluted soil environment. *Biol. Forum Int. J.* 2(2): 112-121.

Silva, J. G. D., deCarvalho, J. J., daLuz, J. M. R., and daSilva, J. E. C, 2016. Fertigation with domestic wastewater: uses and implications. *Afr. J. Biotechnol.* 15: 806-815.

Singh, R. P. 2008. Potential benefits and risks of land application of sewage sludge. *Waste Manage.* 18: 421-430.

Singh, R. P. and Agrawal. 2007. Effects of sewage sludge amendment on heavy metal accumulation and consequent responses of *Beta vulgaris* plants. *Chemosphere.* 67: 2229–2240.

Singh, R. P. and Agrawal, M. 2010. Effect of different sewage sludge applications on growth and yield of *Vigna radiata L.* field crop: metal uptake by plant. *Ecol. Eng.* 36: 969-972.

Singh, R. P. and Agrawal, M. 2008. Variations in heavy metal accumulation, growth and yield of rice plants grown at different sewage sludge amendment rates. *Ecotoxicol. Environ. Saf.* 73: 632-641.

Singh, J. and Kalamdhad, A. S. 2012. Concentration and speciation of heavy metals during water hyacinth composting. *Bioresour. Technol.* 124:169-179.

Singh, J. and Kalamdhad, A. S. 2014. Effect of carbide sludge (lime) on bioavailability and leachability of heavy metals during rotary drum composting of water hyacinth. *Chem. Speciat. Bioavailab.* 26(2): 76-84.

Solanki, P., Kalavagadda, B., Akula, B., Sharma, S. H. K., and Reddy, D. J. 2017. Effect of Sewage Sludge on Marigold (*Tagetes erecta*). *Int. J. Curr. Microbiol. App. Sci.* 6(6): 825-831.

Stenphens, S. R., Alloway, B. J., Parker, A., Carter, J. E., and Hodson, M. E. 2001. Changes in the leachability of metals from dredged canal sediments during drying and oxidation. *Environ. Pollut.* 114: 407–413.

Subbiah, B. V. and Asija, G. L. 1956. A rapid procedure for the estimation of available nitrogen in soils. *Curr. Sci.* 25: 259-260.

Swapnil, R., Chopra, A. K., Pathak, C., Sharma, D. K., Sharma, R., and Gupta, P. M. 2011. Comparative study of some physiochemical parameters of soil irrigated with sewage water and canal water of Dehradun city, India. *Arch. Appl. Sci. Res.* 3(2): 318-325.

Tessier, A., Campbell, P. G. C., and Bisson, M. 1979. Sequential extraction procedure for the speciation of particular trace metals. *Anal. Chem.* 51: 844-850.

Tiquia, S. M. and Tam, N. Y. 2000. Co-composting of spent pig litter and sludge with forced-aeration. *Bioresour. Technol.* 72: 1-7.

Tiwari, K. K., Singh, N. K., Patel, M. P., Tiwari, M. R., and Rai, U. N. 2011. Metal contamination of soil and translocation in vegetables growing under industrial wastewater irrigated agricultural field of Vadodara, Gujarat, India. *Ecotoxicol. Environ. Saf.* 74: 1670–1677.

Tripetchkul, S., Pundee, K., Koonsrisuk, S. and Akeprathumchai, S. 2012. Co-composting of coir pith and cow manure: initial C/N ratio vs physico-chemical changes. *Int. J. Recycling Organic Waste Agric.* (1), p.15.

Veeken, A. K. Nierop, V. Wilde., and Hamelers, B. 2000.Characterization of NaOH-Extracted Humic Acids during Composting of a Biowaste. *Bioresource Technol.* 72: 33-41.

Wakene, N., Heluf, G., and Friesen, D. K. 2005. Integrated use of farmyard manure and NP fertilizers for maize on farmers' fields. *J. Agric Rural. Dev. Trop. Subtrop.* 106(2): 131-141.

Walkley, A. and Black, T. A. 1934. An examinations of Degtjareff method for determining soil organic matter and proposed modification of the chromic acid titration method. *Soil Sci.* 37: 29-38.

Wang, X., Chen, T., Ge, Y., and Jia, Y. 2008. Studies on land application of sewage sludge and its limiting factors. *J. Hazardous Mater.* 160(2): 554-558.

Wang, J. Y., Zhang, D. S., Zhang., Stabnikova, O. and Tay, J. H. 2005. Evaluation of electrokinetic removal of heavy metals from sewage sludge. *J. Hazardous Mater.* 124(3): 139-146.

Wong, J. W. C. and Selvam, A. 2006. Speciation of heavy metals during co-composting of sewage sludge with lime. *Chemosphere* 63: 980-986.

Wong, J. W. C., Fang, M., Li, G. X., and Wong, M. H. 1997. Feasibility of using coal ash residues as co-composting materials for sewage sludge. *Environ. Technol.* 18(5): 563-568.

Wortmann, C. S. 2005. Sewage Sludge Utilization for Crop Production. Department of Agronomy and Horticulture, University of Nebraska-Lincoln, Lincoln, 2005.

Yousefi, J., Younesi, H., and Ghasempoury, S. M. 2013. Co-composting of Municipal Solid Waste with Sawdust: Improving Compost Quality. *Clean Soil Air Water.* 41(2): 185-194.

Yuan, X., Huang, H., Zeng, G., Li, H., Wang, J., Zhou, C., Zhu, H., Pei, X., Liu, Z., and Liu, Z. 2011. Total concentrations and chemical speciation of heavy metals in liquefaction residues of sewage sludge. *Bioresour. Technol.* 102: 4104-4110.

Zheng, G. D., Gao, D., Chen, T. B., and Luo, W. 2007. Stabilization of nickel and chromium in sewage sludge during aerobic composting. *J. Hazardous Mater.* 142(2): 216-221.

Zorpas, A. A., Apostolos, G. V., and Loizidou, M. 1999. Dewater anaerobically stabilized primary sewage sludge composting, metal leachability and uptake by natural clinoptilolite. *Commun. Soil Sci. Plant Anal.* 30: 113-119.

Zorpas, A. A., Arapoglou, D., and Panagiotis, K. 2008. Waste paper and clinoptilolite as a bulking material with dewatered anaerobically stabilized primary sewage sludge (DASPSS) for compost production. *Waste Manag.* 23(1): 27-35.

Zorpas, A. A., Constantinides, T., Vlyssides, A.G., Haralambous, I., and Loizidou, M. 2000. Heavy metal uptake by natural zeolite and metal partitioning in sewage sludge compost. *Biosour. Technol.* 72: 113-119.

Zorpas, A. A. and Loizidou, M. 2008. Sawdust and natural zeolite as a bulking agent for improving quality of a composting product from anaerobically stabilized sewage sludge. *Bioresour. Technol.* 99: 7545-7552.

HEAVY METAL STABILIZED SEWAGE SLUDGE COMPOST AS A GROWTH MEDIUM FOR ORNAMENTALS

by

REHANA M. R.

(2017-11-035)

ABSTRACT

Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN AGRICULTURE

Faculty of Agriculture
Kerala Agricultural University

DEPARTMENT OF SOIL SCIENCE AND AGRICULTURAL CHEMISTRY
COLLEGE OF AGRICULTURE
VELLAYANI, THIRUVANANTHAPURAM - 695 522
KERALA, INDIA

2019

ABSTRACT

The present investigation entitled "Heavy metal stabilized sewage sludge compost as a growth medium for ornamentals" was conducted in the department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani during 2017-2019 with the objective to prepare and characterize heavy metal stabilized sewage sludge compost and to utilize it as a growth medium for marigold. Sewage sludge for the study was obtained from sewage treatment plant, Muttathara Thiruvananthapuram.

The study comprised of two parts viz, preparation of sewage sludge compost and the evaluation of the suitability of the compost as a component for growing media for ornamentals. The composting experiment was laid out in completely randomized block design with eight treatments and three replications. The treatments consisted of sewage sludge + coir pith (50:50) + lime (T_1 - compost 1), sewage sludge + coir pith + zeolite (50:30:20) + lime (T_2 - compost 2), sewage sludge + sawdust (50:50) + lime (T_3 - compost 3), sewage sludge + sawdust + zeolite (50:30:20) + lime (T_4 - compost 4), sewage sludge + coir pith (50:50) + fly ash (T5 - compost 5), sewage sludge + coir pith+ zeolite (50:30:20) + flyash (T_6 - compost 6), sewage sludge + sawdust (50:50) + flyash (T_7 - compost 7) and sewage sludge + sawdust + zeolite (50:30:20) + flyash (T_8 - compost 8).

In the second phase, growing media prepared using the sewage sludge composts and soil in 1:1 ratio were taken as treatments and evaluated using marigold as test crop. The nine treatments were T_1 - soil + sewage sludge, T_2 - soil + compost 1, T_3 - soil + compost 2, T_4 - soil + compost 3, T_5 - soil + compost 4, T_6 - soil + compost 5, T_7 - soil + compost 6, T_8 - soil + compost 7 and T_9 - soil + compost 8. The design adopted was CRD with three replications.

Characterisation of sewage sludge generated from Muttathara treatment plant revealed that the sludge had a pH of 5.36. The organic carbon content was high (17.03%). It was rich in plant nutrients N (1.68%), P (7.73%), K (1.2%), Ca (12%), Mg (4.8%), S (616 mg kg^{-1}), Fe (4500 mg kg^{-1}), Mn (1028.8 mg kg^{-1}), Zn (220 mg kg^{-1}), Cu (250 mg kg^{-1}) and B (23.06 mg kg^{-1}). The sludge contained heavy metals Pb (73.2 mg kg^{-1}), Cr (113.2 mg kg^{-1}), Ni (122 mg kg^{-1}) and Cd (10.8 mg kg^{-1}). Cr, Ni and Cd were above critical limit. As was not detected.

The results of composting experiment revealed that T_7 (Sewage sludge + coirpith (50:50) + flyash) recorded the highest organic carbon percentage (14.47%) followed by

T_5 (14.42%). Composting resulted an increase in pH. In the final compost T_2 recorded the lowest pH (5.23) and the highest pH was noticed in T_8 (7.07). Content of major nutrients, secondary nutrients, micro nutrients and heavy metals increased in the final compost. T_8 recorded the highest amount of nitrogen (1.53%), phosphorus (1.24%) and potassium (0.29%). T_8 (sewage sludge + sawdust + zeolite (50:30:20) + flyash) recorded the least concentration of heavy metals lead (33.06 mg kg^{-1}), nickel (97.623 mg kg^{-1}), cadmium (5.41 mg kg^{-1}), and chromium (47 mg kg^{-1}*).* *E. coli* was not detected in any one of the treatments. Heavy metal fractionation studies of final compost revealed that the mobile fractions of heavy metals (exchangeable and carbonate) decreased in all treatments while the stable fraction of heavy metal (residual) increased. Mobile fractions of lead decreased during composting and was found to be least in T_8 and T_2. Exchangeable and carbonate fractions of chromium decreased during composting and was found to be lowest in T_8 (0.043 and 0.047 mg kg^{-1} respectively). Exchangeable fraction of nickel was found to be lowest in T_6 (0.070 mg kg^{-1}) while carbonate fraction (1.036 mg kg^{-1}) was lowest in T_8. In case of cadmium, exchangeable (0.010 mg kg^{-1}) and carbonate (0.013 mg kg^{-1}) fractions were found to be least in T_8.

Results of pot culture experiment revealed that there was a reduction in pH, electrical conductivity, organic carbon and content of all nutrients in growing media at the end of the experiment. Dehydrogenase activity increased in the post harvest growing media compared to initial for all treatments. T_9 (Soil + compost 8) recorded the maximum no of flowers, flower yield, flower weight, flower diameter and took least number of days to first flowering. It was also superior with respect to vegetative and floral parameters. The heavy metal content in plant (shoot and root) were significantly influenced by the treatments and T_1 (soil + sewage sludge) recorded the highest content for all heavy metals and was above the permissible limit for Cd, Cr and Pb. The lowest heavy metal content in shoot and root were observed in T_9 (soil + compost 8) and was within the permissible limits for all the treatments T_2 to T_9. Arsenic was not detected in shoot and root in any of the treatments. Lead content was also not detected in roots.

Based on the present investigation it can be concluded that sewage sludge generated from sewage treatment Muttathara is rich in organic carbon and other plant nutrients and had a pH of 5.36. The sludge contained heavy metals such as Pb, Cr, Ni and Cd of which Cr, Ni and Cd were above the critical limit. Sewage sludge compost prepared as per the treatments were rich in organic carbon and plant nutrients. During composting there was a drastic reduction in the mobile fractions (exchangeable and carbonate) and an increment in stable fractions (residual) which indicated that composting of sewage sludge with heavy metal adsorbent and different bulking agents decreased the mobility and bioavailability of heavy metals. Results of pot culture experiment indicated that the growth and yield of marigold was higher in the treatment receiving sewage sludge, sawdust, zeolite (50:30:20) and flyash. The heavy metal content in marigold were found to be below the permissible limit in all the treatments indicating that composting of sewage sludge with bulking agents like coirpith, sawdust and adsorbents like zeolite decreased the uptake of heavy metals by plants.

Appendix

Appendix I

SPECIFICATION OF ORGANIC FERTILISER (FCO, 1985)

City compost

(i)	Moisture, per cent by weight	15.0-25.0
(ii)	Colour	Dark brown to black
(iii)	Odour	Absence of foul odour
(iv)	Particle size	Minimum 90% material
	should pass through 4.0 mm IS sieve	
(v)	Bulk density (g/ cm^3)	0.7-0.9
(vi)	Total organic carbon,	
	Per cent by weight, minimum	16.0
(vii)	Total Nitrogen	
	Per cent by weight, minimum	0.5
(viii)	Total phosphates	
	Per cent by weight, minimum	0.5
(ix)	Total potash	
	Per cent by weight, minimum	1.0
(x)	C:N ratio	20:1 or less
(xi)	pH	6.5-7.5
(xii)	Ec (as dS m^{-1})	
	Not more than	4.0
(xiii)	Pathogens	Nil
(xiv)	Heavy metal content, (as mg/kg)	

Per cent by weight, minimum

Arsenic (as AS_2O_3)	10.00
Cadmium (as Cd)	5.00
Chromium (as Cr)	50.00
Copper (as Cu)	300.00
Mercury (as Hg)	0.15
Nickel (as Ni)	50.00
Lead (as Pb)	100.00
Zinc (as Zn)	1000.00

Appendix II

Permissible limits for heavy metals in plant (WHO, 1996)

Elements	Permissible value of plant (mg kg $^{-1}$)
Cd	0.02
Cr	1.30
Cu	10.0
Pb	2.0
Ni	10.0
Zn	0.60