EVALUATION OF SEWAGE SLUDGE AS A GROWTH MEDIUM FOR ORNAMENTALS

by

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(2015-11-039)

THESIS

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DECLARATION

I, hereby declare that this thesis entitled **"Evaluation of sewage sludge 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.

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CERTIFICATE

Certified that this thesis entitled **"Evaluation of sewage sludge as a growth medium for ornamentals"** is a record of research work done independently by Ms. Anjana Asokan under my guidance and supervision and that it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to her.

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LIST OF ABBREVIATIONS AND SYMBOLS USED

%	:	Per cent
As	:	Arsenic
B	:	Boron
Ca	:	Calcium
CD	:	Critical Difference
Cd	:	Cadmium
Cr	:	Chromium
CEC	:	Cation Exchange Capacity
cm	:	Centimeter
Cu	:	Copper
DAT	:	Days after transplanting
$dS\ m^{-1}$	:	deci Siemens per meter
DTPA	:	Diethylene triamine penta acetic acid
EC	:	Electrical conductivity
et al.	:	Co-workers/ co authors
FYM	:	Farmyard manure
Fe	:	Iron
Fig.	:	Figure
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}	:	milli gram per gram
mg kg^{-1}	:	milli gram per kilogram
Mn	:	Manganese
N	:	Nitrogen
ND	:	Not Detected
NS	:	Non significant
P	:	Phosphorus
Pb	:	Lead
pH	:	Negative logarithm of hydrogen ions
S	:	Sulphur
WHC	:	Water holding capacity
Zn	:	Zinc

Introduction

1. INTRODUCTION

Rapid urbanization, mechanization and abandoned population growth has revolved waste management into a burning problem worldwide. As per the 2011 census, the urban population of India covered 28.6 crores, which accounted for 31% of the total population of the country (GOI, 2011). The exceptional urban population growth has put great burden on the value of life concerning air, water soil, housing and power supply.

One of the most important natural reserves on earth is water, without which we cannot imagine a life. As a result of increasing urbanization and further increase in the population, waste water generation has also increased immensely. Water resources are becoming unhygienic from human activities that result in its contamination. Even though the water pollution caused by both human and natural sources, pollution by anthropogenic activities is most serious one.

For an example most of the sewage generated among urban areas which are located on the river banks is readily allowed to flow into the rivers. Even though there is stricter regimentation on discharge of waste water effluents into the rivers have been passed, it progressively raised the construction of new waste water effluent treatment plants.

The resultant insoluble solid deposit generated subsequently after the treatment of sewage is referred to as biosolids, domestic waste water residuals, or sewage sludge. To emphasize the useful nature of this product, it is referred as "biosolids". One of the major ecological threats all over the world is the safe relegation of sewage sludge. Soil application, dumping at sea, land filling or incineration is the important disposal options usually attempted to remove such sludge.

Most inexpensive practice for removal of sewage sludge is land application and this method also deals with the chance to recycle valuable plant nutrients and organic stock to soil which is beneficial for crop growth and production.

The properties of sewage sludge not only determined by the characteristics of the waste water from which it originates but also on the methods by which the waste water is treated. Sewage sludge is normally comprised of organic matter, a wide range of macro and micronutrients, heavy metals, organic micro pollutants and microorganisms.

Thiruvanathapuram Corporation comprises an area of 141.74 sq.km of which 30% is covered by piped sewage system, which serves the core city area. Earlier the sewage collected from the city was pumped into open ground and was used for cultivation of fodder for cattle. This was known as sewage fodder farm and was installed in 1945 at Valiathura in Thiruvanathapuram. The partially treated effluent from the fodder farm used to infiltrate into Parvathy Puthanar. Thus Parvathy Puthanar becomes an open channel for disposing raw sewage.

To solve this problem, a sewage treatment plant was installed at Muttathara, Thiruvanathapuram. The plant which was inaugurated on 30th October 2013 is designed to meet the city's requirements for next thirty years. The estimated average flow is 107 MLD. Activated sludge process with extended aeration is used for the treatment of sewage.

The overall performance of the plant is excellent and removes 94% of the BOD. This generates considerable amount of sewage sludge. Daily generation is 9 to 10 m^3 of sludge which has been accumulating in the plant site for the past two years. If this continues it will affect the operation of the plant and eventually the plant will have to be closed. It is the urgent need of the hour to find out means to utilize this sludge. One option is to utilize the sludge for crop production. However, reports on the presence of heavy metals and pathogens in sewage sludge in many cities are a deterrent for its use to grow food crops without detailed studies. But there is a possibility for its use for growing flowering plants.

With rapid urbanization, considerable cultivable lands have been converted to residential areas. The modern households in the residential areas have very small or practically no open area for gardens. But there is a possibility to grow flowering plants in pots / grow bags. The diminishing availability of good quality growing media for filling pots or grow bags is a constraint in this regard. In this context the potential of sewage sludge as a component in the growing medium for ornamentals may be evaluated. The ability of hyperaccumulators like African marigold to remove the heavy metal, if any present can also be studied. This will open a new frontier for utilization of sewage sludge generated at sewage treatment plant Muttathara.

With this background the present study on "Evaluation of sewage sludge as a growth medium for ornamentals" was undertaken with the following objectives;

(1) Characterisation of sewage sludge generated at sewage treatment plant Muttathara, Trivandrum
(2) Performance evaluation of sewage sludge as growing medium for ornamentals.

Review of Literature

2. REVIEW OF LITERATURE

The brief resume of research work done in India and abroad on various aspects relevant to present investigation entitled "Evaluation of sewage sludge as a growth medium for ornamentals" has been reviewed and presented under appropriate headings.

2.1 CHARACTERISTICS OF SEWAGE SLUDGE

Sewage sludge which is also known as bio solids is one of the final products of the treatment of sewage at wastewater treatment plants (Nicolae, 2011). It consists of by-products of wastewater treatment and commonly sewage sludge is a mixture of water, inorganic and organic materials removed from wastewater coming from various sources (domestic and industrial) and storm water run- off from roads and other paved area through physical, biological, and or chemical treatments (Usman *et al.*, 2012).

Sommers (1977) investigated the chemical characterization of sewage sludge collected for over two years from 8 towns of Indiana and US. The results revealed that the sewage sludge contained approximately 50 % of organic substance and 1-4 % of inorganic carbon. Organic nitrogen, inorganic phosphorous, calcium and magnesium were present in relatively constant amounts in a given sludge throughout the period of sampling.

Maiti *et al.* (1992) characterized the sewage sludge of Calcutta and reported that pH of sewage sludge was neutral to slightly alkaline and had higher salt content. Exchangeable calcium was the main cation followed by magnesium, sodium and potassium. The sludge was found to be rich in organic carbon and available N.

Sewage sludge from Dindigul (Tamil Nadu) was recommended for land application as it was having nearly neutral pH, high organic matter, nitrogen, phosphorous and calcium content and was free from toxic heavy metals such as chromium, lead and mercury (Nandakumar *et al.,* 1998).

Arcak *et al*. (2000) reported that sewage sludge is one of the widely used waste materials for conditioning the soil. Sewage sludge application improves the physical, chemical and biological purposes of soil (Benitez *et al*., 2001). Sewage sludge is used for the agricultural practices because of the presence of high organic matter. Application of sewage sludge to agricultural soil is a common practice because of low costs and recycling of nutrients (Sigua, 2005).

Singh and Agrawal (2010a) characterized the sewage sludge from Dinapur Sewage Treatment Plant (DSTP), Varanasi. This sewage sludge was neutral in pH and had high EC and high concentrations of organic C, total N, available P, Fe, Na, K, Ca, and Mg.

Siuris (2011) characterised the sewage sludge from urban wastewater treatment in the republic of Moldova and reported that it was characterized by high contents of total N, P and the average values exceeded 2 %. Si comes first among the mineral elements (33.24 %) followed by Ca (7.06 %), Fe (2.53 %) and S (1.83 %). Presence of heavy metal was reported and among them Cd, Co, Cu, Cr, Ni and Pb were in large quantities.

Today, the rapid growth of industrialization has resulted in the increased production of sewage sludge, and the storage and disposal of these wastes has become a major problem. To solve this problem to some extent the sewage sludge can be better used in agriculture sector for crop production (Kharub, 2012).

Characterization of sewage sludge for determination of its nutrient potential is important before application to agricultural crops. (Mtshali *et al*., 2014).

2.2 EFFECT OF SEWAGE SLUDGE ON SOIL PROPERTIES

2.2.1 pH, Electrical Conductivity and Organic Carbon

According to Morino *et al.* (1997), sludge application may reduce the pH of soils due to humic acid release and increase the EC of the soils. The decrease in soil pH due to sewage sludge amendment can be attributed to the production of humic acid as a result of degradation of sewage sludge which is rich in organic carbon (Singh and Agrawal, 2010b).

Parkpain *et al*. (2000) reported an increase in pH of acidic soil of Thailand upon sewage sludge amendment. The experiment conducted in calcareous soil using six different doses of sewage sludge in barely indicated that the application of sewage sludge lowered the pH of the soil, although the values always were in the range of 7.75-7.9 (Hussain *et al*, 2010).

Agricultural crops grow well when soil pH is between 6 to 7 due to more availability of nutrients at pH of around 6.5 (Smith, 1994). Martinez *et al*. (2002) reported that sludge pH might vary from either acidic or alkaline. Depending on the extent of treatment and application of sludge, pH of sewage sludge may vary between slightly acidic to neutral and alkaline ranges (Yilmaz and Temizgul, 2012). It generally recommended to maintain soil pH above 6.5 for sludge amended soils (Kauthale *et al*., 2015).

Mtshali *et al*. (2014) reported that the sewage sludge added to low pH soils (soil pH less than 5) decreased the soil pH further and as such it cannot be suggested for application unless it is steadied with lime.

Outhman and Bharose (2014) studied the effect of various levels of sewage sludge on the pH of post-harvest soil at 0-15 cm soil depth and observed a decrease in soil pH with the increase in sewage sludge amendment rate.

Decomposition of organic matter in the sewage sludge produces organic acids resulting in the reduction of soil pH (Veeresh *et al*., 2003). Reduction in soil pH as a result of organic wastes application has been reported by several researchers (Cheng *et al*., 2007; Angin and Yaganoglu, 2011). Ghahdarijani *et al*. (2015) studied the effect of application of sewage sludge and two synthetic humic acids on selected chemical properties of three soils and the results showed that sewage sludge and humic acid application decreased pH of soils.

Ahmed *et al.* (2010) found that electrical conductivity varied when the sludge amendment was carried out with sewage sludge and it increased compared to control due to the formation of complexes of organic matter and heavy metals. The electrical conductivity of soils amended with sewage sludge increases mainly due to the high level of salts present in sewage sludge (Mtshali *et al.,* 2014).

Sewage sludge is a rich source of organic matter and nutrients, which can be used as a good soil organic amendment (Caravaca *et al.,* 2002). The organic matter content of sludge in urban sewage is usually more than 50 per cent of dry matter (Usman *et al.,* 2012).

Antolin *et al.* (2005) assessed the effects of sewage sludge on the growth and yield of barely (*Hordeum vulgare* L.) under semi-arid condition and reported that the repeated sludge applications decreased the pH, increased the total organic carbon and cation exchange capacity.

Jamil *et al.* (2006) reported that the addition of sewage sludge to agricultural soils increased the organic matter content in the soil and lead to the production of humic and carbonic acids, which play a fundamental role in conditioning the soil properties.

Study conducted by Selivanovskaya *et al.* (2007) revealed that the addition of increasing amounts of composted sewage sludge to the soil increased the organic carbon content from 0.7% for the unamended soil to 1.4 to1.5% for the sludge amended soil.

The use of biosolids as a fertilizer significantly increased total organic carbon content in the soil which increases the ability of the soil to retain water (Khai *et al.,* 2008).

The organic carbon in the sludge amended soil can increase as far as three fold compared to inorganic fertilizer amended soil (Nyamangara and Mzezeva, 2001). Since sewage sludge contains organic substances from 50 to 70%, it has been regarded as an important source of plant nutrients (Saruhan *et al.,* 2012).

2.2.2 Soil Physical Properties

According to Gupta (1967) the application of sewage sludge affects physical properties of soil directly by enhancing water retention capacity and indirectly by modification of other physical properties like bulk density, porosity and pore size distribution.

Epstein (1975) conducted a study to determine the effect of 0.5% sewage sludge application to soil on water retention capacity, hydraulic conductivity and aggregate stability. The results indicated that raw as well as digested sludge increased the soil water retention capacity with the greatest increase in the raw sludge amended soil.

Over half of the mass of sewage sludge is organic matter, which improves the physical condition of the soil by reducing the bulk density, increasing aggregate stability and increasing water holding capacity of soils (Khaleel *et al.*, 1981). Otis (1984) reported that the application of sewage sludge reduced the hydraulic conductivity of soils due to pore clogging by suspended solids in the sludge.

According to Sort and Alcaniz (1999) application of sewage sludge has improved soil structure, increased infiltration rate, aggregate stability and soil water holding capacity.

The decrease in bulk density as a result of sewage sludge application is due to a dilution effect from the mixing of added organic substance with the denser mineral fraction of the soil (Powers *et al.*, 1975). Reduced bulk densities were observed in sludge amended plots regardless of soil texture (Chang *et. al.*, 1983). Lindsay (1998) observed that increasing rate of sewage sludge application in wheat plants showed a decrease in bulk density and increase in total porosity of soil.

Mathan (1994) recorded significantly lower bulk density and increased hydraulic conductivity in sewage farm soils. This can be attributed to the improvement in total porosity and aggregate stability due to the addition of organic matter in the form of sewage sludge (Antil and Narwal, 2008).

According to Rattan *et al*. (2001) there is enhanced available water content in the soils owing to continuous application of sewage waters.

The higher organic matter proportion in sludge decreased the bulk density and increased the aggregate stability and these improvements in soil physical properties increased water-holding capacity by promoting higher water retention in sludge-amended soils (Ojeda *et al*., 2003).

Mazen *et al.* (2010) reported that addition of sewage to the desert soil improved the soil texture, raised the organic matter content, water holding capacity and lowered the pH value.

Addition of organic material as sewage sludge will have profound effect on physical properties of soil and provides good soil conditioning effect on most of the soils (Usman *et al*., 2012).

Mondal *et. al.* (2015) observed that application of sewage sludge leads to reduction in bulk density which was lowest at sewage sludge amendment rate of 15 t ha^{-1} (1.45 g cm^{-3}) followed by 10 t ha^{-1} (1.52 g cm^{-3}) and 5 t ha^{-1} (1.58 g cm^{-3}).

2.2.3 Effect of Sewage Sludge on Macro and Micro Nutrient Status in Soil

Sewage sludge serves as a reservoir for nutrients such as N, P, K, Ca, Fe, Mn, Zn, Cu and can help to stabilize soil pH (Peterson *et al.,* 2003). It is rich in nutrients (N, P and K), organic matter and trace elements that is beneficial for plant growth, development and yield (Kauthale *et al.,* 2005).

Magdoff and Amadon (1980) conducted both laboratory and field experiments on corn (*Zea mays*) to evaluate the nitrogen contribution of sewage sludge and found that under laboratory conditions more than 54 % of organic nitrogen added as sewage sludge to soil was mineralized and under field conditions, mineralization of organic nitrogen from sludge was averaged to 55 % during the first year of application.

A study conducted by Mbagwu and Piccolo (1990) on carbon, nitrogen and phosphorus concentration in aggregates of organic waste amended soils revealed that the application of sewage sludge at the rate of 200 t ha^{-1} has increased the total nitrogen and available phosphorus content of soil aggregates by 57 % and 64.2 % respectively. Land application of sewage sludge has been shown to provide potential benefits for agricultural soils in the form of nitrogen (Hogan *et al.,* 2001) and phosphorous (Binder *et al.*, 2002)

Morris and Lathwell (2004) reported that sludge amendment enhanced the available nitrogen content in alkaline soils than acidic soils. Bose and Bhattacharrya (2012) studied the behavior of sludge amended soil with respect to available nitrogen content in soils. They observed that sludge application increased the available nitrogen in 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 levels of sewage sludge amendment.

Nyamangara and Mzezewa (2001) reported an increase in phosphorous content from 2 to 4 mg kg^{-1} in unamended soil to 29 to 114 mg kg^{-1} in the sludge amended soil. Ahmed *et al.* (2010) observed that the application of sewage sludge to agricultural soils mainly those to which high amounts of sludge had been applied showed a higher phosphorous content than the control.

No clear effect for sewage sludge application on K concentration in soil was noted by Mohammad and Athamneh (2004).

Epstein *et al.* (1976) reported that the basic cations present in the sewage sludge favorably affect the distribution of cations on the exchange complexes of acid soils by increasing the distribution of exchangeable Ca and Mg. Cavallaro *et* *al.* (1993) studied the effects of sewage sludge on chemical properties of acid soils and found that the exchangeable Ca was more than doubled in the soil to which highest rate of sludge application was done, although no lime was added to these soils.

An increased concentration of Zn and Cu has been observed in soil and plants with the application of sewage sludge (Barbarick *et al.,* 1998). Kabirinejad and Hoodaji (2012) studied the effects 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}.

2.2.4. Soil Microbial Properties

Kobus *et al.* (1990) observed that the addition of sewage sludge to soil considerably increased the population of bacteria, actinomycetes, and fungi. The microbial count in sewage irrigated soils was higher for bacteria, fungi and actinomycetes which was about 1.34, 1.52 and 1.18 times (for 0-30 cm) higher respectively, as compared to that in normal soils (Karche *et al.*, 2011). In general, addition of organic manure in the form of sewage sludge will increase soil microbial activities, their population and microbial biomass (Usman *et al.,* 2012).

Past applications of sewage sludge has resulted adverse effects on the size of soil microbial biomass due to heavy metal contamination (Brookes and McGrath, 1987). Akmal *et al.* (2005) reported that elevated metal concentration in sewage sludge has been shown to reduce soil microbial biomass levels, inhibit nitrogen fixation by both free living and symbiotic microorganisms and reduced enzyme activities.

Reduction in microbial biomass due to heavy metal exposure have been owed to instantaneous death of microbial cells, disorder of important functions and change in population size and in viability or competitive ability of soil microorganisms (Giller *et al.*, 1998). The most significant harmful effects produced on soil microorganisms from sewage sludge applications are the reduced size of total biomass, reduced nitrogen fixing activity and changes in soil microbial population composition (Viera and Silva, 2003).

The biggest objection in the use of sewage sludge in agriculture is the accumulation of pathogenic organisms in soil (Pillai *et al*., 1996). The bacteria fecal coliform, *Listeria monocytogenes*, and enterococci found in sludge are capable of surviving anaerobic digestion (Sidhu, 2000).

The existence of bacterial pathogens up to 36 weeks in stored dried sludge was reported (Gibbs *et al*., 1997) while a lower survival time of less than 6 weeks was reported in the sludge that had been exposed to land application (Nicholsan *et al*., 2005). Zaleski *et al*. (2005) reported that the number of faecal coliforms and Salmonella decreased as the temperature and desiccation rate increased. These pathogens are extremely sensitive to moisture loss (Orenes *et al*., 2007) implying that the drying of sludge reduces their population. The number of pathogens in sewage sludge could be reduced when the sludge is combined into soils or soil surface due to the moisture loss, solar irradiation, and contact with soil (Ogleni and Ozdemir, 2010).

2.3 EFFECT OF SEWAGE SLUDGE ON HEAVY METAL ACCUMULATION IN SOIL AND PLANT

According to Babel and Dacera (2006) the total content of heavy metals in sediments varies within the limits of 0.5-2.0% of dry matter of sludge, in some cases it may increase up to around 4% d. m. and the main source of heavy metal in sewage sludge are industrial waste water and surface water runoff. Addition of sewage sludge can induce heavy metal and organic contaminant accumulation in soils which can lead to soil and water pollution (Giller *et al*., 2009).

Heavy metal contamination due to sludge application has received much attention owing to concerns regarding uptake by plants and contamination of groundwater or surface waters (Cunningham *et al*., 1975). Heavy metals are often highly persistent in soil, with residence times as long as thousands of years (Alloway, 1990).

Sewage sludge contains appreciable amounts of Zn, Cu, Ni, Cd and Pb (Chander and Brookest, 1991). Alloway and Jackson (1991) reported that heavy metals applied with sewage sludge may be retained in the soil as a result of their adsorption on hydrous oxides, clays, and organic matter; the formation of insoluble salts; or the presence of residual sewage sludge particles. Sloan *et al.* (1997) found that after 15 years of sludge applications in a soil, the rational bioavailability of sludge applied heavy metals were increased in the order of Cd > Zn > Ni > Cu > Cr >Pb. Heavy metal accumulation has been reported in numerous long-term sludge application experiments (Streck and Richter, 1997).

Soil pollution with heavy metals can have implications in phytotoxicity at high concentrations and result in the transfer of heavy metals to the human diet from crop uptake or soil ingestion by grazing livestock (Kabata-Pendias and Mukherjee 1992). Zenhas *et al.* (2000) reported that the heavy metal content increased with the increase in sludge added to soils. Heavy metal accumulation in soils can result in a loss of soil functions leading to concerns about environmental quality protection, maintenance of human health and productivity (Nicholson *et al.*, 2003).

Dying and paint industries release high concentrations of heavy metals especially cadmium, chromium, lead etc to wastewater (Sharma *et al.*, 2006). Lead and nickel have also contributed to the wastewater by metal plating and battery industries (Sharma *et al.*, 2007).

Mahdavi and Jafar (2010) reported that long-term application of sewage sludge in clay loam soil led to accumulation of cadmium and 92% of the cadmium present in sewage sludge retained in topsoil and 7% in the upper subsoil.

Effect of sewage sludge water and canal irrigation water were compared for their physico-chemical properties and heavy metal concentration in soil by

Swapnil *et al.* (2011) and the results depicted that the concentration of Pb, Cu and Zn were found Indian standards except Cd in sewage water irrigated soil.

Absorption, buildup and tolerance of plants to heavy metals may differ between diverse crops and at different levels of sewage sludge amendment. (Bhogal *et al.*, 2003).

Increased accumulation of Cd, Zn, Ni, Hg and other toxic metals were noted in sweet corn when grown in sludge-amended soil, but the content was lesser in corn kernels than in leaves and roots (Dowdy and Larson, 1975).

Reddy and Dunn (1983) reported that concentration of Cd, Ni and Pb in soybean shoots and roots increased as a result of sewage sludge amendment and the metal concentration in soybean increased with increasing levels of sludge amendments.

Wheat (*Triticum aestivum* L. var. holly) grown in sewage sludge [2 and 10 kg m^{-2}] amended sandy and silty loam soils showed significantly higher concentrations of zinc, cadmium and nickel in wheat grains at increasing sewage sludge amendment rates in these soils (Tadesse *et al.*, 1991).

Frost and Ketchum (2000) reported that zinc, copper, cadmium and chromium concentrations of plant tissues increased with sewage sludge application. Different vegetables and forage grasses grown in sewage sludge amended soils showed higher content of Cd, Cr, Co, Pb, Ni and Zn as compared to unamended soil (Sekhar *et al.*, 2002).

Vassilev *et al.* (2002) reported reduction in the photosynthetic rate per unit area in sludge amended soils due to the accumulation of heavy metals in leaves.

El-Naim *et al.* (2004) recorded varying levels of increments in heavy metal concentrations in wheat grains, peanut seeds, onion, guava and top part of clover due to the application of dried sewage sludge.

Content of copper and nickel were reported to be higher in seeds of broad bean plants which were grown in a sewage sludge amended soil (0.45 kg m^{-2}) as related to unamended soil (Garrido *et al.*, 2005). Jing *et al.* (2005) reported retardation in root length at higher rates of sewage sludge amendment which may be due to high metal concentrations in sludge amended soil.

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

Cd, Ni, Zn, Cr and Cu concentration in palak roots were significantly higher in plants grown in 40% sewage sludge amended soil compared to those with 20% sewage sludge. However, Pb concentration was higher at 20% than 40% sewage sludge amendment (Singh and Agrawal, 2007).

The effects of sewage sludge on growth, development and quality of *Zoysia japonica* and *Poa annua* grass species was studied by Wang *et al* (2008). The results showed that the sewage sludge applied in various dosages (0, 15, 30, 60, 120 and 150 ton/ha) increased the heavy metal content in the soil and it was observed that the contamination of Zn, Pb and Cu did not exceed the permissible limit; but Cd exceeded the limit value.

Heavy metal content was found higher in seeds of cowpea plants grown in sewage sludge amended soil. The concentrations of nickel and lead in seeds were above Indian permissible limits at sewage sludge amendment rate above 6 kgm^{-2} (Singh and Agrawal, 2010a).

Sewage sludge amendment rates above 4.5 kg m^{-2} increased the rice yield, but it caused food chain contamination as the content of nickel and cadmium in rice grains were found above the Indian safe limits (1.5 mg kg^{-1}) of human consumption and of Pb (2.5 mg kg^{-1}) for above 6 kg m^{-2}sewage sludge amendment rate. Since aboveground parts of the rice showed higher concentration of Ni, Cd and Pb than the permissible levels it cannot be used as fodder (Singh and Agrawal, 2010b).

Saruhan *et al.* (2012) conducted a study on the effect of sewage sludge treatment on heavy metal content in bird's-foot trefoil plant (*Lotus corniculatus*.L) and reported that increased application of sewage sludge increased the heavy metal content in the plant also.

2.4 EFFECT OF SEWAGE SLUDGE ON GROWTH AND YIELD OF CROPS

The production of sewage sludge compost represent a good way to produce a dry, nutrient rich, stabilized and easy to transport fertilizer which can be applied to horticultural crops (Erdogen *et al.,* 2011). Utilization of sewage sludge as ornamental plant fertilizer can be recommended as it is safe (Roslan *et al.,* 2013).

Gouin (1985) reported that composted sewage sludge at the rate of 33% to 50% of growing medium along with equal parts of peat and sand could use to grow hardy chrysanthemum.

Qasim *et al.* (2001) observed the lowest germination percentage in the control and sludge amendment @ 50t ha^{-1} in maize. But the maximum shoot and root dry weights were observed on application of sludge @ 20 t ha^{-1}.

In a study to know the effects of application of sewage sludge and mineral fertilizer on *Diplotaxis erucoides,* Korboulewsky *et al.* (2002) observed that in the plants which received sewage sludge compost, the blooming was delayed. However, as the biomass increased, the plant developed a bigger root system.

When *Typha lantifolia* plants, commonly known as cat tails, were grown in a mixture of sewage sludge compost, commercial compost and perlite, it resulted in high accumulation of Ni, Cu and Zn in the root and the leaves of the plants, but no significant influence was observed on chlorophyll content in leaves concluding that there was no significant toxic action in the plants by the heavy metals (Manios *et al.,* 2003).

Ozdemir *et al.* (2005) studied the potential of sewage sludge as a growth medium for *Cupressus macrocarpa* and found that the best results in terms of growth performance were obtained from the mixtures prepared with 30% and 50% sewage sludge with garden soil.

Flower pot experiment conducted by Stabnikova *et al.* (2005) with sewage sludge and garden compost revealed that the potting mixture increased the plant development in *Ipomea aquatica* and the highest fresh weight was observed in the 4% garden compost + 2% sewage sludge mixture.

Atila *et al.* (2005) determined the effect of sewage sludge on the seed germination, seedling development and macro-micro nutrient content of pepper seedlings and positive results were reported on seed emergence percentage and pepper seedling growth.

A field study was carried out by Wei and Liu (2005) in order to determine the effect of sewage sludge compost on heavy metal accumulation in soil, seed germination, root development and the yield of barely compared to conventional mineral fertilizers. Results revealed that the sewage sludge compost produced little effect on seed germination but it stimulated the root development at lower application rates.

Studies carried out by Mehmet *et al.* (2005) revealed that the application of sewage sludge to lentil plants increased the seed yield and seed weight per plant.

Lavado (2006) observed yield increments of 30% and 31% in sunflower at 0.7 and 1.4 kg m^{-2} sewage sludge amendment respectively. Moldes *et al.* (2006) evaluated the suitability of composted sewage sludge as a growing medium for broccoli and the results showed that the highest yield was obtained in the medium prepared by mixing the peat with 30% of composted sewage sludge. However; the mixture with the most sewage sludge compost (50%) had the greatest contents of macro and micronutrients.

Cheng *et al.* (2007) studied the effect of composted sewage sludge (CSS) as a soil amendment for turf grass growth. Results of this study showed that CSS at ≤20% levels could use as a slow-release fertilizer for turf grass production and the perennial ryegrass grown in soils with 5–20% CSS had higher clipping yields and higher nutrient contents, compared to the control.

Grigatti *et al.* (2007) observed a decreasing number of flowers in *Begonia semperflorens, Mimulus ssp, Salvia splendens* and Tagetes when increasing the rate of sewage sludge in the growing medium. Tariq *et al.* (2012) found that the media containing sewage sludge alone and in combination with silt showed minimum results for plant growth parameters.

Wang *et al.* (2008) reported that the body diameter, canopy diameter and dry weight values of *Primula* increased in media which contained sewage sludge.

Singh and Agrawal (2008) reported that sewage sludge amendment ratio below 20 per cent might be an alternative option of fertilisers for good yield of lady's finger and also a useful managing option for this solid waste.

Maryam (2011) studied the effect of sewage sludge application on growth rate of three leafy vegetables (spinach, celery and lettuce). Results showed that sewage sludge was highly effective in celery growth compared to spinach and lettuce where the dry and fresh weight of celery plants was increased significantly with the addition of sewage sludge.

Investigation carried out by Cerny *et al.* (2012) revealed that sewage sludge application increased the yield of silage maize by 19-25% compared to control.

Kharub (2012) studied the effects of sewage sludge on the emergence and growth quality of lady's finger with the growing media consisting of five different percentages of soil/sewage sludge (50+0) %, (40+10) %, (25+25) %, (10+40) %, (30+50) % and the results indicated that (30+50) % soil/sewage sludge ratio had a positive effect on the emergence and growth of lady's finger.

The most beneficial effect on the growth, foliage and a decorative value of ivy pelargonium was observed for the medium containing 12.5% of the compost made of sewage sludge and leaves, and 87.5% of sphagnum peat (Zawadzinska and Salachna, 2014).

The sewage sludge in which pathogens are eliminated and which doesn't contain heavy metals when given to the soil as an organic fertilizer is acceptable as an efficient and environment friendly method (Zafari and Kianmehr, 2014).

Materials and Methods

3. MATERIALS AND METHODS

A scientific study on "Evaluation of sewage sludge as a growth medium for ornamentals" was conducted at the College of Agriculture, Vellayani during the period 2015 to 2017. Sewage sludge generated from the sewage treatment plant located at Muttathara, Trivandrum was used for the study. The details of the materials used and techniques employed for studies are described under the following headings.

Study comprises of two phases

1. Characterisation of sewage sludge generated from sewage treatment plant, Muttathara

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

3.1 CHARACTERISATION OF SEWAGE SLUDGE

For conducting this study, sewage sludge generated from sewage treatment plant Muttathara was utilised. Sewage sludge samples were collected from the treatment plant Muttathara, Trivandrum.

3.1.1 Collection of Sewage Sludge Samples

Representative samples were collected from the three zones of the sewage sludge yard. For this, five such samples were collected from each zone and composite sample was prepared by adopting quartering technique. The samples were collected in air-tight plastic bags. Further, the samples were shade dried ground, passed through 2 mm sieve and kept in air-tight containers for various analyses. Fresh samples were used for microbial studies.

3.1.2 Analysis of Sewage Sludge

The samples were analysed for physical, chemical and biological properties namely bulk density, water holding capacity, porosity, pH, EC, organic carbon, total N, P, K, Ca, Mg, S, micronutrients (Fe, Mn , Zn, Cu, B), heavy metals (Pb, Cd. Cr, As, Ni) and microbial contamination following standard procedures as given in Table 1.

Table1. Analytical procedures followed in sewage sludge analysis.

S.No.	Parameter	Methods	Reference
1	pH	pH meter (soil and water taken in a ratio of 1:2.5 w/v)	Jackson(1958)
2	EC	Conductivity meter (soil and water taken in a ratio of 1:2.5 w/v)	Jackson (1958)
3	Organic carbon	Walkley and Black wet digestion	Walkley and Black(1934)
4	Total N	Microkjeldahl digestion and distillation	Jackson (1958)
5	Total P	Diacid (HNO_3:$HClO_4$ in the ratio 9:4) digestion and estimation using spectrophotometer	Jackson (1958)
6	Total K	Diacid (HNO3:HClO4 in the ratio 9:4) digestion and estimation using flamephotometer.	Jackson (1958)
7	Total S	Diacid (HNO3:HClO4 in the ratio 9:4) digestion and estimation using Turbidimetry.	Massoumi and Cornfield (1963)
8	Total B	Diacid (HNO_3:$HClO_4$ in the ratio 9:4) digestion and azomethane- H colorimetric method	Wolf (1971)

Table 1. continued

S.No	Parameter	Method	Refence
9	Total metals (Ca, Mg, Fe, Mn, Zn, Cu, Pb, Cd, Cr, Ni, As)	Diacid (HNO_3:$HClO_4$ in the ratio 9:4) digestion and estimation using Inductively Coupled Plasma Optical Emission Spectrometer.	Kalra (1998)
10	Bulk Density	Laboratory core method	Black *et al.* (1965)
11	Water Holding capacity	Core method	Black *et al.* (1965)
12	Porosity	Core method	Black *et al.* (1965)
13	Coliforms	MPN index method	USDA (2014)
14	Bacteria	Serial Dilution Agar Plating method	Timonin (1940)
15	Fungi		
16	Actinomycetes		

3.2. POT CULTURE EXPERIMENT

A pot culture experiment was conducted at sewage treatment plant, Muttathara to evaluate the suitability of sewage sludge as a growing medium for ornamentals with marigold as test crop.

3.2.1 Experimental Details

Location : Sewage treatment plant, Muttathara

Crop : African marigold

Variety : Orange beauty

Container : UV stabilized grow bag

Season : Summer 2016

Design : CRD

Treatments : 11

Replication : 3

Treatment Details

T_1: Potting mixture alone (soil, sand and FYM 1:1:1)

T_2: Potting mixture + sewage sludge (9: 1)

T_3: Potting mixture + sewage sludge (8:2)

T_4: Potting mixture + sewage sludge (7:3)

T_5: Potting mixture + sewage sludge (6:4)

T_6: Potting mixture + sewage sludge (1:1)

T_7: Potting mixture + sewage sludge (4:6)

T_8: Potting mixture + sewage sludge (3:7)

T_9: Potting mixture + sewage sludge (2:8)

T_{10}: Potting mixture + sewage sludge (1:9)

T_{11}: Sewage sludge alone

Layout of the experiment is given in Figure 1.

3.2.2 Growing Medium

The growing medium used in this experiment were prepared with potting mixture (sand:soil:FYM @ 1:1:1) and dried sewage sludge collected from sewage treatment plant, Muttathara. Sufficient number of grow bags having a capacity of

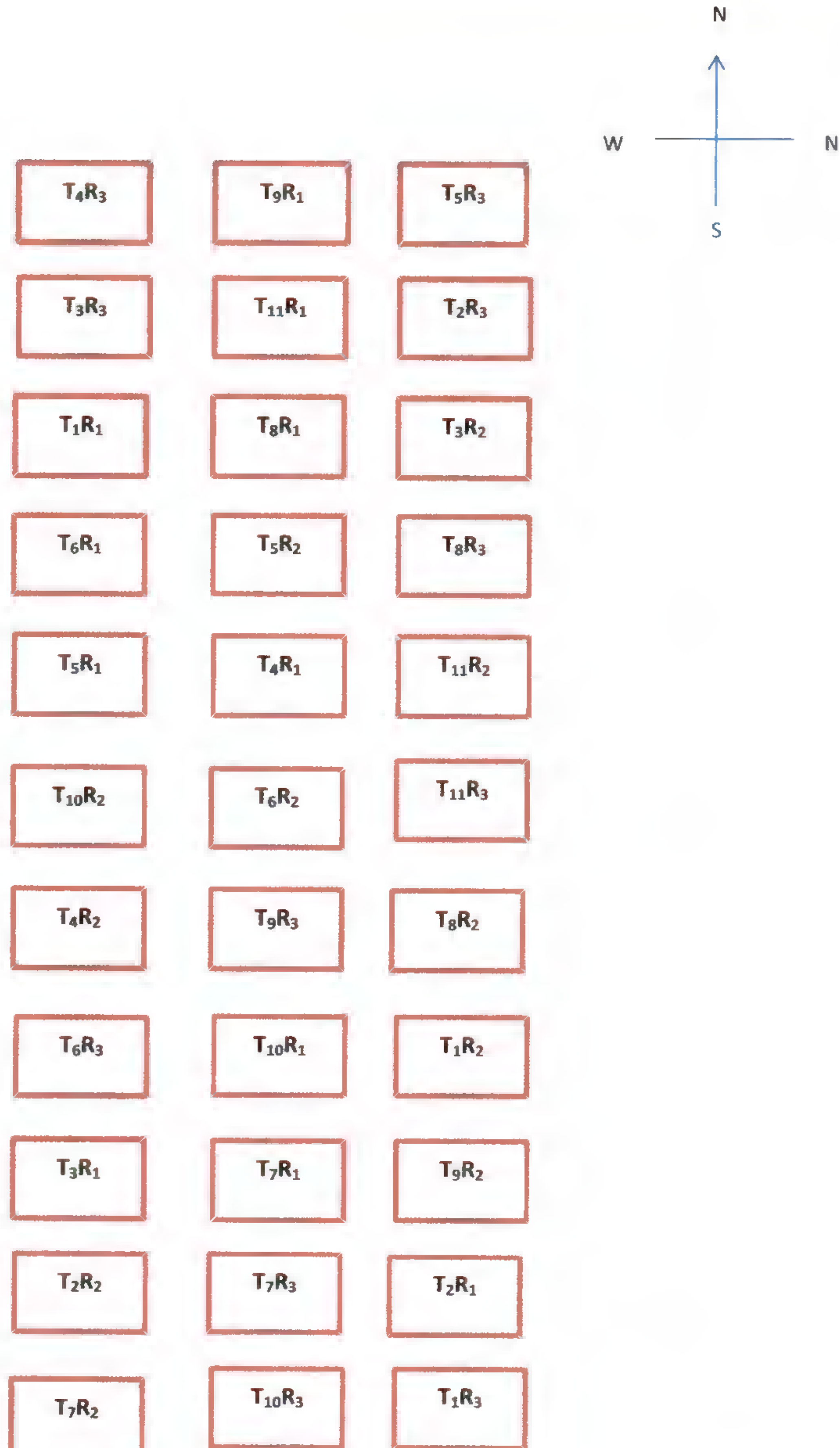

Fig. 1 Layout of field experiment

Plate 1. General view of the experimental field

10 kg were procured and filled with the growing media in different proportions as given in treatments.

3.2.3 Planting

Seedlings were raised in portrays filled with cocopite, 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 doses of fertilizers were applied as per package of practices recommendations (POP) of KAU (2016). Pinching was done to increase the total yield by removing the terminal 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 soil moisture and weather conditions. Weeding was also carried out. Crop was ready for first harvest 28 days after transplanting and subsequent harvests were made at regular intervals.

3.2.4 Analysis of Growing Medium

Samples of growing media were collected from each treatment unit and composite sample was prepared for each treatment, replication wise. These samples were air dried ground and sieved through 2 mm sieve and stored in air tight container in laboratory until analysis. Samples were drawn before planting the test crop (initial) and after the crop (final). They were analysed for physical (bulk density, water holding capacity and porosity), chemical (pH, EC, organic carbon, available N, available P, available K, secondary nutrients, micronutrients and heavy metals) and biological (microbial contamination) properties employing standard procedures which are given in Table 2.

Table 2. Analytical procedures for growing media analysis.

S.No.	Parameter	Method	Reference
1	pH	pH meter	Jackson(1958)
2	EC	Conductivity meter	Jackson (1958)
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 estimation using spectrophotometer.	Bray and Kurtz (1945)
6	Available K	Neutral normal ammonium acetate and using flame photometry	Jackson (1958)
7	Available S	$CaCl_2$ extraction and estimation using spectrophotometer.	Massoumi and Cornfield (1963)
8	Available B	Hot water extraction and estimation using spectrophotometer	Gupta (1967)
9	Extractable metals (Ca, Mg, Fe, Mn, Zn, Cu, Pb, Cd, Cr, Ni, As)	0.5 N HCl extraction and estimation using Inductively Coupled Plasma Optical Emission Spectrometer	Kalra (1998)
10	Bulk Density	Laboratory core method	Black *et al.* (1965)

Table 2. continued

S.No	Parameter	Method	Reference
11	Water Holding capacity	Core method	Black *et al*. (1965)
12	Porosity		
13	Coliforms	MPN index method	USDA (2014)
14	Bacteria	Serial dilution technique	Timonin (1940)

3.2.5 Collection of Plant Samples for Analysis

Plants were uprooted after final harvest of the crop, shoots and roots were separated. Roots were washed in running water to remove adhering soil particles. Shoots and roots were air dried followed by drying in hot air oven at 60 ^{0}C. The oven dry weight was recorded. The dried samples were chopped, powdered and stored in vials for further analysis.

3.2.6 Analysis of Plant Samples

Shoots and roots were separately analysed for heavy metals like Cd, Cr, Ni, Pb and As using standard procedures. The total heavy metal uptake was calculated based on the contents in shoot and root multiplied with their corresponding dry matter yields. Analytical procedure followed for plant analysis was given in Table 3.

Table 3. Analytical procedures for plant sample analysis

Parameter	Method	Reference
Heavy metals (Cd, Cr, Ni, Pb and As)	Diacid (HNO_3:$HClO_4$ in the ratio 9:4) digestion and estimation using Inductively Coupled Plasma Optical Emission Spectrometer.	Kalra (1998)

3.2.7 Plant Growth Parameters

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

3.2.7.1 Plant Height

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

3.2.7.2 Number of Primary Branches Plant^{-1}

The number of primary branches was counted from the tagged plants from each treatment units and the data recorded were averaged to obtain the number of primary branches plant^{-1}.

3.2.7.3 Number of Secondary Branches Plant^{-1}

The number of secondary branches was counted from individual plants when the growth of the plant had stopped and the average was worked out to obtain the number of secondary branches plant^{-1}.

3.2.8 Floral Parameters

3.2.8.1 Days to First Flowering

Numbers 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 the fully opened flowers was measured with a scale and 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 flower weight of each harvests were taken and their average weight expressed in grams.

3.2.8.5 No of Flowers Plant^{-1}

The total number of flowers produced plant^{-1} during the entire flowering period was counted and recorded as the number of flowers plant^{-1}.

3.2.9 Biochemical Analysis

The biochemical analysis namely chlorophyll content in 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 by Arnon (1949). It was measured from the leaf extract by spectrophotometer and expressed in mg g^{-1}.

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 Flavanoid Content in Flower

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

3.2.10 Yield

3.2.10.1 Flower Yield

The total fresh weight of flowers obtained $plant^{-1}$ 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 the shoot and root. For recording oven dry, weight the fresh shoots and roots were first shade dried and then oven dried at 60^0 C to a constant weight and expressed in g $plant^{-1}$.

3.3 Statistical Analysis

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

Results

4. RESULTS

The study entitled "Evaluation of sewage sludge as a growth medium for ornamentals" was carried out in the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani during 2015-2017. The main objectives of the study were to characterise the sewage sludge generated from sewage treatment plant, Muttathara and to evaluate its suitability as a growing medium for ornamentals. The results of the study are presented in this chapter.

4.1 CHARACTERISATION OF SEWAGE SLUDGE GENERATED FROM SEWAGE TREATMENT PLANT, MUTTATHARA.

The sewage sludge generated at Muttathara treatment plant was subjected to various analyses (physical, chemical and biological) to understand its properties. The results obtained are presented in Table 4.

The results revealed that sewage sludge generated from sewage treatment plant Muttathara was extremely acidic (pH-2.91) with an electrical conductivity of 0.57 dS m^{-1} and a high organic carbon (12.2%). The content of N, P and K were 2.05%, 2.65% and 1.80% respectively.

The sludge contained selectively high levels of Ca (1.02%), Mg (0.63%) and S (460 mg kg^{-1}). The content of Fe, Cu, Zn, Mn and B were 3.12%, 225.5 mg kg^{-1}, 224.7 mg kg^{-1}, 0.15% and 13.5 mg kg^{-1} respectively.

The sewage sludge from Muttathara treatment plant was found to be contaminated with heavy metals like cadmium, chromium, nickel and lead. Presence of arsenic was not detected. The cadmium content was 27 mg kg^{-1} which was five times higher than the permissible limit. Other heavy metals reported were Cr (31.5 mg kg^{-1}), Ni (33.5 mg kg^{-1}) and (Pb) 11.5 mg kg^{-1} which were high but within permissible limits.

The bulk density of the sewage sludge was low (0.65 g cc^{-1}) while water holding capacity (26.1%) and porosity (65.7%) were high.

Table 4. Characterisation of sewage sludge generated from sewage treatment plant, Muttathara

Parameters	
pH	2.91
EC (g cc^{-1})	0.57
OC (%)	12.2
Major nutrients	
Total N (%)	2.05
Total P (%)	2.65
Total K (%)	1.80
Secondary nutrients	
Ca (%)	1.02
Mg (%)	0.63
S (mg kg^{-1})	460
Micronutrients	
Fe (%)	3.12
Mn (%)	0.15
Zn (mg kg^{-1})	224.7
Cu (mg kg^{-1})	225.5
B (mg kg^{-1})	13.5
Heavy metals	
Pb (mg kg^{-1})	11.5
Cd (mg kg^{-1})	27
Cr (mg kg^{-1})	31.5
Ni (mg kg^{-1})	33.5
As (mg kg^{-1})	ND
Physical properties	
Bulk density (g cc^{-1})	0.65
Water holding capacity (%)	26.1
Porosity (%)	65.7
Biological properties	
Presence of *E. coli*	>2400MPN/100g
Bacteria (log cfu /ml)	7.36
Fungi (log cfu / ml)	5.14
Actinomycetes (log cfu /ml)	5.11

A heavy load of *E.coli* was also recorded (>2400 MPN/100g) in the sewage sludge. The population of bacteria, fungi and actinomycetes enumerated were 7.36 log cfu/ ml, 5.14 log cfu/ ml and 5.11 log cfu/ ml respectively.

4.2. POT CULTURE EXPERIMENT

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

4.2.1 Physical, Chemical and Biological Properties of Growing Medium Used for the Experiment.

The physcio-chemical characteristics of the initial growing medium prepared by mixing sewage sludge and potting mixture at different proportions as per the treatments are presented here.

4.2.1.1 pH, Electrical Conductivity and Organic Carbon

The results of pH, EC and organic carbon content of initial growing medium are presented in Table 5.

The addition of sewage sludge to growing medium resulted in a significant reduction in pH. Potting mixture alone (T_1) was with the higher pH of 6.23 which was significantly higher than all other treatments. This was followed by T_2 (5.80), T_3 (5.43) and T_4 (4.61) which were significantly different from one another. The lowest pH of 2.89 was observed in the treatment receiving sewage sludge alone (T_{11}) which was significantly different from T_{10} (3.56), T_9 (3.31), T_8 (3.49) and T_7 (3.35) which were on par.

The data on electrical conductivity of the growing media ranged from 0.08 to 0.55 dS m^{-1}. The lowest EC value was noticed in T_1 (potting mixture alone) which was on par with T_2 (potting mixture + sewage sludge 9:1). The treatment receiving sewage sludge alone (T_{11}) recorded the highest EC (0.55 dS m^{-1}) which was on par with T_{10} (potting mixture + sewage sludge 1:9). Significant differences were not observed between treatments T_9 (0.46 dS m^{-1}), T_8 (0.44 dS m^{-1}) and T_7 (0.43 dS m^{-1}).

The organic carbon content increased significantly with increased addition of sewage sludge in the growing medium. Significantly higher value was noted in the treatment T_{11} (12.10%). This was followed by T_{10} (potting mixture + sewage sludge 1:9) and T_9 (potting mixture + sewage sludge 2:8) which were on par with respect to the content of organic carbon. The treatments T_7 (5.30), T_6 (5.15) and T_5 (5.15) were also on par.

4.2.1.2 Physical Properties

The results on physical properties like bulk density, water holding capacity and porosity are represented in Table 6.

The bulk density of growing medium ranged from 0.67 to 1.44 g cc^{-1}. A decrease in bulk density was noticed with enhancement in the proportion of sewage sludge in the medium. Lowest bulk density was observed in T_{11} (sewage sludge alone) and the highest was noticed in T_1 (potting mixture alone). T_{10}- potting mixture + sewage sludge 9:1 ratio, recorded a bulk density of 0.78 g cc^{-1} which was on par T_9 (0.80 g cc^{-1}) and T_8 (0.81 g cc^{-1}).

There was a significant influence of treatments on water holding capacity of growing medium. Highest water holding capacity was associated with T_{10} (26.14%) which was on par with T_{11}- sewage sludge alone (26.11%). This was followed by T_8 (19.93%) and T_9 (19.65%). T_1 (11.76%) recorded lowest water holding capacity which was on par with T_2 (11.80%).

With the increasing addition of sewage sludge, porosity was found to increase from 44.18 per cent (T_1) to 65.72 per cent (T_{11}). The treatments T_{11} (sewage sludge alone), T_{10} (potting mixture + sewage sludge 1:9) and T_9 (potting mixture + sewage sludge 2:8) were found on par with respect to the porosity.

Table 5. Effect of sewage sludge on pH, EC and organic carbon content of growing medium before the experiment

Treatments	pH	EC ($dS\ m^{-1}$)	OC (%)
T_1 Potting mixture alone	6.23	0.08	0.98
T_2 Potting mixture + sewage sludge (9:1)	5.80	0.10	3.21
T_3 Potting mixture + sewage sludge (8:2)	5.43	0.18	4.90
T_4 Potting mixture + sewage sludge (7:3)	4.61	0.29	4.95
T_5 Potting mixture + sewage sludge (6:4)	4.54	0.32	5.15
T_6 Potting mixture + sewage sludge (1:1)	4.26	0.37	5.15
T_7 Potting mixture + sewage sludge (4:6)	3.35	0.43	5.30
T_8 Potting mixture + sewage sludge (3:7)	3.49	0.44	7.20
T_9 Potting mixture + sewage sludge (2:8)	3.31	0.46	7.90
T_{10}Potting mixture + sewage sludge (1:9)	3.56	0.53	9.65
T_{11} Sewage sludge alone	2.89	0.55	12.10
CD (0.05)	0.284	0.036	1.843

Table 6. Effect of sewage sludge on physical properties of growing medium before the experiment

Treatments	BD ($g\ cc^{-1}$)	WHC (%)	Porosity (%)
T_1 Potting mixture alone	1.44	11.76	44.18
T_2 Potting mixture + sewage sludge (9:1)	1.18	11.80	46.17
T_3 Potting mixture + sewage sludge (8: 2)	1.13	14.34	49.72
T_4 Potting mixture + sewage sludge (7:3)	1.08	14.12	52.12
T_5 Potting mixture + sewage sludge (6:4)	1.07	15.04	52.59
T_6 Potting mixture + sewage sludge (1:1)	1.05	16.74	54.45
T_7 Potting mixture + sewage sludge (4:6)	0.87	16.53	55.21
T_8 Potting mixture + sewage sludge (3:7)	0.81	19.93	60.38
T_9 Potting mixture + sewage sludge (2:8)	0.80	19.65	61.78
T_{10} Potting mixture + sewage sludge (1:9)	0.78	26.14	63.61
T_{11} Sewage sludge alone	0.67	26.11	65.72
CD (0.05)	0.039	1.176	4.926

4.2.1.3 Status of Primary Nutrients

The data on the influence of sewage sludge in the content of primary nutrients (N, P and K) in the growing medium are shown in Table 7.

All the treatments varied significantly with respect to available N content. There was a progressive increase from 315.45 kg ha^{-1} in T_1 (potting mixture alone) to 2526.11 kg ha^{-1} in T_{11} (sewage sludge alone). The other treatments resulted in intermediate values, which were significantly different from one another.

The highest phosphorous content was recorded in T_{11} (124.69 kg ha^{-1}), followed by T_{10} (116.61 kg ha^{-1}) which was on par with T_9 (115.33 kg ha^{-1}). The treatment potting mixture alone (T_1) was with lowest content of phosphorous.

There was a significant increase in the potassium content with increasing addition of sewage sludge to growing medium. The treatment T_1 receiving potting mixture alone recorded the lowest available K (145.60 kg ha^{-1}). This was followed by T_2 (257.60 kg ha^{-1}), T_3 (266.66 kg ha^{-1}) and T_4 (268.80 kg ha^{-1}), which were on par. The highest value of 627.20 kg ha^{-1} was seen in the treatment receiving sewage sludge alone (T_{11}).

4.2.1.4 Status of Secondary Nutrients

The status of the secondary nutrients calcium, magnesium and sulphur in growing medium as influenced by the treatments is presented in the Table 8.

The addition of sewage sludge resulted in a progressive increase in exchangeable Ca in growing media from T_1 (potting mixture alone) to T_{11} (sewage sludge alone). The highest calcium content was associated with T_{11} (0.84%) followed by T_{10} (0.693%). T_1 recorded the lowest exchangeable Ca which was significantly lower than all other treatments. This was followed by T_2 (0.143%) which was on par with T_3 (0.15%).

Table 7. Effect of sewage sludge on primary nutrient status in the growing medium before the experiment

Treatments	Av. N (kg ha^{-1})	Av. P (kg ha^{-1})	Av. K (kg ha^{-1})
T_1 Potting mixture alone	315.45	53.08	145.60
T_2 Potting mixture + sewage sludge (9:1)	508.75	78.37	257.60
T_3 Potting mixture + sewage sludge (8:2)	526.84	80.06	266.66
T_4 Potting mixture + sewage sludge (7:3)	638.55	90.54	268.80
T_5 Potting mixture + sewage sludge (6:4)	887.28	101.63	291.20
T_6 Potting mixture + sewage sludge (1:1)	1406.66	107.24	349.13
T_7 Potting mixture + sewage sludge (4:6)	1255.10	105.26	388.26
T_8 Potting mixture + sewage sludge (3:7)	1563.93	112.05	414.40
T_9 Potting mixture + sewage sludge (2:8)	1882.38	115.33	414.63
T_{10} Potting mixture + sewage sludge (1:9)	2147.78	116.61	455.60
T_{11} Sewage sludge alone	2526.11	124.69	627.20
CD (0.05)	19.88	2.868	12.40

Table 8. Effect of sewage sludge on secondary nutrient status in the growing medium before the experiment

Treatments	Ex.Ca (%)	Ex. Mg (%)	Av. S (mg kg^{-1})
T_1 Potting mixture alone	0.083	0.030	13.86
T_2 Potting mixture + sewage sludge (9:1)	0.143	0.033	23.90
T_3 Potting mixture + sewage sludge (8:2)	0.150	0.037	27.18
T_4 Potting mixture + sewage sludge (7:3)	0.246	0.052	41.04
T_5 Potting mixture + sewage sludge (6:4)	0.260	0.053	47.22
T_6 Potting mixture + sewage sludge (1:1)	0.300	0.056	73.70
T_7 Potting mixture + sewage sludge (4:6)	0.333	0.065	78.32
T_8 Potting mixture + sewage sludge (3:7)	0.463	0.083	98.90
T_9 Potting mixture + sewage sludge (2:8)	0.606	0.093	106.66
T_{10} Potting mixture + sewage sludge (1:9)	0.693	0.102	125.53
T_{11} Sewage sludge alone	0.840	0.143	132.22
CD (0.05)	0.032	0.004	1.920

There was an increase in exchangeable Mg content of growing media with increasing addition of sewage sludge. The highest value of 0.143% was associated with the treatment receiving sewage sludge alone (T_{11}). This was followed by T_{10} (0.102%), T_9 (0.093%), T_8 (0.083 %) and T_7 (0.065 %) which were significantly different from one another. The lowest exchangeable Mg was in the treatment receiving potting mixture alone (T_1).

There was a significant increase in the sulphur content with the successive addition of sewage sludge in the growing medium. The highest sulphur content (132.22 mg kg^{-1}) was associated with sewage sludge alone (T_{11}), which was followed by T_{10} (125.53 mg kg^{-1}). T_1 recorded a sulphur content of 13.86 mg kg^{-1} which was lowest among all the treatment.

4.2.1.5 Status of Micronutrients

The results with respect to status of micronutrients (iron, manganese, zinc, copper and boron) in the initial growing medium as influenced by various treatments are presented in Table 9.

Iron content in growing medium was noticed to be increasing from T_1 (potting mixture alone) to T_{11} (sewage sludge alone) with the increasing levels of sewage sludge content. Lowest value of 17.89 mg kg^{-1} was identified in potting mixture alone (T_1) and all other treatments were with significantly higher values. T_{11} (sewage sludge alone) recorded the highest content of iron (470.10 mg kg^{1}).

The highest content of manganese (791.53 mg kg^{-1}) was identified in T_{11} where sewage sludge alone was used. Between T_4 (potting mixture + sewage sludge 7:3 ratio) and T_5 (potting mixture + sewage sludge 6:4 ratio) there was no significant differences observed. The lowest content was noted in the treatment potting mixture alone (13.67 mg kg^{-1}).

With increasing levels of sewage sludge in the growing medium there was a significant increase in the content of available zinc. It ranged from 11.62 to 490.66 mg kg^{-1}. The highest zinc content was associated with the treatment

Table 9. Effect of sewage sludge on micronutrient status in the growing medium before the experiment

Treatments	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})	Cu (mg kg^{-1})	B (mg kg^{-1})
T_1 Potting mixture alone	17.89	13.67	11.62	1.26	0.25
T_2 Potting mixture + sewage sludge (9:1)	63.39	45.87	37.51	6.00	0.60
T_3 Potting mixture + sewage sludge (8:2)	138.80	79.84	55.14	11.21	0.51
T_4 Potting mixture + sewage sludge (7:3)	235.80	172.10	111.40	20.16	0.66
T_5 Potting mixture + sewage sludge (6:4)	346.50	173.66	128.00	34.00	0.67
T_6 Potting mixture + sewage sludge (1:1)	335.43	203.13	174.16	33.85	0.70
T_7 Potting mixture + sewage sludge (4:6)	363.93	342.26	190.93	47.75	0.75
T_8 Potting mixture + sewage sludge (3:7)	363.70	474.20	238.70	64.76	0.75
T_9 Potting mixture + sewage sludge (2:8)	355.00	555.63	327.93	78.21	0.85
T_{10} Potting mixture + sewage sludge (1:9)	426.46	570.66	393.46	85.29	0.95
T_{11} Sewage sludge alone	470.10	791.53	490.66	111.00	1.19
CD (0.05)	13.62	13.63	7.28	3.68	0.012

receiving sewage sludge alone (T_{11}) which was followed by T_{10} (393.46 mg kg^{-1}), T_9 (327.93 mg kg^{-1}), T_8 (238.70 mg kg^{-1}), T_7 (190.93 mg kg^{-1}), T_6 (174.16 mg kg^{-1}), T_5 (128.00 mg kg^{-1}), T_4 (111.40 mg kg^{-1}), T_3 (55.14 mg kg^{-1}) and T_2 (37.51 mg kg^{-1}) . The treatment potting mixture alone (T_1) was having lowest (11.62 mg kg^{-1}) content of Zn.

Status of copper in the initial growing medium ranged from 1.26 (T_1) to 111.00 mg kg^{-1}(T_1). Intermediate values were noted in other treatments with an increasing trend from T_1 to T_{11}. T_5 recorded a copper content of 34 mg kg^{-1} which was on par with T_6 (33.85 mg kg^{-1}). The treatment potting mixture alone resulted the lowest content of copper (1.26 mg kg^{-1}).

The content of boron in growing media ranged from 0.25 to1.19 mg kg^{-1}. The highest boron content (1.19 mg kg^{-1}) was noticed in the treatment sewage sludge alone (T_{11}). This was followed by T_{10} (0.95 mg kg^{-1}) and T_9 (0.85 mg kg^{-1}) which were significantly different from one another. T_7 recorded a boron content of 0.75 mg kg^{-1}which was on par with T_8 (0.75 mg kg^{-1}). The lowest boron content of 0.25 mg kg^{-1} was associated with the treatment receiving potting mixture alone (T_1).

4.2.1.6 Heavy Metal Content

The data on the influence of treatments on the content of heavy metals viz, cadmium, chromium, nickel, lead and arsenic in the growing medium is given in Table 10.

Increased addition of sewage sludge resulted in a significant increase in the content of available Cd in the growing medium. The lowest cadmium content (0.01 mg kg^{-1}) was observed in the treatment T_1 (potting mixture alone) which was followed by T_2 (0.06 mg kg^{-1}) and T_3 (0.14 mg kg^{-1}) which were on par. This was followed by T_4 and T_5 in which the content of Cd was 0.36 mg kg^{-1}. The highest Cd content of 2.14 mg kg^{-1} was associated with the treatment receiving sewage sludge alone (T_{11}).

Table 10. Effect of sewage sludge on heavy metal status in the growing medium before the experiment

Treatments	Cd ($mg\ kg^{-1}$)	Cr ($mg\ kg^{-1}$)	Ni ($mg\ kg^{-1}$)	Pb ($mg\ kg^{-1}$)	As ($mg\ kg^{-1}$)
T_1 Potting mixture alone	0.01	0.02	0.06	ND	ND
T_2 Potting mixture + sewage sludge (9:1)	0.06	0.09	0.37	0.12	ND
T_3 Potting mixture + sewage sludge (8:2)	0.14	0.14	0.75	0.20	ND
T_4 Potting mixture + sewage sludge (7:3)	0.36	0.33	1.46	0.23	ND
T_5 Potting mixture + sewage sludge (6:4)	0.36	0.34	1.62	0.41	ND
T_6 Potting mixture + sewage sludge (1:1)	0.65	0.35	2.18	0.53	ND
T_7 Potting mixture + sewage sludge (4:6)	0.76	0.37	3.12	0.91	ND
T_8 Potting mixture + sewage sludge (3:7)	0.95	0.44	3.82	1.44	ND
T_9 Potting mixture + sewage sludge (2:8)	1.33	0.59	5.18	1.50	ND
T_{10} Potting mixture + sewage sludge (1:9)	1.66	0.63	6.08	1.50	ND
T_{11} Sewage sludge alone	2.14	0.70	7.80	1.90	ND
CD (0.05)	0.017	0.049	0.589	0.230	

ND- Not Detected

With the increasing levels of sewage sludge in the growing medium, content of available Cr also increased significantly. The highest Cr content (0.70 mg kg^{-1}) was associated with T_{11} (sewage sludge alone) followed by T_{10} (0.63 mg kg^{-1}) and T_9 (0.59 mg kg^{-1}) which were on par. The lowest value (0.02 mg kg^{-1}) was noticed in the treatment potting mixture alone (T_1). The treatments T_4 (0.33 mg kg^{-1}), T_5 (0.34 mg kg^{-1}), T_6 (0.35 mg kg^{-1}) and T_7 (0.37 mg kg^{-1}) were on par with respect to the content of Cr.

There was a significant increase in the content of nickel in the growing medium with the successive addition of sewage sludge, and the values between 0.06 to 7.80 mg kg^{-1}. T_{11} which received sewage sludge alone as treatment showed highest concentration of nickel. Lowest value was noticed in the treatment receiving potting mixture alone (T_1), followed by T_2 (0.37 mg kg^{-1}).

The lead content in the growing medium varied from 0.12 to1.90 mg kg^{-1}. The highest value was observed in the treatment sewage sludge alone (T_{11}) followed by T_9 and T_8 (1.50 mg kg^{-1}). Presence of lead was not detected in T_1 which received potting mixture alone as treatment. The lowest lead content was noticed in T_2 which contained potting mixture and sewage sludge in the ratio of 1:9. The lead content was increasing with the addition of sewage sludge in the growing medium.

Arsenic content was not detected in any of the treatments in the growing medium before the experiment.

4.2.1.7 Bacterial Population

The data generated on total bacterial population influenced by various treatments are given in Table 11.

There was a significant difference between the treatments with respect to the total bacterial population of growing medium. It was found to be maximum in T_2 (6.977 log cfu/ ml) which received potting mixture and sewage sludge in the ratio of 1:9. Minimum bacterial population was recorded in T_8 (6.085 log cfu/ ml) which was on par with T_4 (6.147 log cfu/ml).

4.2.1.8 Presence of E.coli

E.coli was not detected in any of the treatment in the initial growing medium.

4.2.2 Physical, Chemical and Biological Properties of Growing Medium after the Experiment

After raising the test crop (marigold), the growing medium was analysed for various physical, chemical and biological properties.

4.2.2.1 pH, EC and Organic Carbon

The data on pH, EC and organic carbon content of growing medium as influenced by various treatments at the end of the experiment are given in Table 12.

The pH of growing medium at the end of the experiment varied from 2.87 to 5.40. The treatment receiving potting mixture alone recorded a pH of 5.40 which was on par with T_2 (4.84) and significantly higher than all other treatments. With the addition of sewage sludge pH was found decreasing and the lowest pH of 2.87 was noticed in T_{11} (sewage sludge) and this was followed by T_9 (3.06) and T_{10} (3.13) which were on par. Significant differences were not observed between T_5, T_6 and T_7.

There was an increase in the EC with the successive addition of sewage sludge in the growing medium. The highest EC of 0.52 dS m^{-1} was observed in the treatment T_{11} (sewage sludge alone), which was on par with T_{10} (potting mixture + sewage sludge in the ratio of 1:9). The lowest EC (0.07 dS m^{-1}) was noticed in the treatment receiving potting mixture alone (T_1) which was on par with T_2 (potting mixture + sewage sludge 9:1).

Table 11. Effect of sewage sludge on bacterial population in the growing medium before the experiment

Treatments	log cfu/ml
T_1 Potting mixture alone	6.445
T_2 Potting mixture + sewage sludge (9:1)	6.977
T_3 Potting mixture + sewage sludge (8:2)	6.480
T_4 Potting mixture + sewage sludge (7:3)	6.147
T_5 Potting mixture + sewage sludge (6:4)	6.202
T_6 Potting mixture + sewage sludge (1:1)	6.203
T_7 Potting mixture + sewage sludge (4:6)	6.565
T_8 Potting mixture + sewage sludge (3:7)	6.085
T_9 Potting mixture + sewage sludge (2:8)	6.127
T_{10} Potting mixture + sewage sludge (1:9)	6.187
T_{11} Sewage sludge alone	6.192
CD (0.05)	0.266

Table 12. Effect of sewage sludge on pH, EC and organic carbon content of growing medium after the experiment

Treatments	pH	EC ($dS\ m^{-1}$)	OC (%)
T_1 Potting mixture alone	5.40	0.07	0.33
T_2 Potting mixture + sewage sludge (9:1)	4.84	0.10	2.10
T_3 Potting mixture + sewage sludge (8: 2)	3.85	0.16	2.95
T_4 Potting mixture + sewage sludge (7:3)	3.84	0.26	4.15
T_5 Potting mixture + sewage sludge (6:4)	3.73	0.30	4.65
T_6 Potting mixture + sewage sludge (1:1)	3.57	0.37	7.00
T_7 Potting mixture + sewage sludge (4:6)	3.28	0.38	7.20
T_8 Potting mixture + sewage sludge (3:7)	3.95	0.41	7.30
T_9 Potting mixture + sewage sludge (2:8)	3.06	0.45	7.70
T_{10} Potting mixture + sewage sludge (1:9)	3.13	0.51	7.80
T_{11} Sewage sludge alone	2.87	0.52	10.90
CD (0.05)	0.892	0.025	2.104

The organic carbon content of final growing media varied from 0.33 to10.90 per cent. The maximum organic carbon content was found in T_{11} (10.90%) which contained sewage sludge alone as treatment. It was followed by T_{10} (7.80%) which was on par with T_9 (7.70%), T_8 (7.30%), T_7 (7.60%) and T_6 (7.00%). The lowest organic carbon content of 0.33% was recorded in the treatment receiving potting mixture alone (T_1). The treatments T_2 (potting mixture + sewage sludge 9:1), T_3 (potting mixture + sewage sludge 8:2) and T_4 (potting mixture + sewage sludge 7:3) were on par with respect to organic carbon content of final growing media with organic carbon values of 2.10, 2.95 and 4.15 per cent respectively.

4.2.2.2 Physical Properties

The results on physical properties like bulk density, water holding capacity and porosity are presented in Table 13.

There was a reduction in the bulk density with the increasing content of sewage sludge in the growing medium. The highest bulk density (1.17 g cc^{-1}) was recorded in the treatment with potting mixture alone (T_1) and the lowest value of 0.65 g cc^{-1} in the treatment with sewage sludge alone (T_{11}). This was followed by T_{10} (potting mixture + sewage sludge 9:1). The treatments T_9 (0.81 g cc^{-1}) and T_8 (0.84 g cc^{-1}) were on par with respect to the bulk density.

Water holding capacity of growing medium after the experiment ranged from 11.40 to 27.40 per cent. The highest water holding capacity was noticed in the treatment receiving sewage sludge alone (T_{11}). There was an increase in the water holding capacity with the increasing content of sewage sludge in the growing medium. The lowest water holding capacity was noticed in T_1, which received potting mixture alone as treatment. This was on par with T_2 (potting mixture + sewage sludge 9:1) and T_3 (potting mixture + sewage sludge 8:2) in which recorded water holding capacity values of 11.76 and 14.09 per cent respectively.

With the successive addition of sewage sludge in the growing medium, the porosity was found increasing from 41.85 to 63.95 per cent. The highest porosity was recorded in T_{11} (63.95 %) which was on par with T_{10} (61.66 %) and T_9 (59.08 %). T_1 (potting mixture alone) recorded the lowest porosity of 41.85 % which was on par with T_2 (potting mixture + sewage sludge 9:1). Significant differences were not observed between the treatments T_3, T_4, T_5 and T_6.

4.2.2.3 Status of Primary Nutrients

The status of primary nutrients (N, P and K) in the final growing medium is shown in Table 14.

There was a significant difference between the treatments with respect to available nitrogen content of the growing medium at the end of the experiment. The highest value of 1692.03 kg ha^{-1} was noticed in the treatment receiving sewage sludge alone (T_{11}), followed by T_{10} (1432.20 kg ha^{-1}) which contained potting mixture and sewage sludge in the ratio of 1:9. The lowest value of 171.43 kg ha^{-1} was associated with the treatment receiving potting mixture alone (T_1).

There was a significant increase in the available phosphorous status with increasing concentration of sewage sludge. T_{11} (sewage sludge alone) recorded the highest phosphorous content (104.44 kg ha^{-1}) followed by T_{10} (89.63 kg ha^{-1}). The lowest phosphorous content was obtained in the treatment receiving potting mixture alone as treatment (19.08 kg ha^{-1}).

The available potassium status in the final growing medium varied from 126.93-488.36 kg ha^{-1}. The highest available potassium was associated with T_{11}. This was followed by T_9 (231.46 kg ha^{-1}), T_{10} (242.66 kg ha^{-1}) and T_8 (224.00 kg ha^{-1}) which were on par. The lowest value was associated with T_1 (potting mixture alone).

4.2.2.4 Status of Secondary Nutrients

The variations in the status of secondary nutrients in the growing medium (final) due to the treatments are presented in Table 15.

Table13. Effect of sewage sludge on the physical properties of growing medium after the experiment

Treatments	BD ($g\ cc^{-1}$)	WHC (%)	Porosity (%)
T_1 Potting mixture alone	1.17	11.40	41.85
T_2 Potting mixture + sewage sludge (9:1)	1.07	11.76	43.30
T_3 Potting mixture + sewage sludge (8: 2)	1.12	14.09	49.48
T_4 Potting mixture + sewage sludge (7:3)	1.02	14.32	50.01
T_5 Potting mixture + sewage sludge (6:4)	1.04	15.04	52.00
T_6 Potting mixture + sewage sludge (1:1)	0.87	16.72	52.98
T_7 Potting mixture + sewage sludge (4:6)	0.85	16.74	53.29
T_8 Potting mixture + sewage sludge (3:7)	0.84	19.65	57.28
T_9 Potting mixture + sewage sludge (2:8)	0.81	19.99	59.08
T_{10} Potting mixture + sewage sludge (1:9)	0.78	26.14	61.66
T_{11} Sewage sludge alone	0.65	27.40	63.95
CD (0.05)	0.036	9.087	5.187

Table 14. Effect of sewage sludge on primary nutrient status in the growing medium after the experiment

Treatments	Av. N ($kg\ ha^{-1}$)	Av. P ($kg\ ha^{-1}$)	Av. K ($kg\ ha^{-1}$)
T_1 Potting mixture alone	171.43	19.08	126.93
T_2 Potting mixture + sewage sludge (9:1)	218.18	33.24	156.80
T_3 Potting mixture + sewage sludge (8:2)	275.96	48.21	164.20
T_4 Potting mixture + sewage sludge (7:3)	464.12	56.98	180.23
T_5 Potting mixture + sewage sludge (6:4)	647.25	59.59	197.86
T_6 Potting mixture + sewage sludge (1:1)	698.27	65.99	205.33
T_7 Potting mixture + sewage sludge (4:6)	819.72	71.57	201.60
T_8 Potting mixture + sewage sludge (3:7)	1042.76	82.64	224.00
T_9 Potting mixture + sewage sludge (2:8)	1236.09	87.18	231.46
T_{10} Potting mixture + sewage sludge (1:9)	1432.20	89.63	242.66
T_{11} Sewage sludge alone	1692.03	104.44	488.36
CD (0.05)	20.13	1.105	19.28

Table15. Effect of sewage sludge on secondary nutrient status in the growing medium after the experiment

Treatments	Ex. Ca (%)	Ex. Mg (%)	Av. S ($mg\ kg^{-1}$)
T_1 Potting mixture alone	0.016	0.023	12.72
T_2 Potting mixture + sewage sludge (9:1)	0.016	0.035	26.00
T_3 Potting mixture + sewage sludge (8:2)	0.020	0.036	23.03
T_4 Potting mixture + sewage sludge (7:3)	0.023	0.053	23.62
T_5 Potting mixture + sewage sludge (6:4)	0.029	0.053	23.39
T_6 Potting mixture + sewage sludge (1:1)	0.031	0.055	32.73
T_7 Potting mixture + sewage sludge (4:6)	0.033	0.055	27.60
T_8 Potting mixture + sewage sludge (3:7)	0.032	0.066	63.43
T_9 Potting mixture + sewage sludge (2:8)	0.051	0.092	77.80
T_{10} Potting mixture + sewage sludge (1:9)	0.053	0.093	82.33
T_{11} Sewage sludge alone	0.076	0.113	116.50
CD (0.05)	0.008	0.007	7.81

There was an increase in the exchangeable Ca content from T_1 to T_{11} with the addition of sewage sludge. The highest calcium content was associated with T_{11} (0.076 %) followed by T_{10} (0.053 %) and T_9 (.051 %) which were on par. The treatment receiving potting mixture alone (T_1) recorded the lowest exchangeable Ca content (0.016 %) which was on par with T_2 (0.016 %) and T_3 (0.020).

There was a significant influence of treatments on exchangeable Mg content of growing medium at the end of the crop. The highest value of 0.113 % was observed in T_{11} (sewage sludge alone) which was followed by T_{10} (potting mixture + sewage sludge 9:1) and T_9 (potting mixture + sewage sludge 8:2) which were on par (0.093 and 0.092 per cent respectively). The lowest exchangeable Mg was associated with the treatment T_1 (0.023 %) followed by T_2 (0.035 %) and T_3 (0.036 %) which were on par.

There was a significant increase in the sulphur content with the successive addition of sewage sludge in the growing medium. The highest sulphur content (116.50 mg kg^{-1}) was associated with sewage sludge alone (T_{11}), which was followed by T_{10} (82.33 mg kg^{-1}) and T_9 (77.80 mg kg^{-1}) which were on par. T_1 recorded a sulphur content of 12.72 mg kg^{-1}, which was lowest among all the treatment.

4.2.2.5 Status of micronutrients

The data on the effect of various treatments on the availability of micronutrients (iron, manganese, zinc, copper and boron) are presented in Table 16.

The iron content in the growing medium after the experiment ranged from 14.96 to 357.26 mg kg^{-1}. The highest value was in T_{11} (sewage sludge alone) followed by T_{10} (342.86 mg kg^{-1}), T_8 (325.10 mg kg^{-1}), T_9 (267.93 mg kg^{-1}) and T_6 (263.63 mg kg^{-1}). The content of available Fe lowest was in the treatment T_1 (14.96 mg kg^{-1}), which received potting mixture alone.

Table 16. Effect of sewage sludge on micronutrient status in the growing medium after the experiment

Treatments	Fe ($mg\ kg^{-1}$)	Mn ($mg\ kg^{-1}$)	Zn ($mg\ kg^{-1}$)	Cu ($mg\ kg^{-1}$)	B ($mg\ kg^{-1}$)
T_1 Potting mixture alone	14.96	8.05	5.70	0.70	0.59
T_2 Potting mixture + sewage sludge (9:1)	64.68	15.19	19.20	4.46	0.70
T_3 Potting mixture + sewage sludge (8:2)	83.40	49.90	23.20	16.80	0.79
T_4 Potting mixture + sewage sludge (7:3)	182.26	72.47	63.26	26.10	0.79
T_5 Potting mixture + sewage sludge (6:4)	195.46	78.70	99.93	37.40	0.81
T_6 Potting mixture + sewage sludge (1:1)	263.63	133.33	116.26	42.96	0.86
T_7 Potting mixture + sewage sludge (4:6)	245.83	169.33	160.46	47.96	0.90
T_8 Potting mixture + sewage sludge (3:7)	325.10	146.00	186.83	74.44	0.92
T_9 Potting mixture + sewage sludge (2:8)	267.93	126.00	269.66	68.66	0.93
T_{10} Potting mixture + sewage sludge (1:9)	342.80	136.00	288.33	81.23	1.07
T_{11} Sewage sludge alone	357.26	182.00	290.66	91.03	1.13
CD (0.05)	13.73	5.98	11.38	1.93	0.032

There was a significant influence of treatments on available Mn content in the growing medium. The highest content of Mn (182.00 mg kg^{-1}) was recorded in T_{11} which contained sewage sludge alone as treatment, followed by T_7 (169.33 mg kg^{-1}). The lowest content of 8.05 mg kg^{-1} was associated with the treatment receiving potting mixture alone (T_1).

Significant variations were observed between treatments for zinc content of growing medium (final). The highest content (290.66 mg kg^{-1}) was reported in T_{11}, which was on par with T_{10} (288.33). The treatment receiving potting mixture alone recorded the lowest zinc content (5.70 mg kg^{-1}) which was followed by T_2 (potting mixture + sewage sludge 9:1) and T_3 (potting mixture + sewage sludge 8:2) which were on par with values of 19.20 mg kg^{-1} and 23.20 mg kg^{-1} respectively.

There was a significant increase in the copper content from T_1 to T_{11} with the increasing proportion of sewage sludge in the growing medium. T_1 recorded the lowest copper content (0.70 mg kg^{-1}) and the highest value was associated with T_{11} (91.03 mg kg^{-1}) followed by T_{10} (81.23 mg kg^{-1}).

Content of available boron ranged from 0.59 to 1.13 mg kg^{-1} in the growing medium after the experiment. T_{11} (sewage sludge alone) recorded a boron content of 1.13 mg kg^{-1} which was highest among all the treatments followed by T_{10} (1.07 mg kg^{-1}). This was followed by T_8 (potting mixture + sewage sludge 3:7) and T_9 (potting mixture+ sewage sludge 2:8) which were on par. The lowest boron content was noticed in T_1 (0.59 mg kg^{-1}) and there was no significant difference between T_3, T_4 and T_5.

4.2.2.6 Heavy Metal Content

The treatments significantly influenced the heavy metal content in the growing medium after the experiment and the results are given in Table 17.

The presence of cadmium was not detected in the growing medium where potting mixture alone was used (T_1). With increasing content of sewage sludge in

Table 17. Effect of sewage sludge on heavy metal status in the growing medium after the experiment

Treatments	Cd (mg kg^{-1})	Cr (mg kg^{-1})	Ni (mg kg^{-1})	Pb (mg kg^{-1})	As (mg kg^{-1})
T_1 Potting mixture alone	ND	ND	0.03	ND	ND
T_2 Potting mixture + sewage sludge (9:1)	0.01	ND	0.24	0.08	ND
T_3 Potting mixture + sewage sludge (8:2)	0.02	0.01	0.63	0.22	ND
T_4 Potting mixture + sewage sludge (7:3)	0.06	0.11	1.28	0.36	ND
T_5 Potting mixture + sewage sludge (6:4)	0.10	0.16	1.18	0.68	ND
T_6 Potting mixture + sewage sludge (1:1)	0.14	0.19	2.29	0.31	ND
T_7 Potting mixture + sewage sludge (4:6)	0.32	0.22	3.11	0.44	ND
T_8 Potting mixture + sewage sludge (3:7)	0.45	0.23	3.39	0.49	ND
T_9 Potting mixture + sewage sludge (2:8)	0.49	0.25	3.14	0.59	ND
T_{10} Potting mixture + sewage sludge (1:9)	0.65	0.33	6.30	0.70	ND
T_{11} Sewage sludge alone	0.73	0.39	6.56	0.69	ND
CD (0.05)	0.046	0.046	0.165	0.126	

ND – Not Detected

growing medium there was an increase in cadmium content also. The highest value of 0.73 mg kg^{-1} was recorded in T_{11} (sewage sludge alone) which was significantly higher than all other treatments. This was followed by T_{10} (0.65 mg kg^{-1}). The treatments T_9 (potting mixture+ sewage sludge 1:9) and T_8 (potting mixture+ sewage sludge 2:8) which recorded on par results with 0.49 mg kg^{-1} and 0.45 mg kg^{-1} respectively.

Content of chromium was not detected in the treatments, T_1 (potting mixture alone) and T_2 (potting mixture+ sewage sludge, 1:9). The highest chromium content (0.39 mg kg^{-1}) was observed in T_{11} (sewage sludge alone) and the lowest value of 0.01 mg kg^{-1} was in T_3 (potting mixture +sewage sludge 8:2). T_9 recorded a chromium content of 0.25 mg kg^{-1} which was on par with T_8 (0.23 mg kg^{-1}).

The content of nickel in the growing medium was from 0.03 to 6.56 mg kg^{-1}. The treatment receiving potting mixture alone (T1) recorded the lowest nickel content of 0.03 mg kg^{-1} and the highest value (6.56 mg kg^{-1}) was recorded in the treatment with sewage sludge alone (T_{11}).

There was a significant influence of treatments on the available lead content of the final growing medium. The highest lead content of 0.70 mg kg^{-1} was observed in the treatment T_{10} (potting mixture + sewage sludge 1:9). This was followed by T_{11} (0.69 mg kg^{-1}) which were on par. Lead content was not detected in the treatment receiving potting mixture alone (T_1) and the lowest value (0.08 mg kg^{-1}) was associated with T_2 (potting mixture + sewage sludge 9:1).

Arsenic was not detected in the final growing medium in any of the treatment.

4.2.2.7 Bacterial Population

The data generated on total bacterial population as influenced by various treatments are given in Table 18.

The bacterial population in the growing medium at the end of the experiment was significantly influenced by the treatments. The highest bacterial population was recorded in T_1 (7.785 log cfu/ ml) which was on par with T_3 (7.685 log cfu/ ml). There was a significant decrease in the bacterial population with increasing content of sewage sludge in the growing medium. T_{10} (6.515 log cfu/ ml) recorded the lowest bacterial population which was on par with T_{11} (6.365 log cfu/ ml).

4.2.2.8 Presence of E.coli

The presence of *E.coli* was not observed in any of the treatments.

4.2.3 Plant Growth Parameters

The treatments significantly influenced the plant growth parameters of marigold and the results are shown in Table 19.

4.2.3.1 Plant Height

There was significant decrease in the plant height with increasing content of sewage sludge in growing medium. The maximum plant height (91.33 cm) was observed in T_2 which received potting mixture + sewage sludge in the ratio of 9:1 as treatment which was on par with T_3 (potting mixture + sewage sludge 8:2). The lowest plant height (48.00 cm) was recorded in the treatment where sewage sludge alone was used (T_{11}). This was on par with T_{10} (52.00 cm) and T_9 (58.33 cm).

4.2.3.2 Number of Primary Branches

There was no significant influence of treatments on the number of primary branches in marigold. The values ranged from 9.73 (T_1) to 12.64 (T_5).

4.2.3.3 Number of Secondary Branches

The number of secondary branches ranged from 6.00 to 21.00. The maximum number of secondary branches was observed in T_2 (potting mixture +

Table 18. Effect of sewage sludge on bacterial population in the growing medium after the experiment

Treatments	log cfu/ ml
T_1 Potting mixture alone	7.785
T_2 Potting mixture + sewage sludge (9:1)	7.070
T_3 Potting mixture + sewage sludge (8:2)	7.685
T_4 Potting mixture + sewage sludge (7:3)	7.085
T_5 Potting mixture + sewage sludge (6:4)	7.000
T_6 Potting mixture + sewage sludge (1:1)	6.985
T_7 Potting mixture + sewage sludge (4:6)	6.870
T_8 Potting mixture + sewage sludge (3:7)	6.825
T_9 Potting mixture + sewage sludge (2:8)	6.925
T_{10} Potting mixture + sewage sludge (1:9)	6.515
T_{11} Sewage sludge alone	6.365
CD (0.05)	0.176

Table 19. Effect of sewage sludge on growth parameters of marigold

Treatments	Plant height (cm)	No. of primary branches	No. of secondary branches
T_1 Potting mixture alone	69.00	9.73	6.24
T_2 Potting mixture + sewage sludge (9:1)	91.33	12.45	15.33
T_3 Potting mixture + sewage sludge (8: 2)	83.00	12.52	21.00
T_4 Potting mixture + sewage sludge (7:3)	66.00	12.09	14.66
T_5 Potting mixture + sewage sludge (6:4)	75.66	12.64	12.00
T_6 Potting mixture + sewage sludge (1:1)	61.66	11.35	6.00
T_7 Potting mixture + sewage sludge (4:6)	70.33	12.28	9.66
T_8 Potting mixture + sewage sludge (3:7)	69.66	10.04	12.00
T_9 Potting mixture + sewage sludge (2:8)	58.33	9.88	14.00
T_{10} Potting mixture + sewage sludge (1:9)	52.00	10.12	7.00
T_{11} Sewage sludge alone	48.00	11.57	7.00
CD (0.05)	10.91	NS	5.25

sewage slugde 9:1) and the minimum number of was associated with T_6 (potting mixture + sewage sludge 1:1) which was on par with T_7 (9.66), T_{10} (7.00), T_{11} (7.00) and T_1 (6.24).

4.2.4 Floral Parameters

The floral parameters of marigold were significantly influenced by the treatments and the results are shown in Table 20.

4.2.4.1 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 the lowest in T_2 which receiving potting mixture + sewage sludge 9:1 ratio (28.66). This was on par with T_1 (29.33) and T_3 (30.66). Increasing content of sewage sludge in the medium resulted in a delay in first flowering. T_{11} (sewage sludge alone) took the minimum number of days (37.66) which was on par with T_{10} (37.33), T_9 (35.66), T_8 (36.00) and T_7 (37.00).

4.2.4.2 Flower Diameter

Observed values of flower diameter varied from 3.82 to 6.75 cm. Flower diameter was highest in T_2 (6.75 cm) followed by T_3 (6.01 cm) which were on par. The smallest flower diameter was noticed in T_9 (3.82 cm) which was on par with T_{10} (4.15 cm), T_{11} (4.46 cm) and T_8 (4.10 cm).

4.2.4.3 Flower Length

The flower length of marigold was significantly influenced by the treatments. Increasing concentration of sewage sludge in growing medium resulted in a significant reduction in flower length. The highest flower length of 10.33 cm was associated with T_2 (potting mixture+ sewage sludge 9:1) which was on par with T_3 (8.76 cm), T_4 (9.00 cm) and T_1 (8.29 cm). This was followed by T_5 (7.28 cm), T_6 (7.05 cm), T_7 (6.60 cm) and T_8 (7.23 cm) which were on par. T_{11} (sewage sludge alone) recorded the lowest flower length of 5.66 cm.

Table 20. Effect of sewage sludge on floral parameters of marigold

Treatments	Days to flowering (Days)	Flower diameter (cm)	Flower length (cm)	Flower weight (g)	No of flowers $plant^{-1}$
T_1 Potting mixture alone	29.33	4.41	8.29	5.18	64.56
T_2 Potting mixture + sewage sludge (9:1)	28.66	6.75	10.33	8.88	79.60
T_3 Potting mixture + sewage sludge (8:2)	30.66	6.01	8.76	7.04	74.66
T_4 Potting mixture + sewage sludge (7:3)	32.66	5.00	9.00	4.51	58.31
T_5 Potting mixture + sewage sludge (6:4)	33.33	4.67	7.28	4.81	59.33
T_6 Potting mixture + sewage sludge (1:1)	32.33	5.63	7.05	2.96	61.36
T_7 Potting mixture + sewage sludge (4:6)	37.00	5.53	6.60	3.64	55.69
T_8 Potting mixture + sewage sludge (3:7)	36.00	4.10	7.23	4.14	61.50
T_9 Potting mixture + sewage sludge (2:8)	35.66	3.82	8.10	3.18	53.63
T_{10} Potting mixture + sewage sludge (1:9)	37.33	4.15	8.20	3.94	49.20
T_{11} Sewage sludge alone	37.66	4.46	5.66	4.69	46.80
CD (0.05)	3.144	0.912	2.403	1.842	8.707

4.2.4.4 Flower Weight

There was a significant reduction in the flower weight with increasing content of sewage sludge in the growing medium. The highest flower weight (8.88 g) was noticed in T_2 which received potting mixture + sewage sludge in 1:9 ratio followed by T_3 (7.04 g) and T_1 (5.18 g). The treatment T_6 recorded the lowest flower weight of 2.96 g followed by T_9 (3.18 g), T_7 (3.64 g), T_{10} (3.94 g), T_8 (4.14 g), T_4 (4.51 g) and T_{11} (4.69 g) which were on par.

4.2.4.5 Number of Flowers Plant^{-1}

Maximum number of flowers per plant (79.60) was recorded in T_2 (potting mixture + sewage sludge 9:1), which was on par with T_3 (74.66). This was followed by T_1 (64.56), T_4 (58.31), T_5 (59.33), T_6 (61.36) and T_8 (61.50) which were on par. The lowest number of flowers was associated with T_{11} (46.80) which was on par with T_{10} (49.20) and T_9 (53.63).

4.2.5 Biochemical Properties

The data on biochemical properties of marigold like chlorophyll content in leaves, xanthophyll and flavonoid content in flower are shown in Table 21.

4.2.5.1 Chlorophyll Content in Leaves

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

4.2.5.2 Xanthophyll Content in Flower

The treatments did not significantly influence the xanthophyll content of marigold flowers. The highest value of 21.16 mg g^{-1} was in T_3 (potting mixture+ sewage sludge 8:2) and the lowest value of 18.33 mg g^{-1} was in T_{11} (sewage sludge alone)

4.2.5.3 Flavanoid Content in Flower

Flavonoid content in flower was not significantly influenced by the treatments and the values ranged from 176.66 to 188.33 mg of ME/g.

4.2.6 Yield and Yield Attributes

The treatments significantly influenced the yield and yield attributes of marigold as shown in Table 22.

4.2.6.1 Dry Matter Yield of Shoot

On analyzing the results of dry matter yield of shoot, the highest dry matter production of shoot (66.37 g) was associated with T_3 (potting mixture + sewage sludge 8:2) which was on par with T_2 (64.37 g), T_4 (61.84 g), T_5 (58.48 g), T_6 (53.45g) and T_1 (56.02 g). The lowest dry matter production was in T_{11} (32.04) which was on par with T_{10} (38.05 g), T_9 (42.90 g) and T_8 (41.63 g).

4.2.6.2 Dry Matter Yield of Root

The treatments significantly influenced the dry matter production in roots also. The maximum dry matter yield of root (3.03 g) was recorded in T_3 (potting mixture + sewage sludge 8:2) which was on par with all the treatments except T_1 (potting mixture alone) which had a dry matter yield of 0.96 g.

4.2.6.3 Flower Yield

There was a significant influence of treatments on flower yield. Significantly higher flower yield (706.36 g) was recorded in T_2 (potting mixture + sewage sludge 9: 1) and this was followed by the treatment T_3 (592.52 g). With increasing content of sewage sludge in the growing medium, there was a significant reduction in the flower yield. The treatments T_4 (335. 42 g), T_5 (344.91 g), T_6 (317. 29 g), T_7 (275.53 g) and T_1 (334.65 g) were on par. The lowest flower yield was associated with T_{11} (187.76 g) which was on par with T_{10} (202.99 g), T_9 (204.91 g) and T_8 (213.90 g).

Table 21. Effect of sewage sludge on biochemical properties of marigold

Treatments	Total Chlorophyll (mg g^{-1})	Xanthophyll (mg g^{-1})	Flavonoid (mg of ME/g)
T_1 Potting mixture alone	0.223	20.23	182.16
T_2 Potting mixture + sewage sludge (9: 1)	0.223	21.00	180.33
T_3 Potting mixture + sewage sludge (8: 2)	0.224	21.16	180.00
T_4 Potting mixture + sewage sludge (7:3)	0.225	20.83	180.66
T_5 Potting mixture + sewage sludge (6:4)	0.226	20.83	188.33
T_6 Potting mixture + sewage sludge (1:1)	0.222	19.33	182.16
T_7 Potting mixture + sewage sludge (4:6)	0.226	18.50	181.00
T_8 Potting mixture + sewage sludge (3:7)	0.226	19.16	176.66
T_9 Potting mixture + sewage sludge (2:8)	0.226	19.66	187.16
T_{10} Potting mixture + sewage sludge (1:9)	0.224	19.16	185.16
T_{11} Sewage sludge alone	0.224	18.33	178.83
CD (0.05)	-	-	-

Table 22. Effect of sewage sludge on yield and yield attributes of marigold

Treatments	Drymatter yield of shoot (g)	Drymatter yield of root (g)	Flower yield (g)
T_1 Potting mixture alone	56.02	0.96	334.65
T_2 Potting mixture + sewage sludge (9:1)	64.37	3.03	706.36
T_3 Potting mixture + sewage sludge (8:2)	66.37	3.00	592.52
T_4 Potting mixture + sewage sludge (7:3)	61.84	2.80	335.42
T_5 Potting mixture + sewage sludge (6:4)	58.48	2.72	344.91
T_6 Potting mixture + sewage sludge (1:1)	53.45	2.44	317.29
T_7 Potting mixture + sewage sludge (4:6)	48.45	2.26	275.53
T_8 Potting mixture + sewage sludge (3:7)	41.63	1.94	213.90
T_9 Potting mixture + sewage sludge (2:8)	42.90	2.14	204.91
T_{10} Potting mixture + sewage sludge (1:9)	38.05	2.11	202.99
T_{11} Sewage sludge alone	32.04	2.02	187.76
CD (0.05)	13.85	1.14	71.17

4.2.7 Heavy Metal Content in Shoot

The data on the influence of sewage sludge on heavy metal content in shoots influenced the heavy metal content in shoots of marigold are presented in Table 23.

4.2.7.1 Chromium

As the content of sewage sludge in growing medium increased, there was a significant increase in chromium content in shoot also. It was the highest (17.73 mg kg^{-1}) in the treatment receiving sewage sludge alone (T_{11}) which was significantly higher than all other treatments. This was followed by T_{10} (14.83 mg kg^{-1}). The treatments T_1 (potting mixture alone) had the lowest chromium content of 7.5 mg kg^{-1}.

4.2.7.2 Cadmium

The cadmium content in shoots of marigold plants ranged from 1.56 to 30.33 mg kg^{-1}. The highest cadmium content was reported in T_{11} (sewage sludge alone) followed by T_{10} (28.00 mg kg^{-1}). The treatments T_9 (potting mixture + sewage sludge 1:9) and T_8 (potting mixture + sewage sludge 2:8) were on par (18.83 and 18.50 mg kg^{-1} respectively). The treatments T_1 (potting mixture alone) and T_2 (potting mixture + sewage sludge 9:1) did not have any influence on the content of cadmium in shoots. The lowest content was noticed in the treatment T_3 (1.56 mg kg^{-1}).

4.2.7.3 Nickel

As the content of sewage sludge in the growing medium increased, there was significant increase in nickel content in shoot. The treatments T_1 (potting mixture alone) and T_2 (potting mixture + sewage sludge 9:1) did not have any influence on the content of nickel in shoots. The highest value (12.86 mg kg^{-1}) was associated with T_{11} (sewage sludge alone) followed by T_{10} (11.49 mg kg^{-1}) and T_9 (11.43 mg kg^{-1}) which were on par. The lowest content was recorded in T_3

Table 23. Effect of sewage sludge on heavy metal content in shoots of marigold

Treatments	Cr ($mg\ kg^{-1}$)	Cd ($mg\ kg^{-1}$)	Ni ($mg\ kg^{-1}$)	Pb ($mg\ kg^{-1}$)	As ($mg\ kg^{-1}$)
T_1 Potting mixture alone	7.50	ND	ND	ND	ND
T_2 Potting mixture + sewage sludge (9:1)	8.35	ND	ND	6.33	ND
T_3 Potting mixture + sewage sludge (8:2)	8.54	1.56	1.83	10.40	ND
T_4 Potting mixture + sewage sludge (7:3)	8.83	4.16	3.16	11.16	ND
T_5 Potting mixture + sewage sludge (6:4)	9.00	7.83	7.90	11.33	ND
T_6 Potting mixture + sewage sludge (1:1)	10.00	12.66	8.00	13.82	ND
T_7 Potting mixture + sewage sludge (4:6)	10.66	14.66	8.13	15.00	ND
T_8 Potting mixture + sewage sludge (3:7)	13.66	18.50	8.33	16.55	ND
T_9 Potting mixture + sewage sludge (2:8)	13.67	18.83	11.43	17.00	ND
T_{10} Potting mixture + sewage sludge (1:9)	14.83	28.00	11.49	19.00	ND
T_{11} Sewage sludge alone	17.73	30.33	12.86	30.62	ND
CD (0.05)	0.752	1.61	1.02	5.90	

ND- Not Detected

(potting mixture + sewage sludge 8:2). T_8 (8.33 mg kg^{-1}), T_7 (8.13 mg kg^{-1}), T_6 (8.00 mg kg^{-1}) and T_5 (7.90 mg kg^{-1}) gave on par results.

4.2.7.4 Lead

There was a significant influence of treatments on the lead content of shoot in marigold plants. Lead content was not detected in the treatment receiving potting mixture alone (T_1) and the lowest detected value was associated with T_2 (6.33 mg kg^{-1}). The treatment sewage sludge alone (T_{11}) recorded the highest lead content in shoot (30.62 mg kg^{-1}) followed by T_{10} (19.00 mg kg^{-1}), T_9 (17.00 mg kg^{-1}), T_8 (16.55 mg kg^{-1}), T_7 (15.00 mg kg^{-1}) and T_6 (13.82 mg kg^{-1}) which were on par.

4.2.7.5 Arsenic

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

4.2.8 Heavy Metal Content in Roots

The data on heavy metal content in roots as influenced by the various treatments are given in Table 24.

4.2.8.1 Chromium

The treatments significantly influenced the chromium content in the roots of marigold plants. With the increasing addition of sewage sludge in the growing medium, the chromium content in the roots of marigold also increased. Sewage sludge alone (T_{11}) recorded the highest chromium content of 33.00 mg kg^{-1} followed by T_{10} (29.66 mg kg^{-1}), T_9 (29.33 mg kg^{-1}) and T_7 (27.59 mg kg^{-1}) which were on par. The lowest chromium content in root (12.33 mg kg^{-1}) was observed in the treatment receiving potting mixture alone (T_1). The treatments T_2 (23.50 mg kg^{-1}), T_3 (23.66 mg kg^{-1}), T_4 (24.16 mg kg^{-1}), T_5 (24.22 mg kg^{-1}) and T_6 (25.00 mg kg^{-1}) gave on par results.

Table 24. Effect of sewage sludge on heavy metal content in roots of marigold

Treatments	Cr (mg kg^{-1})	Cd (mg kg^{-1})	Ni (mg kg^{-1})	Pb (mg kg^{-1})	As (mg kg^{-1})
T_1 Potting mixture alone	12.33	ND	7.79	ND	ND
T_2 Potting mixture + sewage sludge (9:1)	23.50	ND	12.70	ND	ND
T_3 Potting mixture + sewage sludge (8:2)	23.66	ND	14.26	ND	ND
T_4 Potting mixture + sewage sludge (7:3)	24.16	1.66	16.10	ND	ND
T_5 Potting mixture + sewage sludge (6:4)	24.22	3.33	16.33	ND	ND
T_6 Potting mixture + sewage sludge (1:1)	25.00	3.46	17.40	ND	ND
T_7 Potting mixture + sewage sludge (4:6)	27.59	4.00	18.15	ND	ND
T_8 Potting mixture + sewage sludge (3:7)	27.46	4.16	21.00	0.65	ND
T_9 Potting mixture + sewage sludge (2:8)	29.33	8.00	22.00	1.46	ND
T_{10} Potting mixture + sewage sludge (1:9)	29.66	8.16	22.60	3.18	ND
T_{11} Sewage sludge alone	33.00	8.23	26.05	4.29	ND
CD (0.05)	2.19	0.483	4.01	0.250	

ND- Not Detected

4.2.8.2 Cadmium

The cadmium content in the roots of marigold plants ranged from 1.66 mg kg^{-1} to 8.23 mg kg^{-1}. There was a significant increase in the cadmium content in root of marigold plants with the increasing amount of sewage sludge in the growing medium. T_1 (potting mixture alone), T_2 (potting mixture + sewage sludge 9:1) and T_3 (potting mixture + sewage sludge 8:2) did not contain cadmium in the roots. The highest cadmium content in root was noticed in T_{11} which was on par with T_{10} (8.16 mg kg^{-1}) and T_9 (8.00 mg kg^{-1}).

4.2.8.3 Nickel

The treatments significantly influenced the nickel content in roots of marigold plants. With the increasing addition of sewage sludge in the growing medium, the nickel content in the roots of marigold was also increased. Sewage sludge alone (T_{11}) recorded the highest nickel concentration in root (26.05 mg kg^{-1}) which was on par with T_{10} (22.60 mg kg^{-1}). This was followed by T_9 (potting mixture + sewage sludge 2:8) and T_8 (potting mixture + sewage sludge 3:7) which were on par (22.00 and 21.00 mg kg^{-1} respectively). The lowest nickel content in root was associated with the treatment receiving potting mixture alone (7.79 mg kg^{-1}).

4.2.8.4 Lead

The presence of lead could not be detected in roots of marigold plants from treatments T_1 to T_7. The highest lead concentration in root (4.29 mg kg^{-1}) was associated with T_{11} (sewage sludge alone) which was followed by T_{10} (3.18 mg kg^{-1}), T_9 (1.46 mg kg^{-1}) and T_8 (0.65 mg kg^{-1}).

4.2.8.5 Arsenic

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

4.2.9 Heavy Metal Uptake

The treatments significantly influenced the total uptake of heavy metals by marigold plants and the results are presented in Table 25.

4.2.9.1 Chromium

The uptake of chromium by marigold plants ranged from 0.431 mg $plant^{-1}$ to 0.649 mg $plant^{-1}$. Significantly higher chromium uptake (0.649 mg $plant^{-1}$) was observed in T_9 (potting mixture + sewage sludge 2:8) which was on par with T_{11} (0.635 mg $plant^{-1}$), T_{10} (0.626 mg $plant^{-1}$), T_8 (0.621 mg $plant^{-1}$), T_7 (0.578 mg $plant^{-1}$), T_6 (0.595 mg $plant^{-1}$), T_5(0.590 mg $plant^{-1}$), T_4 (0.613 mg plant $^{-1}$), T_3 (0.637 mg plant $^{-1}$) and T_2 (0.608 mg $plant^{-1}$). Chromium uptake was the lowest in the treatment receiving potting mixture alone (0.431 mg $plant^{-1}$).

4.2.9.2 Cadmium

With the increasing quantity of sewage sludge in the growing medium the uptake of cadmium also increased. The highest cadmium uptake was observed in T_{10} (1.08 mg $plant^{-1}$) followed by T_{11} (0.937 mg $plant^{-1}$). Cadmium uptake was not observed in T_1 (potting mixture alone) and T_2 (potting mixture + sewage sludge 9:1). The lowest cadmium uptake was noticed in T_3 (0.103 mg $plant^{-1}$) .

4.2.9.3 Nickel

The treatments significantly influenced the uptake of nickel by marigold plants. The highest nickel uptake (0.547 mg $plant^{-1}$) was observed in T_9 (potting mixture + sewage sludge 1:9) which was on par with T_5 (0.505 mg $plant^{-1}$). This was followed by T_{10} (0.484 mg $plant^{-1}$) and T_{11} (0.464 mg $plant^{-1}$) which were on par. The treatment receiving potting mixture alone recorded the lowest value (0.007 mg $plant^{-1}$) which was on par with T_2 (0.038 mg $plant^{-1}$).

4.2.9.4 Lead

The treatments significantly influenced the uptake of lead by marigold plants. T_{11} (sewage sludge alone) recorded the highest uptake of lead by marigold

Table 25. Effect of sewage sludge on heavy metal uptake studies by marigold

Treatments	Cr (mg kg^{-1})	Cd (mg kg^{-1})	Ni (mg kg^{-1})	Pb (mg kg^{-1})
T_1 Potting mixture alone	0.431	ND	0.007	ND
T_2 Potting mixture + sewage sludge (9:1)	0.608	ND	0.038	0.407
T_3 Potting mixture + sewage sludge (8:2)	0.637	0.103	0.164	0.690
T_4 Potting mixture + sewage sludge (7:3)	0.613	0.261	0.240	0.690
T_5 Potting mixture + sewage sludge (6:4)	0.590	0.465	0.505	0.660
T_6 Potting mixture + sewage sludge (1:1)	0.595	0.685	0.470	0.703
T_7 Potting mixture + sewage sludge (4:6)	0.578	0.719	0.434	0.696
T_8 Potting mixture + sewage sludge (3:7)	0.621	0.784	0.387	0.690
T_9 Potting mixture + sewage sludge (2:8)	0.649	0.824	0.547	0.732
T_{10} Potting mixture + sewage sludge (1:9)	0.626	1.080	0.484	0.729
T_{11} Sewage sludge alone	0.635	0.937	0.464	0.989
CD (0.05)	0.112	0.081	0.071	0.204

plants (0.989 mg plant^{-1}) followed by T_9 (0.732 mg plant^{-1}), T_{10} (0.729 mg plant^{-1}), T_6 (0.703 mg plant^{-1}), T_7 (0.696 mg plant^{-1}), T_8 (0.690 mg plant^{-1}), T_5 (0.660 mg plant^{-1}), T_4 (0.690 mg plant^{-1}) and T_3 (0.690 mg plant^{-1}) which were on par. The lowest lead uptake was recorded in the treatment receiving potting mixture alone (0.407 mg plant^{-1}).

Discussion

5. DISCUSSION

The results generated from this study entitled "Evaluation of sewage sludge as a growth medium for ornamentals" are discussed hereunder.

5.1 CHARACTERIZATION OF SEWAGE SLUDGE GENERATED FROM SEWAGE TREATMENT PLANT, MUTTATHARA.

Characterisation of sewage sludge is important before application of sewage sludge to soil for agricultural purpose because such characterization helps determine the potential of sewage sludge for nutrient supplementation, increasing plant yields and also identify the presence of heavy metals and microbial contaminants (Mtshali *et al.*, 2014).

Various physical, chemical and biological analysis of sewage sludge revealed that sewage sludge generated from sewage treatment plant, Muttathara was extremely acidic (pH-2.91) and had an electrical conductivity of 0.57 dS m^{-1}. The low pH of sewage sludge can be attributed to the release of humic acid as a result of biodegradation of sewage sludge which is rich in organic carbon. Similar results were reported by Singh and Agrawal (2010a); Maiti *et al.* (1992). The high values for electrical conductivity may be due to the high level of salts present in sewage sludge and due to the formation of complexes of organic matter and heavy metals. The results are in line with the findings of Mtshali *et al.* (2014); Ahmed *et al.* (2010).

Sewage sludge from sewage treatment plant, Muttathara is having a high organic carbon content of 12.2 %. This may be due to the high content of organic matter in sewage sludge. The high organic carbon and organic matter status of sewage sludge also reflected on the status of primary and secondary nutrients (N, P, K, Ca, Mg and S status of 2.05%, 2.65%, 1.80%, 1.02%, 0.63%, 460 mg kg^{-1} respectively). The total iron content was 3.12%, which was also high. Content of manganese and zinc were 0.15% and 224.7 mg kg^{-1} respectively. It was also having 225.5 mg kg^{-1} of copper and 13.5 mg kg^{-1} of boron. The sewage sludge can be used for the agricultural practices because of the presence of high organic content and plant available nutrients. Similar results were also reported by Singh and Agrawal (2010a) in sewage sludge from Dinapur Sewage Treatment Plant (DSTP) Varanasi which had high concentrations of organic C, total N, available P, Fe, Na, K, Ca, Mg, Cu, Mn and Zn.

Physical properties namely water holding capacity (26.1 %) and porosity (65.7 %) were high, but bulk density was low (0.65 g cc^{-1}). This may be due to the large quantity of organic substances present in sewage sludge which possess high water holding capacity and porosity. Because of the same reason the bulk density is low which is an advantage for the loading, transportation and application. Similar reports were put forwarded by Siuris (2011).

Presence of toxic metals and pathogens restricts the direct use of sewage sludge in agricultural lands. The sewage sludge from Muttathara treatment plant was found to be contaminated with heavy metals like cadmium, chromium, nickel and lead. Presence of arsenic was not detected. The cadmium content was 27 mg kg^{-1} which was five times higher than the permissible limit. Other heavy metals reported were Cr (31.5 mg kg^{-1}), Ni (33.5 mg kg^{-1}) and (Pb) 11.5 mg kg^{-1}, which were relatively high but within permissible limits. The main sources of heavy metal in sewage sludge are industrial waste water and surface water runoff. Similar findings were reported by Chander and Brookest (1991); Singh and Agrawal (2010b).

The analysis of biological properties of sewage sludge from sewage treatment plant, Muttathara revealed that it had a heavy load of *E.coli* (>2400 MPN/100g). This can be attributed to the fact that the raw sewage that reaches Muttathara plant is from an average of 141.74 sq. km of Thiruvanathapuram corporation which includes mostly residential areas with very few industries.

The population of bacteria, fungi and actinomycetes were also high with counts of 7.36 log no of cfu/100g, 5.14 log no of cfu/100g and 5.11 log no of cfu/100g respectively. The high content of organic matter in the sludge coupled with the fact that activated sludge process with extended aeration is employed in the treatment process would have resulted in better multiplication and survival of these organisms resulting in their higher number in the sludge. The results are in line with the findings of Kobus *et al.* (1990); Sidhu (2000) and Usman *et al.* (2012).

5.2. POT CULTURE EXPERIMENT

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

5.2.1 Physical, Chemical and Biological Properties of Growing Medium

The results generated on physical, chemical and biological characteristics of the growing medium before and after raising the crop are discussed here.

5.2.1.1 pH, Electrical Conductivity and Organic Carbon

The treatments showed significant effect on pH of both initial and final growing medium, before and after the experiment. The addition of sewage sludge to growing medium resulted in a significant reduction in pH (Fig.2). In the case of initial growing medium the highest pH (6.23) was recorded in the treatment potting media alone which decreased significantly with the addition of sewage sludge and the lowest pH of 2.89 was recorded in the treatment receiving sewage alone. The same trend of result was seen in the case of growing medium after the experiment also. This reduction in soil pH with the addition of sewage sludge may be due to the release of humic acid as a result of biodegradation of sewage sludge which is rich in organic carbon. Similar results have been reported by Morino *et al.* (1997); Singh and Agrawal (2010b) and Outhman and Bharose (2014).

Electrical conductivity of both initial and final growing medium was increased with increasing concentration of sewage sludge in the growing medium. In the initial growing medium T_{11} recorded the highest EC (0.55 dS m^{-1}) which was on par with T_{10} (potting mixture + sewage sludge 1:9) and the lowest EC value was noticed in T_1 (potting mixture alone), which was on par with T_2

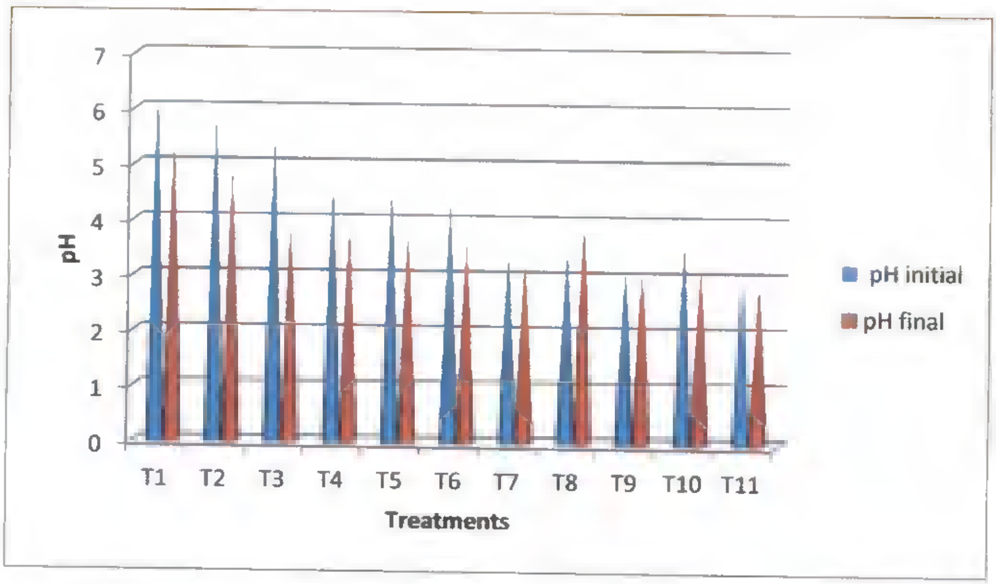

Fig. 2. Effect of sewage sludge on pH of the growing medium (before and after the experiment)

(potting mixture + sewage sludge 9:1). In the final growing medium also the highest EC of 0.52 dS m^{-1} was recorded by T_{11} (sewage sludge alone) which was on par with T_{10} (potting mixture + sewage sludge in the ratio of 1:9) and the lowest EC of 0.07 dS m^{-1} was obtained in the treatment receiving potting mixture alone (T_1) which was on par with T_2 (potting mixture + sewage sludge 9:1). The increase in electrical conductivity as a result of sewage sludge addition in all the treatments compared to control (potting mixture alone) can be attributed to the high level of salts present in sewage sludge and to the formation of metallic salts, which are complexes of organic matter and heavy metals present in the sewage sludge. Similar observations were made by Ahmed *et al.* (2010); Mtshali *et al.* (2014).

The organic carbon content increased significantly with increasing inclusion of sewage sludge in the growing medium (Fig.3). In the initial growing medium the highest value (12.10 per cent) was recorded with treatment T_{11} (sewage sludge alone) which was significantly higher than all other treatments and the lowest value among all the treatment was recorded by potting mixture alone (T_1). Similar trend was noticed in final growing medium also, where the highest organic carbon content was noticed when sewage sludge alone was used as growing medium (10.90 per cent) and the lowest value was associated in the treatment potting mixture alone (0.33 per cent). The sewage sludge used in the experiment had a high organic carbon content of 12.2 % which would have resulted in the higher organic carbon content in the treatment receiving higher quantities of sludge. The results are in line with the findings of Jamil *et al.* (2006); Selivanovskaya *et al.* (2007) and Saruhan *et al.* (2012).

5.2.1.2 Physical Properties

There was a reduction in the bulk density of growing medium with the increasing concentration of sewage sludge in the case of both initial and final growing medium. Before raising crop, the bulk density of growing medium ranged from 0.67 to 1.44 g cc^{-1}. The lowest bulk density was observed in T_{11}

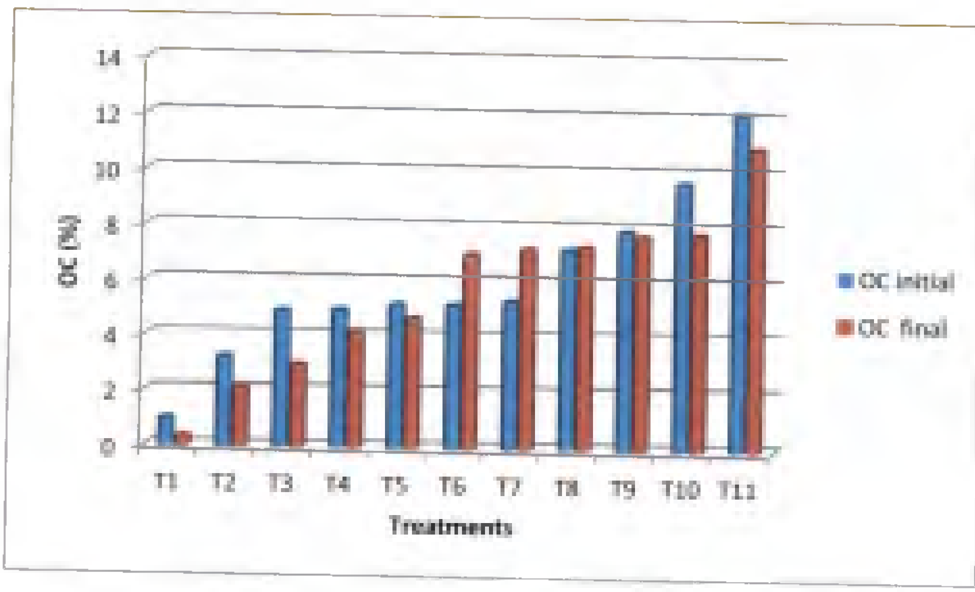

Fig. 3. Effect of sewage sludge on organic carbon content of growing medium (before and after the experiment)

(sewage sludge alone) and the highest was noticed in T_1 (potting mixture alone). Other treatments gave intermediate values. Considering the bulk density of final growing medium, the highest bulk density (1.17 g cc^{-1}) was recorded in the treatment with potting mixture alone (T_1) and the lowest value of 0.65 g cc^{-1} was noticed in the treatment sewage sludge alone (T_{11}). The decrease in bulk density as a result of sewage sludge application may be due to a dilution effect resulting from the mixing of added organic matter (sewage sludge) which is having lower bulk density, with the more dense mineral fraction of the potting mixture. Sewage sludge addition would have also indirectly influenced the bulk density of soil by improving the structural stability and increasing the porosity as a result of better aggregation of soil. Similar results were shown by Powers *et al.* (1975); Chang *et al.* (1983) and Mondal *et al.* (2015).

In the initial growing medium the highest water holding capacity was associated with T_{10} (26.14 %) which was on par with T_{11} (26.11 %) while the lowest water holding capacity was associated with T_1 (potting mixture alone) which was on par with T_2 (11.80 %). The final growing medium also showed similar trend (Fig. 4). Water holding capacity of final growing medium ranged from 11.40-27.40 %. The highest water holding capacity was noticed in the treatment receiving sewage sludge alone (T_{11}) and the lowest in the treatment, T_1 which received potting mixture alone. There was a significant increase in the water holding capacity with the increasing content of sewage sludge in the growing medium before and after the crop (Fig. 4). Since over half of the mass of sewage sludge contain organic matter, its application would have directly influenced the water holding capacity of soil by promoting higher water retention in sludge-amended soils. Similar results were observed by Epstein (1975); Gupta *et al.* (1977) and Ojeda *et al.* (2003).

With the increasing addition of sewage sludge, porosity was found to increase from 49.18 per cent (T_1) to 65.72 per cent (T_{11}) in the initial growing medium. In the final growing medium significantly higher porosity was recorded in T_{11} (63.95 %) which was on par with T_{10} (61.66 %) and T_9 (59.08 %). T_1

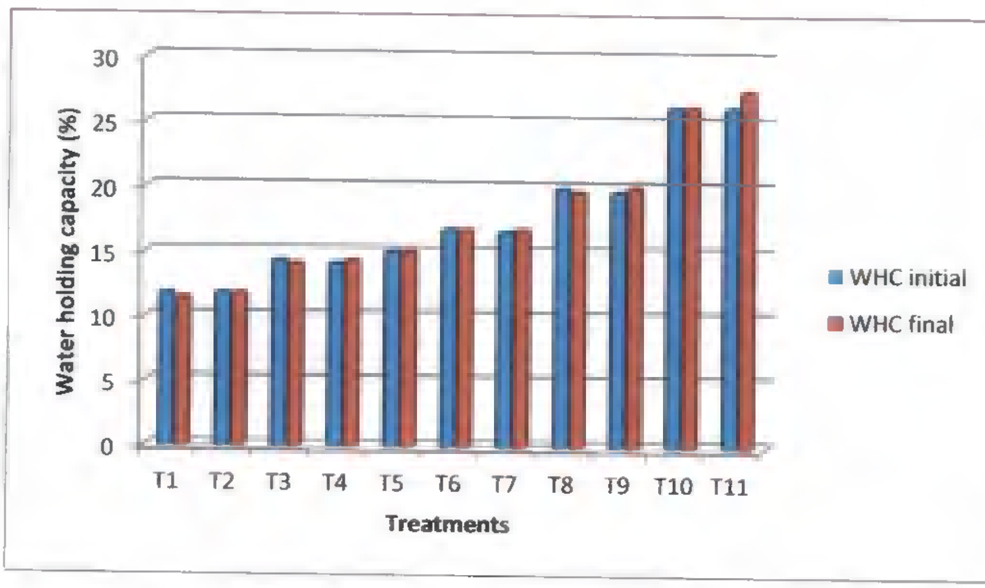

Fig. 4. Effect of sewage sludge on water holding capacity of growing medium (before and after the experiment)

(potting mixture alone) recorded the lowest porosity of 41.85 % which was on par with T_2 (potting mixture + sewage sludge 9:1). The significant increase in porosity with the addition of sewage sludge can be attributed to the addition of bulk quantity of organic matter of low bulk density resulting in better soil aggregation which in turn would have increased the total pore volume and porosity in the treatments receiving higher quantities of sewage sludge. Similar reports were put forward by Lindsay (1998); Antil and Narwal (2008).

5.2.1.3 Status of Primary Nutrients

The status of N, P and K in the growing media showed a significant increase with increasing content of sewage sludge in the medium both before and after the experiment. The highest values in the initial growing medium were associated with T_{11} (sewage sludge alone) with N, P and K values of 2526.11 kg ha^{-1}, 124.69 kg ha^{-1} and 627.20 kg ha^{-1} respectively and the lowest in T_1 (315.45 kg ha^{-1} N, 53.08 kg ha^{-1} P, 145.60 kg ha^{-1}K) (Fig. 5). The same trend of results was observed in the final samples also (Fig. 6). This can be attributed to the contribution of N, P and K from sewage sludge. A decline in the content of these nutrients was observed in the final growing medium in comparison to the initial growing medium. This may be due to crop removal of these nutrients. Even after crop growth high level of N, P and K in the final growing medium. This is attributed to the fact that sewage sludge used in the experiment is rich in N, P and K with values of 2.05% N, 2.65% P and 1.80% K respectively and also contains higher quantities of proteinic material and polyphosphate compounds from detergents. Increase in available nitrogen could also be the contribution from the decomposition of organic matter. An increase in available N, P and K through the application of sewage sludge has also been found in previous studies conducted by Peterson *et al.* (2003); Ahmed *et al.* (2010) and Outhman and Bharose (2014).

5.2.1.4 Status of Secondary and Micro Nutrients

As in the case of primary nutrients, both in initial and final growing medium, the status of secondary nutrients also showed a significant increase with

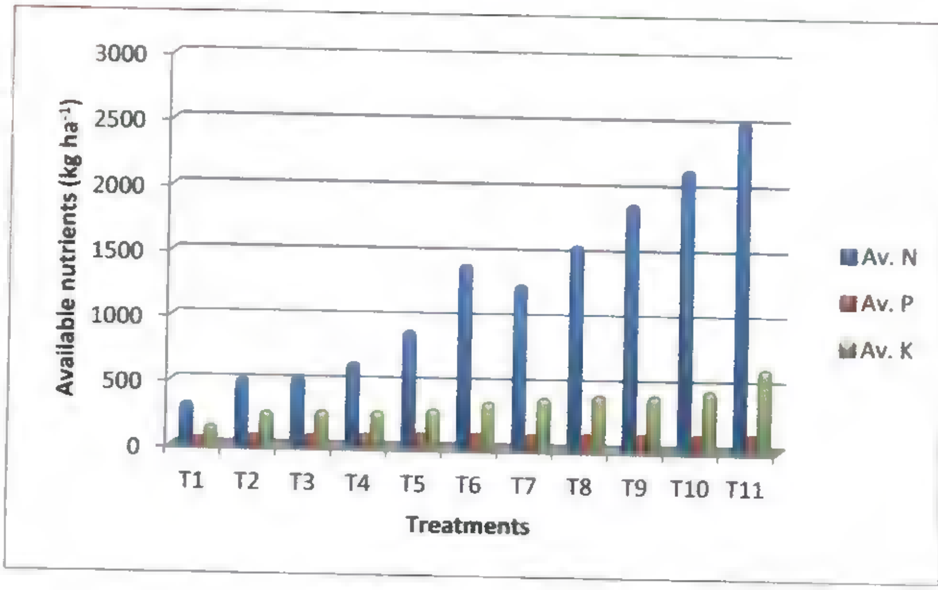

Fig. 5. Effect of sewage sludge on primary nutrient status in growing medium before the experiment.

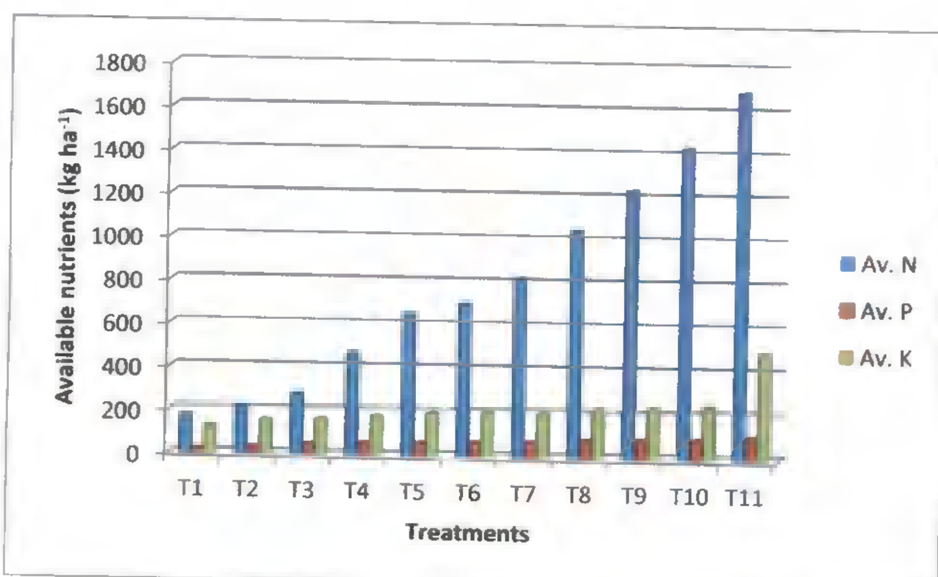

Fig. 6. Effect of sewage sludge on primary nutrient status in the growing medium after the experiment.

increasing quantity of sewage sludge in growing medium. It was the lowest in T_1 (potting mixture alone) and showed a concomitant increase with increasing levels of sewage sludge up to T_{11} (sewage sludge alone). This may be due to the higher content of these nutrients in the sewage sludge and their incorporation to the growing medium in due course. The results are in agreement with those reported by May *et al.* (1973); Hussain (2009).

The present study revealed that the available micronutrients like iron, manganese, zinc, copper, and boron content in the growing medium showed significant increase with the application of sewage sludge. The highest micronutrient status was recorded in the treatment (T_{11}) receiving sewage sludge alone and the lowest in T_1 which received potting mixture alone as treatment. Significant increase in the micronutrient status with sewage sludge addition may be due to presence of high amount of these micronutrients in the sewage sludge used for this study. As the micronutrient availability is also influenced by other factors like soil pH a decrease in soil pH would have lead to release of cations from the exchangeable sites to soil solution, thus increasing their availability to plants. Similar observations were also made by Samara and Kallianou (2000); Singh and Agrawal (2006).

5.2.1.5 Heavy Metal Content

The treatments significantly influenced the heavy metal content in the growing medium. The content of heavy metals like cadmium, chromium, nickel and lead in the growing medium significantly increased with the addition of sewage sludge. But arsenic was not detected in any of the treatment both in initial and final growing medium. In the initial growing medium the highest available cadmium, chromium, nickel and lead content was recorded in the treatment T_{11} which received sewage sludge alone. The lowest heavy metal content was noticed in the treatment receiving potting mixture alone (T_1) (Fig. 7). As in the case of initial growing medium, final growing medium also showed the same trend for heavy metal availability. The metal concentration in the sewage sludge depends

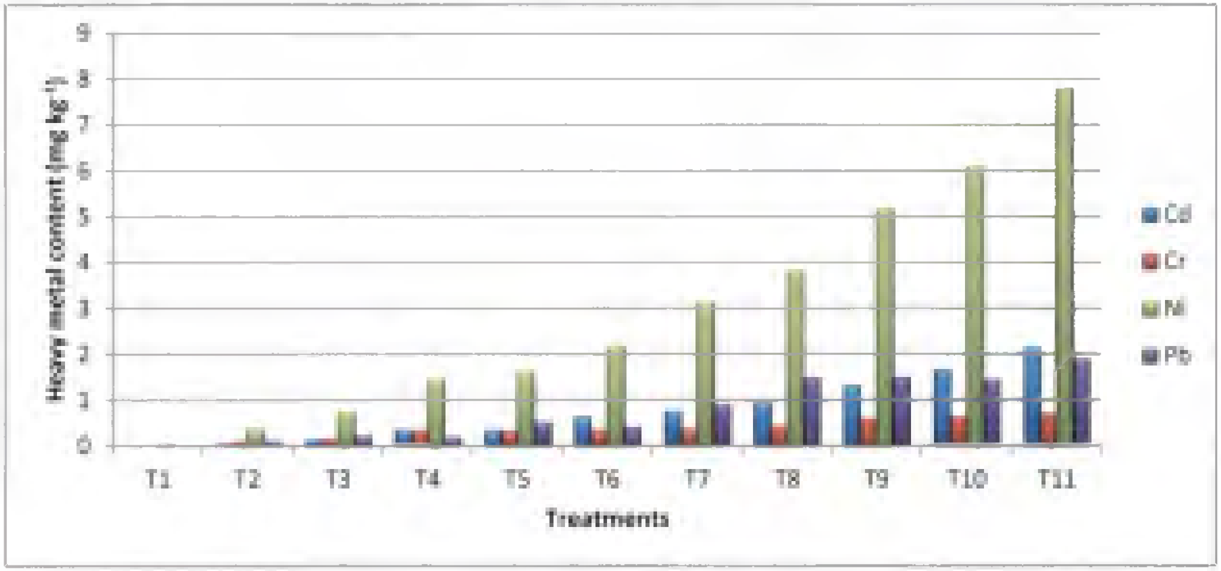

Fig. 7. Effect of sewage sludge on heavy metal content in the growing medium before the experiment

on several factors such as sewage origin and sludge treatment processes. The sludge used for the present study contains the heavy metals like cadmium, chromium, nickel and lead in which cadmium was five times more than permissible limit. Even though, the other heavy metals present within permissible limit, their values are high and this may be the main reason for increasing heavy metal content in the growing medium with the increasing concentration of sewage sludge. The bioavailability of the sludge born metals to soil is further influenced by soil properties such as pH, redox potential, sesquioxide content, organic matter and sludge application rate. The increasing availability of heavy metal also may be attributed to soil pH. It is because metal solubility tends to increase at lower pH and decrease at higher pH values. It should be noted that in the present study, the pH of the growing medium decreased significantly with increasing levels of sewage sludge addition. The association between adsorption and pH is due partly to competition of H^+ (and Al^{3+}) ions for adsorption sites at low pH resulting in decreased metal adsorption. Similar reports were put forwarded by Alloway (1990); Samara and Kallianou (2000); Karatas *et al.* (2006) and Wang *et al.* (2008).

5.2.1.6 Biological Properties

The study revealed that bacterial population in the growing medium before and after the crop was significantly influenced by the treatments. In the initial growing medium the maximum population was recorded in T_2 which received potting mixture and sewage sludge in the ratio of 1:9. It decreased as the content of sewage sludge in the growing medium increased with the lowest value in T_8. The same trend of result was observed in final growing medium where T_1 (potting mixture alone) recorded the highest bacterial population which was on par with T_3 (potting mixture + sewage sludge 8:2). Beyond this there was a significant reduction in bacterial population. This reduction is may be due to elevated heavy metal concentration in sewage sludge, which would have resulted in the instantaneous death of microbial cells, or would have caused disorder of important functions and change in population size and in viability or competitive ability of soil microorganisms. Similar results were observed by Brookes and McGrath (1987); Giller *et al.* (1998).

Though the sewage sludge used in the experiment contained a high load of *E.coli* (> 2400 MPN/100g) the presence of *E.coli* was not detected in any of the treatments. It should be noted that sewage sludge was dried before use. Drying would have reduced the number of faecal coliforms due to the elevated temperature and desiccation on exposure to the sunlight and interaction with the other components of growing medium. The results are in line with the findings of Gibbs *et al.* (1997); Zaleski *et al.* (2005) and Ogleni and Ozdemir (2010).

5.2.2 Plant Growth and Floral Parameters

Plant growth parameters like height of the plant and number of secondary branches were significantly influenced by the treatments. There was significant decrease in the plant height with increasing content of sewage sludge in growing medium (Fig. 8). The maximum plant height (91.33 cm) was observed in T_2 which received potting mixture + sewage sludge in the ratio of 9:1 as treatment which was on par with T_3 (potting mixture + sewage sludge 8:2). The lowest plant height (48.00 cm) was recorded in the treatment where sewage sludge alone was used. The maximum number of secondary branches was also recorded in T_2. There was no significant influence of treatments on the number of primary branches in marigold.

Among different floral parameters T_2 recorded the highest value for flower length (10.33 cm), flower diameter (6.75 cm), flower weight (8.88 g) and number of flowers (79.60). (Fig.9, Fig.10). All these parameters were reduced significantly with the increasing addition of sewage sludge. This may be due to the fact that even though the increasing rate of sewage sludge addition to the growing media improved physical, chemical and biological properties of soil, application rates over a particular limit has lowered the pH in the soil environment, which led to reductions in plant growth and floral parameters. This

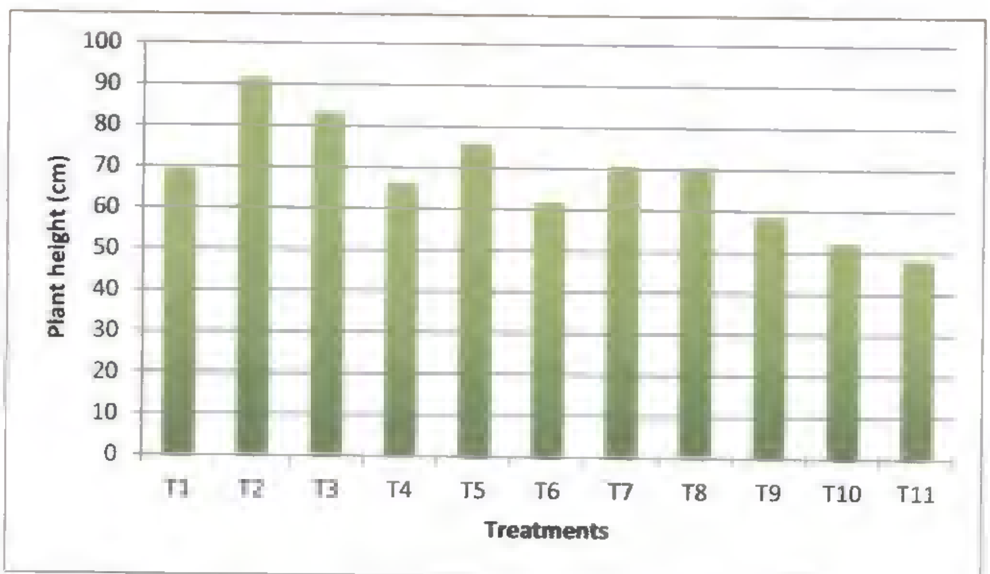

Fig. 8. Effect of sewage sludge on plant height of marigold

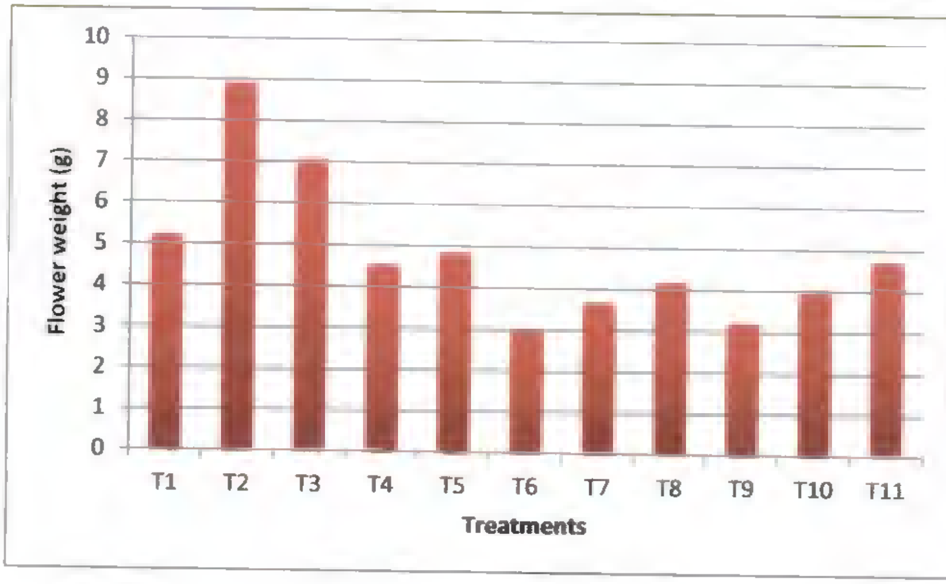

Fig. 9. Effect of sewage sludge on flower weight of marigold

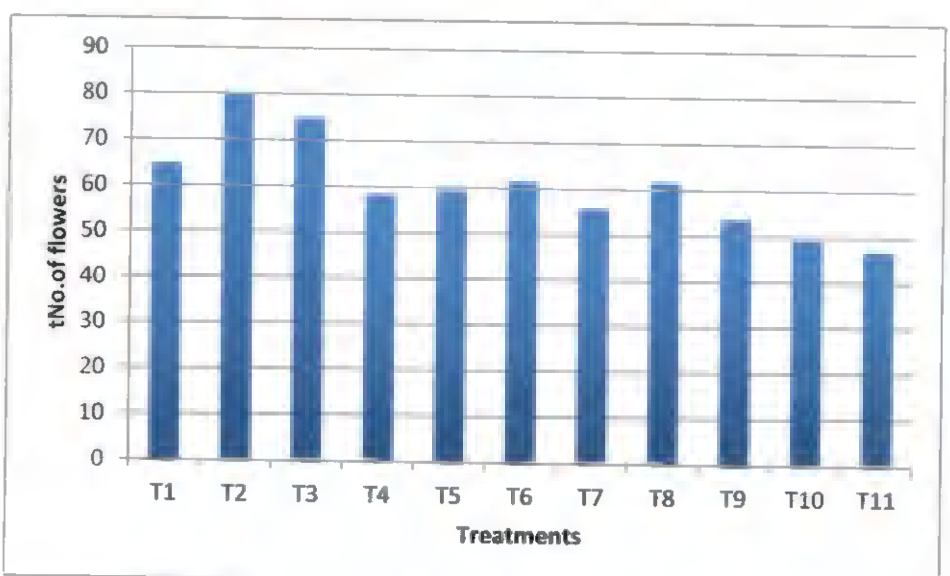

Fig.10. Effect of sewage sludge on flower number of marigold

is consonance with the findings of Smith (1992); Singh and Sinha (2004); Grigatti *et al.* (2007) and Singh and Agrawal (2007).

Biochemical properties like chlorophyll content in leaves, xanthophyll and flavonoid content of flowers was not significantly influenced by the treatments concluding that no significant toxic action was imposed in the plants by the metals.

5.2.3 Yield and Yield Attributes

The dry matter yield in shoot and root were significantly influenced by the treatments with a significant reduction with the increasing levels of sewage sludge in growing medium. The treatment receiving potting mixture and sewage sludge in 8:2 ratio (T_3) gave the highest value for both shoot and root yield. The increased nutrient availability in the treatments containing sewage sludge as part of growing media would have resulted in increased dry matter yield of shoot and root. However the decrease observed in the treatments receiving more than 2 parts of sewage sludge can be attributed to the negative influence of heavy metals present in the sludge which would have suppressed plant growth.

The results on dry matter yield of marigold also reflected on the flower yield. There was a decline in flower yield with increasing levels sewage sludge application beyond T_2 (potting mixture + sewage sludge 9:1) (Fig. 11). The higher doses of T_8, T_9, T_{10} and T_{11} were on par with lowest flower yield clearly indicating the retarding effect of higher levels of sewage sludge application on flower yield. As in the case of dry matter yield, this can be attributed to the effect of higher levels of heavy metals associated with these treatments.

Yield decrease due to the sewage sludge addition may be due to the presence of heavy metals in the sewage sludge, and also due to strongly acidic condition in the growing medium. Similar observation was made by Moreno *et al.* (1997). Once the heavy metals enter the plant especially cadmium, it is transported throughout the metabolically active sites in the shoots where it exerts

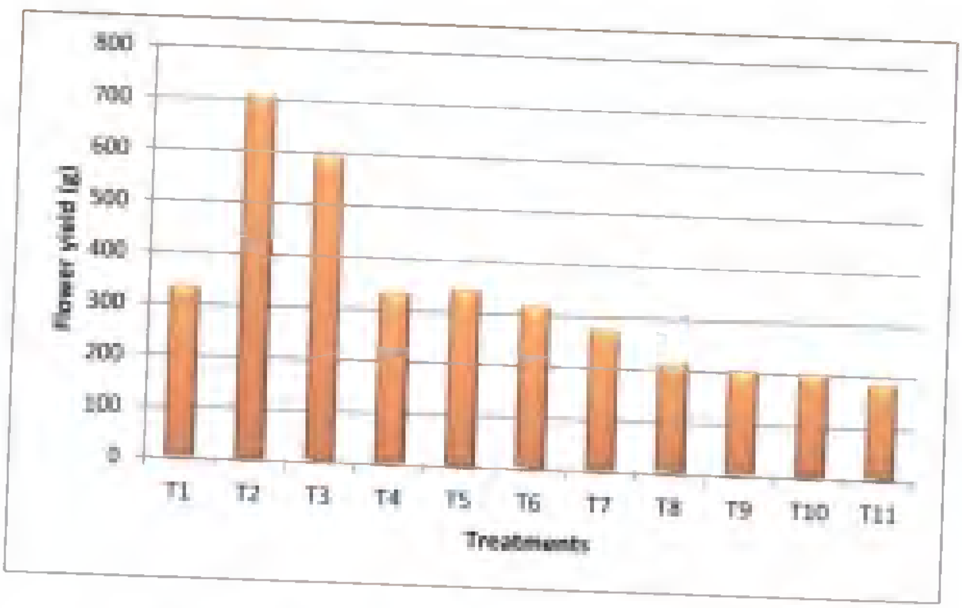

Fig.11. Effect of sewage sludge on flower yield of marigold

the toxic effect (Ghoshroy and Nadakavukaran, 1990). Reduction in flower yield and dry matter production can be attributed to the inhibition of growth and membrane damages due to heavy metal toxicity as stated by Moya *et al.* (1993); Furher (1982).

5.2.4 Heavy Metal Content and Uptake

The treatments significantly influenced the content of heavy metal in shoot and root and their uptake by marigold plants.

The content of all the four heavy metals cadmium, chromium, nickel and lead were significantly influenced by the treatments. As the content of sewage sludge in growing medium increased, there was a significant increase in heavy metal content in shoot (Fig. 12). T_{11} which contained sewage sludge alone recorded the highest content for all the heavy metals, chromium (17.73 mg kg^{-1}), cadmium (30.33 mg kg^{-1}), nickel (12.86 mg kg^{-1}) and lead (30.62 mg kg^{-1}) which was much above the permissible limits of 1.3 mg kg^{-1} for chromium, 0.02 mg kg^{-1} for cadmium, 10 mg kg^{-1} for nickel and 2 mg kg^{-1} for lead (WHO, 1996).

Heavy metal content in roots also increased significantly with the increasing addition of sewage sludge to the growing medium (Fig. 13). The highest content of chromium (33.00 mg kg^{-1}), cadmium (8.23 mg kg^{-1}) , nickel (26.05 mg kg^{-1}) and lead (4.29 mg kg^{-1}) were observed in the treatment receiving sewage sludge alone (T_{11}) which was much above the critical limit for heavy metals in plant tissue.

Even though the sewage sludge used in the experiment had only cadmium above the permissible limit, it was observed that the content of all the heavy metals in plant were above the permissible limit. This indicates that significant bioaccumulation of heavy metals has occurred in marigold plants. Among the four heavy metal Cr and Ni content was more in roots than shoots, the other two (Cd and Pb) was more in shoots. The high accumulation of heavy metal in roots may be attributed to the fact that roots are the first target organ to come in contact with

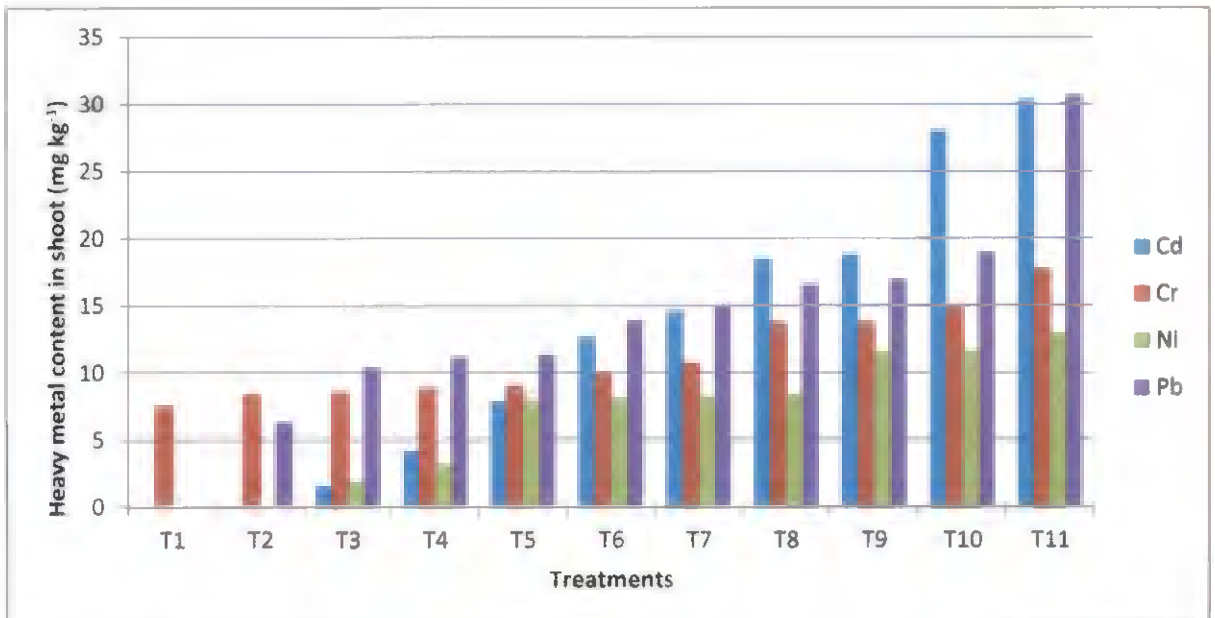

Fig.12. Effect of sewage sludge on heavy metal content in shoots of marigold plants

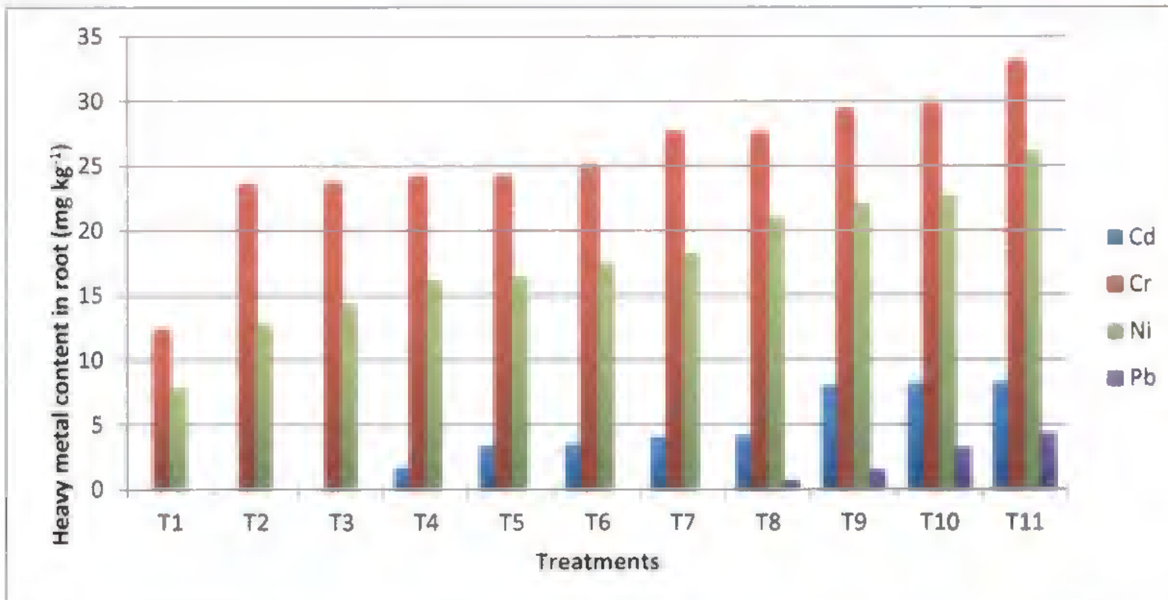

Fig.13. Effect of sewage sludge on heavy metal content in roots of marigold plants

heavy metals; therefore higher accumulation has occurred in the root tissues and also complexation of heavy metals with the sulphydryl groups resulting in less translocation of metals to shoots as stated by Singh *et. al.* (2004). Similar results were also reported by Singh and Sinha (2005); Singh and Agrawal (2007) and Singh and Agrawal (2008). It is noteworthy that even in the treatment T_2 (potting mixture + sewage sludge 9:1) which was superior with respect to growth characters, flower yield and floral characters the content of lead and cadmium were well above the critical limit in the case of shoot and cadmium and nickel in the case of root. This can be attributed to the low pH of the growing medium in the treatment T_2 which would have significantly increased the bioavailability of these heavy metals in the growing medium.

Uptake of heavy metals by marigold plants was significantly influenced by all the treatment. Significantly higher chromium uptake (0.649 mg plant^{-1}) was observed in T_9 (potting mixture + sewage sludge 2:8) which was on par with all the treatments except T_1 (potting mixture alone) which indicates significantly higher uptake of the heavy metal even in the lowest level of sewage sludge used (potting mixture + sewage sludge 9:1). The highest cadmium uptake was observed in T_{10} (1.08 mg plant^{-1}) followed by T_{11} (0.937 mg plant^{-1}). The highest nickel uptake (0.547 mg plant^{-1}) was observed in T_9 (potting mixture + sewage sludge 1:9) which was on par with T_5 (0.505 mg plant^{-1}) and the lead uptake was the highest in T_{11} (sewage sludge alone).

Heavy metal uptake in plants increased with increasing sewage sludge application rates, indicating that marigold readily absorbed the heavy metals from the growing medium due to its higher availability under different sewage sludge application ratios. This varying trend in uptake suggests that all the heavy metals in growing medium are not uniformly taken up marigold plants and even uptake is not concentration dependent phenomena for all the heavy metals. The uptake of heavy metals by plants depends on various factors such as soil physico-chemical properties, sewage sludge composition, sludge application rate, plant species, climatic factors and chemical speciation of metals as stated by Greger, (1999);

Mahdy *et al.*(2007). The low pH of the growing medium after amendment of sewage sludge along with higher organic matter and moisture may have increased the heavy metal availability and further uptake by plants during the present study. The results are in line with the findings of Singh and Agrawal (2007); Singh and Agrawal (2010b).

Summary

6. SUMMARY

The study entitled "Evaluation of sewage sludge as a growth medium for ornamentals" was carried out in the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani during 2015-2017. The main objectives of the study were to characterise the sewage sludge generated from sewage treatment plant, Muttathara, Thiruvanathapuram and to evaluate its suitability as a growing medium for ornamentals.

The study involved two separate phases. In the first phase sewage sludge samples were collected from the Muttathara treatment plant and it was analysed for physical (bulk density, water holding capacity and porosity), chemical (pH, EC, organic carbon, N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, B, Cd, Cr, Ni, As and Pb), and biological (microbial contamination) properties.

In the second phase, growing media prepared using sewage sludge and potting mixture at different proportions were taken as treatments. Eleven treatments namely T_1- potting mixture alone (soil, sand and FYM 1:1:1), T_2- potting mixture + sewage sludge (9:1), T_3- potting mixture + sewage sludge (8:2), T_4- potting mixture + sewage sludge (7:3), T_5- potting mixture + sewage sludge (6:4), T_6- potting mixture + sewage sludge (1:1), T_7- potting mixture + sewage sludge (4:6), T_8- potting mixture + sewage sludge (3:7), T_9- potting mixture + sewage sludge (2:8), T_{10}- potting mixture + sewage sludge (1:9), and T_{11}- sewage sludge alone were selected. Suitability of these growing media for ornamentals was evaluated in a pot culture experiment using marigold as test crop. The design adopted was CRD with three replications. The physical, chemical and biological properties of the growing media were analysed before and after the crop. The plant growth parameters (plant height, no. of primary branches, no. of secondary branches), yield and yield attributes (dry matter yield of shoot and root, flower yield) were recorded. The content and uptake of heavy metals in plant (shoot and root) were analysed.

The results obtained from the study are summarised below;

- The sewage sludge generated from Muttathara treatment plant was strongly acidic (pH 2.91) and had electrical conductivity of 0.57 dS m^{-1} which was high.
- It had high organic (12.2 %) indicating high organic matter status.
- It was rich in nutrients N (2.05 %), P (2.65 %), K (1.80 %), Ca (1.02 %), Mg (0.63 %), S (460 mg kg^{-1}), Fe (3.2 %), Mn (0.15 %), Zn (224.7 mg kg^{-1}), Cu (225.5 mg kg^{-1}) and B (13.5 mg kg^{-1}).
- Physical properties namely water holding capacity (26.1 %) and porosity (65.7 %) were high. Bulk density was very low (0.65 g cc^{-1}).
- The sludge contained the heavy metals Pb (11.5 mg kg^{-1}), Cr (31.5 mg kg^{-1}), Ni (33.5 mg kg^{-1}) and Cd (27 mg kg^{-1}) of which the cadmium content was 5 times above the permissible limit.
- Biological analysis revealed that there is a heavy load of *E.coli* present in this sludge sample (> 2400 MPN/ 100g).
- Analysis of physical, chemical and biological properties of growing media revealed that pH decreased with the increasing content of sewage sludge in the growing medium. T_{11} which received sewage sludge alone as treatment recorded the lowest pH (2.89) and the highest pH was noticed in T_1 (6.23) which contained potting mixture alone as treatment.
- There was a significant increase in the organic carbon content with increasing levels of sewage sludge in the growing media. The highest organic carbon content of 12.10 per cent was associated with T_{11} (sewage sludge alone) and T_1 (potting mixture alone) recorded the lowest organic carbon content of 0.98 per cent in the initial growing medium. Same trend was observed in the final growing medium also.
- The physical properties like water holding capacity and porosity were significantly increased from T_1 (potting mixture alone) to T_{11} (sewage sludge alone) both in the initial and final growing media.
- But the bulk density decreased significantly with the increasing addition of sewage sludge and the lowest bulk density was noticed in treatment

receiving sewage sludge alone (T_{11}) and the highest value was associated in the potting mixture (T_1) both in initial and final growing media.

- The status of major nutrients, secondary nutrients and micronutrients were also found increasing from T_1 to T_{11}. Treatment receiving sewage sludge alone (T_{11}) recorded significantly higher value for all the nutrients.
- There was a significant increase in the content of heavy metal with the increasing addition of sewage sludge. The content of Cd, Cr, Ni and Pb in the growing media increased from T_1 (potting mixture alone) to T_{11} (sewage sludge alone) in both initial and final sample.
- Presence of *E. coli* was not detected in any of the treatments both in initial and final growing media.
- Results on plant growth parameters showed that T_2 (potting mixture + sewage sludge 9:1) recorded the maximum plant height (91.33 cm) and number of secondary branches (21.00). The number of primary branches was not significantly influenced by the treatments.
- T_2 recorded the maximum number of flowers (79.60 $plant^{-1}$) and flower yield (706.36 g $plant^{-1}$). It was also superior with respect to floral parameters like flower length (10.33 cm), flower diameter (6.75 cm), flower weight (8.88 g) and took minimum number of days for first flowering.
- The treatments did not significantly influence biochemical properties like chlorophyll in leaves, xanthophyll and flavonoid in flower.
- The heavy metal content in plant (shoot and root) was significantly influenced by treatments and the highest was recorded in T_{11} (sewage sludge alone) and the values were found above the permissible in all the treatments containing sewage sludge.
- Even in the treatment which preferred best with respect to growth characters, yield and yield attributes (potting mixture + sewage sludge in 9:2 ratio) the content of lead and chromium were above the critical limit in shoot and that of cadmium and nickel in the case of root.

Based on the results of the present investigation it can be concluded that the sewage sludge generated from sewage treatment plant Muttathara is rich in organic carbon and plant nutrients. However it is highly acidic and also contain heavy metals. Presence of heavy metals and microbial contamination are limiting its direct use as a growth media. *E. coli* though detected in raw sewage sludge, was not present in the growing media prepared with the sludge.

The pot culture experiment results indicated that the growth and yield of marigold was significantly higher in the treatment receiving potting mixture and sewage sludge in the ratio 9:1. The content of heavy metals (Cd, Cr, Ni, Pb) in shoot and root of marigold were found above the permissible limit in treatments containing sewage sludge indicating significant bioaccumulation of heavy metal from sewage sludge by marigold.

Based on the present study it can be concluded that the sewage sludge from sewage treatment plant, Muttathara in the present form cannot be used for the production of food crops. It can be used as a component of growing medium for ornamental crops at a maximum rate of 10% of the growing medium by weight.

However as it is a very rich source of primary, secondary and micronutrients, studies have to be conducted to reduce its acidity and to decrease the bioavailability of heavy metals so that it can be better utilized for crop production.

Future line of work

1. Identification of suitable methods for remediation of heavy metal present in the sludge.

2. Screening of crops and varieties suitable for sewage sludge treated soil.

3. Studies on nutrient release pattern of major and micronutrients from sewage sludge.

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Appendices

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 order
(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, maximum	
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

EVALUATION OF SEWAGE SLUDGE AS A GROWTH MEDIUM FOR ORNAMENTALS

by

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ABSTRACT OF THE THESIS

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ABSTRACT

The study entitled "Evaluation of sewage sludge as a growth medium for ornamentals" was carried out in the Department of Soil Science and Agricultural Chemistry, College of Agriculture, Vellayani during 2015-2017. The main objectives of the study were to characterise the sewage sludge generated from sewage treatment plant, Muttathara and to evaluate its suitability as a growing medium for ornamentals.

The study involved two separate phases. In the first phase sewage sludge samples were collected from the Muttathara treatment plant and it was analysed for physical (bulk density, water holding capacity and porosity), chemical (pH, EC, organic carbon, N, P, K, Ca, Mg, S, Fe, Mn, Zn, Cu, B, Cd, Cr, Ni, As and Pb), and biological (microbial contamination) properties.

In the second phase, growing media prepared using sewage sludge and potting mixture at different proportions were taken as treatments. Eleven treatments namely T_1- potting mixture alone (soil, sand and FYM 1:1:1), T_2- potting mixture + sewage sludge (9:1), T_3- potting mixture + sewage sludge (8:2), T_4- potting mixture + sewage sludge (7:3), T_5- potting mixture + sewage sludge (6:4), T_6- potting mixture + sewage sludge (1:1), T_7- potting mixture + sewage sludge (4:6), T_8- potting mixture + sewage sludge (3:7), T_9- potting mixture + sewage sludge (2:8), T_{10}- potting mixture + sewage sludge (1:9), and T_{11}- sewage sludge alone were selected. Suitability of these growing media for ornamentals was evaluated in a pot culture experiment using marigold as test crop. The design adopted was CRD with three replications. The physical, chemical and biological properties of the growing media were analysed before and after the crop. The plant growth parameters (plant height, no. of primary branches, no. of secondary branches), yield and yield attributes (dry matter yield of shoot and root, flower yield) were recorded. The content and uptake of heavy metals in plant (shoot and root) were analysed.

The results revealed that the sewage sludge generated from Muttathara treatment plant was strongly acidic (pH 2.91). The organic carbon content was high (12.2%). It was rich in plant nutrients N (2.05%), P (2.65%), K (1.80%), Ca (1.02%), Mg (0.63%), S (460 mg kg^{-1}), Fe (3.2%), Mn (0.15%), Zn (224.7 mg kg^{-1}), Cu (225.5 mg kg^{-1}) and B (13.5 mg kg^{-1}). Physical properties namely water holding capacity (26.1%) and porosity (65.7%) were high. Bulk density was very low (0.65 g cc^{-1}). The sludge contained the heavy metals Pb (11.5 mg kg^{-1}), Cr (31.5 mg kg^{-1}), Ni (33.5 mg kg^{-1}) and Cd (27 mg kg^{-1}). Presence of *E.coli* was also detected (> 2400 MPN/ 100g).

Analysis of physical, chemical and biological properties of growing media revealed that pH decreased with the increasing content of sewage sludge in media. T_{11} recorded the lowest pH (2.89) and the highest pH was noticed in T_1 (6.23). There was a significant increase in the organic carbon content with increasing levels of sewage sludge in the growing media. The water holding capacity, porosity, content of major nutrients, secondary nutrients and micronutrients were also found to increase from T_1 to T_{11}. The content of heavy metals Cd, Cr, Ni and Pb increased from T_1 to T_{11}. Presence of *E. coli* was not detected in any of the treatments. The analysis of post-harvest growing medium also showed the same trend for all the parameters.

T_2 recorded the maximum number of flowers (79.60 $plant^{-1}$) and flower yield (706.36 g $plant^{-1}$). It was also superior with respect to vegetative and floral parameters but was on par with T_3. The heavy metal content in plant (shoot and root) was significantly influenced by treatments and the highest in T_{11}. The treatments did not significantly influence chlorophyll in leaves and xanthophyll, flavonoid in flower.

Based on the results of the present investigation it can be concluded that the sewage sludge generated from sewage treatment plant Muttathara is rich in organic carbon and plant nutrients. However it is highly acidic and also contain heavy metals. Presence of heavy metals and microbial contamination are limiting its direct use as a growth media. *E. coli* though detected in raw sewage sludge, was not present in the growing media prepared with the sludge. The pot culture experiment results indicated that the growth and yield of marigold was significantly higher in the treatment receiving potting mixture and sewage sludge in the ratio 9:1. The content of heavy metals (Cd, Cr, Ni, Pb) in shoot and root of marigold were found to be above the permissible limit in treatments containing sewage sludge indicating significant bioaccumulation of heavy metal from sewage sludge by marigold.