POTENTIAL OF URBAN WASTE COMPOST FOR ORGANIC FARMING

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CERTIFICATE

This is to certify that the research work presented in the thesis entitled **"Potential of urban waste compost for organic farming "** is based on the authentic record of original work done by Mrs. Lathika C (Reg. No. 3984) under my supervision and guidance at Kerala Forest Research Institute, Peechi, Thrissur in partial fulfillment of the requirements of the degree of Doctor of Philosophy and that no part of this work has previously formed the basis for the award of any degree, diploma, associateship, fellowship or any other similar title or recognition. All the relevant corrections and modifications suggested by the audience during the pre-synopsis seminar and recommendation by the Doctoral Committee of the candidate has been incorporated in the thesis.

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DECLARATION

The research work presented in the thesis entitled **"Potential of urban waste compost for organic farming "** submitted in partial fulfillment of the requirements of the degree of Doctor of Philosophy of Cochin University of Science and Technology, is a bonafide record of the research work done by me under the supervision of **Dr. M P Sujatha,** Principal Scientist and Head, Soil Science Department, Kerala Forest Research Institute, Peechi, Thrissur. No part of this work has previously formed the basis for the award of any degree, diploma, associateship, fellowship or any other similar title or recognition.

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Lathika C

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Abstract

ABSTRACT

Considering the significance of organic farming for healthy soil, healthy food, healthy environment, and potential risks of contamination anticipated in urban waste composts, this study was carried out at Kerala Forest Research Institute during 2011-2016. The study was launched in the context of probing an alternate option for the continuous supply of organic amendments for the recent organic farming drive in the State. The aim of the study was mainly to evaluate the possibility of using the compost produced out of different types of urban wastes at various composting centres in Kerala. The main objectives of the study were (1), to analyse the nutrient composition, heavy metal content, pesticide residue and pathogenicity of urban and rural waste composts commonly available in Kerala (2), to study the effect of urban waste dumping on accumulation of heavy metals and other contaminants in soils and plants (3), to evolve appropriate remedial measures to minimize soil and plant health hazards caused by the application of urban waste composts.

The first objective mainly focused on evaluating the quality of urban and rural waste composts commonly available in Kerala and to categorize them based on their quality. To fulfil the objectives, samples of both urban and rural waste composts were collected from various composting units throughout the state, and they were analysed for various quality parameters using standard procedures. Based on the data generated for various parameters, quality index and clean index for each compost was developed. The results in general indicated that, most of the urban wastes composting units in Kerala were not following proper segregation and scientific method of composting, while proper methods were adopted at rural waste composting units. The values for quality and clean indices revealed that, compost produced at Sakthan was with high fertilising potential, and hence grouped in the category of “best quality”. None of the urban waste composts were qualified to be under “very good and good” category. The composts produced at Attingal, Adat and Kongad belonged to the category “medium quality”. But the

composts from Laloor, Kodungallur, Vilappinsala, Chalakkudy, Palakkad, Kozhikkod and Perinthalmanna were not suited for organic farming.

The second objective, mainly focused on the long term effect of urban wastes on soil characteristics, accumulation of toxic heavy metals in plants and, the effect of dumpyard leachate on soil and water bodies in the surrounding areas. The study was conducted at the urban waste dump yard areas at Laloor in Thrissur, and Theruvusala in Palakkad. In order to evaluate the soil characteristics, soil samples were collected from the two study areas and analysed for various quality parameters using standard procedures. The effect of urban waste dumping on accumulation of heavy metals in plants was studied by conducting field experiments using plant species belonging to edible crop (*Amaranthus tricolor),* grass *(Vetiveria zizionoids),* tree grass (*Bambusa bamboo*) and timber *sp*. (*Tectona grandis*). The plant samples collected at various stages of growth were assayed for accumulation of heavy metals such as Pb, Cd, Cr and Ni. The influence of leachate emerging from the dump yard areas, on soil and water quality of surrounding areas were assessed by collecting soil and water samples from 0 m, 100 m, 250 m and 500 m away from the waste dumpyard areas in north, south, east and west directions. The collected soil and water samples were analysed for various quality parameters using standard procedures. Results revealed that urban waste dumping in general, resulted in the improvement of pH, enrichment of organic carbon, higher reserves of essential plant nutrients and toxic heavy metals in soil. Results also revealed that intensity of pollution in soil was very high due to Cd, followed by Pb, Cr and Ni. Based on the values generated for bio concentration and translocation factors, it was inferred that amaranth and vetiver should not be grown on soils contaminated with heavy metals while bamboo and teak could be used for phyto remediation. The study also revealed that important water quality parameters such as color, odour, taste, pH, hardness, NO_3, Fe, coliform etc. were significantly affected due to the discharge of urban waste leachate to the surrounding well, while the influence on other parameters were relatively less.

The third objective tried to explore the measures to minimize the contamination in urban waste composts, by dilution technique, and also by modifying the existing technology for urban waste composting. Dilution technique was experimented in already produced urban waste compost by diluting it with good quality weed compost and assessing the accumulation of heavy metals in plants. The possibility of producing a good quality compost by improving the methods adopted in the current composting technology was also looked into by modifying composting methods with indigenous inoculum. Results revealed that concentration and uptake of heavy metals by various plants were decreasing on diluting the urban waste compost with good quality weed compost and this reduction was very high at higher dose. Urban waste, completely segregated at two levels (at source of waste generation and composting unit) and composted using jeevamrutham as inoculum, through aerobic windrow method, led to the production of good quality compost in a shorter period, with adequate nutrients, minimum contamination of heavy metals and absence of pathogenic organisms.

Introduction

CHAPTER 1
INTRODUCTION

Organic farming is a conventional farming system for maintaining optimum soil health and making the soil capable of supplying all essential nutrients to crop for its proper growth and development. As per the definition of the United States Department of Agriculture (USDA) "organic farming is a system which avoids or largely excludes the use of synthetic inputs such as fertilizers, pesticides, hormones, feed additives etc. and to the maximum extent feasible rely upon crop rotations, crop residues, animal manures, off-farm organic waste, mineral grade rock additives and biological system of nutrient mobilization and plant protection". Thus the major principles of organic farming include maintaining the long term fertility of soils, avoiding all forms of pollution, production of good quality food stuffs *etc*.

Currently, organic farming has attained significant attention due to the deleterious effect of continuous use of chemical fertilizers and synthetic pesticides on soil health, pollution of environment and contamination of food chain. The demand for organic products has also created new export opportunities for the developing world. Application of any organic manure is supposed to improve the physical, chemical and biological condition of soil by providing organic matter and plant nutrients. But the apprehension towards organic farming is mainly on quality and non-availability of sufficient organic supplements and relatively low yield compared to chemical farming. The wider gap between the demand and supply of traditionally used organic manures such as farmyard manure, dung of various animals, poultry manure, green manure, crop residues in farm fields *etc*., prompted to probe for another alternative in this regard.

It is in this context, a contemporary environmental issue on management of urban waste is being projected as an unsolved menace in Kerala, creating problems to public health and environment. Age old practice of dumping urban wastes in open yard areas has resulted in the development of huge heaps of organic wastes, under different stages of decomposition. The shortage of organic amendments for the recent organic farming drive in the State, coupled with waste management problems prompted the recycling of organic wastes generated from various sections of society to organic manure, thus probing a best alternative for waste disposal. It was also noticed that decomposed urban organic wastes from dump yard sites were being used for organic farming. But the quality potential of these recycled wastes, produced at various urban waste composting units in the State is yet to be explored. Usually, the urban organic wastes are supposed to be contaminated with toxic heavy metals and pathogenic organisms, and there is a great chance of accumulation of these contaminants in the compost produced out of such wastes. Application of composts with excessive levels of heavy metals leads to contamination of soil, water bodies and agricultural produce, thus paving way to their entry into food chain. The content of heavy metals in the human body beyond maximum permissible level leads to a number of nervous, cardiovascular, renal and neurological impairment, as well as bone diseases and several other health disorders (WHO 1992, Steenland and Boffetta 2000, Jarup 2003). Some diseases such as multiple sclerosis, parkinson's disease, alzheimer's disease and muscular dystrophy are caused due to the chronic effects of heavy metals (Jolly *et al.,* 2013). Repeated long-term exposure of heavy metals and their compounds may even cause cancer (Jaishankar *et al* ., 2014). *E coli* and all other pathogens are most toxic and cause severe abdominal cramps, diarrhoea etc. The recent global issue on Maggi noodles is reported mainly due to the toxic levels of Pb from soil through onion (The Hindu, 2015). Even the chocolates, available in the markets are reported to contain heavy metals such as Cd, Pb and Ni (Karthika, 2016). Hence, considering the significance of organic farming for healthy soil, healthy food, healthy environment, and potential risks of contamination anticipated due to the use of urban waste composts for organic farming, this study was carried out with the following objectives

Objectives

- To analyse the nutrient composition, heavy metal content, pesticide residue and pathogenicity of urban and rural waste compost commonly available in Kerala
- To study the effect of urban waste dumping on accumulation of heavy metals and other contaminants in soils and plants
- To evolve appropriate remedial measures to minimize soil and plant health hazards caused by the application of urban composts

Review of literature

CHAPTER 2

REVIEW OF LITERATURE

Municipal solid waste management is one of the major environmental problems in Indian cities and about 90% of such wastes are disposed of unscientifically in open dumps and landfills (Sharholy *et al.* 2008). Recycling of the urban organic waste in a scientific composting method is very essential for sustainable agriculture and resource management (Bernal *et al.*, 2008). Albaladejo *et al.* (2009) remarked the recycling of urban wastes as a valuable alternative for disposal of wastes. Rao *et al.* (2009) stated that the hygienic disposal of organic wastes by composting was an environmentally sound and economically viable technology. Literature available on different types of composting technologies, changes during the process of composting, quality of compost produced, influence of urban wastes / composts on soil, plant and water quality, remedial measures to minimize contaminations in the composts etc. are mainly reviewed in this chapter, with a special focus on composting of urban waste.

2.1. Composting technology

2.1.1. ***Abroad***

According to FAO (1980), among the different composting methods, Indian Bangalore method and Passive composting of manure piles belonged to anaerobic method, The Indian Indore method and Chinese rural composting were aerobic methods, and windrow composting (turned windrows and passively aerated windrows) was passive aerobic composting method.

Swan *et al*. (2002) studied the thermophilic aerobic composting of municipal solid waste on a commercial scale, which essentially included two main types: turned or forced aeration systems. Turned systems were commonly based upon the windrow system, in which the feed stocks being piled in elongated heaps up to two m height and 50 m length. The decomposition process was facilitated by a diverse population of microbes and generally involved the development of thermophilic temperatures as a result of biologically produced heat.

Deera (2004) reported that enclosed, in-vessel systems were a legal requirement in many countries for composting wastes containing food and animal by-products. Further, some countries (e.g., UK) insisted the attainment of sanitization temperatures twice in a two-stage batch process to ensure complete destruction of pathogens. Inoculation of municipal solid waste with specific organisms could enhance the speed of composting (Wei and Liu., 2007).

According to Farrell and Jones (2009) mechanical biological treatment of mixed waste streams was becoming increasingly popular method for treating municipal solid waste. They concluded that the resultant organic product containing toxic contaminants could be used for land remediation and restoration schemes. Home composting had been proposed as an alternative or a complimentary way to manage household organic waste by Andersen *et al*. (2012).

2.1.2. ***India***

The Indian Bangalore method of composting was developed at Bangalore in India by Acharya (1934). This method was basically recommended when night soil and refuse were used for preparing the compost. The method overcomes many disadvantages of the Indore method such as problem of heap protection from adverse weather, nutrient losses due to high winds / strong sun rays, frequent turning requirements, fly nuisance etc. But the time involved in the production of a finished compost was much longer. The method was suitable for areas with scanty rainfall (FAO 1980)

The Indian indore method was developed for composting of mixed plant residues, animal dung and urine, earth, wood ash and water (FAO, 1980).

Vermicomposting technology is used to prepare compost from farm and livestock wastes. Earthworms continuously feed upon the organic residues and produce casts. This casts is generally termed as vermi compost. Casts of earthworms are usually rich in nutrients and organic matter and therefore serve as a good source of manure for growing crops. Certain earthworms like *Eisenia foetida*, *Perionyx excavatus* and *Eudrilus eugeniae* are specifically suited for the preparation of vermi compost (Kale, 1998).

Dandotiya and Agarwal (2012) studied the methods of disposal and management of nutritionally rich food, kitchen waste and garden waste with different ratio of dung mixture followed by release of earthworms and maintained for 80 days. According to them vermi technology using *Eudrilus eugeniae* worms played an important role in waste management with great output of vermi compost. They also reported that releasing of these earthworms in organic waste rich moist soils could be best for *in situ* recycling of waste biomass.

Comparative evaluation of different available and practiced composting methods viz. vermi, indigenous, biodynamic and novcom composting in terms of their end product/ compost quality as well as respective cost was carried out by Bera *et al.* (2013). Compost produced under novcom composting method showed better results in terms of total NPK content and microbial population, which was significantly higher than the values obtained incase other types of composts studied.

Rawat *et al.* (2013) reported that composting was the simplest way to restore value in municipal solid waste. Aerobic composting using windrow method after proper segregation of municipal solid waste was recognized as a cost-effective method, which could produce a good quality soil amendment.

Deswal and Lawra (2014) studied the management of municipal solid waste in developing countries like India using GIS technology and found that use of GIS in municipal solid management could help in leapfrogging the management technology in developing countries.

Biradar *et al*. (2006) found that the toxic weed *Parthenium hysterophorus* could be used for compost and green manure. Varshney and Babu (2008) reported that weeds like water hyacinth, chromolaena, lantana, parthenium, ipomea*, etc.* were rapidly spreading and proper utilization of such biomass could be achieved through appropriate technologies like vermicompost, mulch, phytoremediation etc.

2.1.3. *Kerala*

Girija *et al*. (2005) reported that the aquatic weeds *Salvinia molesta* and *Eichhornia crassipes* were good for vermicomposting.

Sushama *et al*. (2007) reported that thermophilic stage was essential for the rapid degradation of feed stocks and coirpith with *Pleurotus* spp., glyricidia +20% cowdung slurry and goat manure were found ideal for compost preparation.

Varma (2007) studied the various technological options, and their salient features, environmental implications, cost norms and suitability to the biophysical environment of Kerala for urban waste management and concluded that windrow-composting, vermi-composting and biomethanation (anaerobic composting for biogas) were the most appropriate techniques.

According to John (2013), application of microbial inoculum was superior for composting of mixed weeds over vermi composting.

2.2. Changes during the process of composting

2.2.1. *Carbon, Nitrogen and C:N*

During composting, the loss of weight was mainly due to mineralization of organic matter (Garcia *et al*.,1990). Inbar *et al*. (1990) observed a steady decrease in the content of water soluble carbon in cattle manure during composting. According to Eghball *et al*.

(1997), carbon was lost due to bio-oxidation, in which carbonaceous materials are transformed into CO_2. Ansari and Rajpresaud (2012) composted organic wastes like grass, water hyacinth, water hyacinth + grass in different combinations through vermicomposting and found a decrease in organic carbon in all with gradual decrease at later stage of vermicomposting.

Parthasarathi and Renganathan (1999) reported that the content of N in vermicompost increased 3.07 times over ordinary compost.

Eiland *et al*. (2001) studied the impact of different initial C/ N ratio (11, 35, 47, 50 and 54) on composting process for 12 months using shredded straw and different amounts of pig slurry. Composts with lowest initial C/ N ratio showed no change during composting process while other treatments showed significant decrease after three months of composting. Tripathi and Bhardwaj (2004) explained the changes occurring in C/N ratio in thermo composting due to the loss of carbon as carbon dioxide. But in vermicomposting, in addition to loss of C, increase in N content of the substrate caused reduction in C/ N ratio. Nair *et al*. (2006) evaluated the combination of thermo composting and vermicomposting methods to improve the treatment efficiency and optimum period required to produce good quality compost. The 21 days trial showed that C/N ratio was reduced to below 20 in pre composted vermicompost as against 21 days of thermo-composting.

2.2.2. *Nutrient content*

Tiquia and Tam (1998) studied changes in chemical properties during composting of spent litter from pig pens at different moisture contents. Study revealed that total P and K of the spent litter piles increased gradually during composting and were not affected by differences in their moisture contents.

Jusoh *et al.* (2013) reported that application of effective microorganisam to the composting process of rice straw with goat manure and green waste increased the macro and micronutrient content.

The study by Azeem *et al.* (2014) depicted that the poultry litter and fast food waste in 75:25 ratio released maximum amount of macro nutrients and micronutrients.

2.2.3. Pathogens and pesticide residues

Avery *et al.* (2012) investigated the ability of pathogenic microbes to enter source-separated green wastes and their survival during the composting process. Common pathogens, e.g., *Escherichia coli*, *Salmonella spp., Campylobacter spp., and Giardia spp.,* were found destroyed or inactivated during composting over periods of 1 to 16 weeks.

2.3. Quality of compost

The quality of compost is determined mainly for the protection of environment and humans from any harmful substances (Epstein *et al.,* 1992 and Anon, 1998).

Several official and private organizations in different countries have established standards and specifications for compost quality to improve crop production and protect public health and environment (Bertoldi, 1993 and Brinton, 2000**)**. The quality of compost is a degree of compost stability and maturity. Stability is related to microbial activity and refers to the resistance of compost organic matter to further degradation, whereas maturity is associated with plant growth potential or phyto toxicity and describes the fitness of compost for land application (Sullivan and Miller, 2001 and Bernal *et al.,* 2008).

Ahamad (2010) studied the stability and maturity indices of 14 commercially produced composts in Saudi Arabia. The stability and maturity indices indicated that most compost samples had a poor quality and should have no access to the market.

Kavitha and Subramanian (2007) conducted a study to transform the normal compost into bioactive compost using *Azotobacter sp*., *Pseudomonas sp*., *Phosphobacteria sp*. and the waste materials like poultry litter and spent wash. This enrichment process increased both the quality and nutrient content of the municipal solid waste compost significantly.

Saha *et al.*(2010) studied the quality of municipal solid waste compost produced in 29 cities of India. Results indicated that municipal solid waste composts were generally low in nutrients as compared to the composts prepared from rural wastes.

Brinton, *et al.*(2012) established analysis-based quality guidelines for composts and it exhibited significant spatial, site and time-related variability.

Whirt *et al* (2012) stressed the importance of compost testing for heavy metals and plant essential nutrients to prevent the transport of toxic elemental loads and successful marketing of composted products.

Rawat *et al.* (2013) quantified toxicity due to heavy metals in compost samples from three highly populated cities of India viz., Delhi, Ahmedabad and Bangalore. The samples were analysed for both total heavy metals and extractable fractions. Few samples were found with higher concentration of metals than the prescribed limits for its application as compost in Indian municipal solid waste rules**.**

Lathika and Sujatha (2015) reported that most of the urban waste composts in Kerala contained heavy metals more than the prescribed limit of FAI (2007).

2.4. Factors influencing quality of compost

2.4.1. *Types of feed stocks*

A number of parameters can significantly affect compost quality which includes the source and nature of the raw materials or feedstock, pre-treatment and the composting method (He *et al.,*1992). Trace metal concentrations can vary highly among compost batches from the same facility because of feedstock variability (Wong and Lau, 1985, Richard and Woodbury, 1992).

According to US EPA (1994), the type of feedstock used in the composting process, whether it is green waste, biowaste, commercial organics or sludge tends to have an effect on the quality of compost produced and green waste feedstock can produce good quality compost with little contamination .

According to (Ward *et al.,* 2005), the chemical composition of composted biodegradable municipal waste varied widely with seasonal variation in raw input.

Physical and chemical properties of commercial compost based on their feed stocks and location of origin were investigated by Zmora *et al.,* (2008). Even though there was a wide variation in compost properties, there was significant correlation of properties based on the type of feedstock.

2.4.2. *Pre processing of wastes*

According to Oosthnoek and Smit (1987), the heavy metal concentrations were lowest in compost samples that had undergone the highest degree of source segregation. Richard and Woodbury (1992) reported that quality of the compost produced depends on the degree of source separation, amount of pre-processing and post processing, biological process, technology employed and finally the maturation stage.

Epstein *et al.* (1992) reported that several European countries and organizations in the United States were advocating source separation of organics and prohibition of mixed municipal solid waste composting.

Richard and Woodbury (1992) found that the lowest levels of contaminants were achieved by source separation of compostable organic waste. Separation strategies considered included source separation of either compostables or contaminants prior to collection, wet/dry collection schemes, and manual or mechanical separation at a centralized facility.

Various studies have shown that source separated bio waste contained less contaminant in comparison to non segregated municipal solid waste (Brinton and Brinton 1992; Epstein *et al.,* 1992; Woodberry, 1992 and Saha *et al.,* 2010).

According to US EPA (1994), pre-processing of feedstock might have a significant impact on the quality of the compost produced.

2.4.3. *Nutrient content*

Eghball *et al*.(1997) composted the beef cattle feedlot in a windrow on an open concrete area and found that loss of N during composting ranged from 19 to 42 % while P loss was low (<2%). N/P ratio in the manure decreased during composting, indicating a greater soil P buildup potential with compost application. Nutrient and salt loss during composting resulted in reduced electrical conductivity of the composted manure.

Tiquia *et al. (*2002) reported significant loss of N, P, K and Na during composting of hoop manure in windrows. Bernal *et al.* (2008) also reported the loss of N during the process of composting.

Channappagoudar *et al*. (2007) conducted composting experiments with different sps. of weeds such as *Parthenium hysterophorus*, *Cassia serecia* and *Chromolaena odorata*. High N content was in composts prepared from parthenium (2.95 %) and chromolaena

(2.32 %) at pre flowering stage. It was also seen that the composts prepared after flowering contained less per cent of N.

2.4.4. *Toxic heavy metals*

Lara *et al.* (1987) found that the levels of heavy metals in mixed municipal solid waste compost were considerably lower than levels in sewage sludge and sludge compost. Although concentrations of heavy metals in solid organic waste were somewhat lower than in mixed municipal solid waste compost, there was no evidence that either type poses a risk to human health or the environment.

Potentially toxic elements in municipal solid waste could be due to a number of components including batteries, solder, wine bottle caps, old circuit boards etc. In addition, pigments and stabilisers in plastics also contribute potentially toxic elements (Richard and Woodbury 1992).

Woodbury (1992) and Mamo *et al.,* (2002) stated that composts produced from municipal solid waste contained trace amounts of metals and metalloids.

Gillet (1992) reported the presence of heavy metals such as Cd, Cu, Pb and Zn in all municipal solid waste compost. Among heavy metals, Cd was the most hazardous contaminant in terms of food-chain contamination (McLaughlin *et al.,* 1999). Therefore, Cd should receive close inspection in relation to the application of municipal solid waste compost to agricultural soils (Woodbury, 1992).

The principal potentially toxic elements in municipal solid waste compost are Cd, Cr, Cu, Hg, Ni, Pb and Zn. According to the United Nations Environment Programme, the most significant potential environmental problem arising from compost use is its potential to impart potentially toxic elements to the soil (UNEP, 1996).

Zhou *et al.* (2012) reported that low quality alkaline batteries, galvanized nails, zinc-plated nails, and copper wires had a significant impact on the zinc, copper, arsenic, lead, and cobalt contents of compost. Copper wires showed the highest impact on copper content, Galvanized nails contributed to final levels of zinc reaching 30%.

Heavy metals are naturally present in the environment, soil, food and widely used in manufacturing processes, in the built environment and, consequently get transferred to composted organic residuals (Lineres, 1992).

Gillet (1992) showed great concerns about toxic heavy metals such as Cd, Cu, Pb and Zn elements entering the food chain through food crops to which composts have been applied as fertilizer. According to Luo *et al.,* (2011) the intensive uncontrolled processing of e-waste has resulted in the release of large amounts of heavy metals in the local environment, and caused high concentrations of metals to be present in the surrounding soils and water.

2.4.5. *Pesticide residue*

Peter (2000) reported that yard waste compost samples contained chlordane residues, at low levels and no other pesticide was detected. The source of chlordane was the residential soil incorporated with the raw yard waste during collection.

Buyuksonmez *et al.* (2000) stated that pesticides in composting feedstock were not a major cause for concern because the pesticides were decomposed during the composting process. Some recalcitrant pesticides, notably organo chlorine compounds, continued to be of concern because these organo chlorines tend to remain adsorbed on complex organic matrices, thus becoming unavailable to microbial degradation. Notable examples of such compounds were chlordane, dieldrin and DDT.

Gabriela *et al.* (2007) reported that addition of organic matter and nutrient could affect the adsorption, movement, and biodegradation of pesticides.

Fatih *et al.* (2013) reported low concentration of pesticide residues in composting feedstock and finished compost. According to them, composting did not always speed up the degradation of all pesticides. The nature of the pesticide, specific composting conditions and procedures, the microbial communities present, and the duration of composting affected the extent and the mechanisms of degradation.

2.4.6. *Pathogenicity*

Day and Shaw (2001) studied the pathogenic contamination in municipal solid waste composts and found that *Salmonella* and coliform bacteria entered the wastes through disposable diapers, faecal matter and hospital wastes, and these pathogens were destroyed during the composting.

Saha *et al.* (2010) carried out a study on pathogenicity of urban wastes composts in different cities in India and reported that 17% of the sample contained total coliform, but *Salmonella* was not detected in any of the samples.

2.5. Influence of urban wastes / composts on soil, water and plant

2.5.1. *Potential effects of urban wastes / composts on soil*

The importance of municipal solid waste compost application primarily lies in its ability to improve the soil quality in terms of its physical properties instead of its significance as a manure, because the physical changes in soil properties permit the nutrients to be utilized more efficiently (McConnell *et al.,* 1993).

Application of compost to agricultural soils enhanced the plant nutrient status of soil (Chen *et al.,* 1996), maintained soil organic matter at higher levels as compared to inorganic fertilizers (Weber *et al.,* 2007), improved soil physico-chemical properties (Alvarenga *et al.,* 2007), promoted beneficial soil organisms and reduced plant pathogens (Abawi and Widmer, 2000), improved water holding capacity of soil (Wells *et al.,* 2000), established a low cost and an effective disposal method (Gigliotti *et al.,* 2012 and Spargo *et al.,* 2006), and reduced the need for inorganic fertilizers (Bellamy *et al.,* 1995).

Pinamonti *et al.* (1997) demonstrated that the municipal solid waste compost, used over a six year period, increased concentrations of Zn, Cu, Ni, Pb, Cd and Cr in the soil- both in total and EDTA extractable form.

Lal and Kimble (1999) reported increased soil organic carbon due to the addition of municipal solid waste compost improved soil quality, reduced soil erosion, increased biomass and agronomic productivity. According to Gruhn *et al.,* (2000), application of municipal solid waste compost in agricultural soils could directly alter soil physico-chemical properties and promote plant growth.

Three consecutive applications of municipal solid waste compost, with metal contents below permissible limits, to a sandy soil under intensive farming conditions resulted in an increase of metal elements like Cu, Ni, Pb, and Zn in the upper 25cm of the soil (Madrid *et al.,* 2007).

It has been reported that the accumulation of heavy metals in soil due to the use of municipal solid waste compost eventually exceeded the critical limits because of its continuous use (Zhang *et al.* (2006).

Ayari *et al.* (2010) conducted a field study to evaluate long-term heavy metal accumulation in the top 20 cm of a Tunisian clayey loam soil amended for four consecutive years with municipal solid waste compost at three levels (0, 40 and 80 t/ha/y). Compared to untreated soils, compost-amended soils showed significant increase in the content cadmium, chromium, copper, nickel, lead and zinc in the last three years, especially for plots amended with municipal solid waste compost at 80 t/ha/y.

Partha *et al.* (2011) evaluated the soil contamination due to metals in/and around largest hazardous/industrial waste disposal site located in Hyderabad city. Analysis of soil samples from 45 sampling points in the surrounding areas of dumpsite showed significant spatial variation of heavy metals (As, Cr, Cu, Ni, Zn and Pb). The results of the study revealed that soils in the downstream and vicinity of dumpsite were considerably contaminated by metals with their concentrations beyond threshold values.

2.5.2. *Influence of urban wastes / composts on water quality*

Nartey *et al.*(2012) studied that water samples from four water bodies that flow through some solid waste dump sites in the Accra metropolitan area of Ghana and the results revealed that major sources of pollutants of the water bodies were organic waste as well as coliform bacteria derived from these waste dumps.

Raman and Narayanan (2008) studied the ground water quality from Pallavam solid waste landfill site in Chennai and found that most of the parameters of water were not in the acceptable limit in accordance with the IS 10500 Drinking Water Quality Standards

Nagarajan *et al.* (2012) studied the leachate and groundwater samples from Vendipalayam, Semur and Vairapalayam landfill sites in Erode city, Tamil Nadu, India. The results revealed the presence of various physicochemical parameters including heavy metals (Cd, Cr, Cu, Fe, Ni, Pb, Fe and Zn) in the water samples. The concentrations of Cl^-, NO_3^-, SO_4^{2-}, NH_4^+ were found to be in considerable levels in the groundwater samples particularly near to the landfill sites, likely indicating that groundwater quality is being significantly affected by leachate percolation.

Babu *et al.* (2013) studied physico-chemical characteristics of groundwater in the environs of Visakha Steel City of Andra Pradesh. Water samples were collected from Haphazard urbanization, industrialization and improper disposal of solid wastes leading area. They observed higher content of different elements in groundwater, mainly due to effluents, from industries and leachates from improper handling of urban solid wastes.

Pillai *et al.* (2014) found that the physico- chemical parameters of the leachate from the dump yard site at Lalur exceeded the specified standards for disposal into surface water bodies or sources.

Hossain *et al.* (2014) studied physical, chemical and bacteriological properties of ground water samples of Rowfabad landfill at Chittagong, Bangladesh and reported the presence of coliform and heavy metal content in the water samples.

Anilkumar *et al.*(2015) reported that concentration of nitrate (88 mg/l) and total dissolved solids (726 mg/l) in the ground water near the municipal solid waste dumping sites was alarming and contamination with fecal coliform (8 CFU/100ml) made the water unsuitable for drinking purpose.

Jaseela and Harikumar (2015) reported that the wells in proximity to the landfill were most affected by leachate percolation and groundwater samples within 300m radius around the Njelianparamba dumping site in Kozhikkode, Kerala were highly contaminated through landfill leachate.

Sidhardhan *et al.* (2015) recommended proper design, constructions and management of dumpsite using engineering principles to minimize the impact of leachate of a dumpsite on groundwater quality and environment in general.

2.5.3. *Influence of urban wastes / composts on plant*

Hontenstine and Rothwell (1973) carried out a study on sorghum crop with the application of municipal solid waste compost to a sandy soil @ 64 t ha^{-1} and reported equal or greater sorghum yield than soils treated with N-P-K fertilizer grade10 - 4.4 - 8.3 at the rate of two t ha^{-1}.

Elevated contents of Zn and Cu in the tissues of sludge and refuse compost treated leafy vegetables were observed by Wong *et al.* (1983).

Crops grown on the metal contaminated soils take up heavy metals in quantities excessive enough to cause clinical problems both to animals and human beings consuming these metal rich plants (Tiller, 1986).

A long-term field experiment on potatoes, where municipal solid waste compost had been applied for 13 years, revealed that the content of Cd increased 270% in a sandy soil and 170% in a clay soil. In a four-year experiment with corn, the addition of municipal solid waste compost@30 t ha^{-1} caused an increase of Cd in the grain from

0.02 µg g^{-1} to 0.10 µg g^{-1} but the content of Pb in the leaves of Chinese cabbage and radish decreased from 1.3 µg g^{-I} to 0.5µg g^{-I} (Petruzelli *et al.*,1989).

Application of municipal solid waste compost to vegetable crops showed positive yield response in Chinese cabbage, tomatoes, carrots, spinach, lamb's lettuce, radish, bean, blackeye pea and potatoes (Chu and Wong, 1987; Fritz and Venter, 1988 and Bryan and Lance, 1991).

Shiralipour, *et al.* (1992) reported that soil incorporation of composted municipal solid waste usually resulted in a positive effect on the growth and yield of a wide variety of crops and the restoration of ecologic and economic functions of land.

Woodbury (1992) reported that plant uptake of Cu, Ni, Zn, As and Pb from municipal solid waste compost would be slight, but boron might occasionally cause phyto toxicity.

Illera *et al.* (2000) reported that municipal solid waste compost, which originated from non-selective waste affected the public health due to heavy metals, which migrated into food chain, especially when the applied to food crops.

Mahmoodabadi *et al.*(2010) demonstrated that application of municipal solid waste compost to soybean var. A3237 increased dry weight of shoot.

Kasthuri *et al.* (2011) carried out pot culture experiment to study the effect of characterized municipal solid waste compost amendments (0, 50, 100, 250, 500, 750 and 1000 g) with garden soil (6 kg) on the growth and the yield of green gram (*Vigna radiata* (L) wilczek) and fenugreek (*Trigonella foenum-graecum* L.). The growth and the yield of green gram and fenugreek were enhanced by the application of municipal solid waste compost.

Murray *et al.* (2011) studied the effect of varying organic matter content on the potential human health risk of consuming vegetables grown in urban garden soils. Metal accumulation among edible tissues of green bean (*Phaseolus vulgaris* L.), lettuce (*Lactuca sativa* L.), and carrot (*Daucus carota* L.) grown in five urban garden soils amended with 0%, 9%, or 25% (v/v) compost was determined. Overall, the consumption of lettuce and green bean pods grown in some urban gardens posed a potential human health risk due to toxic levels of Cd or Pb.

Luo *et al.,* (2011) reported that vegetables grown in the e wastes dumped sites were contaminated with Cd and Pb, which could be a potential health concern to local residents. They also stressed the studies on the leachability and migration potential of these toxic chemicals at the contaminated sites.

Cortez and Ching (2014) studied the heavy metal concentrations (Cu, Zn, Cd and Pb) in dumpsite soil and accumulation in Zea mays (corn) growing in the area close to dumpsite in Manila, Philippines, covered with rich vegetation and being used as agricultural land. Concentrations of heavy metals in the dumpsite soil and plant parts were higher compared to normal farmland.

2.6. Remedial measures to minimize contaminations

Chehregani, *et al.* (2007) recommended *E. cheiradenia* as an effective plant for soil detoxification and phytoremediation in heavy metals polluted soils.

Nayana and Malode, (2012) studied the problems and prospects of municipal solid waste compost at Sukali and landfill site at Amravati. They used plants *Cassia tora* (Caesalpinioideae) to remove contaminants in waste soil polluted by various heavy metals. They concluded that if the municipal solid waste landfill continued, it might create a serious environmental problems and investigation revealed that *Cassia tora* had a capacity to accumulate metals from waste soil.

Nayana and Malode, (2012) evaluated the potential of *Pongamia pinnata* (Leguminosae- Papillionoideae) for phytoremediation of Cr, Cu and Ni. and the results revealed that all these metal concentrations were lower down in soil except Fe after two month experiment.

Singh and Kalamdhad, (2012) experimented various heavy metal reduction techniques during composting of different waste materials. During the composting process, the metal content could be reduced by the addition some chemicals, microbial inoculants and earthworm. In comparison to other chemicals, natural zeolite was found to be a good amendment because it has ability to exchange sodium and potassium with toxic metals. During the vermi composting, earthworms accumulated high concentration of heavy metals in the non-toxic forms by utilizing them for physiological metabolism.

Farrang *et al.* (2013) studied the phyto remediation potentiality and accumulation characteristics of sixteen elements and heavy metals; namely, N, P, K, Ca, Mg, Mn, B, Cu, Fe, Ni, Pd, Co, As, Cr, Cd, Mo, in the different parts of four plants; *Amaranthus hybridus, Chenopodium ambrosioides, Mentha longifolia* and *Typha domingensis*. Results revealed that the phytoremediation potentiality of above species was in the order *T.domingenesis*> *A.hybridus*> *M.longifolia*> *C.ambrosioides*. Comparing different plant parts of the studied species, the accumulation was mostly in the order stem> root> leaves.

Mojiri *et al.,* (2013) reported that *Typha domingensis* was an effective accumulator plant for phytoremediation of Pb, Ni and Cd.

Khoramnejadian and Saeb (2016) reported that *Amaranthus retroflexus* had a good ability to remove heavy metal from contaminated soils and phytoremediation by *Amaranthus retroflexus* as a good and economical choice for remediation of contaminated site.

Nutrient composition, heavy metal content, pesticide residue and pathogenicity of urban and rural waste composts commonly available in Kerala

CHAPTER 3

NUTRIENT COMPOSITION, HEAVY METAL CONTENT, PESTICIDE RESIDUE AND PATHOGENICITY OF URBAN AND RURAL WASTE COMPOSTS COMMONLY AVAILABLE IN KERALA

3.1. Introduction

The main goal of organic farming is to achieve a sustainable crop yield on a long term basis by improving overall health of soil. Application of any organic manure is supposed to enrich the soil with organic matter and essential plant nutrients along with improving physical and biological conditions of the soil. But, the content of plant nutrients in the composted organic manure mainly depend on the quality of feed stock used and method of composting. There are some potential risks associated with composts, such as accumulation of heavy metals, pathogenic organisms, pesticide residues and other organic pollutants. Use of compost for organic farming without understanding its quality can cause adverse effect on crop quality and environment. Relatively low crop yield, normally noticed in organic farming methods is suspected due to the use of organic manures with inferior quality. Green manures, the potential suppliers of essential nutrients, fail to meet the demand of current seasonal crops due to the time gap for decomposition and associated losses of nutrients through various means. This necessitated the use of compost, produced out of various feed stocks for the immediate supply of nutrients in organic farming. At present, there is no assurance of the quality of commercial composts commonly used for organic farming. Hence this part of the study mainly focuses on the quality of urban and rural waste composts commonly available in Kerala and to categorize them based on their quality.

3.2. Materials and Methods

3.2.1. *Study area*

The samples of urban waste composts were collected from eleven composting units operating under different local bodies viz., panchayaths, municipalities and corporations in the State. Sampling was done during the year 2011. Samples of compost made out of rural wastes were collected from Integrated Rural Technology Centre (IRTC) Mundoor, Kerala Agricultural University (KAU) Vellanikkara, Kerala Forest Research Institute (KFRI) Peechi and farmer's field at Vettukadu, Thrissur during the same year (Fig.1). Details on feed stock, inoculum used, composting method, time taken for composting etc. were also collected at the time of sampling.

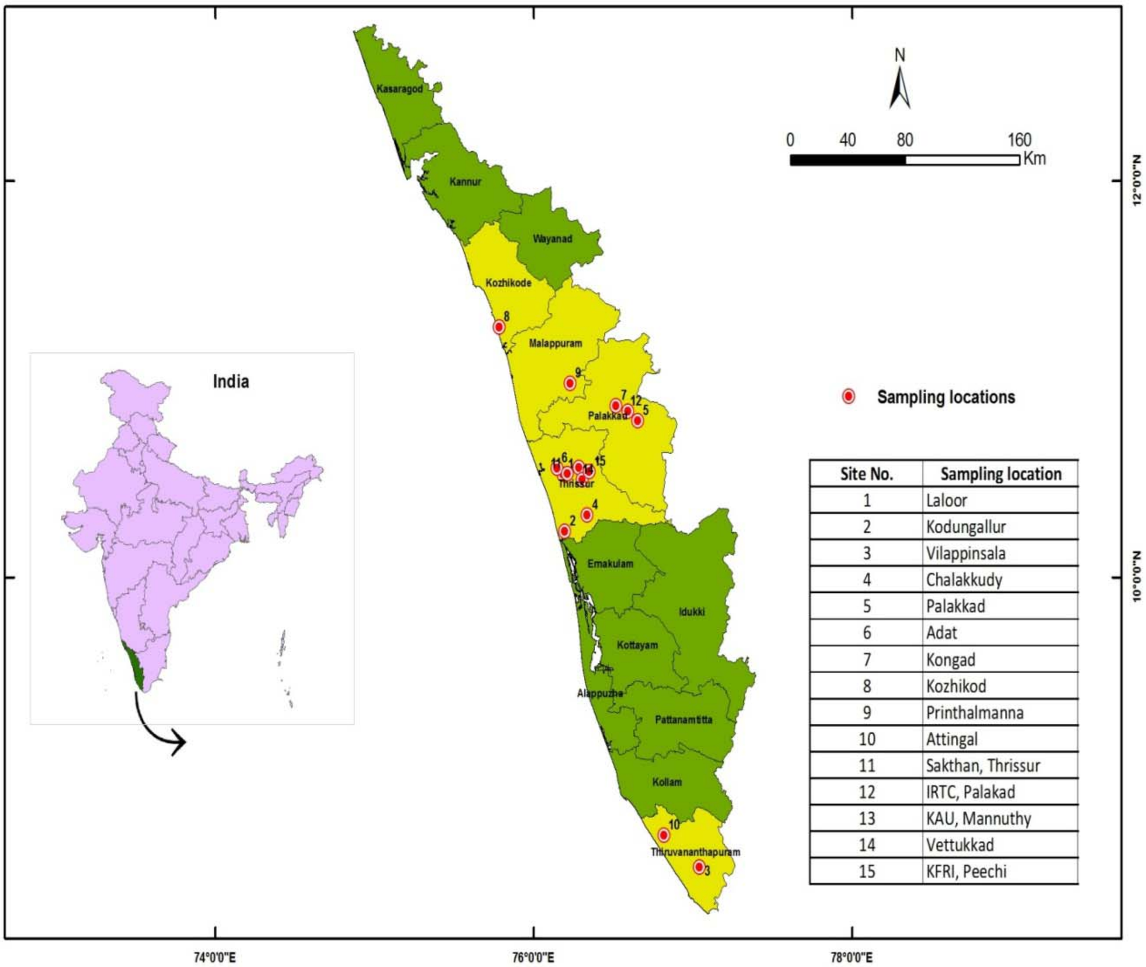


Fig.1.Sampling locations

3.2.2. *Sampling method*

The samples were collected once from each unit by following the methods of US-EPA part 503 rule (US-EPA, 1995) i.e. composite sample of several grab samples combined.

Laloor

Vilappinsala

Plate 1. Urban waste composting units at Laloor and Vilappinsala

Attingal

Attingal

Sakthan

Plate 2. Urban waste composting units at Attingal and Sakthan

3.2.3. *Laboratory analysis*

Collected samples were analysed for physical and chemical characteristics, pathogenicity and pesticide residues. For chemical analysis, compost samples were dried in hot air oven at 65 ^{o}C ± 5 for 48 hr, powdered and kept ready for analysis.

3.2.3.1. *Physical Characteristics*

Colour and content of moisture were the important physical parameters tested.

Colour

Colour of various compost samples were evaluated by physical appearance.

Moisture

Content of moisture in the compost samples were determined gravimetrically by estimating the loss in weight at 70 ^{0}C.

3.2.3.2. *Chemical Characteristics*

Prior to chemical analysis, samples were dried in hot air oven at 65±5 ^{0}C for 48 hrs and powdered. Then the samples were chemically assayed for macronutrients, micronutrients and heavy metals.

pH

The pH of the compost samples were determined in 1:5 compost : water using digital type Cyber scan 510 pH meter (Jackson, 1958).

Electrical conductivity

Electrical conductivity of the compost samples were measured in 1:5 compost : water using conductivity meter (Jackson, 1958).

Carbon

Weighed 10 g of the sample in a pre weighed crucible and dried in an oven at 105 ^{0}C for 6 hrs. After that, it was ignited in a muffle furnace at 650 – 700 ^{o} C for 6 hrs and then kept in a desiccator for 12 hrs. The difference in weights was used to estimate organic matter and from this, content of carbon was determined. The carbon content of the composts were determined using the following formula (Black *et al*., 1965).

$$\text{Total organic matter \%} = \frac{\text{Initial wt.} - \text{final wt. x } 100}{\text{Initial wt.}}$$

Total C (%) = total organic matter (%) / 1.724

Macronutrients, micronutrients and heavy metals

In order to determine N, P, K, micronutrients and heavy metals, 0.5 g of powdered sample was taken in a digestion tube, 10 ml conc. H_2SO_4 was added with a pinch of salicylic acid, and digested by adding hydrogen peroxide till the sample was clear. All the digested samples were made up to 100 ml with distilled water (Black *et al*., 1965).

Nitrogen

Content of N in the compost samples were estimated using microkjeldhal method (Bremner and Mulvaney, 1982).

C / N ratio

The C / N ratio was calculated by dividing per cent of organic carbon by per cent of N.

Phosphorus, potassium, calcium and magnesium

Content of P in the digested sample was estimated by vanadomolybdate yellow colour method using spectrophotometer (Piper, 1966), K by feeding the sample to digital type Elico (CL-360) flame photometer and Ca and Mg (Piper, 1966) using Atomic Absorption Spectrophotometer (Varian, 240).

Micronutrients and Heavy Metals

Content of micronutrients such as Fe, Cu, Zn and Mn and heavy metals such as Cd, Pb, Cr and Ni in the digested samples were determined (Carbonell *et al.,* 2009b) using Atomic Absorption Spectrophotometer (Varian, 240).

3.2.3.3. *Pesticide residues*

Pesticide residues with respect to organochlorides like alpha HCH, gama HCH/Lindane, delta HCH, endosulfan-I, endosulfan-II, endosulfan sulphate, P,P'-DDE, P,P'-DDD, P,P'-DDT and organophosphorous like phorate, chlorpyriphos, malathion, parathion-methyl, quinolphos, profenophos, ethion were determined by chloroform extraction followed by injection to GC/ MS

Five g compost sample was taken in 50 ml centrifuge tube and soaked in 10 ml of water for 10 minutes and the sample were extracted using 15 ml acetonitrile in a 50 ml centrifuge tube with 150µL of acetic acid. Subsequently six g anhydrous magnesium sulphate and 1.5 g sodium acetate were added, immediately shaken for one min. and then the extract was centrifuged at 1500 rpm for 5 min. Ten ml of the upper layer was transferred to a 15 ml centrifuge tube containing 500 mg of Primary Secondary Amine (PSA) and 1.5 g of anhydrous magnesium sulphate. The centrifuge tube was shaken for 30 seconds followed by centrifugation for one min. at 1500 rpm. Six ml from the upper layer was taken and concentrated to dryness using Turbovap (50 ^{0}C) and final volume was made up to one ml using n-hexane and analysed by Gas Chromatograph (Nair *et al*., 2013).

3.2.3.4. *Pathogenicity*

Ten g of the compost sample was added to 90 ml of sterile distilled water in a 250 ml of conical flask to get 10^{-1} dilution. There were three replicates for each soil sample. The flasks for each sample were shaken uniformly for 30 min. Ten ml of the 10^{-1} dilution samples were transferred to 90 ml water to get 10^{-2} dilution. The process was repeated to get dilution up to 10^{-6} for each sample. The flasks were shaken uniformly for 5 min. after first dilution for each sample. For the isolation of microorganisms pour plate method was used. One ml of the desired dilution was added to the sterile petridish. Sterile medium in bearable temperature was then added to the plate aseptically; rotate the plate carefully for the dispersion of sample throughout medium. The agar plates were then incubated in an inverted position at room temperature. Three replica plates were inoculated for each sub sample of compost sample (Aneja, 2001). After incubation period, the enumeration of pathogenic microorganisms (bacteria, fungi, and actinomycetes) in the compost sample was done with pour plate technique.

Selective media such as Mc Conkey agar (High Media. Technical data, M081B), PDA (High Media. Technical data, M096) blood agar (High Media. Technical dataM834), thiosulphate citrate bile salts sucrose agar (High Media. Technical data M870A) and EMB agar (High Media. Technical data, M317) were used to enumerate pathogenic microbes present in the samples. Plating was carried out for different dilutions from 10^{-2} to 10^{-8} of which dilutions of 10^{-4} and 10^{-5} were standardized for enumeration (Aneja, 2001).

3.2.3.5. *Quality evaluation*

Quality of composts was evaluated based on the values generated for clean and quality indices. Quality Indices of the composts were calculated using the equation QI= $\frac{\sum_{n}^{i=1} SiWi}{\sum_{n}^{i=1} Wi}$ Where, *Si* is the score value and *Wi* is the weighing factor of the i^{th} quality parameter of analytical data.

For calculating clean index, the weighing factor was 10 (maximum) for Cd due to its high mammalian toxicity, medium to low phyto toxicity potential and a functional role to the organism. For other heavy metals, weighing factor varied from 1 to 10. The clean index value of compost was calculated using the following formula.

CI= $\frac{\sum_{n}^{j=1} SjWj}{\sum_{n}^{j=1} Wj}$ Where Sj is the score value and Wj is weighing factor of the j^{th} heavy metal of the analytical data The higher the value for clean index (CI), the lesser the contamination due to heavy metal.

3.3. Results and Discussion

The details on different approaches adopted for composting of urban and rural wastes in various composting units of the State and the quality of composts thus produced with respect to physical and chemical characteristics, pathogenicity and pesticide residues are described in the following paragraphs.

3.3.1. *Basic informations on the urban and rural waste composts*

Urban waste composts

Samples of urban waste composts were collected from various composting units in the State such as Laloor in Thrissur, Chappara in Kodungallur, Vilappinsala in Trivandrum, Panambilly nagar in Chalakkudy, Theruvusala in Palakkad, Adat in Thrissur, Kongad in Palakkad, Njeliyamparamba in Kozhikode, Perinthalmanna in Malappuram, Attingal in Trivandrum and Sakthan in Thrissur. Details on feed stock used, segregation status, inoculum used, composting period etc. at these composting units were also collected and recorded (Table 1). At all the composting units, the feedstock used were either urban wastes or market wastes. The urban wastes contained all the waste generated in the urban area while market wastes contained the wastes especially from vegetable market. Regarding segregation of wastes, the composting units at Laloor, Kodungallur, Vilappinsala, Chalakkudy and Palakkad did not follow segregation either at source of collection or just before composting. But at Adat, Kongad, Kozhikode, Perinthalmanna and Attingal, wastes were segregated at composting units. The complete segregation of wastes was followed only at Sakthan, wherein the organic wastes from vegetable market was used for composting.

Cow dung was used as inoculum at Laloor, Palakkad, Adat, Kongad and Perinthalmana. But at Chalakkudy, Kozhikode, Attingal and Sakthan, unknown inoculum available in the market was used for composting. It was also observed that at Kodungallur and Vilappinsala, no inoculum was used for composting.

Table 1. Basic informations on the urban waste composts collected from various composting units in Kerala

Composting unit	Feed stock	Segregation status	Inoculum used	Composting method	Composting period, days
Laloor	Urban organic waste	NS	Cow dung	Windrow	150
Kodungallur	Market waste	NS	Nil	Windrow	180
Vilappinsala	Urban organic waste	NS	Nil	Windrow	180
Chalakkudy	Market waste	NS	Commercial inoculum	Windrow	120
Palakkad	Urban organic waste	NS	Cow dung	Windrow	120
Adat	Market waste	PS	Cow dung	Vermi	120
Kongad	Market waste	PS	Cow dung	Windrow	120
Kozhikkode	Urban organic waste	PS	Commercial inoculum	Windrow	120
Perinthalmanna	Market waste	PS	Cow dung	Windrow	120
Attingal	Market waste	PS	Commercial inoculum	Windrow	120
Sakthan	Market waste	CS	Commercial inoculum	Aerobic	30

NS - non segregated, PS-partially segregated, CS-completely segregated

Closer examination of the composting process at various composting units during sample collection revealed that pre-processing of wastes were not followed at five centres namely Laloor, Kodungallur, Vilapinsala, Chalakkudy and Palakkad. At all these sites, non-segregated wastes were heaped and left for several months without turning during decomposition. But at other centres viz., Adat, Kongad, Kozhikode, Perinthalmanna and Attingal, non-biodegradable wastes like plastics, rubber, metals etc. were manually removed prior to composting (termed as ‘partially segregated’). At one unit, namely Sakthan, biodegradable wastes were collected from individual households and vegetable markets, shredded and ground before composting using microbial inoculum. In the composting yards at Palakkad, Laloor, Attingal, Chalakkudy and Kozhikode microbial cultures and cow dung were being used as inoculum. Post-processing methods mainly involved air-drying of the composts followed by sieving, either mechanically or manually to remove bigger sized inert particles.

The composting period at various centres varied between 30 to 180 days. Minimum composting period of 30 days was noted at Sakthan and maximum (180) at Kodungallur and Vilappinsala. Usually, the composting period depends up on the nature of feed stock, inoculum used and the process of composting. At Kodungallur and Vilappinsala, they were not adding any inoculum during composting and this might be the reason for longer composting period at these centres. The composting period at most of other centres was 120 days irrespective of the feed stock, inoculum and composting process. This might be due to the unscientific method of composting, targeted on already fixed time period. At Sakthan, the shredding and grinding of wastes before the application of inoculum and keeping them in specially designed boxes permit faster decomposition within a short period of 30 days.

Rural waste composts

Samples of rural waste composts were collected from various centres such as Integrated Rural Technology Centre, Mundoor; Kerala Agricultural University, Vellanikkara; farmer's field at Vettukad, Thrissur and Kerala Forest Research Institute, Peechi. The main feed stocks used at these centres for composting were vegetable wastes, paper wastes, mushroom wastes, coir pith, ayurvedic medicinal wastes, agricultural wastes, kitchen wastes, mixed wastes etc. Most of the units were following composting on a small scale.

Table 2. Basic informations on the rural waste composts collected from various composting units in Kerala

Composting unit	Feed stock	Segregation status	Inoculum used	Composting method	Composting period, days
IRTC	Vegetable waste	CS	Cow dung	Vermi	50
IRTC	Paper waste	CS	Cow dung	Vermi	75
IRTC	Mushroom waste	CS	Cow dung	Vermi	30
KAU	Coir pith	CS	Microbial consortium	Windrow	120
KAU	Ayurvedic medicinal waste	CS	Microbial consortium	Windrow	120
Vettukad	Agricultural waste	CS	Cow dung	Windrow	120
IRTC	Kitchen waste	CS	Cow dung	Vermi	30
KFRI	Mixed weeds	CS	Jeevamrutham	Aerobic	75

CS-completely segregated

At all the centres, completely segregated wastes were used for composting with cow dung, microbial consortium or jeevamrutham as inoculum. At IRTC, where small scale composting was done, vermitechnology was used for composting of vegetable wastes. The commonly used earthworms in vermitechnology were *Eudrilus eugenia* and *Eisenia foetida.* Windrow method was adopted by Kerala Agricultural University for composting of coir pith and ayurvedic medicinal wastes. At Kerala Forest Research Institute, weeds were composted following aerobic composting technology using jeevamrutham as inoculum.

The composting period of kitchen wastes and mushroom wastes in vermicomposting was only 30 days while for paper wastes and vegetable wastes it took about 75 and 50 days respectively. Composting of coir pith, ayurvedic medicinal wastes and agricultural wastes at KAU through windraw method using cow dung or inoculum was completed only after 120 days while composting of weeds through aerobic method using jeevamrutham as inoculum took only 75 days at KFRI. Unlike in the case of urban wastes, rural wastes were being composted properly in a scientific manner and hence the nature of feed stock, composting method and type of inoculum was found to have a profound influence on the composting period. Use of easily degradable mushroom wastes, kitchen wastes, vegetable wastes and, application of jeevamrutham were found to bring down the composting period to a great extent.

3.3.2. *Physical characteristics of composts*

Colour and moisture content were the important physical parameters tested in both urban (Table 3) and rural (Table 4) waste composts.

Colour

Most of the composts in general were with acceptable colour varying from brown to coffee brown, except those from Vilappinsala, which was ash in colour. According to the Fertiliser Control (Amendment) Order (2013), it is desired to have dark brown to black in the finished products. Variation in colour is normally due to the differences in the type of raw materials and process of composting methods. The heat generated during the initial period of composting is believed to have profound effect on the colour of the compost produced. The ash colour of the compost from Vilappinsala clearly demonstrate the loss of carbon at high temperature developed during composting. The temperature of the heat generated during composting depends up on the type of feed stock and activity of micro organisms.

With respect to the colour of rural waste composts, most of them were with desirable coffee brown with the absence of foul odour. The coffee brown colour of the compost generally indicate high content of organic carbon, which is considered as the key factor in composts for organic farming.

Moisture

Content of moisture in the urban composts (Table 3) varied from 18.3 per cent to 27.1 per cent. Higher content of moisture was in the samples from Laloor (27.1 per cent) and lower in those from Palakkad (19 per cent). According to the Fertiliser Control (Amendment) Order (2013), it is desired to have 25 per cent moisture in the finished products. Most of the samples except those from Laloor, Kodungallur and Perinthalmanna were within the prescribed limit. But in rural waste composts, the content of moisture was within the limit (25 per cent) except those produced from mushroom waste compost (27.4 per cent). Composts with less moisture contents may not have been fully stabilized or may have been stored for long periods leading to moisture loss (Saha *et al*, 2010). While excessively dry composts are often dusty and unpleasant to handle. Compost with too high moisture content becomes too clumpy and increase transportation cost.

3.3.3. *Chemical characteristics of composts*

Both urban and rural waste composts were assayed for various chemical characteristics such as pH, EC, organic carbon, C:N, nutrient potential and heavy metals. The data obtained are presented and discussed in the following paragraphs.

pH

A considerable variation in pH was observed between various urban waste composts, and the values ranged from 7.1 to 9.1. The highest value of pH was seen in the samples from Kodungallur (9.1) and the lowest in Attingal (7.1). The samples from Chalakkudy, Adat, Attingal and Sakthan were within the limit (7.1 to 7.4) prescribed by Fertiliser Control (Amendment) Order (2013).

With regard to rural composts (Table 4), the pH varied between 5.0-7.3, the low pH was recorded by compost produced out of coir pith waste and the highest in case of mixed weed (7.3) compost. The pH of some composts, even though varied between 6-6.4, were only slightly less than the desired level. High pH noted in some samples might be due to improper method of composting. However, considering the acidic nature of the soils of Kerala, the matured composts with pH more than 6.0 are beneficial for improving the chemical condition of the soil. The data obtained in this study revealed that the coir pith compost, which is acid in nature, is not suitable for acidic soils of Kerala.

Table 3. Physical and chemical characteristics of urban waste composts produced at various composting units in Kerala

Composting unit	Colour	Moisture (%)	pH	EC(dS/m)	C (%)	C:N*
Laloor	Slightly Brown	27.1±0.37	8.5±0.03	0.53±0.01	11.50±1.01	16.60±0.82
Kodungallur	Slightly brown	26.2±0.24	9.1±0.15	1.85±0.05	11.43±0.35	13.13±0.67
Vilappinsala	Ash colour	18.3±0.19	8.4±0.03	0.44±0.01	13.20±0.15	13.87±0.67
Chalakkudy	Brown	23.2±0.39	7.3±0.03	2.03±0.07	11.33±0.23	14.03±0.32
Palakkad	Brown	19.0±0.32	8.2±0.18	0.72±0.03	12.57±0.58	11.23±0.09
Adat	Slightly brown	23.3±0.23	7.4±0.03	1.28±0.04	15.33±0.30	13.07±1.17
Kongad	Slightly ash	24.4±0.27	8.1±0.09	0.44±0.01	20.47±0.12	18.73±0.62
Kozhikkod	Coffee brown	25.4±0.2	8.2±0.09	0.41±17.37	17.37±0.26	15.97±0.20
Perinthalma-nna	Coffee brown	21.0±0.19	7.8±0.09	0.76±0.01	14.70±0.35	13.50±0.83
Attingal	Coffee brown	19.7±0.26	7.1±0.06	0.80±0.01	16.23±0.17	15.67±0.62
Sakthan	Coffee brown	23.7±0.90	7.3±0.12	0.43±0.01	15.80±0.90	11.43±0.58

*Values for N is given in the Table 5

Table.4. Physical and chemical characteristics of rural waste compost produced out of various feed stocks in Kerala

Feed stock	Colour	Moisture (%)	pH	EC (dS/m)	C (%)	C:N*
Market waste	Coffee brown	23.7±0.19	6.4±0.15	1.80±0.53	32.4±0.72	16.6±0.42
Paper waste	Slightly brown	22.9±1.07	6.2±0.17	1.97±0.40	26.9±0.16	25.6±0.49
Mushroom waste	Coffee brown	27.4±0.44	6.0±0.15	2.07±0.21	25.9±0.16	13.3±0.25
Coir pith	Coffee brown	16.6±0.50	5.0±0.15	2.70±0.10	28.2±0.16	17.1±0.12
Ayurvedic Medicinal waste	Coffee brown	15.9±0.33	6.1±0.10	2.10±0.44	20.5±0.33	11.3±0.15
Agriculture waste	Coffee brown	24.3±0.43	7.0±0.10	2.13±0.21	23.5±0.16	14.2±0.10
Vegetable waste	Coffee brown	23.7±0.90	7.1±0.06	0.60±0.03	22.7±0.96	18.1±1.51
Mixed weeds	Coffee brown	23.1±0.19	7.3±0.10	3.43±0.21	39.7±0.40	13.9±1.12

* Values for N is given in the Table 6

Electrical conductivity

Electrical conductivity of the urban waste composts ranged between 0.4-2.1 dS/m. The lowest value was observed with Kozhikkod and highest with Chalakkudy.

But slightly higher values of electrical conductivity varying between 0.6-3.43 dS/m was observed in rural waste composts. Since all the samples under study were within the prescribed limit of Fertiliser Control (Amendment) Order (2013) i.e. ≤ 4 dS/m, they were found suited for organic farming under Kerala condition. Relatively higher EC in rural waste composts might indicate comparatively higher nutrient content.

Carbon

The content of carbon in the urban waste composts varied from 11.3 to 20.5 per cent. In this study, only three samples, those from Kongadu, Kozhikkod and Attingal were within the prescribed limit (≥14 per cent). The composts with coffee brown colour were found to contain higher of organic carbon. But the sample from Kongad, inspite of its higher organic carbon, was slightly ash in colour, the reason for which is not known. Relatively low carbon in the urban waste composts is attributed to various factors such as presence of non carbonaceous materials, improper method of composting as well as the feed stocks with low content of carbon.

Compared to urban waste composts, the carbon content of rural wastes composts were relatively higher ranging from 20.5 to 39.7 per cent. The lowest value was observed in ayurvedic medicinal waste compost (20.5 per cent) and higher in mixed weed compost (39.7 per cent). According to Fertiliser Control (Amendment) Order (2013), the desired level of carbon in the composts is ≥14 per cent and all the rural composts were within the desired limit. Most of the rural wastes used as feed stock for composting are of plant origin with higher content of carbon, obviously resulting its higher level in the compost.

C/N

Carbon to nitrogen ratio (C:N) is considered as a chemical indicator for compost maturity with respect to organic matter. In the present study, C:N ratio in the urban waste composts ranged from 11.2:1 to 18.7:1. Wider C:N ratio was recorded in the samples from Kongad (18.7:1) and lowest in those from Palakkad (11.2:1). The prescribed limit (Fertiliser Control (Amendment) Order (2013) of C:N in the compost is less than 20:1 and hence all the samples qualify with respect to this parameter.

The C:N ratio in the rural waste composts ranged from 11.3:1 to 25.6 :1. The narrow value was in medicinal waste compost and wider value in paper waste compost. C: N ratio of all the samples analysed in this study except paper compost were within the limit of Fertiliser Control (Amendment) Order (2013). Ideal compost feedstock mixtures are supposed to have an initial C:N ratio of about 30:1, decreasing to less than 20:1 as composting process proceeds (Sullivan and Miller, 2001). Usually, the content of N in the paper is negligible. But in the present study, the paper compost was produced by adding cow dung and other miscellaneous sweepings and kitchen wastes, and these might have caused the elevated levels of C and N in the final compost.

Nutrient potential

Nutrient supplying power of the composts were evaluated based on the content of essential macro and micro nutrients needed for the growth and development of plants.

Macro nutrients

Nitrogen, phosphorus and potassium, being the major nutrients taken by the plants from soil are considered as important nutrient quality parameters of composts. Total N, P and K in the urban waste composts ranged between 0.69 to 1.4 per cent; 0.25 to 1.18 per cent and 0.26 to 2.25 per cent respectively (Table 5). Highest value of N was observed in Sakthan compost (1.38 per cent) and lowest in Laloor (0.69 per cent). According to Fertiliser Control (Amendment) Order (2013), the content of N in the composts must be ≥0.5 per cent and the data generated in this study indicated that all the samples were with more than the prescribed limit of this nutrient. With respect to P, its content was highest in the sample from Chalakkudy (1.18 per cent) and the lowest in Kodungallur (0.25 per cent). Generally in all the samples, the content of P was ≥0.5 per cent, the limit prescribed by Fertiliser Control (Amendment) Order (2013). As in the case of P, samples from Chalakkudy contained higher content of K (2.23 per cent) and those from Kodungallur were poor (0.26 per cent) in this nutrient. In general, most of the samples except those from Chalakkudy, Perinthalmanna, Attingal and Sakthan had relatively poor content of K, less than the limit (≥0.5 per cent) prescribed by Fertiliser Control (Amendment) Order, (2013). The higher content of K in some of the samples is attributed to the contribution from the feed stocks such as wastes from banana and flowers, containing relatively higher reserve of this nutrient.

In the rural waste composts, content of N, P, and K ranged between 1.05-2.87 per cent, 0.31-2.09 per cent and 0.18-1.37 per cent respectively (Table 6). Lower N was observed in paper waste compost and highest in mixed weed compost. All the composts exceeded the limit (≥0.5 per cent) prescribed by Fertiliser Control (Amendment) Order (2013).

Table 5. Content of macro nutrients in the urban waste composts produced at various composting units in Kerala

Composting units	Nutrients (per cent)				
	N	P	K	Ca	Mg
Laloor	0.69±0.05	0.79±0.11	1.23±0.08	2.04±0.03	0.67±0.05
Kodungallur	0.87±0.03	0.25±0.05	0.26±0.07	1.19±0.07	0.32±0.02
Wilappinsala	0.96±0.04	0.73±0.07	0.61±0.14	3.06±0.10	0.20 ±0.01
Chalakkudy	0.81±0.03	1.18±0.06	2.23±0.29	3.33±0.15	1.30 ±0.03
Palakkad	1.12±0.06	0.54±0.03	0.56±0.10	1.85±0.05	0.88 ±0.05
Adat	1.19±0.08	0.34±0.05	0.73±0.04	1.44±0.18	0.57 ±0.02
Kongad	1.09±0.04	0.44±0.08	0.56±0.09	0.45±0.04	0.30 ±0.03
Kozhikkode	1.09±0.00	0.80±0.10	0.59±0.08	0.33±0.02	0.18 ±0.02
Perinthalmanna	1.09±0.04	0.72±0.03	0.83±0.14	0.55±0.04	0.19 ±0.01
Attingal	1.04±0.05	1.10±0.04	1.43±0.31	0.46±0.04	0.19 ±0.01
Sakthan (Thrissur)	1.38±0.01	0.87±0.03	0.98±0.08	0.42±0.07	0.19 ±0.00

With respect to P, the lowest was in agricultural waste compost (0.31 per cent) and highest in mushroom waste compost (2.09 per cent). Most of the samples were within the limit (≥0.5 per cent) prescribed by Fertiliser Control (Amendment) Order (2013) except in those from coir pith waste (0.34 per cent) and agricultural waste (0.31 per cent). Content of K was lower in agricultural waste compost (0.18 per cent) and higher in mixed weed compost (1.37 per cent).

With respect to the secondary nutrients such as Ca and Mg, the values ranged between 0.28-3.33 per cent and 0.14- 1.35 per cent respectively in the urban waste compost. Samples from Chalakkudy were with highest content of Ca and Mg and those from Kozhikode with lowest level of these nutrients (Table 5).

Table 6. Content of macro nutrients in the rural waste composts produced out of various feed stocks in Kerala

Feed stock	Nutrients (per cent)				
	N	P	K	Ca	Mg
Market waste	1.96±0.01	1.40±0.07	0.74±0.09	0.55±0.03	0.26±0.02
Paper waste	1.05±0.03	1.23±0.06	0.60±0.01	0.43±0.03	0.23±0.03
Mushroom waste	1.95±0.03	2.09±0.05	0.65±0.02	0.89±0.02	0.47±0.04
Coir pith	1.65±0.02	0.34±0.04	0.84±0.04	1.51±0.03	0.42±0.04
Medicinal waste	1.82±0.01	0.61±0.03	0.78±0.07	1.54±0.07	0.37±0.01
Agricultural waste	1.66±0.02	0.31±0.03	0.18±0.05	1.26±0.04	0.26±0.02
Vegetable waste	1.26±0.05	0.61±0.03	0.83±0.15	1.35±0.09	0.89±0.02
Mixed weeds	2.87±0.21	0.77±0.06	1.37±0.15	2.70±0.10	1.33±0.06

In rural composts, content of Ca and Mg ranged between 0.43-2.7 per cent and 0.23-1.33 per cent respectively, the lowest value of both nutrients in paper waste compost and highest in mixed weed compost (Table 6). Since Fertiliser Control (Amendment) Order (2013) has not prescribed any limit for the above nutrients, it is not possible to make any remarks on their adequacy in these samples.

Micronutrients

Data on micronutrients such as Fe, Cu, Zn and Mn in the urban waste composts (Table 7) ranged between 0.25-1.71 per cent; 132.13 - 288.3 mg kg^{-1}; 87.6 -328.6 mg kg^{-1} and 132.3-441.1 mg kg^{-1} respectively. The prescribed limit of Cu and Zn Fertiliser Control (Amendment) Order (2013) in the composts are <300 mg kg^{-1} and <1000 mg kg^{-1} with no limit for Fe and Mn. The data obtained in this study indicated a high reserve of these nutrients in all the urban waste composts.

Table 7. Content of micronutrients in the urban waste compost produced at various composting units in Kerala

Composting units	Fe (%)	Cu (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})
Laloor	0.84±0.02	164.57±2.25	435.50±13.96	119.27±5.20
Kodungallur	0.92±0.07	188.30±1.81	249.97±2.05	113.70±5.36
Vilappilsala	0.51±0.02	132.13±2.36	383.00±3.74	87.63±1.12
Chalakkudy	1.71±0.19	175.20±3.94	417.43±4.91	328.60±9.32
Palakkad	0.49±0.02	186.90±2.31	295.93±3.23	87.80±0.99
Adat	0.50±0.02	288.27±5.60	441.07± 3.34	110.50±2.40b
Kongadu	1.09±0.03	273.63±8.32	347.20±2.80	243.30±4.37
Kozhikkode	0.83±0.02	158.40±10.63	132.29±1.72	317.50±6.51
Perinthalmanna	1.52±0.03	192.63±4.33	326.78±3.16	174.20±2.57
Attingal	0.44±0.04	234.43±8.42	210.67±0.59	101.73±1.50
Sakthan	0.25±0.03	147.83±5.87	267.80±7.80	187.13±5.21

Content of Fe, Cu, Zn and Mn in the rural waste compost ranged between 0.27-2.8 per cent, 38.7- 164.3 mg kg^{-1}, 73-247 mg kg^{-1} and 57.3-592.4 mg kg^{-1} respectively (Table 8). As in the case of urban waste composts, all the rural waste composts were also with high reserve of all the micronutrients.

Table 8. Content of micronutrients in the rural waste compost produced out of various feed stocks in Kerala

Feed stock	Fe (%)	Cu (mg kg^{-1})	Mn (mg kg^{-1})	Zn (mg kg^{-1})
Market waste	1.11±0.01	164.3±12.74	345.1±6.49	247.0±2.00
Paper waste	2.80±0.04	162.3±4.93	570.9±22.01	242.7±2.00
Mushroom waste	1.17±0.01	38.7±3.79	592.4±5.29	217.9±2.44
Coir pith	1.93±0.01	56.0±2.00	112.0±12.46	155.7±1.90
Medicinal waste	0.66±0.01	152.0±3.00	57.3±4.78	84.6±1.06
Agriculture waste	0.56±0.01	60.7±2.08	71.8±9.31	73.0±1.44
Vegetable waste	0.48±0.02	161.6±16.86	221.3±3.04	121.6±5.29
Mixed weeds	0.27±0.00	100.7±13.05	128.7±2.52	121.3±27.74

Heavy metals

Contamination of composts with heavy metals is considered as an undesirable quality parameter. In the present study, content of Cd, Pb, Cr and Ni in the urban waste composts ranged between 2.3 – 7.4 mg kg^{-1}, 85.6 – 606.1 mg kg^{-1}, 4.6 – 99.7 mg kg^{-1} and 4.4 – 85.6 mg kg^{-1} respectively (Table 9). According to Fertiliser Control (Amendment) Order (2013), the minimum prescribed limit of Cd was 5mg kg^{-1}. But the samples from Laloor, Kodungallur, Vilappinsala, Chalakkudy, Palakkad and Kongad contained more than the maximum limit while those from Adat, Kozhikkode, Perinthalmanna, Attingal and Sakthan were within the limit. The higher content of Cd was in the sample from Laloor (7.4 mg kg^{-1}) and lower in that from Sakthan (2.3 mg kg^{-1}). The content of Pb was higher in Kodungallur (606.1 mg kg^{-1}) and lower in Kongad (85.6 mg kg^{-1}). According to Fertiliser Control (Amendment) Order (2013), the prescribed maximum limit of Pb was 100 mg kg^{-1}. But most of the samples, except those from Kongad and Sakthan were with more than the permissible limit. In the case of Cr, the values ranged between 4.6 – 99.6 mg kg^{-1} and the samples from Laloor, Kodungallur and Vilappinsala were with more than the permissible limit (50 mg kg^{-1}). Content of Ni was higher in the sample from Laloor (85.57 mg kg^{-1}) and lowest in those from Sakthan (4.4 mg kg^{-1}). According to Fertiliser Control (Amendment) Order (2013), the permissible limit of this metal was 50 mg kg^{-1}, and the samples from Laloor, Kodungallur, Vilappinsala, Chalakkudy and Palakkad exceeded the permissible limit.

Table 9. Content of heavy metals in the urban waste compost produced at various composting units in Kerala

Composting units	Heavy metal content, mg kg^{-1}			
	Cd	Pb	Cr	Ni
Laloor	7.37±0.26	326.70±16.4	77.40±7.73	85.57±3.78
Kodungallur	6.33±0.32	606.07±25.82	60.6±4.66	70.70±0.49
Vilappilsala	5.83±0.13	210.00±12.73	99.65±0.54	68.80±3.12
Chalakkudy	5.53±0.18	360.37±8.63	48.03±0.92	68.40±0.87
Palakkad	6.63±0.12	278.13±2.08	43.30±1.80	52.77±0.55
Adat	3.77±0.67	109.30±9.57	32.50±1.40	18.63±0.66
Kongad	5.40±0.40	85.63±5.12	35.70±4.38	12.73±1.01
Kozhikkode	4.60±0.64	384.02±32	40.83±0.38	38.76±0.64
Perinthalmanna	4.47±0.28	241.48±58.04	38.79±0.39	47.01±1.11
Attingal	3.73±0.29	116.30±19.11	10.83±0.29	14.57±0.54
Sakthan	2.27±0.42	91.83±2.40	4.64±0.09	4.40±0.40

The data in general revealed that the compost produced at Laloor, Kodungallur and Vilappinsala were invariably contaminated with most of the heavy metals. Normally, the point sources of heavy metals in municipal solid wastes include batteries, paints, electronics, ceramics, plastics, inks/ dyes etc. (Déportes *et al*., 1995; Richard and Woodbury, 1992; Sharma and Agarwal, 2004). Non segregation of uraban wastes at the composting units of Laloor, Kodungallur and Vilappinsala might have contributed higher content of heavy metals at these units.

Table 10. Content of heavy metals in the rural waste compost produced at various feed stocks in Kerala

Feed stock	Heavy metal content, mg kg^{-1}			
	Cd	Pb	Cr	Ni
Market waste	3.80±0.96	36.0±2.25	30.0±0.20	34.0±0.20
Paper waste	2.67±0.31	32.5±3.08	34.0±2.31	33.2±1.59
Mushroom waste	0.90±0.20	62.3±14.22	32.7±1.77	32.6±2.15
Coir pith	1.80±0.56	89.0±3.12	41.8±1.01	22.6±1.95
Medicinal waste	2.50±0.56	209.7±11.56	22.5±1.00	37.7±1.66
Agriculture waste	4.07±0.15	56.5±1.94	24.5±1.29	28.8±1.55
Vegetable waste	1.97±0.38	117.3±2.98	16.4±1.93	16.1±0.21
Mixed weeds	1.60±0.62	46.6±12.12	20.4±4.28	26.3±4.16

Presence of heavy metals such as Cd (0.9-4.07 mg kg^{-1}), Pb (46.6-209.7 mg kg^{-1}), Cr (16.4-41.8mg kg^{-1}) and Ni (16.1-37.7mg kg^{-1}) were observed in the rural waste composts also (Table 10). Content of Cd was lower in mushroom waste compost and higher in agricultural waste compost. Relatively lower content of Pb was in mixed weed compost and higher in medicinal waste compost. Content of Cr was lower in vegetable waste compost and higher in coir pith waste compost. Medicinal waste compost recorded relatively higher content of Ni and this metal was lower in vegetable waste compost. However, the content of all the heavy metals in the rural waste composts were within the limit prescribed by Fertiliser Control (Amendment) Order (2013) except the content of Pb in medicinal waste compost. Presence of relatively lower levels of heavy metals in all the rural waste composts might be due to the contribution from different types of feed stocks used for composting. The substratums usually used for the production of mushrooms are the residues of rice straw, rice husk and banana leaves. These agricultural residues may contain lower levels of heavy metals, which later on is found accumulated in the compost produced out of these residues.

3.3.4. *Pesticide residues*

Residues of organochlorine pesticides like alpha HCH, gama HCH/Linda, delta HCH, endosulfan-I, endosulfan-II, endosulfan sulphate, P,P'-DDE, P,P'-DDD, P,P'-DDT and organophosphorous pesticides like phorate, chlorpyriphos, malathion, parathion-methyl, quinaphos, profenophos, ethion were analysed in all the urban and rural waste composts (**Appendix 1**). According to the Fertiliser Control (Amendment) Order (2013), composts must be free from pesticide residues.. The data obtained in the present study revealed non detectable level of above pesticides in all the samples analysed.

3.3.5. *Pathogenic organisms*

The compost samples collected from various sites were subjected to enumeration of pathogenic micro organisms and the data is given in the Table 11. Presence of

Table 11. Pathogenic contamination of urban waste composts produced at different composting units in Kerala

Composting unit	Pathogenic contamination >10^3 cfu/g			
	E.coli	Salmonella	*Vibrio sps.*	*Fusarium oxysporum*
Laloor	$2.5x10^3$	$2.57x10^3$	NG	$1.03X10^3$
Kodungallur	$1.8x10^3$	NG	NG	NG
Wilappinsala	NG	NG	NG	NG
Chalakkudy	NG	NG	NG	NG
Palakkad	$1.78x10^3$	$1.2x10^3$	NG	NG
Adat	NG	NG	NG	NG
Kongad	$1.2x10^3$	NG	NG	$4X10^3$
Kozhikkode	NG	NG	NG	$2.13X10^3$
Perinthalmanna	$1.8x10^3$	NG	NG	NG
Attingal	NG	NG	NG	NG
Sakthan	NG	NG	NG	NG

Salmonella was detected (>10^3 cfu/g) in the urban waste compost from Laloor and Palakkad. Total coliform was also detected (>10^3 cfu/g) in the urban waste composts collected from Palakkad, Kongad, Laloor, Kodungallur and Perinthalmanna.

Table 12. Pathogenic contamination of rural waste composts produced out of various feed stocks in Kerala

Feed stock	Pathogenic contamination >10^3 cfu/g			
	E.coli	Salmonella	*Vibrio sps.*	Fungi
Market waste	NG	NG	NG	NG
Paper waste	NG	NG	NG	NG
Mushroom waste	NG	NG	NG	NG
Coir pith	NG	NG	NG	NG
Ayurvedic medicinal waste	NG	NG	NG	NG
Agriculture waste	NG	NG	NG	NG
Vegetable waste	NG	NG	NG	NG
Mixed weeds	NG	NG	NG	NG

Contamination due to pathogens was not observed in any of the composts produced out of rural wastes. Generally small scale composting process was adopted in all the rural waste composting units and proper handling might have reduced the pathogenic contamination. The heat generated during composting also might have killed all the pathogenic organisms. According to Fertiliser Control (Amendment) Order (2013), a good compost must be free from pathogenic contamination. Harmful pathogens like Salmonella and Coliform bacteria can enter in the solid wastes through disposable diapers, faecal materials and hospital wastes etc., which may cause illness in human beings during their handling. However, as the temperature rises during composting period, these pathogens are usually destroyed as they reach their thermal death point (Day and Shaw, 2001)

3.3.5. *Quality evaluation*

Quality of both urban and rural waste composts for organic farming was evaluated based on the values developed for quality and clean indices.

Quality indices

In order to assess the fertilizing potential of each compost, quality index was developed by assigning score value and weighing factor for each parameter based on the quality control values (Table 13 and Table 14).

Table 13. Quality control values of various parameters in composts as per Fertiliser Control (Amendment) Order, guide lines (2013)

Parameters	QC value
Moisture (% wm)	25
pH(1:5)	6.5-7.5
EC(dS/m)	≤ 4
OC (% dm)	≥ 14
N (% dm)	>0.5
C:N	<20:1
P as P_2O_5 (% dm)	≥0.5
K as K_2O (% dm)	≥0.5

Parameters	QC value
NPK (%)	3
Cu (mg kg^{-1} dm)	< 300
Zn (mg kg^{-1} dm)	<1000
Cd (mg kg^{-1} dm)	<5
Pb (mg kg^{-1} dm)	<100
Cr (mg kg^{-1} dm)	<50
Ni (mg kg^{-1} dm)	<50

The weighing factor was maximum for organic carbon, N, C:N and NPK due to its important role in improving soil quality. Weighing factor for other parameters varied from 3 to 10, depending on their potential in improving soil health. Quality Index value was calculated using the formula QI = $\frac{\sum_{n}^{i=1} SiWi}{\sum_{n}^{i=1} Wi}$, where Si is the score value and Wi is the weighing factor of the ith quality parameter of analytical data.

Table 14. Criteria for assigning score value and weighing factor

Parameters	Score values					Weighing factor
	5	4	3	2	1	
pH	≤7.5	7.4-7	6.9-6.5	6.4-5.5	<5.4 or >8	8
EC	≤3.5	3.5-3.9	4-4.3	4.4-4.9	>5	3
OC	>20	15-20	12-15	10-12	<10	10
N	>1.25	1.01-1.25	0.81-1	0.51-0.8	<0.51	10
C:N ratio	<10.1	10.1-15	15.1-20	20.1-25	>25	10
P	>0.6	0.41-0.6	0.21-0.4	0.11-0.2	<0.11	6
K	>1	0.76-1	0.51-0.75	0.26-0.50	<0.26	7
NPK	>4	4-3.1	3-2.6	2.5-2.1	<2	10
Ca	>3	2-3	1.2-2	0.5-1.2	<0.5	7
Mg	>1.2	1-1.2	0.5-0.9	0.2-0.5	<0.2	7
Cd	<2	2-3.2	3.2-5	5.1-6.2	>6.2	10
Pb	<90	91-150	151-250	251-350	>351	8
Cr	<4.5	4.6-14.5	14.6-24.5	24.6-50	>50	8
Ni	<4	4.1-24	25-50	51-75	>76	5

(Saha et al., 2010)

The Quality index values developed for urban waste composts varied from 2.4 to 3.8 (Table 15). Very high values for quality index (3.8) were obtained for the composts from Sakthan. Most of the urban waste composts were with relatively high values for quality index, except those from Kodungallur and Laloor. The urban waste composts in the decreasing order of their quality were Sakthan, Chalakkudy > Attingal, Perinthalmanna > Adat > Kongad, Palakkad, Kozhikkod, Vilappinsala > Laloor, >, > Kodungallur.

Table 15. Quality and clean indices for urban waste composts collected from various composting units in Kerala

Composting unit	Quality index	Clean index
Laloor	2.9	1.2
Kodungallur	2.4	1.2
Vilappinsala	3.0	2.0
Chalakkudy	3.6	1.8
Palakkad	3.1	1.6
Adat	3.4	3.2
Kongad	3.1	3.4
Kozhikkod	3.1	2.3
Perinthalmanna	3.5	2.8
Attingal	3.5	3.6
Sakthan	3.8	4.4

Table 16. Quality and clean indices for rural waste composts made out of various feed stocks

Feed stock	Quality index	Clean index
Market waste	3.7	2.2
Paper waste	3.1	2.8
Mushroom waste	3.9	3.9
Coir pith	3.6	3.0
Medicinal waste	4.0	2.8
Agricultural waste	3.8	2.5
Vegetable waste	4.2	4.1
Mixed weeds	4.7	4.2

In the case of rural waste composts, the quality indices varied between 3.1 to 4.7. Relatively higher quality index was observed in the mixed weed compost and lowest in paper waste compost. All the rural waste composts were with very high quality indices.

The rural waste composts in the decreasing order of their quality were mixed weed > vegetable waste> ayurvedic medicinal waste>mushroom waste > agricultural waste > market waste > coir pith>paper waste.

Clean index

The values for clean index indicate the purity of composts. The clean index values in urban waste composts ranged from 1.2 to 4.4, the higher value with Sakthan compost and lower with Laloor and Kodungallur (Table 15). Normally, the composts with clean index > 4 is highly recommended for organic farming (Saha *et al*., 2010). In the present study, the urban waste composts only from Sakthan is found to have the desired values for clean index.

In the case of rural waste composts, values for clean index ranged from 2.2 to 4.2, the higher value with mixed weed compost and lower with market waste compost.

3.3.7. *Fertilizing potential*

The fertilizing potential of composts were evaluated based on the values generated for quality and clean indices. Saha *et al*. (2010) evaluated the fertilizing potential of composts based on the values for organic carbon, C:N, N, P and K. But in this study, we took account of all the parameters given in Table 14 to arrive at the fertilizing potential.

The composts with quality index >3.5 and clean index >4 were considered as “best quality” for organic farming owing to the high manurial value potential and low heavy metal content . Among the urban waste composts, the compost only from Sakthan qualified for this category of “best quality”.

Composts with quality index 3.1 - 3.5 and clean index >4 were with “very good quality” owing to the medium fertilizing potential and low heavy metal content. None of the urban waste compost qualified for under this category.

A compost to qualify as “good quality compost “ should have a quality index of >3.5 and clean index 3.1-4, indicating high fertilizing potential and medium heavy metal content.

A medium quality compost is supposed to have quality index 3.1-3.5 and clean index 3.1-4, with medium fertilizing potential and medium heavy metal content. The compost produced at Attingal Adat and Kongad belonged to this category.

The composts with quality index < 3.1 and clean index <3 can not be used for organic farming due to low fertilizing potential and the content of heavy metals beyond the permissible limit. Accordingly, urban composts from Laloor, Kodungallur, Vilappinsala, Chalakkudy, Palakakd, Kozhikkode and Perinthalmanna are not suited for organic farning.

In the case of rural composts, mixed weed and vegetable waste composts were in the category of “best quality. The compost produced from mushroom waste were in the category of “ good quality”. Rural composts produced from market waste, paper waste, coir pith, ayurvedic medicinal waste and agricultural waste were not qualified for organic farming, owing to the low value for clean index.

Effect of urban waste dumping on accumulation of heavy metals and other contaminants in soils and plants

CHAPTER 4
EFFECT OF URBAN WASTE DUMPING ON ACCUMULATION OF HEAVY METALS AND OTHER CONTAMINANTS IN SOILS AND PLANTS

4.1. Introduction

Sensitisation of general public through social media on the contaminated food chain triggered by the use of toxic agricultural chemicals, leading to social ill health and malignant diseases has paved the away for a drastic move towards the production of safe food through organic farming in Kerala. Even though, the organically produced food products are supposed to be free from the residues of toxic chemicals, the organic manures, especially those produced through unscientific methods and contaminated feed stocks are reported to contain toxic levels of heavy metals and pathogens, which may invariably worsen the social health conditions still further. Inadequate supply of traditional organic amendments has prompted the use of recycled urban organic wastes for the production of crop produce. Even though, the recycled urban wastes are available in plenty, the effect of continuous application of urban waste on soil, and plant is not yet studied in the State. It is assumed that, continuous application of urban waste compost for organic farming on a same land for a long period of time may simulate the condition of an open dumpyard area, where the land is continuously loaded with urban wastes. Thus the present study was designed in such a way to find out the long term effect of urban waste on soil characteristics of dumpyard area and accumulation of toxic heavy metals in plants. The study also looked into the influence of leachate from waste on soil and water bodies in the surrounding areas. Details on the study areas, methodology, results obtained etc. are explained in the following paragraphs.

4.2. Materials and Methods

4.2.1. *Study area*

Sites for the study were selected at urban waste dump yard area at Laloor ($10^0$30'54.5" N and $76^0$11'14.5" E) in Thrissur and at Theruvusala ($10^0$45'56.9'' N and $76^0$41'22.1''E) in Palakkad (Fig. 2).

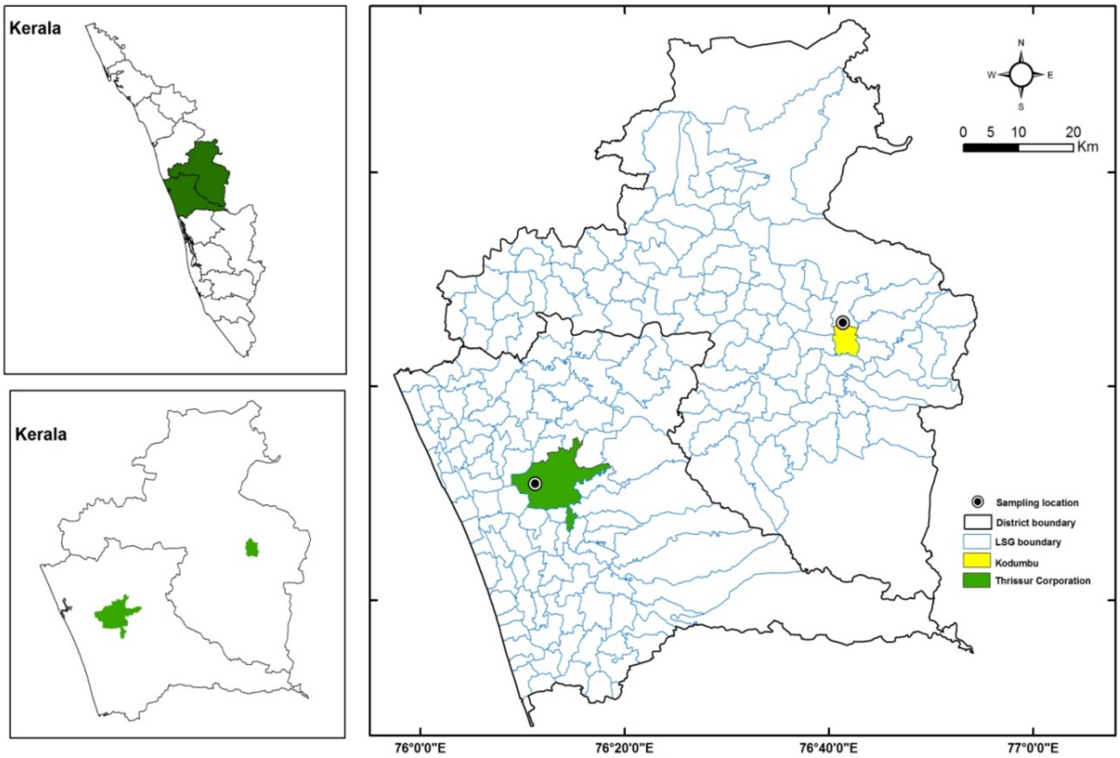


Fig. 2. Location map of study areas

The urban waste dumpyard area at Laloor is situated three kilometres away from Thrissur town. Laloor was selected as waste dumping site of Thrissur town during the period of Sakthan Thampuran, about 150 years ago. The man who brought dead bodies and stool became the first son of Laloor. About 160 ton of wastes per day were being dumped in the open yard of Laloor without any segregation till 2012. But currently, no more wastes are dumped in the dumpyard sites because of the strong protests from the public. Since 2012, the decomposed urban waste in the dumpyard area is sold as organic manure without any knowledge about their quality. During monsoon seasons, rain water that falls on this waste heaps run down through the decayed wastes and this leachate contaminate the surface and ground water in the surrounding areas.

Municipal wastes of Palakkad are dumped in Theruvusala, situated near Koottupatha (Palakkad-Walayar road), five kilometres away from Palakkad town. Palakkad municipality generates about 70 ton wastes per day. Out of this, 10 ton of organic wastes are used for composting since 2007 and the rest of the wastes are dumped at 5.86 acres of land at Theruvusala. Municipal wastes include all types of organic and inorganic wastes and they were not segregated properly.

4.2.2. *Effect of urban waste dumping on soil characteristics*

4.2.2.1. *Collection of soil samples*

Representative soil samples from 0-20 and 20-40 cm depths were collected from the two study areas to determine the initial soil characteristics. There were a total of thirty six samples per site. Soil samples were air dried, powdered, sieved through 2mm sieve and kept ready for analysis.

4.2.2.2. *Laboratory analysis*

The processed samples were analyzed for pH, electrical conductivity, organic carbon, available nutrients such as N, P, K, Ca, Mg, Cu, Fe, Mn, Zn and heavy metals such as Cd, Pb, Cr and Ni by adopting standard procedures as described below.

pH

The pH of soil water suspension (1:2.5) was determined using digital type Cyber scan 510 pH meter (Jackson,1958).

Electrical conductivity

Electrical conductivity of soil water suspension (1:2.5) was measured using ELICO conductivity meter (Jackson,1958).

Organic carbon

Organic carbon was estimated by sulphuric acid and potassium dichromate wet digestion (Wakley and Black, 1934) as described by Jackson (1958).

Nitrogen

Available N was estimated by alkaline permanganate method (Subbiah and Asija, 1956).

Phosphorous

Available P was extracted by Bray No.1 extractant (0.03 *N* NH_4F + 0.025 *N* HCl soil solution ratio 1:10 (period of extraction 5 minutes) and the P content was determined colorimetrically by ascorbic acid reduced molybdophosphoric blue colour method in hydrochloric acid systems (Watanabe and Olsen, 1965).

Exchangeable bases (K, Ca and Mg)

Exchangeable K, Ca and Mg were estimated from neutral normal ammonium acetate extract of the soil. Five g of soil was extracted with neutral normal ammonium acetate (1:5) for 10 minutes, filtered and the filtrate was used to determine K using digital type Elico (CL-360) flame photometer (Jackson,1958). The same filtrate was used to estimate Ca and Mg (Piper, 1966) using atomic absorption spectrophotometer (Varian, 240).

Available micronutrients

Available Fe, Mn, Zn and Cu were determined using 0.1 N HCl as the extractant for acid soils and DTPA for neutral and alkaline soils (soils with pH 6.5 and above).The elements in solution are estimated (Lindsay and Norvell, 1978) by atomic absorption spectrophotometer (Varian 240).

Total heavy metals

Half a gram of the sample was taken in a digestion tube and 10 ml con. H_2SO_4 and a pinch of salicylic acid was added to the weighed sample. This mixture was kept overnight and digested using a block digester (Kel plus) in a digestion chamber by adding H_2O_2 in every two hours, at a temperature of 340 ^{0}C till the sample was clear. After the completion of digestion, the digestion tubes were taken from the block and allowed to cool. Each digested sample was transferred to 100 ml standard flask and made up to the mark with distilled water (Black *et al*., 1965). Content of Cd, Pb, Cr and Ni were determined (Carbonell *et al.,* 2009b) by feeding the samples to Atomic Absorption Spectrophotometer **(**Varian, 240**)**.

Available heavy metals

Available heavy metals were determined by feeding the DTPA extract (Lindsay and Norvell, 1978) of the samples to Atomic Absorption Spectrophotometer (Varian, 240).

Fractions of heavy metals

Fractions of heavy metals such as exchangeable, bound to iron and manganese oxides, bound to organic matter and residual forms were determined BCR (European community Bureau of Reference) method (Ure *et al*., 1992).

4.2.2.3. *Indicators of pollution*

Pollution index

Pollution index was calculated by dividing the concentration of metals in refuse soil by the concentration of metals in the reference soil.

Enrichment factor

Enrichment factor was calculated using the following equation

$$EF_X=[X_S/E_S(ref)]/[X_C/E_C(ref)]$$

Where Xs is the content of examined element in the examined environment, Es (ref) is the content of examined element in the reference environment,

Xc is the content of the reference element in the examined environment,

Ec (ref) is the content of the reference element in the reference environment.

Quantification of the degree of pollution

To quantify the degree of pollution in the refuse dump soils, the geoaccumulation index (Igeo) was calculated (Forstner *et al*., 1993)

Igeo=ln(Cn/1.5*Bn)

Where Cn- measured concentration of metal in the refuse dump soil

1.5 back ground matrix correction factor

Bn- back ground value of heavy metal

4.2.3. *Effect of urban waste dumping on accumulation of heavy metals in plants*

4.2.3.1. *Experimental details*

To study the effect of urban waste dumping on accumulation of heavy metals, a field experiment was conducted at urban waste dumpyard area at Laloor in Thrissur and Theruvusala at Palakkad during 2012. Different plant species belonging to edible crops (*Amaranthus tricolor),* grass *(Vetiveria zizionoids),* tree grass (*Bambusa bamboo*) and timber tree (*Tectona grandis*) were selected for the experiment. Seedlings of above plant species were selected from KFRI nursery. The experiment was conducted in plots of size 20m*20m by adopting completely randomised design, replicated three times. One month old seedlings were planted during the month of June 2012, at a spacing of one metre, each block containing 20 seedlings. The growth of plants were monitored for a period of three months in amaranth, twelve months in vetiver and twenty four months in bamboo and teak.

4.2.3.2. *Biomass estimation*

The species selected for the experiment were with different life cycle. Hence the biomass estimations were done at varying intervals. In the case of bamboo and teak, biomass was collected at 3, 6, 12 and 24 months growth period, biomass of vetiver at 3,

Amaranth Vetiver

Teak Bamboo

Plate 3. Field experiment at Laloor

Amaranth

Vetiver

Teak

Bamboo

Plate 4. Field experiment at Palakkad

6 and 12 months intervals and that of amaranth at three months growth. The plant samples were collected, washed thoroughly and separated into root, stem and leaves. Then they were oven dried at a temperature of 65 ± 5^0C. Dried samples of root, stem and leaves were weighed separately.

4.2.3.3. *Determination of heavy metals in plants*

Concentration of heavy metals

In order to estimate the content of heavy metals in plants 0.5g of the powdered samples were digested in sulphuric acid-salicylic acid-hydrogen peroxide mixture (1:1 ratio) and made up to 100 ml. Content of heavy metals such as Cd, Pb, Cr and Ni in the digested samples were determined using Atomic Absorption Spectrophotometer (Varian, 240).

Uptake of heavy metals

Uptake of heavy metals by the plants were calculated using following formula.

Uptake= Plant biomass * Heavy metal concentration in the plant

4.2.3.4. *Quantification of phyto extraction efficiency of heavy metals*

Phyto extraction was the most useful phytoremediation techniques for removal of heavy metals and metalloids from polluted environment. The efficiency of phyto extraction was quantified by calculating bioconcentration factor (Zhuang *et al*., 2008) and translocation factor (Padmavathiamma and Li, 2007).

Bioconcentration factor

Bioconcentration factor was calculated using the following formula.

Bioconcentration Factor (BCF) $= C_{\text{harvested tissue}} / C_{\text{soil}}$

Where $C_{\text{harvested tissue}}$ is the concentration of the target metal in the plant harvested tissue and C_{soil} is the concentration of the same metal in the soil (substrate).

Translocation factor

Translocation factor indicates the efficiency of the plant in translocating the accumulated metal from its roots to shoots.

Translocation Factor (TF) = C_{shoot}/C_{root}

Where C, is the concentration of the metal in plant shoots and C $_{root}$ is concentration of the metal in plant roots.

4.2.4. *Effect of urban waste leachate on soil and water quality of surrounding area*

Dumping of urban wastes at a particular site for many years is supposed to contaminate nearby soils and water bodies due to the flow of leachate from wastes at different stages of decomposition.

4.2.4.1. *Effect of urban waste leachate on soil*

In order to study the effect of leachate on soils of surrounding area, surface soil samples (0-20 cm) were collected from 0 m, 100 m, 250m and 500 m away from dumyard area in North, South, East and West directions, replicated three times.

Laboratory analysis of soils samples for various chemical characteristics such as pH, EC, OC, Cd, Pb, Cr and Ni were carried out by adopting the procedure described under the sections 4.2.2.2.

4.2.4.2. *Effect of urban waste leachate on water*

In order to study the influence of urban waste leachate on quality of surrounding water bodies, water samples were collected from 12 open wells, which meet the drinking requirements of families residing in the nearby housing colonies at Laloor and Palakkad. Water samples were collected from the wells, located at 100 m, 250 m and 500 m away from the dumpyard areas. The containers used for sampling were pre cleaned, non reactive plastic bottles (1 liter) and sterilized bottles (100 ml) for physico – chemical and microbiological analysis respectively.

Laboratory analysis

The water samples were analysed for various parameters by adopting standard procedures as detailed below.

pH

pH of the water samples was determined using digital type Cyber scan 510 pH meter (APHA, 2012).

Electrical conductivity

Electrical conductivity was measured using ELICO conductivity meter (APHA, 2012).

Total hardness

Complexometry was the principle used for the determination of total hardness. About 50 ml of the sample was taken in a conical flask, two ml of NH_4Cl NH_4OH buffer of pH 10 was added and titrated against 0.01M EDTA using Eriochrome Black -T as the indicator. At the end point, the colour changed from wine red to blue (APHA, 2012).

Calcium and magnesium hardness

Determination of calcium hardness is also based on the principle of complexometry. To the 50 ml water sample, one ml of NaOH was added and titrated against 0.01M EDTA using mureoxide indicator. At the end point, color changed from pale pink to violet. The magnesium hardness was obtained by subtracting calcium hardness from total hardness. Calcium and magnesium concentrations in the water samples were estimated from their corresponding hardness (APHA, 2012).

Chloride

Chloride concentrations were determined by argentometric method. About 50 ml of the sample was taken in a conical flask. One ml potassium chromate indicator was added and titrated against standard silver nitrate solution. At the end of the reaction, colour changed from yellow to reddish orange (APHA, 2012).

Nitrate-N

Cadmium reduction technique followed by spectrophotometry was used for the estimation of Nitrate-N. Nitrate was reduced almost quantitatively to nitrite, which then passed through a column containing amalgamated cadmium fillings. The nitrite thus produced was determined by diazotizing with sulphanilamide and coupling with N (1-Naphthyl) ethyl diamine to form a high colored azo dye, which was measured colorimetrically. The amount of azo dye formed will be proportional to the initial concentration of nitrate–N over a wide range of concentrations. The estimation of dye was made at 543nm using spectrophotometer (APHA, 2012).

Phosphate- P

Ammonium molybdate – spectrophotometer was the method used for the estimation of phosphate- P. Ammonium molybdate reacts with phosphate to form molybdophosphoric acid, which was reduced to blue colored complex 'molybdenum blue' by the addition of stannous chloride. Fifty ml of sample was taken to which 2ml ammonium molybdate solution and 5 drops of stannous chloride solution were added. After 10 minutes, but before 12 minute the colour was measured using spectrophotometer at 690 nm (APHA, 2012).

Heavy metals

Heavy metals such as Cu, Zn, Fe, Mn, Cd, Pb, Cr and Ni in the water samples were determined using Atomic Absorption Spectrophotometer (APHA, 2012).

Statistical analysis

The data obtained for various treatments from the experiments were subjected to analysis of variance (ANOVA) (Panse and Sukhatme, 1985) using statistical soft ware package SPSS (Norusis, 1988). Mean comparison test was carried out through DMRT (Duncan's Multiple Range Test). The correlation analysis was conducted by Pearson correlation and the level of significance was set at $p<0.05$ (two-tailed).

4.3. Results and Discussions

4.3.1. *Effect of urban waste dumping on soil characteristics*

The soil samples collected from the two study areas were analysed for various physical and chemical properties and the data obtained are presented and discussed here under.

4.3.1.1. *Basic soil properties*

The data provided in the Table 17 indicated that the surface soils of waste dumping area at Laloor were slightly acidic in reaction with a mean pH value of 6.1 and the acidity increased at subsurface layer (pH 5.9). A higher content of organic carbon at surface (2.8 per cent) and subsurface layer (2.4 per cent) were also noticed. But the electrical conductivity was low (1 dSm^{-1} to 0.97 dSm^{-1}) at both surface and subsurface layers.

Table 17. Effect of urban waste composts on basic characteristics of soils

Location	Depth (cm)	pH	EC (dSm^{-1})	OC (%)
Laloor	0-20	6.1	1.0	2.8
	20-40	5.9	0.97	2.4
Palakkad	0-20	6.8	1.13	3.5
	20-40	6.7	1.2	3.1

At Palakkad, pH of the soil was neutral in reaction with medium level of electrical conductivity (1.13 - 1.2 dSm^{-1}) and very high content of organic carbon (3.1 to 3.5 per cent) at both surface and sub surface layers. Usually, the pH of dumpyard compost mainly depends up on the quality of the waste dumped into such areas. The variation in the pH observed between the two sites is attributed to the wide variation in the quality of wastes. At both sites, pH was decreasing with increasing depth. Goswami and Sarma (2008) also found a decrease in pH with increase d soil depth in the dump yard site of Guwahati city in Assam. Different factors like leaching action of wastes, soil nature, mechanical composition, etc. may be responsible for the decrease in pH.

As expected, continuous application of urban organic wastes for a long period of time resulted in the enrichment of soil organic carbon at both sites. Goswamy and sarma (2008), also reported a high level of organic carbon (1.85 %) in the dumpyard area of Guwahati city in India.

4.3.1.2. *Primary and secondary nutrients*

The soils of waste dumping area at Laloor was with a high content of N (672 kg ha^{-1}) in the surface layer and medium in sub surface (448 kg ha^{-1}). But the content of P was very high (77.1 - 75.3 kg ha^{-1}) in both layers. Moderate levels of K, (238.6 to 207.2 kg ha^{-1}) Ca (1963 to 1923 mg kg^{-1}) and Mg (983 to 951 mg kg^{-1}) at both the layers were also noticed.

Table 18. Effect of urban waste dumping on the content of available primary and secondary nutrients in soils

Sampling sites	Depth (cm)	N (kg ha^{-1})	P (kg ha^{-1})	K(kg ha^{-1})	Ca (mg kg^{-1})	Mg (mg kg^{-1})
Laloor	0-20	672	77.1	238.6	1963	983
	20-40	448	75.3	207.2	1923	951
Palakkad	0-20	1568	101.5	303.7	4300	510
	20-40	896	75.9	283.1	3700	374

But at Palakkad, higher levels of N (1568 kg ha^{-1}), high levels of P (101.5 kg ha^{-1}) , moderate levels of K (303.7 kg ha^{-1}), adequate levels of Ca (4300 to 3700 mg kg^{-1}) and Mg (510 to 374 mg kg^{-1}) were observed at both the layers. Similar observations were also made by Saritha *et al* (2014) in Coimbatore. Compared to Laloor, content of all the nutrients were higher at Palakkad. The data in general revealed increased soil fertility with respect to the major nutrients at both sites, definitely the contribution from the added organic wastes. Similar hike in the major nutrients in the soils of dumpyard areas was also reported by Irishimah *et al*. (2003) and Goswamy and Sarma (2008).

4.3.1.2. *Micronutrients*

The content of available micro nutrients such as Fe, Cu, Mn and Zn in the soils of both study areas are given in Table 19. The content of these nutrients at both the sites ranged from 2036.1 to 2165.8 mg kg^{-1}, 38.2 to 41.2 mg kg^{-1}, 126.7 to 146.4 mg kg^{-1} , 111.4 to 129.3 mg kg^{-1} respectively. With respect to Fe, Cu, Mn and Zn the data in general indicated a very high content of all the micro nutrients at both the sites. Compared to normal soils, relatively higher levels of all the micronutrients were observed, which was the contribution from the wastes.

Table 19. Effect of urban waste dumping on the content of available micro nutrients in soils

Location	Depth (cm)	mg kg^{-1}			
		Cu	Zn	Mn	Fe
Laloor	0-20	38.2	113.8	128.6	2135.8
	20-40	41.2	111.4	126.7	2036.1
Palakkad	0-20	40.8	129.3	146.4	2165.8
	20-40	39.6	128.6	145.3	2164.3

4.3.1.3. *Heavy metals*

The content of plant available heavy metals such as Cd, Pb, Cr and Ni ranged between 2.39 to 3.43 mg kg^{-1} , 22.1 to 22.4 mg kg^{-1}, 13.5 to 14.9 mg kg^{-1}, 11.9 to 12.3 mg kg^{-1} respectively at Laloor and 3.22 to 4.24 mg kg^{-1}, 38.7 to 39.8 mg kg^{-1}, 14.1 to 15.6 mg kg^{-1}, 13.7 to 14.3 mg kg^{-1} respectively at Palakkad. The data in general revealed

Table 20. Effect of urban waste dumping on the availability of heavy metals in soils

Location	Depth (cm)	mg kg^{-1}			
		Cd	Pb	Cr	Ni
Laloor	0-20	3.43	22.4	14.9	11.9
	20-40	2.39	22.1	13.5	12.3
Palakkad	0-20	4.24	39.8	15.6	14.3
	20-40	3.22	38.7	14.1	13.7

relatively low content of these metals at both the sites. Most of the heavy metals are supposed to be chelated with organic carbon, making them less available for plant uptake. But there is a chance of release of this heavy metals from the organic bound and other forms, once the available pool starts depleting.

Table 21. Effect of urban waste dumping on the total content of heavy metals in soils

Sampling sites	Depth (cm)	Total (mg kg^{-1})			
		Cd	Pb	Cr	Ni
Laloor	0-20	26.3	630.0	164.7	135.3
	20-40	23.4	542.6	185.6	148.9
Palakkad	0-20	39.5	546.2	153.2	113.3
	20-40	35.4	489.7	168.3	103.8

Unlike in the content of available heavy metals, the total content of Cd, Pb, Cr and Ni. were very high at both the sites and the values ranged from 23.4 to 26.3 mg kg^{-1}, 542.6 to 630 mg kg^{-1}, 164.7 to 185.6 mg kg^{-1}, 135.3 to 148.9 mg kg^{-1} respectively at Laloor and 35.4 to 39.5 mg kg^{-1}, 489.7 to 546.2 mg kg^{-1}, 153.2 to 168.3 mg kg^{-1}, 103.8 to 113.3 mg kg^{-1} respectively at Palakkad. Very high content of heavy metals at both sites clearly demonstrate their accumulation in the forms, which are not readily available to plants. Potentially toxic elements in municipal solid waste could be due to a number of components including batteries, solder, wine bottle caps, old circuit boards etc. In addition, pigments and stabilisers in plastics also contribute potentially toxic elements (Richard and Woodbury 1992). Luo *et al.* (2011) also reported large amounts of heavy metals in the local environment due to the intensive uncontrolled processing of e-waste. Illera *et al*. (2000) observed considerably increased levels of Pb and Cd due to the application of bio solid and municipal solid waste as a consequence of the high contents and high availability of these metals in mixed solid waste (MSW) landfill.

4.3.1.3. *Speciation of heavy metals*

The mobility and toxicity of heavy metals mainly depend on metal speciation in the environmental medium. The chemical speciation of heavy metals in the soil samples were carried out using a modified sequential chemical extraction procedure to provide further information on metal distribution with different operationally defined geochemical phases (Table 22). Fractions of heavy metals such as exchangeable, bound to iron and manganese oxides, bound to organic matter, and residual forms were estimated and the data are detailed below. The values obtained for different forms of heavy metals at two different depths were averaged to indicate content in a depth of 0-40 cm.

Exchangeable metal fractions

The exchangeable fractions of heavy metals are easily available to plants and the content of this fraction with respect to Cd, Pb, Cr and Ni at Laloor were 3.22, 13.19, 1.82, 8.51 mg kg^{-1} and those at Palakkad were 3.08, 16.32, 4.44, 8.41 mg kg^{-1} . Among the two study areas, the exchangeable metal fraction of Cd was high at Laloor, while Pb, Cr and Ni were high at Palakkad.

Table. 22. Effect of urban waste dumping on different fractions of heavy metals in soils

Location	Heavy metals, mg kg^{-1}	Exchangeable	Bound to Fe & Mn oxides	Bound to organic matter	Residual
Laloor	Cd	3.22	4.50	5.54	2.27
Palakkad		3.08	3.56	4.10	3.34
Laloor	Pb	13.19	10.62	34.50	12.73
Palakkad		16.32	12.71	53.58	21.09
Laloor	Cr	1.82	3.35	24.38	82.96
Palakkad		4.44	5.31	18.48	79.9
Laloor	Ni	8.51	8.12	8.44	75.5
Palakkad		8.41	9.57	16.08	75.9

Metal forms bound to iron and manganese oxides

The forms bound to iron and manganese oxides with respect to Cd, Pb, Cr and Ni at Laloor were 4.50, 10.62, 3.35, 8.12 mg kg $^{-1}$ and those at Palakkad were 3.56, 12.71, 5.31, 9.57 mg kg $^{-1}$ respectively. Among the two study areas, this form of Cd was high at Laloor and those of Pb, Cr and Ni were high at Palakkad.

Metal forms bound to organic matter

Organic matter bound forms of Cd, Pb, Cr and Ni at Laloor were 5.54, 34.5, 24.38, 8.44 mg kg^{-1} and at Palakkad the values of this fraction were 4.10, 53.58, 18.48, 16.08 mg kg^{-1} respectively. Among the dumping sites, organic matter bound form of Cd and Cr were lower at Laloor and those of Pb and Ni were high at Palakkad.

Residual metal forms

Residual metal forms of Cd, Pb, Cr and Ni at Laloor were 2.27, 12.73, 82.96, 75.50mg kg^{-1} respectively and 3.34, 21.09, 79.9, 75.9 mg kg^{-1} respectively at Palakkad. Among the study areas, Cd, Pb and Ni were higher at Palakkad and Cr was higher at Laloor.

Among the various fractions of Cd, organically bound form dominated at both the sites. The order of abundance at Laloor was organic bound > iron and manganese bound > exchangeable > residual, and at Palakkad the order was organic matter > residual forms > iron and manganese bound > exchangeable .

In the case of Pb also organic bound forms dominated at both sites. The order of abundance of fractions of this metal was organic bound > exchangeable > residual > iron and manganese bound at Laloor and, organic bound >residual > exchangeable> iron and manganese bound at Palakkad.

But in the case of Cr and Ni there was a very high accumulation of residual metal forms at both the sites. The order of the abundance of Cr was residual > organic bound > iron and manganese bound > exchangeable at Laloor, and residual> organic bound > iron and manganese bound > exchangeable forms at Palakkad. The order of abundance of Ni was residual > exchangeable > organic bound > iron and manganese bound at Laloor, and residual > organic bound > iron and manganese bound > exchangeable forms at Palakkad.

Lu *et al* (2007) also found Cd in exchangeable form, Pb in reducible form and Ni predominantly in residual form in urban soils of Guangzhou, in China. As observed in this study, dominance of residual fractions of Cr and Ni were also reported by Lago *et al* (2013) in the soils of copper mines at Touro, Spain. Prasanth *et al* (2013) also reported the dominance of residual fraction of Ni in the soils of Koratty region in Kerala. But Aikpokpodion *et al* (2012) reported extractable fraction as most abundant in the case of lead and residual in the case of Cd in the soils of cocco plantation in Nigeria. Higher concentration of metals in the exchangeable phase would indicate high solubility and bioavailability than other metal bound forms.

4.3.1.3. *Percentage distribution of heavy metal fractions*

The percentage distribution of heavy metal fractions at both sites are represented in the Fig. 3. In the case of Cd, 21-22 % fractions were exchangeable, 25 – 29 % bound to Fe and Mn oxides, 29-36 % bound to organic matter and 14-24 % residual forms when

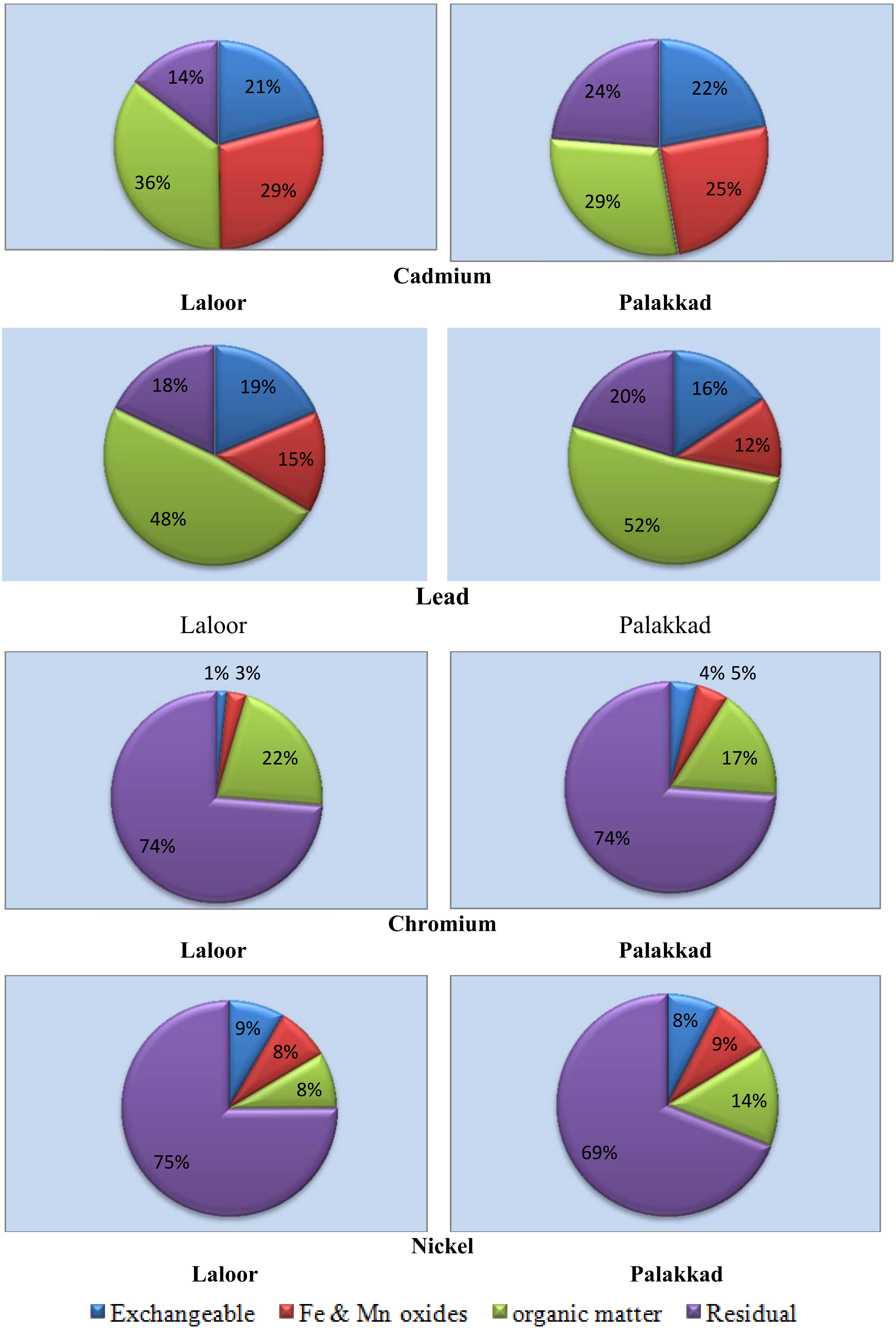


Fig. 3. Percentage distribution of various heavy metals in the study areas

both sites are considered together. With respect to Pb, 16-19 % fractions were exchangeable, 12-15 % bound to Fe and Mn oxides, 48-52 % bound to organic matter and 18-20 % residual forms.

But in the case of Cr, 74 % fractions were residual and only 17-22 % organic bound fractions at both the sites. The exchangeable fractions and those bound to Fe and Mn oxide were also very low, 1-4 % and 3-5% respectively. With respect to Ni, 69-75 % fractions were residual, 8-9 % exchangeable and Fe and Mn bound forms, and 8-14 % organic bound forms.

4.3.1.3. *Pollution Index*

Pollution index indicates the degree of contamination of each metal and it was calculated using the following formula and the data is provided in the Fig.4 .

Metal concentration in refuse soil/ Metal concentration in reference soil

The pollution index of Cd varied between 8.2 - 9.4, Pb between 6.5 - 9.1, Cr between 5.7 - 6.9 and Ni between 3.7 - 4.6 at both study areas.

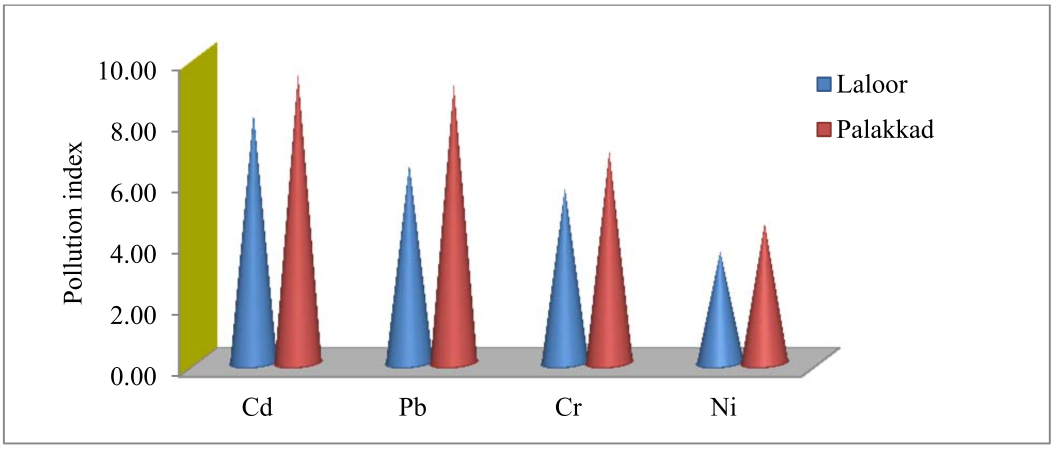


Fig.4. Pollution index of heavy metals in the study areas

Based on the values of pollution index, it is inferred that dumpyard areas of Palakkad is more polluted with respect to all heavy metals than Laloor. The order of heavy metals in the increasing order of pollution index at both the sites were Ni < Cr < Pb < Cd.

4.3.1.4. *Enrichment factor*

Enrichment factor is a tool to assess the degree of enrichment and comparing the contamination in different environment (Loska *et al*, 2003).

Enrichment factor was calculated using the following equation

$EF_X=[X_S/E_S(ref)]/[X_C/E_C(ref)]$, Where Xs is the content of examined element in the examined environment, Es (ref) is the content of examined element in the reference environment, Xc is the content of the reference element in the examined environment, Ec (ref) is the content of the reference element in the reference environment.

An element is regarded as a reference element (Fe) if it is of low occurrence variability and is present in the environment in trace amounts. It is also possible to apply an element of geochemical nature whose substantial amounts occur in the environment but has no characteristic effects i.e. synergism or antagonism towards an examined element.

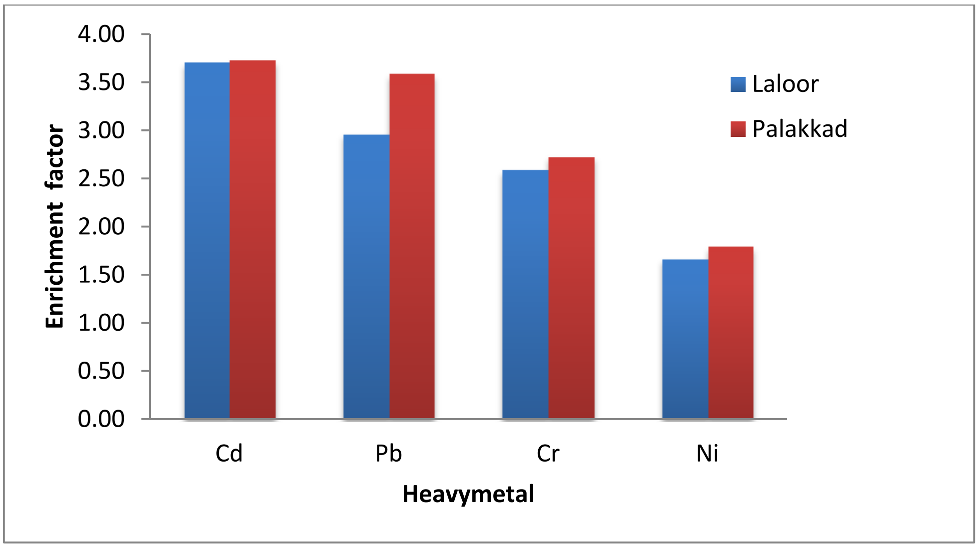


Fig.5. Enrichment factor of heavy metals in the study areas

Five contamination categories are recognized on the basis of the enrichment factor: EF < 2 indicates deficient to minimal enrichment; EF = 2-5 moderate enrichment; EF = 5-20 severe enrichment; EF = 20-40 very high enrichment; and EF > 40 extremely high enrichment, (Manno *et al*., 2006).

The values of enrichment factor varied between 3.71- 3.73 for Cd, 2.96 – 3.59 for Pb, 2.59 – 2.73 for Cr, and 1.66 – 1.79 for Ni at both the sites (Fig.5). The enrichment factor was very high for Cd, followed by Pb, Cr and Ni, which indicates high contamination due to cadmium. Usually the contamination due to Cd occurs from agricultural waste, sludges and fertiliser. (McLaughlin *et al.,* 1999) arrived at a conclusion that Cd was the most hazardous contaminant in terms of food-chain contamination.

4.3.7. *Quantification of the degree of pollution*

To quantify the degree of pollution in the refuse dump soils, the geoaccumulation index, I geo was calculated using the following equation formulated by Forstner *et al*.(1993).

Table 23. Classification of pollution based on geo accumulation index

Igeo	Igeo class	Contamination intensity
>5	6	Very strong
>4-5	5	Strong to very strong
>3-4	4	Strong
>2-3	3	Moderate to strong
>1-2	2	Moderate
$>0^{-1}$	1	Incontaminate to moderate
<0	0	Practically uncontaminated

Forstner et al.,1993

Igeo = ln(Cn/1.5*Bn),

Where Cn- measured concentration of metal in the refuse dump soil

Bn- back ground value of heavy metal, 1.5 back ground matrix correction factor

The data generated for the geo- accumulation index of each heavy metal based on the metal concentration in refuse soil and back ground soil are given in the Table 24. The values of geo- accumulation index derived for different heavy metals conveyed that

Table 24. Classification of pollution in the study area based on geo accumulation index

Study area	Metal	Refuse soil	Background soil	Igeo	Class
Laloor	Cd, $mgkg^{-1}$	68.45	8.50	5.45	Very strong
Palakkad		64.73	7.01	6.29	Very strong
Laloor	Pb, $mgkg^{-1}$	71.04	10.99	4.33	Strong to very strong
Palakkad		103.71	11.49	6.06	Very strong
Laloor	Cr, $mgkg^{-1}$	259.20	45.90	3.82	Strong
Palakkad		206.21	30.21	4.62	Strong to very strong
Laloor	Ni, $mgkg^{-1}$	180.07	49.71	2.43	Moderate to strong
Palakkad		193.96	42.82	3.04	Strong

degree of pollution with respect to Cd (5.5 – 6.3) was very strong , and it was strong to very strong in the case of Pb (4.3 – 6.1), strong to very strong for Cr (3.8 – 4.6) and moderate strong to strong for Ni (2.4 – 3.3) at both dumpyard areas. Based on the values of geo accumulation index, it is inferred that degree of pollution was high in the case of Cd followed by Pb, Cr and Ni at both sites. Contamination of soils with Cd is attributed to anthropogenic factors than pedogenic factors.

4.3.2. *Effect of urban waste dumping on accumulation of heavy metals in plants*

4.3.2.1. *Biomass*

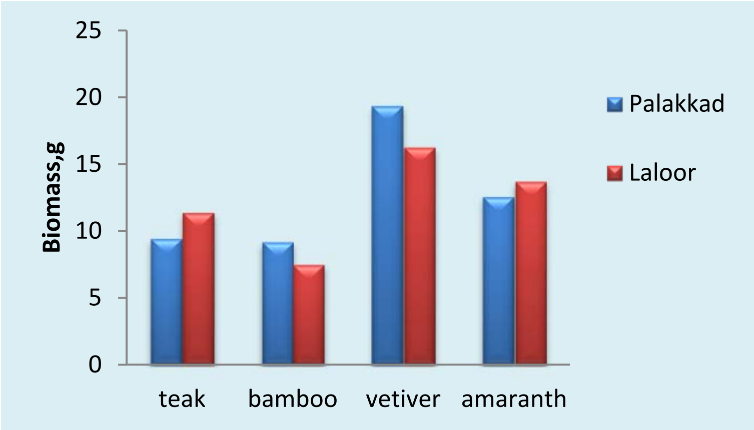
Biomass of various plant species at different growth stages were determined to quantify the accumulation of heavy metals in the plants. On comparing the biomass at three months after planting (Fig.6), it was observed that the highest biomass was recorded in vetiver (16.3-19.4 g) followed by amaranth (12.6-13.7 g), teak (9.4-11.4 g) and lowest in bamboo (7.5-9.2 g) at both study areas.

Within a period of six months growth, higher biomass was recorded in vetiver (113.5-114.3 g) followed by bamboo (93.3-116.4 g) and teak (48.4-57.2g) at Laloor and Palakkad. Biomass data for amaranth was not available during this growth stage because, the vegetative growth of amaranth got completed within three months after planting.

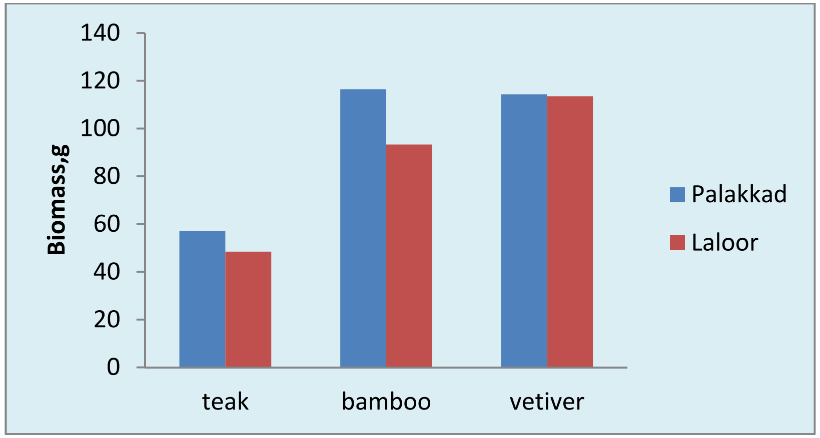
At 12 months after planting, biomass was higher in bamboo (295-380.2 g), followed by vetiver (232.4-263.6 g), and teak (105.5-116.8 g) respectively at both study areas.

After 24 months, bamboo recorded higher biomass (541.4-685.5 g) compared to teak (199.2-172.3 g) at both study areas. Biomass data for vetiver was not available during this period because, it attained harvestable stage within 12 months after planting.
The biomass of various plant parts of each plant species at different growth stages were also determined to quantify the accumulation of heavy metals in various plant parts (Fig. 6).

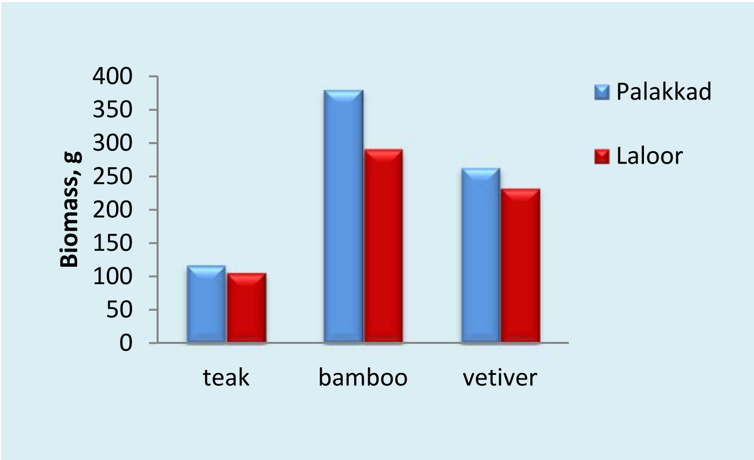
With respect to amaranth, higher weight was recorded in case of stem (17.3-20.9 g), followed by leaf (12.1 – 13.2 g) and root (7.2 -8.1 g) at both study areas.



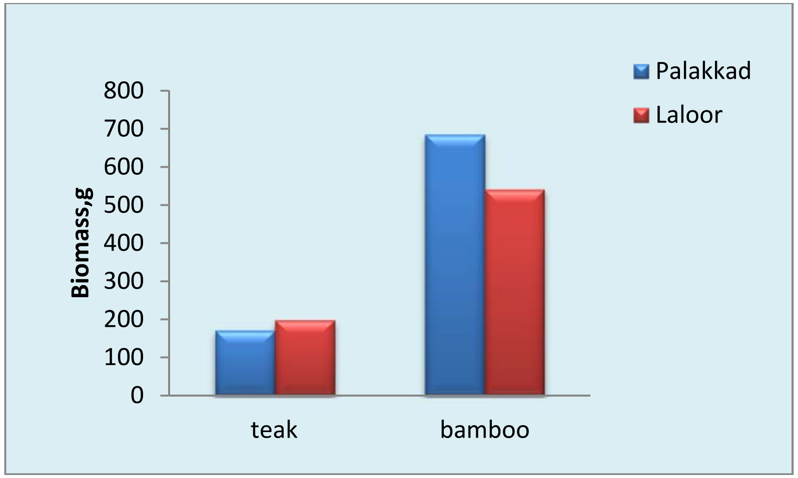
3 months after planting



6 months after planting



12 months after planting



24 months after planting

Fig.6. Biomass of various plant species at different stages of growth

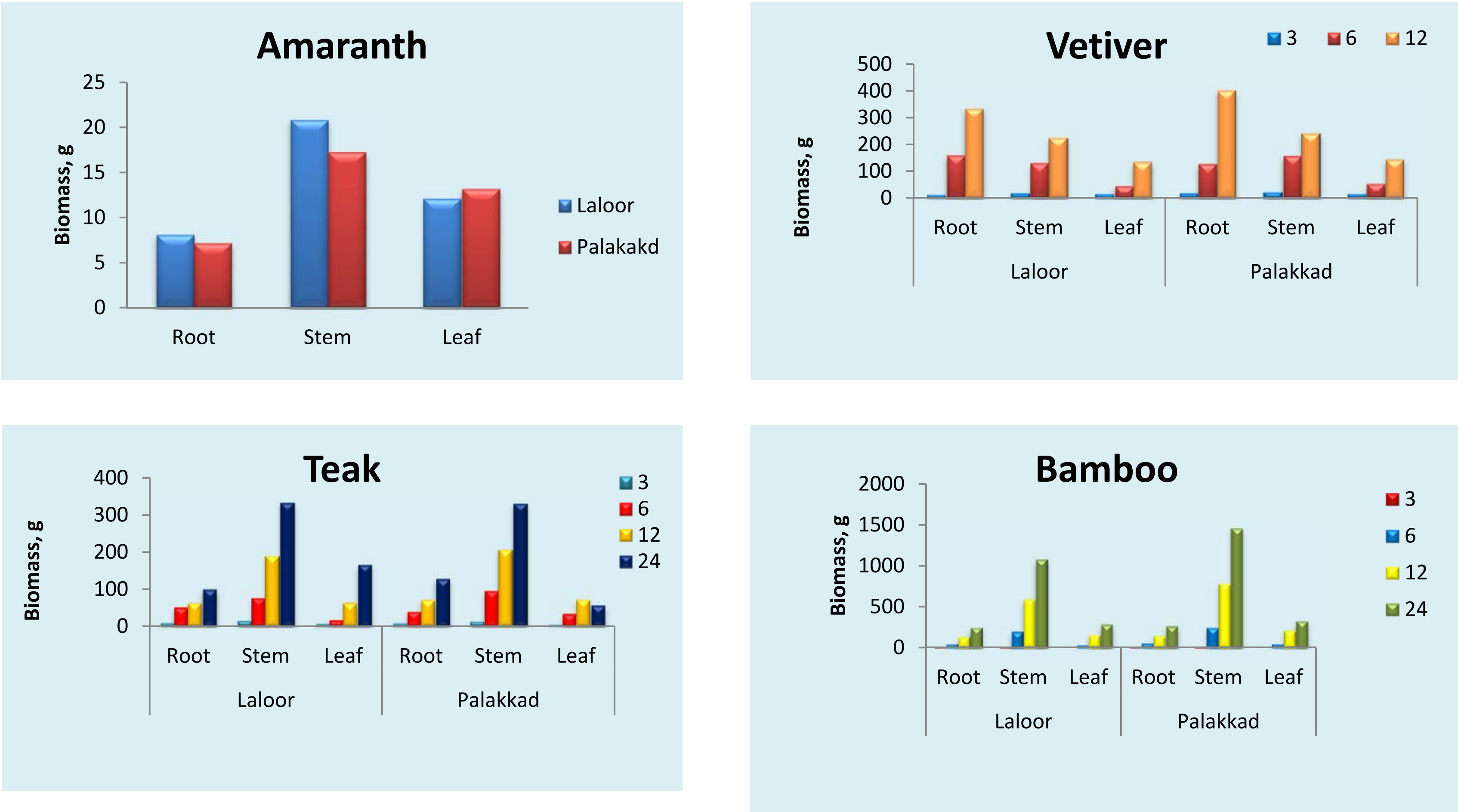


Fig.7 . Biomass of various plant parts of amaranth, vetiver, teak and bamboo

In vetiver, at all the growth stages (3, 6 and 12 months after planting), biomass was highest in root (335 - 403 g), followed by stem (225.8 – 242.3 g) and leaf (136.2 -145.4 g) at Laloor and Palakkad.

In the case of teak, during 3-24 months growth period, stem recorded higher biomass 16.13-333.4 to 14 – 331.5 g , compared to root (10-100.4 to 9.4 – 128.2 g) and leaves (8-166.7 to 5-57.1 g) at Laloor and Palakkad. The biomass was significantly increasing with increase in the growth period at both sites.

In the case of bamboo, within 3- 24 growth period, the higher biomass was in stem (1081.8- 1461.4 g) followed by leaves (292 – 329.5 g) and roots (250.4 – 265.6 g) at both dumpyard areas.

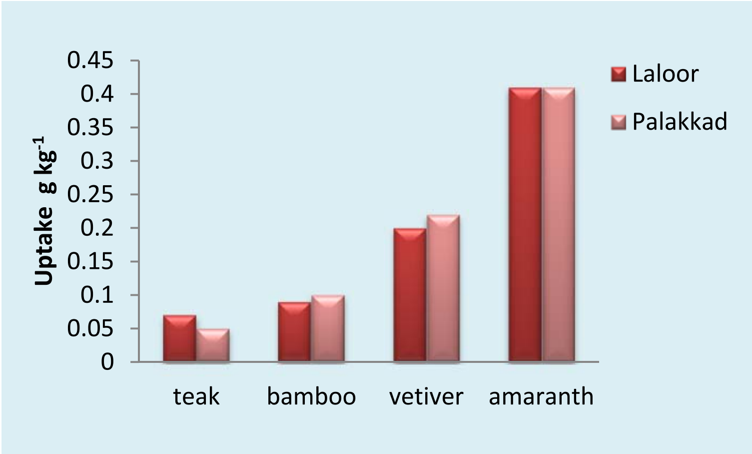
4.3.2.2. *Accumulation of heavy metals in plants*

Accumulation/uptake of heavy metals (Cd, Pb, Cr and Ni) in various plant species were estimated by multiplying the concentration of each metal with the biomass. The data on the concentration of heavy metals are provided in the appendix 1 and the uptake in the Fig. 8.

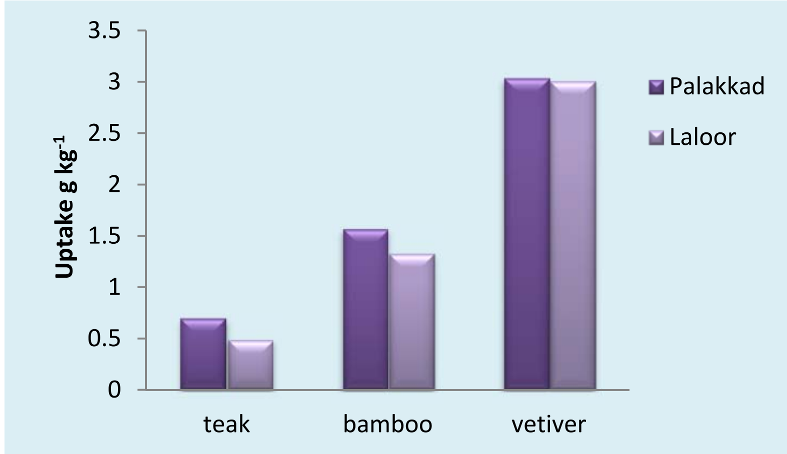
Cadmium

Three months after planting, uptake of Cd was higher in amaranth (0.41- 0.41 g kg^{-1}) followed by vetiver (0.19-0.2 g kg^{-1}), bamboo (0.09-0.1 g kg^{-1}) and teak (0.05-0.07 g kg^{-1}) at Laloor and Palakkad.

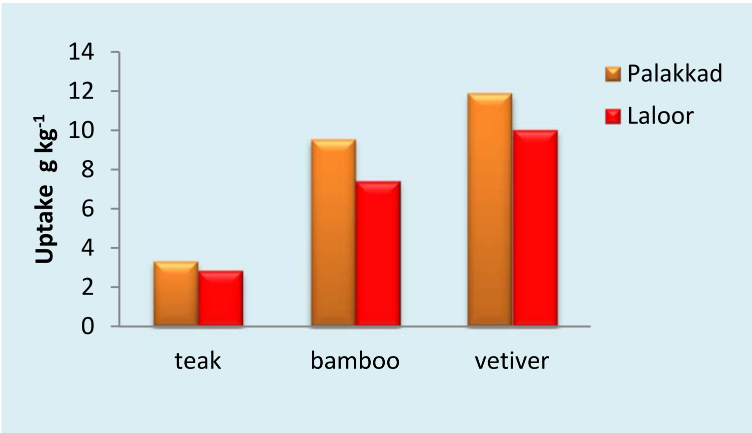
At 6 and 12 months after planting, vetiver recorded higher uptake of Cd (3.01-11.9 g kg^{-1}) compared to bamboo (1.33-9.6 g kg^{-1})) and teak (0.49-3.4 g kg^{-1}) at Laloor and Palakkad. At 24 months after planting, bamboo (24.3-34.5 g kg^{-1}) recorded higher uptake of Cd compared to teak (9.7-9.1 g kg^{-1}). In general, it is inferred from the data that uptake of Cd was increasing significantly with increase in the growth of all the species at both the sites.



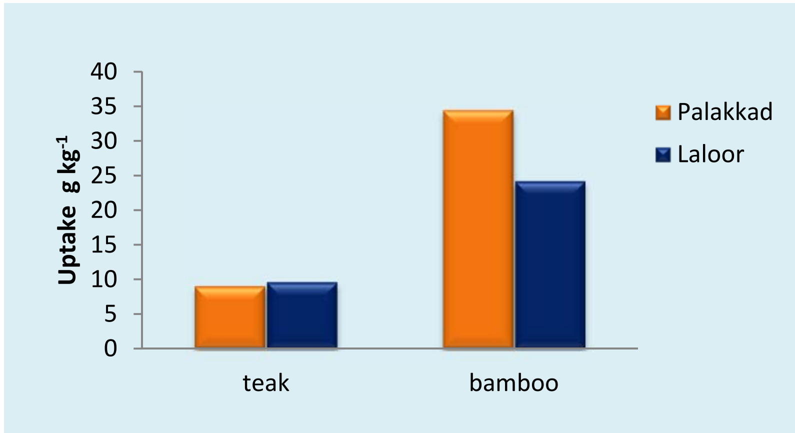
3 months after planting



6 months after planting

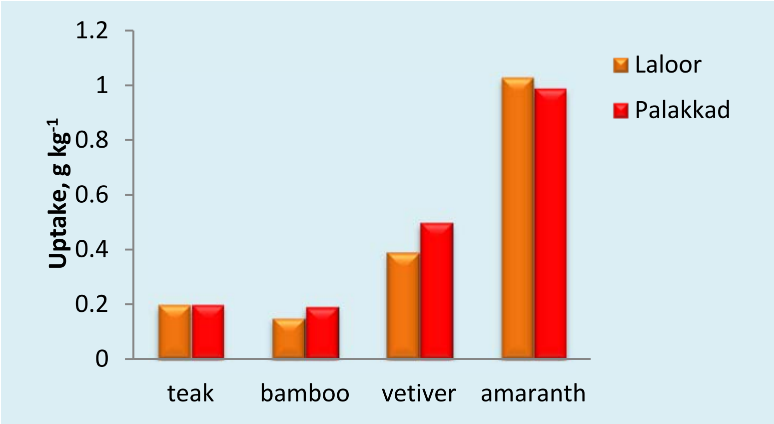


12 months after planting

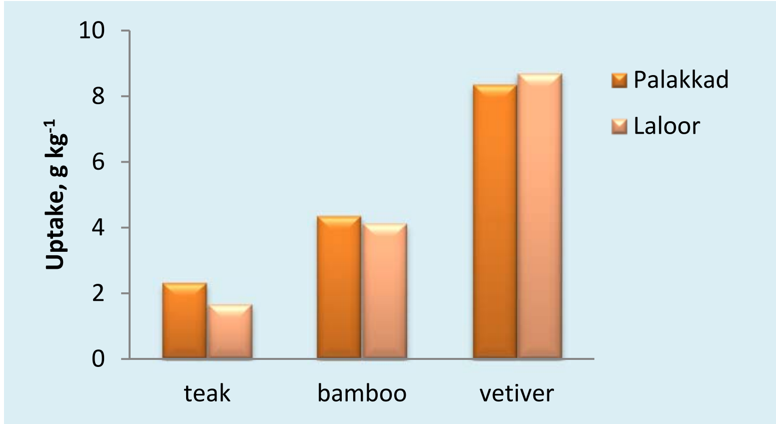


24 months after planting

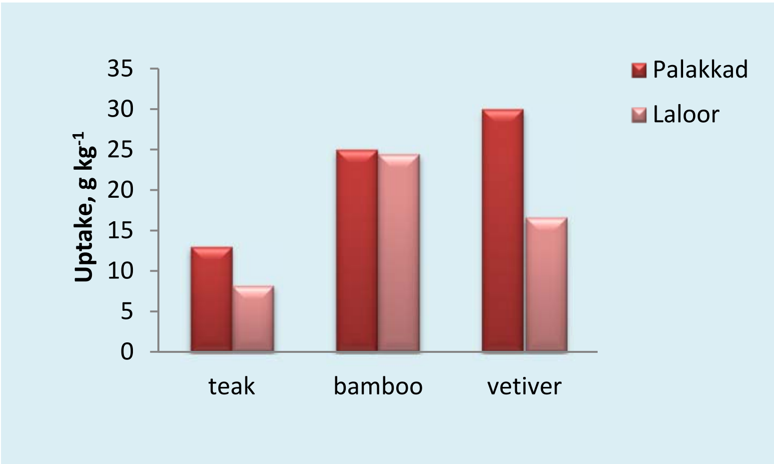
Fig.8. Uptake of Cd by amaranth, vetiver, teak and bamboo at different stages of growth



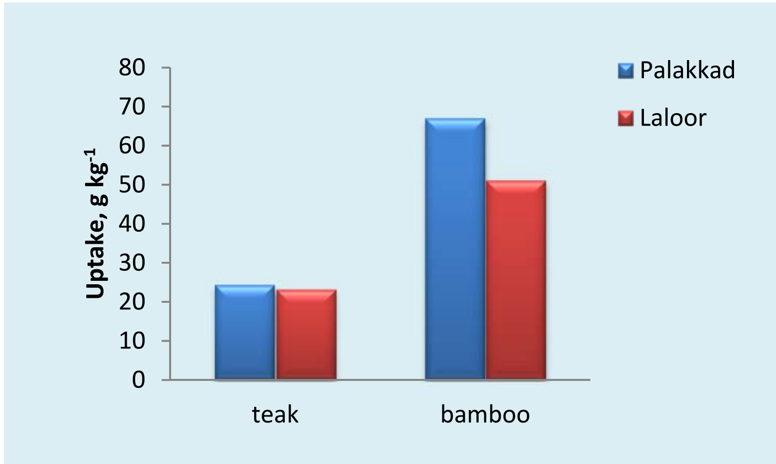
3 months after planting



6 months after planting



12 months after planting



24 months after planting

Fig.9. Uptake of Pb by amaranth, vetiver, teak and bamboo at different stages of growth

Lead

In the case of Pb, at 3 months after planting, amaranth recorded higher uptake ((1.03-0.99 g kg^{-1}) followed by vetiver (0.39-0.5 g kg^{-1}), teak (**0.2** -0.2g kg^{-1}) and bamboo (0.15-0.2 g kg^{-1}) at Laloor and Palakkad.

Within 6 months period, uptake of Pb was higher in vetiver (8.7-8.4 g kg^{-1}) followed by bamboo (4.1- 4.4 g kg^{-1}) and teak (1.7-2.3 g kg^{-1}) at both study areas. At 12 months after planting, bamboo (24.5-25 g kg^{-1}) showed higher uptake of Pb at both study areas, whereas in vetiver, uptake of Pb was highest in Palakkad (30 g kg^{-1}) compared to Laloor (16.7 g kg^{-1}). At 24 months after planting also, bamboo recorded higher uptake of Pb (51.2-67 g kg^{-1}) compared to teak (23.3-24.5 g kg^{-1})). In general, it was seen that uptake of Pb was increasing significantly with increase in the growth of all the species at both study areas.

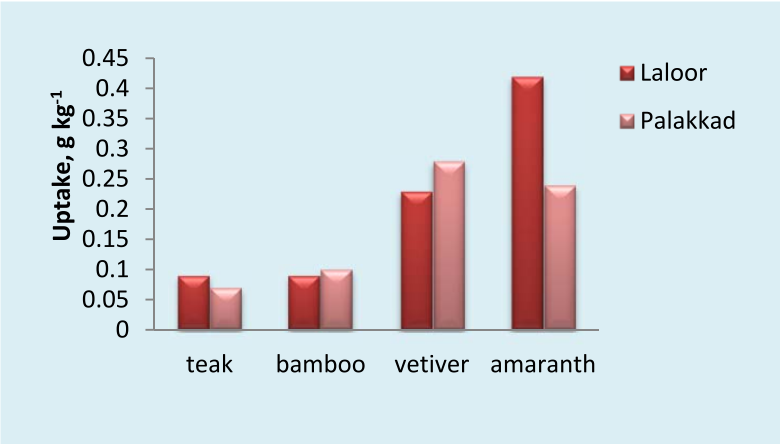
Chromium

Among the plant species, uptake of Cr at 3 months growth stage was higher in amaranth and vetiver (0.24-0.42 g kg^{-1}) & (0.23-0.28 g kg^{-1}) followed by bamboo (0.09-0.1 g kg^{-1}) and teak (0.07-0.09 g kg^{-1}) at Laloor and Palakkad.

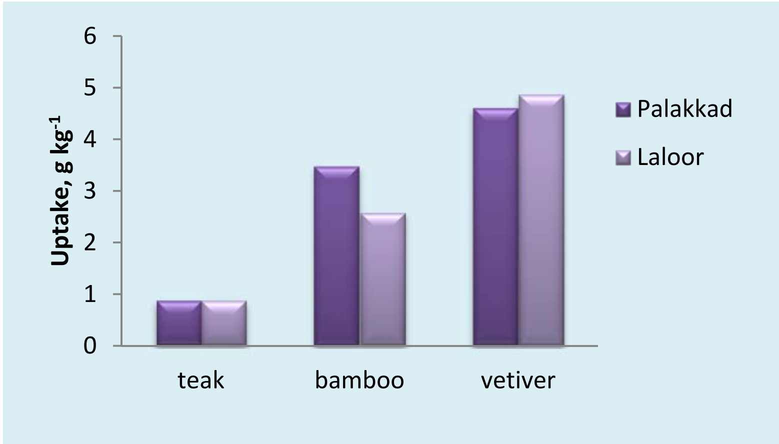
At 6 and 12 months after planting, the uptake of Cr increased significantly in vetiver (4.6-16.1 g kg^{-1}) followed by bamboo (2.6-21 g kg^{-1}) and teak (0.9-3.4 g kg^{-1}) at Laloor and Palakkad. But within a period of 24 months, higher uptake of Cr was in bamboo (42.1-52.5 g kg^{-1}) followed by teak (12-16 g kg^{-1}) at both study areas. With increase in growth period, uptake of Cr also got increased in all the plant species.

Nickel

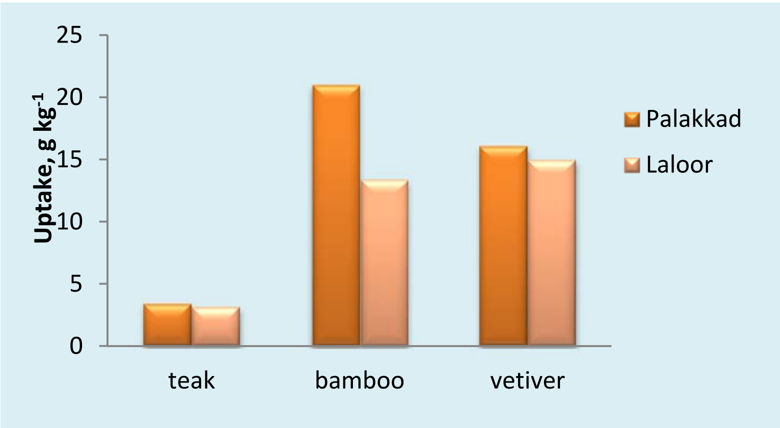
In the case of Ni, uptake was higher in amaranth (0.89 - 0.98g kg^{-1}) followed by vetiver (0.57- 0.68 g kg^{-1}), bamboo (0.17-0.25 g kg^{-1}) and teak (0.12- 0.13 g kg^{-1}) at 3 months after planting. At 6 and 12 months after planting, the uptake of Ni was higher in vetiver 9.5- 10.39 g kg^{-1} to 26.6- 34.1 g kg^{-1} and bamboo 4.5-5.7 g kg^{-1} to 29.8 - 37.5 g kg^{-1} and low in teak 1.87-2.5 g kg^{-1} and 10.6-11.2 g kg^{-1}). At 24 months after planting also, bamboo recorded higher uptake of Ni (64 - 84.9 g kg^{-1}) compared to teak (26.9-28.8 g kg^{-1}). Data in general revealed increased uptake of Ni with increase in the growth of all the species at both study areas.



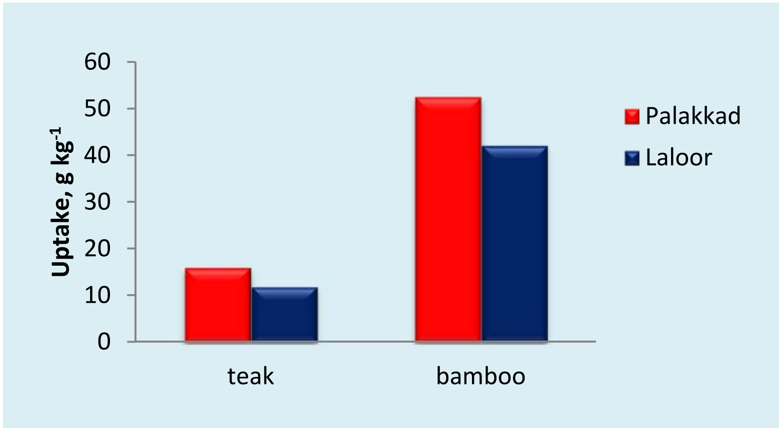
3 months after planting



6 months after planting

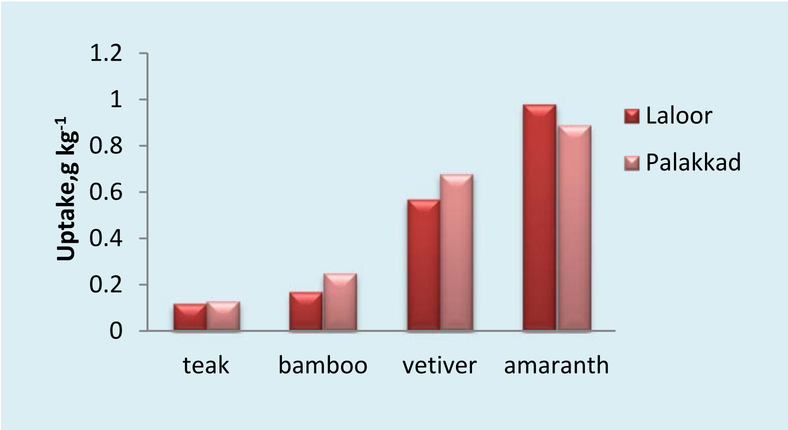


12 months after planting

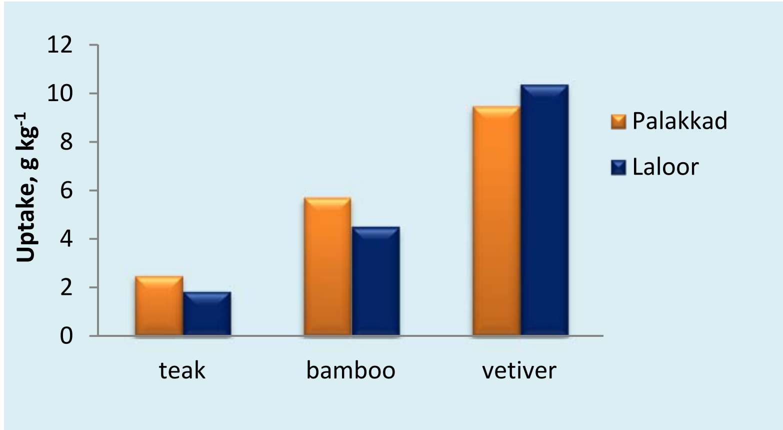


24 months after planting

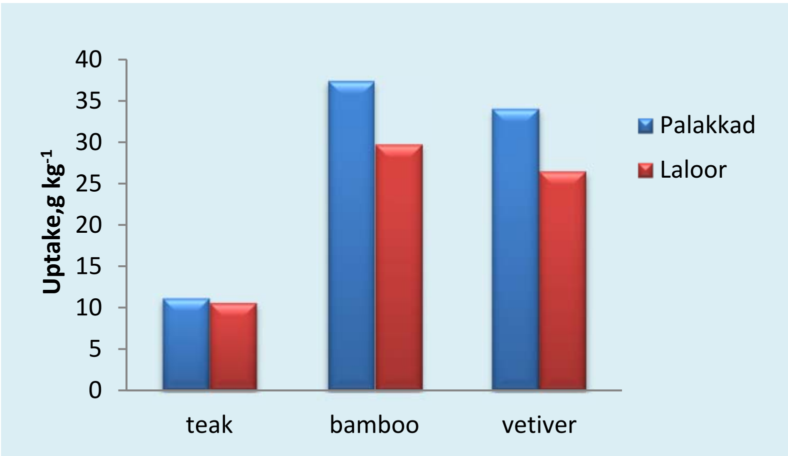
Fig.10. Uptake of Cr by amaranth, vetiver, teak and bamboo at different stages of growth



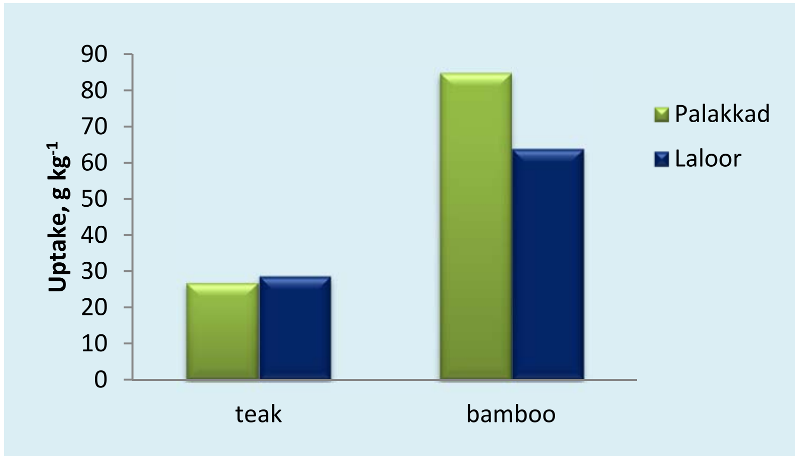
3 months after planting



6 months after planting



12 months after planting



24 months after planting

Fig.11. Uptake of Ni by amaranth, vetiver, teak and bamboo at both study areas

4.3.2.3. *Models for predicting heavy metal accumulation*

The data obtained on the accumulation of heavy metals in the previous study revealed that bamboo and teak are capable of absorbing large quantities of heavy metals from the soil. These plants, being the non edible and long duration species, can be used for phyto remediation. In this context , it has become essential to predict the heavy metal accumulation by bamboo and teak during their entire growth period. Hence an attempt was made to develop an equation based on the biomass and uptake. For predicting the biomass yield, the equation developed by Jijeesh (2014) was used for bamboo and Sreejesh (2016) for teak. Jijeesh (2014) predicted a model for calculating the biomass of bamboo using girth value, LnY= -2.858 +1.518*Ln G and using girth and height value predicted the model Ln Y= -2.756 +0.713*LnG+1.024 *Ln H for calculating biomass. Using this equation 6 year growth biomass of bamboo was 31.66 kg and 7 year growth biomass was 51.33 kg. Sreejesh (2016) developed a model for predicting the biomass of teak, Volume of biomass* specific gravity

$$V = \frac{A1+A2}{2} * L$$

Using this equation, biomass in five year old teak was 65.38 kg, in 10 year 146.82 kg and in 30 year 358.9 kg.

Using the above prediction models for biomass, the regression equations for predicting the uptake of Cd, Pb, Cr and Ni was developed for bamboo and teak, and they are given in Table 25.

Table 25. Models for predicting heavy metal accumulation in bamboo and teak

Correlation	Teak		Bamboo	
	Equation	R^2	Equation	R^2
K_{bm}/Cd	K_{up}=0.054x-1.578	0.923	K_{up}=0.048x-3.016	0.931
K_{bm}/Pb	K_{up}=0.139x-3.389	0.964	K_{up}=0.099x-4.23	0.980
K_{bm}/Cr	K_{up}=0.078x-2.547	0.871	K_{up}=0.078x-3.988	0.964
K_{bm}/Ni	K_{up}= 0.0161x-4.302	0.949	K_{up}= 0.125x-5.011	0.987

4.3.2.4. *Quantification of phytoextraction efficiency of heavy metals*

Phytoextraction is considered as the most useful phytoremediation technique for removal of heavy metals and metalloids form polluted environment. The efficiency of phytoextraction can be quantified by calculating bioconcentration factor (Zhuang *et al*., 2008) and translocation factor (Padmavathiamma and Li, 2007). Both BCF and TF are important in hyperaccumulators for phytoextraction of heavy metals. The evaluation and selection of plant sps. depends on BCF and TF values (Translocation factor greater than one indicates the translocation of metals from roots to above ground parts (Jamil *et al*., 2009). Some studies proved that both BCF and TF greater than one have the potential to be used as phyto extraction (Yoon *et al*., 2006).

Bioconcentration factor

Bioconcentration factor indicates the efficiency of a plant species in accumulating a metal into its plant parts from the surrounding environment (Ladislas *et al*., 2012).

Bioconcentration Factor (BCF) =$C_{\text{harvested tissue}}/C_{\text{soil}}$

Where $C_{\text{harvested tissue}}$ is the concentration of the target metal in the plant harvested tissue and C_{soil} is the concentration of the same metal in the soil (substrate).

The values for BCF generated in this study (Fig. 12) indicated that, in amaranth, higher BCF was obtained for Pb (2.29-3.35), followed by Cd (1.14-1.34) Ni (1.15-1.15) and Cr (0.33-0.36) within a period of three months, at both study areas. This convey the fact that, among the various heavy metals, absorption and accumulation of Pb is very high in amaranth and the metals in the decreasing order of absorption are Pb> Cd>Ni>Cr.

In vetiver, higher BCF value was obtained for Pb (0.73-0.83), followed by Cd (0.41-0.45) Ni (0.39-0.43) and Cr (0.16-0.16), at three months after planting at both study areas. Within 6 months duration also, the BCF values were higher for Pb (2.03-2.92) followed by Ni (1.07-1.09), Cd (0.96-1.25) and Cr (0.34-0.45) at both areas. The BCF values after 12 months growth was also high for Pb (2.29-3.37) followed by Cd (1.72-2.16), Ni (1.31-2.37) and Cr (0.64-1.25) at Laloor and Palakkad.

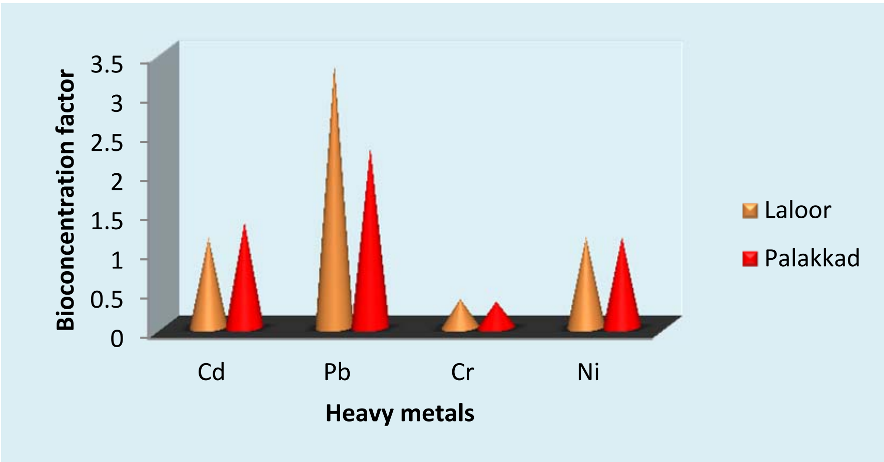
The higher BCF value in teak at three months growth stage was for Pb (0.47-0.6), followed by Cd (0.25-0.28) Ni (0.18-0.22) and Cr (0.12-0.12 at both study areas. After 6 months period also, it was higher for Pb (0.96-1.56) followed by Ni (0.24-0.58), Cd (0.41-0.5) and Cr (0.18-0.46) at both areas. At twelve months after planting also lead was taken up up in more quantity (2.98-3.64) followed by Cd (1.08-1.46), Ni (1.57-1.8) and Cr (0.32-0.87) at Laloor and Palakkad. The order of decreasing BCF at 24 months after planting was Pb (3.92-4.5) followed by Ni (2.09-2.22), Cd (1.89-2.02) and Cr (0.66-1.11) at both the sites.

In case of bamboo, higher BCF was seen in Pb (0.57-0.59), followed by Cd (0.52-0.59), Ni (0.37-0.45) and Cr (0.17-0.19) at three months growth stage at both study areas. At six months stage also, higher BCF for Pb (1.25-2.18) followed by Ni (0.94-0.95), Cd (0.67-0.69) and Cr (0.33-0.47) at both areas. After a period of twelve months also lead was taken up Pb (2.35-4.71) followed by Cd(1.26-1.63), Ni (1.91-2.19) and Cr (0.56-1.62) at Laloor and Palakkad. The order of decreasing BCF after 24 months growth was Pb (3.02-4.71) followed by Ni (2.13-2.21), Cd (2.21-2.57) and Cr (0.96-1.3) both at Laloor and Palakkad.

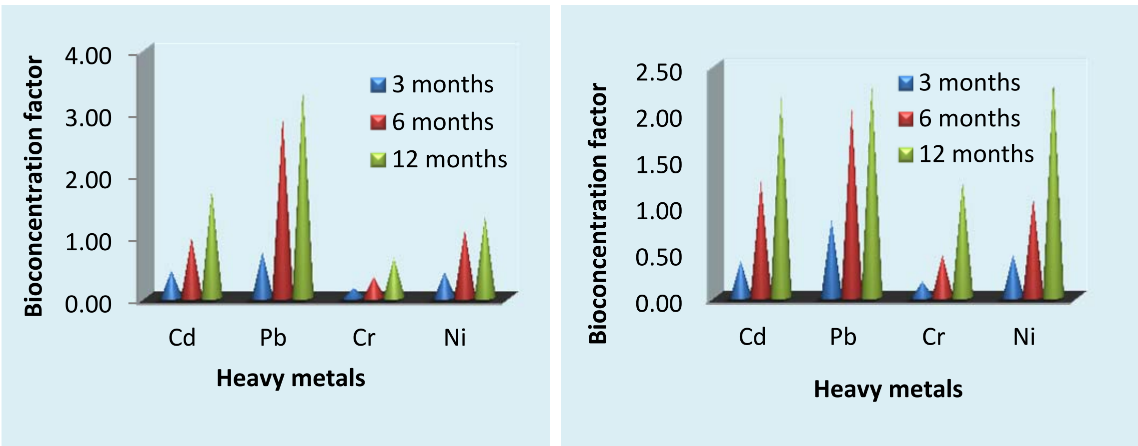
Thus the results in general conveyed that among the heavy metals, absorption of Pb was higher in all the plant species at all the stages of growth, followed mainly by Cd, Ni and lowest in the case of Cr.

On comparing the BCF values of heavy metals among various plant species, it is realised that at three months after planting, amaranth absorb relatively more Pb, Cd, Ni and Cr followed by vetiver, bamboo and teak. After a period of six months, it was higher in vetiver followed by bamboo and teak. The higher absorption of heavy metals at 12 and 24 months after planting was in bamboo compared to teak.

Based on the results obtained in this study it is inferred that, among the various heavy metals, plants absorb larger quantity of Pb followed by Cd, Ni and Cr irrespective of the nature of plant species. It is assumed to be due to the relatively higher concentration of Pb in the soil compared to other heavy metals. But this concept was not found true in the case of Cd. Even though, the content of Cd in the soil was low in comparison with Ni and Cr, it is absorbed by the plants in relatively higher quantity. The data on percentage distribution of heavy metal fractions in the soils of the study area (4.3-1.3 %) had revealed that exchangeable fraction of Cd (18- 23 %) was higher in comparison with the same fractions of Cr (1-2 %) and Ni (4-5 %). Usually, the exchangeable fractions of metals are easily available and absorbed by the plants compared to other fractions. This clearly substantiate the reason for higher absorption of Cd by all the plants inspite of its lesser content in the soil.



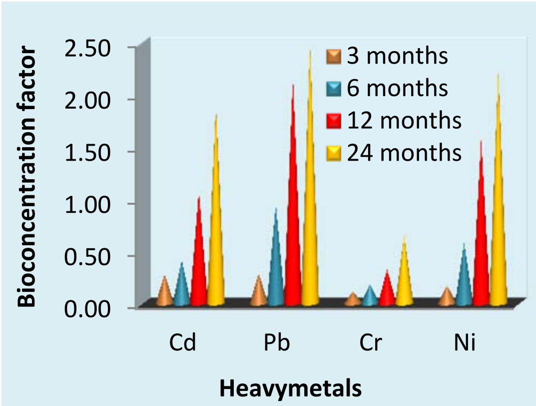
Amaranth

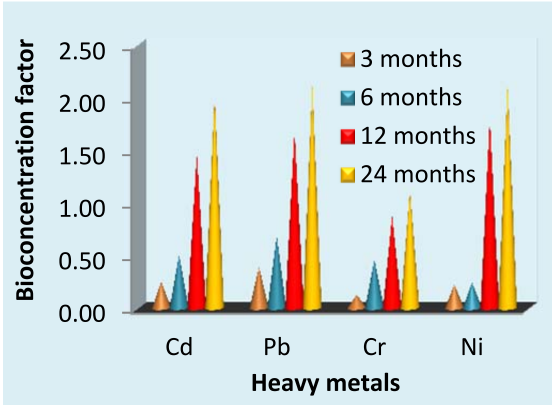


Vetiver

Laloor Palakkad

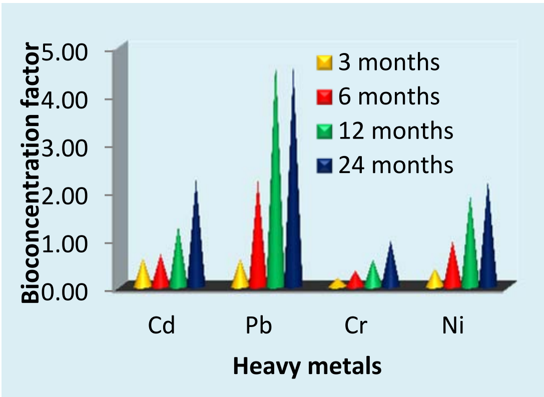
Fig.12. Bioconcentration factor of heavy metals in amaranth and vetiver

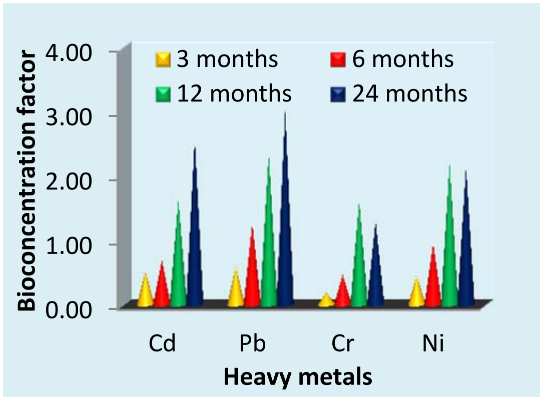




Teak

Laloor Palakkad





Bamboo

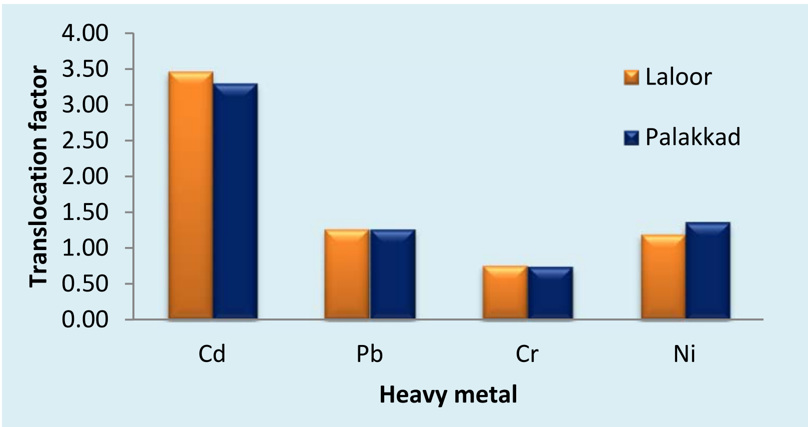
Laloor Palakkad

Fig. 13. Bioconcentration factor of heavy metals in teak and bamboo

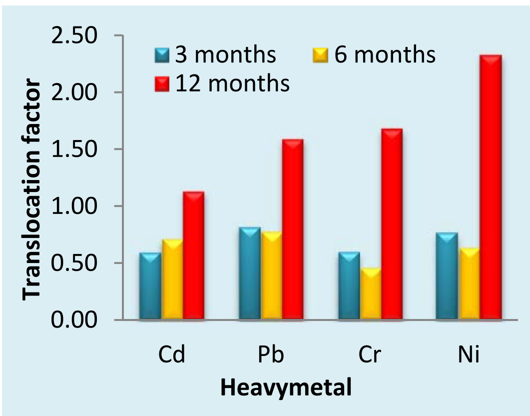
Absorption of heavy metals by various plant species was also found to differ at various stages of growth. Higher absorption of metals at three, six, twelve and twenty four months was noticed in amaranth, vetiver, bamboo and teak respectively. This point out the fact that shorter the lifecycle of plants, greater will be the absorption of metals during the initial stages of growth. The evaluation and selection of plants for phytoremediation purposes depend on BCF value (Wu *et al*., 2011). Plant species with BCF greater than 1 have the potential to be used for phytoextraction (Yoon *et al*., 2006). According to Cluis (2004) hyper accumulators have BCF greater than 1, sometimes reach in 50-100. Naseem *et al*. (2009) reported that BCF was a convenient and reliable way for quantifying the relative difference in the bioavailability of heavy metals to plants.

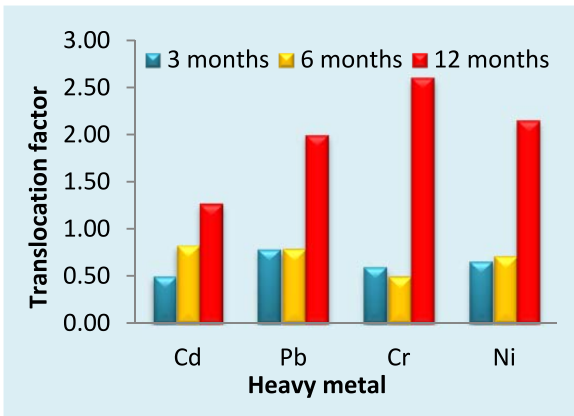
Translocation Factor (TF)

Translocation factor indicates the efficiency of the plant in translocating the accumulated metals from its roots to shoots (Padmavathiamma and Li, 2007). Translocation factor indicates the efficiency of the plant in translocating the accumulated metal from its roots to shoots.



Amaranth





Vetiver

Laloor   Palakkad

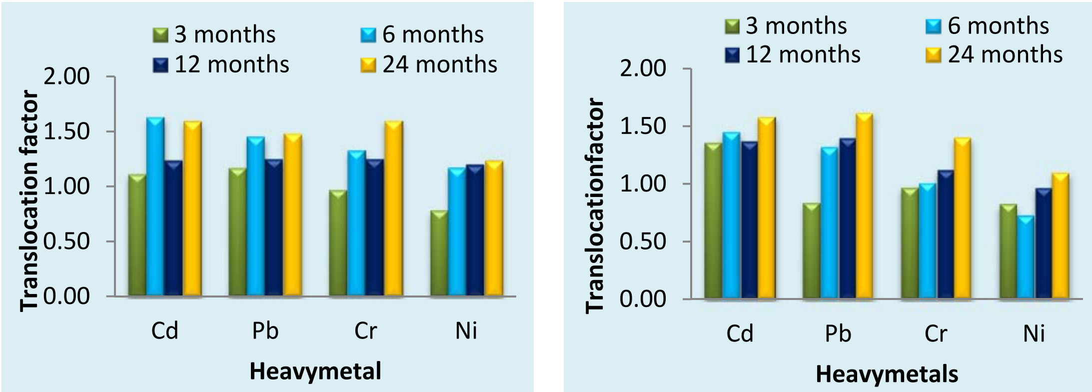
Fig.14. Translocation factor of heavy metals in amaranth and vetiver

Translocation Factor (TF) = C_{shoot}/C_{root}

Where C shoot is concentration of the metal in plant shoots and C root is concentration of the metal in plant roots.

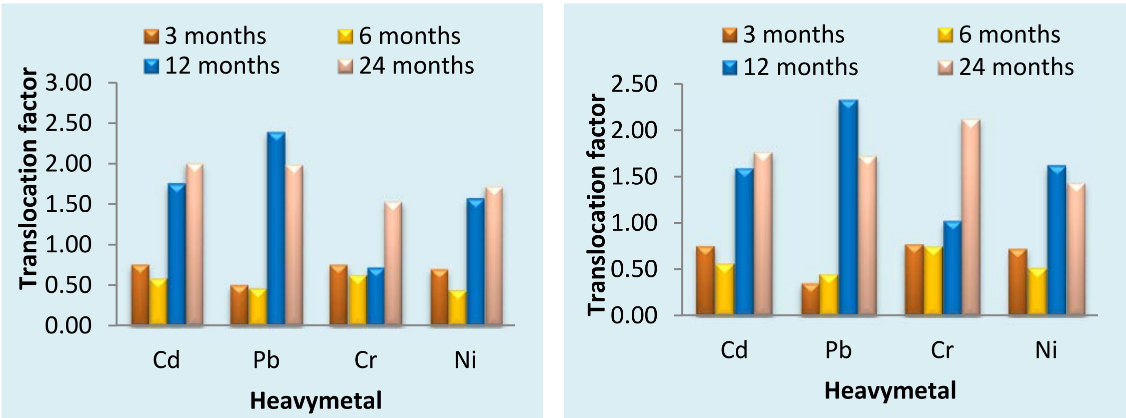
In the case of amaranth, the value for translocation factor of Cd, Pb, Cr and Ni was 3.31-3.47 , 1.27-1.27, 0.74- 0.76-, 1.2-1.36 respectively at both study areas. Among the metals, the translocation factor was higher in Cd and the metals in the decreasing order of translocation factor was Cd<Pb<Ni<Cr. The data revealed that accumulation of heavy metals in amaranth was higher in shoot and low in root.

In the case of vetiver, the values for translocation factor of Cd, Pb, Cr and Ni were 0.51-0.6 , 0.79-0.82, 0.6-0.6, 0.66-0.77 at three months after planting, at both study areas. After a period of six months, the values for Cd, Pb, Cr and Ni were (0.71-0.83), (0.78-0.79), (0.6-0.6) and (0.64-0.72) respectively at both study areas. Similarly at 12 months after planting, the values of translocation factor for Cd, Pb, Cr and Ni were (1.14-1.27), (1.59-2), (1.68-2.61) and (2.16-2.33) respectively at both study areas. Among the metals, the translocation factor was high for Pb and the metals in the decreasing order was Pb< Cr<Cd<Ni. In teak, the values for translocation factor of Cd, Pb, Cr and Ni were 1.11-1.36 , 0.84-1.17, 0.97-0.97, 0.79-0.83 at three months after planting, at both study areas. After a period of six months, the values ranged between 1.45-1.63, 1.32-1.45, 1.01-1.33 and 0.73-1.17 respectively for Cd, Pb, Cr and Ni at both areas. The translocation factors at 12 months after planting for Cd, Pb, Cr and Ni were (1.13-1.37), (1.25-1.4), (1.12-1.25) , (0.97-1.2) respectively at both study areas. After a period of 24 months growth, the values for translocation factor of Cd, Pb, Cr and Ni were (1.58-1.59), (1.48-1.62), (1.4-1.6), (1.12-1.23) respectively at both study areas.



Teak

Laloor Palakkad



Bamboo

Laloor Palakkad

Fig. 15. Translocation factor of heavy metals in teak and bamboo

In bamboo, the values for translocation factor of Cd, Pb, Cr and Ni were 0.76-0.76, 0.36-0.51, 0.76-0.78, 0.7-0.73 respectively at three months after planting, at both study areas. After a period of six months planting, the translocation factors for Cd, Pb, Cr and Ni ranged between (0.56-0.59, 0.45-0.46, 0.63-0.75 and 0.44-0.52 respectively at both study areas. After a period of 12 months, the values for translocation factor were 1.62-1.76, 2.33-2.39, 0.72-1.03, 1.57-1.63 for Cd, Pb, Cr and Ni respectively at both sites. At 24 months after planting, the values for translocation factor ranged between 1.77-2.01 for Cd, 1.73-1.99 for Pb, 1.53-2.12 for Cr and 1.44-1.72 for Ni at both study areas.

Usually, if the translocation factor of a metal in a plant species is greater than 1, then that plant is considered as a hyper accumulator of the metal in question (Yoon *et al*., 2006). Accordingly, amaranth was a hyper accumulator with respect to Cd, Pb and Ni at three months after planting. But in the case of vetiver, translocation of all the heavy metals from roots to other plant parts started only at 12 months after planting. In teak, during three months period, only Cd was translocated, while after six months, Cd, Pb and Cr also was translocated. In teak, translocation of all the metals from roots to aerial parts took place only at 12 months after planting. In the case of bamboo also, translocation of heavy metals from roots to other plant parts was operational only at 12 months after planting. Thus the results in general point out the fact that, amaranth being a leafy vegetable, translocates heavy metals to aerial parts within three months period and hence cannot be grown on soils contaminated with heavy metals. Roots, being the economic part of vetiver, and heavy metals are translocated from roots only after 12 months, it also cannot be grown on soils contaminated with heavy metals. But bamboo and teak, being non edible plants , and initiate the translocation of heavy metals at 12 months after planting, can be used for phyto remediation of soils, contaminated with heavy metals. Translocation factor value greater than 1 indicated the translocation of the metal from root to above ground part (Jamil *et al*., 2009). Mojori *et al.* (2013) and Subhashini and Swamy (2014) also recommended the use of various plant species for phyto remediation based on translocation factors.

4.3.3. *Impact of urban waste leachate on soil and water quality of surrounding areas*

In this part of study, the influence of leachate emerging from the dump yard areas, on soil and water quality was assessed. For this, soil samples were collected from north, south, east and west directions from 0 m, 100 m, 250m and 500 m away from the waste dumpyard areas at Laloor and Palakkad and analysed for various properties. The data obtained on various soil and water quality parameters are presented and discussed in the following parameters.

4.3.3.1. *Influence of urban waste leachate on soil characteristics*

pH

Data provided in the Table 26 indicated that the soil at Laloor was moderately acidic (5.8-6.1) in reaction within 100 m. But at 250 and 500 m distance, the soil was relatively more acidic (pH 5.5-5.6). In Palakkad, pH of the soils varied between 6.5-6.6, indicating higher quality of water than Laloor. Even though, a slight increase in the pH of soil with increase in the distance from the dumpyard site was noticed at Laloor, a reverse trend was noticed at Palakkad. This indicate relatively less influence of urban waste leachate on soils at Palakkad compared to Laloor. Normally, urban waste leachates are acid in reaction due the organic acids released during the decomposition of wastes, thus making the soils of surrounding area more acidic.

Table 26. Influence of urban waste leachate on soil characteristics of surrounding area

Soil property	Distance (m^2)	Laloor	Palakkad
pH	0	5.76 ± 0.07^{b}	6.49 ± 0.06^{a}
	100	6.08 ± 0.12^{c}	6.64 ± 0.04^{b}
	250	5.58 ± 0.08^{ab}	6.50 ± 0.05^{a}
	500	5.49 ± 0.06^{a}	6.65 ± 0.03^{b}
EC(dS/m)	0	0.96 ± 0.02^{d}	1.06 ± 0.03^{b}
	100	0.86 ± 0.02^{c}	0.80 ± 0.02^{a}
	250	0.77 ± 0.03^{b}	0.80 ± 0.02^{a}
	500	0.66 ± 0.02^{a}	0.79 ± 0.03^{a}
OC(%)	0	2.35 ± 0.10^{c}	3.23 ± 0.07^{d}
	100	1.50 ± 0.07^{b}	2.56 ± 0.07^{c}
	250	0.95 ± 0.03^{a}	2.24 ± 0.07^{b}
	500	0.79 ± 0.02^{a}	1.43 ± 0.08^{a}

Electrical conductivity

The data on electrical conductivity varied between 0.96-0.66 dS/m at Laloor and 1.06-0.79 dS/m at Palakkad. There was a general decrease of this parameter with increase in the distance from the dump yard, mainly due to the relatively less soluble salts in the leachate with increase in the distance from the dump yard.

Organic carbon

With regard to organic carbon, its content varied between 0.79- 2.35 % at Laloor and 1.43-3.23 % at Palakkad. It was decreasing drastically towards 500 m distance from the dump yard area at both sites. Urban wastes, usually contain a high proportion of organic wastes and continuous application of such wastes will definitely elevate the carbon levels of soils as well as the leachate emerging from such soils.

Heavy metals

The data on the content of heavy metals in soils with increase in the distance from the dumpyard areas are provided in the Table 27. A gradual decrease in the content of Cd was observed both at Laloor (28.88 mg kg^{-1}- 18.89 mg kg^{-1}) and Palakkad (42.8-10.8 mg kg^{-1}) with increase in the distance from the centre of the dumpyard site towards 500 m away in north, south, east and west directions. Similarly, the content of Pb also decreased from 588.67 mg kg^{-1} to 249 mg kg^{-1} at Laloor and from 537.02 mg kg^{-1} to 286.33 mg kg^{-1} at Palakkad . With regard to the content of Cr also a gradual decrease was observed at Laloor (163.17 mg kg^{-1}- 72.67 mg kg^{-1}) and Palakkad (153.3mg kg^{-1}-104.59 mg kg^{-1}) with increase in the distance from dumpyard site at all directions. The content of Ni also varied from 118.33mg kg^{-1} to 98.67 mg kg^{-1} and 112.47 mg kg^{-1}-90.49 mg kg^{-1} respectively at Laloor and Palakkad.

The results in general conveyed that the content of all the nutrients and heavy metals were decreasing with increase in the distance from the dumpyard site. This illustrates the fact that the urban wastes and leachate emerging out of those wastes have profound

Table 27. Influence of urban waste leachate on the content of heavy metals in soils

Heavy metal	Distance from dumpyard	Laloor	Palakkad
Cd ($mg\ kg^{-1}$)	0m	28.88±0.83^{c}	42.83±5.10^{c}
	100m	28.13±1.09^{c}	32.97±0.79^{b}
	250m	23.70±0.90^{b}	18.08±1.70^{a}
	500m	18.89±0.67^{a}	10.78±0.19^{a}
Pb ($mg\ kg^{-1}$)	0m	588.67±11.61^{d}	537.02±11.47^{c}
	100m	443.17±13.29^{c}	366.26±7.76^{b}
	250m	341.17±14.16^{b}	299.58±2.92^{a}
	500m	249.00±5.30^{a}	286.33±5.37^{a}
Cr ($mg\ kg^{-1}$)	0m	163.17±3.24^{c}	153.30±6.14^{b}
	100m	123.17±6.18^{b}	186.25±2.40^{c}
	250m	90.00±7.08^{a}	140.59±5.62^{b}
	500m	72.67±7.55^{a}	104.57±2.32^{c}
Ni ($mg\ kg^{-1}$)	0m	118.33±5.54^{b}	112.47±2.72^{b}
	100m	96.00±5.81^{a}	107.65±1.98^{b}
	250m	102.33±5.66^{ab}	94.97±2.16^{a}
	500m	98.67±7.82^{a}	90.49±1.12^{a}

influence on the soil characteristics of the surrounding area. Presence of heavy metals in the soils near by dumpyard area due to the migration of leachate had also been reported by Kanmani and Gandhimathi (2013).

4.3.3.2. *Influence of urban waste leachate on water quality*

Influence of urban waste leachate on quality of water in the surrounding areas were examined by collecting water samples, which meet the drinking requirements of families residing in the nearby housing colonies at Laloor and Palakkad.

At Laloor, a total of 12 water samples were collected, out of which 6 were from 100 m distance, 3 from 250 m distance and the remaining 3 from 500 m distance away from dumpyard. At Palakkad, three samples were collected from 100 m distance, 5 from 250 m distance and four from 500 m distance. The important water quality parameters were determined and the data are provided in the Tables 28 and 29.

Colour is an important parameter to evaluate the quality of water. According to BIS water quality standards (BIS, 2012), the drinking water should be colourless. But in the present study some samples from both sites were muddy and this disclosed the fact that they were not qualified for drinking. According to BIS water quality standards, the drinking water should be odourless. Data revealed that most of the samples were odourless except, three from Laloor, which were with some non acceptable smell. With regard to taste, five water samples from Laloor and one from Palakkad were not with acceptable taste.

The non acceptable quality parameters of water such as colour, odour and taste were found decreasing with increasing distance from the dump yard at both sites, which clearly illustrated the direct and adverse impact of urban waste leachate on water.

The data provided in Table 28 and Table 29 on various physico chemical properties of water collected from both study areas during pre and post monsoon periods indicated that most of the quality parameters were far less than the permissible level prescribed by BSI except in the case of pH , nitrate and Fe at both sites and, total hardness and calcium hardness at Palakkad. Most of the values were found decreasing with increase in the distance from the dumpyard at both the sites, and this evidently demonstrate the fact that leachate from dumpyard sites had profound influence on chemical properties of water in the surrounding wells.

Table 28. Influence of urban waste leachate on water quality at Laloor

Parameter	Pre monsoon			Post monsoon			BIS
	100 m	250 m	500 m	100 m	250 m	500 m	
Colour	Muddy	Colourless	Colourless	Muddy-Colourless	Colourless	Colourless	Colourless
Odour	Non agreeable	Non agreeable	Agreeable	Agreeable	Agreeable	Agreeable	Agreeable
Taste	Non agreeable	Non agreeable	Agreeable	Agreeable	Agreeable	Agreeable	Agreeable
pH	4.8	5.7	6.3	5.6	6.5	6.3	6.5-7.5
EC(µS/cm)	134.98	121.16	94.6	108.32	100.04	94.65	-
Total hardness	72.50	50.14	28.1	96.07	75.70	28.05	200
Ca(mg/l)	7.18	4.69	2.34	7.35	4.80	2.34	75
Mg(mg/l)	1.88	1.53	1.15	1.63	1.28	1.15	30
Chlorides(mg/l)	12.75	9.90	8.43	6.77	8.23	84.33	250
Phosphate(mg/l)	3.33	0.80	1.31	1.49	1.87	1.31	5
Nitrate(mg/l)	55.55	40.74	33.87	32.22	31.86	33.87	45
Cu (mg/l)	0.09	0.09	0.00	0.00	0.00	0.00	0.05
Zn (mg/l)	1.36	1.04	1.3	1.30	0.80	0.82	5
Mn (mg/l)	0.03	0.00	0.02	0.02	0.00	0.00	0.1
Fe (mg/l)	0.44	0.56	0.27	0.27	0.52	0.59	0.3
Pb (mg/l)	0.33	0.58	0.00	0.05	0.01	0.00	0.1
Cd (mg/l)	0.02	0.01	0.00	0.00	0.00	0.00	0.01
Cr (mg/l)	0.01	0.02	0.00	0.01	0.02	0.01	0.001
MPN	45-240	16-180	4-240	3-80	3-80	2-16	1CFU/10ml

Raman *et al*. (2008), Han *et al*. (2013) and Jaseela and Harikumar (2015) also reported high content of NO_3 and Fe in the well water, close to the dumpyard. According to them NO_3 could be the contribution from organic wastes while the metal scrap and tin were

Table 29. Influence of urban waste leachate on water quality at Palakkad

Parameter	Premonsoon			Postmonsoon			BIS
	100m	250m	500m	100m	250m	500m	
Colour	Muddy	Colourless	Colourless	Colourless	Colourless	Colourless	Colourless
Odour	Non agg-Agg.	Non agg-Agg.	Agg.	Agg.	Agg.	Agg.	Agg.
Taste	Non agg.-Agg.	Agg.	Agg.	Agg.	Agg.	Agg.	Agg.
pH	5.9	6.4	6.3	6.4	6.4	6.3	6.5-7.5
EC(µS/cm)	213.97	122.34	90.95	135.30	96.02	68.53	-
Total hardness	382.00	398.80	339.55	287.67	222.58	172.88	200
Ca(mg/l)	93.87	88.20	68.53	63.80	54.98	51.03	75
Mg(mg/l)	14.70	13.54	13.70	10.70	9.80	13.30	30
Chlorides(mg/l)	14.77	12.02	10.95	8.87	8.94	10.48	250
Phosphate(mg/l)	3.06	1.06	0.68	1.43	0.58	0.19	5
Nitrate(mg/l)	55.17	29.88	19.15	19.20	19.88	6.25	45
Cu (mg/l)	0.03	0.02	0.00	0.01	0.00	0.00	0.05
Zn (mg/l)	1.76	1.37	0.34	0.34	0.18	0.00	5
Mn (mg/l)	0.54	0.20	0.00	0.00	0.00	0.00	0.1
Fe (mg/l)	0.51	0.21	0.06	0.00	0.01	0.00	0.3
Pb (mg/l)	0.05	0.01	0.00	0.04	0.00	0.00	0.1
Cd (mg/l)	0.00	0.00	0.00	0.00	0.00	0.00	0.01
Ni (mg/l)	0.03	0.01	0.00	0.00	0.00	0.00	0.2
Cr(mg/l)	0.01	0.02	0.01	0.01	0.02	0.01	0.001
MPN	45-160	16-80	4-35	3-18	3-18	2-16	1CFU/10ml

the source of Fe. Relatively, lower values of most of the parameters were observed during post monsoon season than pre monsoon period. The results of the study corroborates with the findings of Vasanthi *et al.* (2008) that wells located close to the disposal area were with higher levels of electric conductivity, total dissolved solids, total hardness, chlorides and sulphate. The findings of Maiti *et al.* (2016) from the study at urban waste dump sites at Kolkatta also support the fact that water contaminants exceed the permissible limit of BIS standards.

The number of coliform form unit exceeded the permissible limit (1/10ml) in all the samples from both dumpyard areas and they were significantly decreasing with increase in the distance from the dump yard areas. Contamination of coliform was mainly due to the discharge of urban waste leachate to the water bodies (Chavan and Zamare, 2014; Pande *et al.*, 2015) and their count was relatively higher during premonsoon season.
Thus, the results in general pointed out that the important water quality parameters such as colour, odour, taste, pH, hardness, $NO_{3,}$ Fe, coliform etc. were significantly affected due to the discharge of urban waste leachate to the surrounding well while the influence on other parameters were relatively less. The study also revealed that contamination of well water due to the urban waste leachate was relatively less during post monsoon compared to pre monsoon period. Vasanthi *et al.* (2008) found that the contaminant concentrations tend to decrease during the post monsoon seasons and increase during the premonsoon seasons in most of the water samples.

Appropriate remedial measures to minimize soil and plant health hazards caused by the application of urban waste composts

CHAPTER 5

APPROPRIATE REMEDIAL MEASURES TO MINIMIZE SOIL AND PLANT HEALTH HAZARDS CAUSED BY THE APPLICATION OF URBAN WASTE COMPOSTS

5.1. Introduction

The potential risks associated with the use of urban waste composts for organic farming are contamination due to toxic heavy metals and pathogenic organisms (Ayari *et al.*, 2010). The source of contamination of heavy metals in the urban wastes are the industrial products such as batteries, sprays, kitchenware, paints, ink, electronic components etc. Heavy metals are the major environmental contaminants and pose a severe threat to human and animal health by their long term persistence in the environment. The contamination of composts with toxic heavy metals and pathogenic organisms occurs due to improper segregation and unscientific method of composting. However, this part of the study tries to explore the measures to minimize the contamination in the urban waste composts, by dilution technique, and also by modifying the existing technology for urban waste composting. Dilution technique was experimented in already produced urban waste compost. The possibility of producing a good quality compost by improving the methods adopted in the current composting technology was also looked into. The methodology adopted and the results obtained in the above two experiments are detailed hereunder.

5.2. Materials and Methods

5.2.1. *Dilution technique*

This experiment mainly focused on diluting the contamination of urban waste compost by mixing it with good quality compost, produced out of weeds, and monitoring the concentration and uptake of heavy metals by different plant species. This dilution technique was experimented in the urban waste composts, already produced at one of the composting unit, Laloor, in Thrissur (Dt.). The experiment was conducted through a pot culture during September 2012 to August 2013 at Field Research Centre of KFRI, Velupadam in Thrissur Dt.

5.2.1.1. *Pot culture experiment*

The pot culture experiment was conducted using four different plant species viz. amaranth *(Amaranthus tricolor),* vetiver *(Vetiveria zizanioides),* bamboo *(Bambusa bamboo)* and teak *(Tectona grandis)* at Field Research Centre of KFRI at Velupadam in Thrissur Dt. For this, surface soils (0–15 cm) were collected from the same site at Velupadam and filled in 112 cement pots of uniform size of 10 kg capacity. Urban waste compost for the experiment was collected from the urban waste composting unit at Laloor, and weed compost from KFRI, Peechi.

The treatments consisted of different levels of urban waste compost and weed compost, individually and in combination.

Treatments

Control

1. Weed compost - 1 kg/pot
2. Weed compost - 2 kg/pot
3. Urban compost - 1 kg/pot
4. Urban compost - 2 kg/pot
5. Weed compost + Urban compost - 1 kg/pot (1:1)
6. Weed compost + Urban compost - 2 kg/pot (1:1)

Composts were applied in each pot as per the treatment and mixed well with soil, one week prior to the planting of seedlings. Two months old seedlings of teak, one month old seedlings of bamboo, one month old rhizomes of vetiver and two weeks old seedlings of amaranth were planted in the pots @ one seedlings/ pot. Watering was done daily to maintain optimum soil moisture. The experiment was laid out by adopting Randomized Block Design with four replications and continued up to one year.

Plate 5. Pot culture experiment at field research centre, Velupadam

5.2.1.2. *Biomass estimation*

The species selected for the experiment were with different life cycle. Hence the biomass estimation was done at varying intervals. At three month after planting, amaranth was harvested and the rest of three plant species were allowed to grow up to one year. Then they were harvested, washed thoroughly, separated into root, stem and leaves, oven dried at a temperature of 65±5 ^{0}C and weighed.

5.2.1.3. *Laboratory analysis*

Soil sample

Initial characteristics of the soil used for the experiment with respect to chemical properties, micronutrients and heavy metals were determined using the procedure described under section 4.2.2.2 in chapter 4.

Composts

Various physico-chemical characteristics of the composts used for the experiment were determined by adopting the procedure described under section 3.2.3. in chapter 3.

Plant sample

Biomass, concentration and uptake of heavy metals in plants were determined by adopting the procedure described under section 4.2.3 in chapter 4.

5.2.1.4. *Statistical analysis*

Data for various treatments from the experiments were subjected to analysis of variance (ANOVA) (Panse and Sukhatme, 1985) using statistical software package SPSS (Norusis, 1988). Mean comparison test was carried out through DMRT (Duncan's Multiple Range Test).

5.2.2. *Modification of composting technology*

The results obtained under objective 1 clearly demonstrated that most of the urban waste composts produced at various composting centres in the State were contaminated with heavy metals, and hence not suitable for organic farming. Contamination of urban waste composts with heavy metals is supposed to be due to the lack of proper segregation of inorganic components before composting. Similarly, improper method of composting, without generating required amount of heat for the destruction of pathogenic organisms also resulted in the production of contaminated compost. So, this part of the study mainly intended to modify the existing methods in the composting technology for urban waste composting.

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5.2.2.1. *Experimental details*

The experiment was conducted at the urban waste composting unit of Chalakkudy municipality in Thrissur (Dt.). Urban wastes from Chalakkudy municipal area were collected with the help of members from kudumbasree units. Half of the collected wastes were kept separately as non segregated waste and the other half segregated completely by removing all the non biodegradable components. In the case of segregated wastes, there were two levels of segregation, one at the site of collection, and the other at the site of composting. Both the segregated and non segregated groups were again divided into four sub groups. The treatments consisted of different types of inocula such as cow dung, jeevamrutham (combination of cow dung-2 kg, cow urine- 1 lr, pulses- 100 gm, jaggery- 100gm and soil- five hand fuloff were mixed in 20 lr. water) and commercial inocula, applied to the first, second and third sub groups of segregated and non segregated wastes, and the fourth one was kept as control (Table 30). Thus, there were three treatments and one control under both

Plate 6. Conventional composting of urban waste at Chalakkudy

Segregation

Application of jeevamrutham

Turning

Mature compost

Plate 7. Composting of urban waste using jeevamrutham

Table 30. Treatments used in the experiment

Treatment 1	Control	NS
		CS
Treatment 2	Urban waste + Cow dung	NS
		CS
Treatment 3	Urban waste + Comercial inoculam	NS
		CS
Treatment 4	Urban waste + Jeevamrutham	NS
		CS

segregated and non segregated groups of wastes and the whole experiment was replicated three times.

5.2.4. *Determination of heavy metals and pathogenic organisms*

Content of nutrients and heavy metals in the composts used for the experiment were determined by adopting the procedure described under section 3.2.3. in chapter 3. Bioassay of pathogenic organisms was carried out by adopting the procedure as detailed under 3.2.3.4 in the chapter 3.

5.2.4.5. *Quality evaluation*

Quality evaluation of composts, produced by adopting various composting methods were carried out using the equations described under section 3.2.3.5 in the chapter 3.

5.3. Results and Discussion

5.3.1. *Dilution technique*

5.3.1.1. *Initial properties of soil used for the experiment*

The various properties of soil used for the experiment are given in Table 31. The pH of soil was strongly acid in reaction (pH 5.2) with very little content of soluble salts and

Table 31. Initial characteristics of soil used for the experiment

Particulars	Value
Chemical properties	
pH (1:2.5)	5.2
EC (1:2.5) dS/m	0.01
Organic carbon (%)	0.7
Available N (kg ha^{-1})	179.2
Bray extractable P (kg ha^{-1})	2.7
Exchangeable K (kg ha^{-1})	14.1
Exchangeable Ca (mg kg^{-1})	320
Exchangeable Mg (mg kg^{-1})	63
Micronutrients	
Cu (mg kg^{-1})	38.5
Fe (mg kg^{-1})	1.78
Zn (mg kg^{-1})	12.3
Mn (mg kg^{-1})	21.4
Heavy metals	
Cd (mg kg^{-1})	0.71
Pb (mg kg^{-1})	28.7
Cr (mg kg^{-1})	19.8
Ni (mg kg^{-1})	13.8

low level of organic carbon (0.7 %). With regard to plant availability of major nutrients, the soil was with low levels of N (179.2 kg ha^{-1}), P (2.7 kg ha^{-1}), K (14.1 kg ha^{-1}) and Mg (63 mg kg^{-1}), but with adequate levels of Ca (320 mg kg^{-1}) .

5.3.1.2. *Initial properties of composts used for the experiment*

Two different types of composts viz., urban waste compost, collected from Laloor and weed compost from KFRI nursery were used for the experiment. The basic characteristics of these composts with respect to physical and chemical properties are given in Table 32. Content of moisture in the urban waste compost was low (16%) compared to weed compost (22%). The urban compost was slightly acid (pH 6.2) in reaction while weed compost was slightly alkaline (pH 7.6). The soluble salt of urban waste compost was low (1.84 dS/m) while it was relatively higher (3.62 dS/m) in weed compost. Very low content of organic carbon (7.6%) was recorded in urban waste compost compared to weed compost (33.5%). With regard to the content of N, P, K, Ca and Mg, weed compost was found to be a good reserve (2.7%, 1.1%, 1.3%, 0.81% and 0.41% respectively) of these nutrients. With respect to micronutrients, relatively higher accumulation of Cu, Zn and Mn were observed in the urban waste compost (157.3 mg kg^{-1}, 104.7 mg kg^{-1} and 291.3 mg kg^{-1} respectively) than weed compost (95.5 mg kg^{-1}, 92.9 mg kg^{-1} and 248.5 mg kg^{-1} respectively). But the content of Fe was higher in weed compost (0.95 %) than in urban waste compost (0.44 %).

Table 32. Physical and chemical characteristics of composts used for the experiment

Particulars	Urban waste compost	Weed compost
Physical properties		
Colour	Slightly brown	Coffee brown
Moisture (%)	16	22
Chemical properties		
pH	6.2	7.6
EC(ds/m)	1.84	3.62
Major nutrients		
OC (%)	7.6	33.5
N(%)	0.8	2.7
C:N ratio	9.5	12.4
P(%)	0.56	1.1
K(%)	0.6	1.3
Ca(%)	0.47	0.81
Mg(%)	0.26	0.41
Micronutrients		
Cu(mg kg^{-1})	157.3	95.47
Fe(%)	0.44	0.95
Zn(mg kg^{-1})	104.7	92.9
Mn(mg kg^{-1})	291.3	248.5
Heavy metals		
Cd(mg kg^{-1})	16.5	0.3
Pb(mg kg^{-1})	639.9	8.1
Ni(mg kg^{-1})	192.1	36.8
Cr(mg kg^{-1})	286.4	24.5

Contamination with heavy metals such as Cd, Ni, Pb and Cr were at toxic levels in urban waste compost (16.5 mg kg^{-1}, 639.9 mg kg^{-1}, 192.1 mg kg^{-1} and 286.4 mg kg^{-1} respectively) while they were very low and within the permissible limit in weed compost (0. 3 mg kg^{-1}, 8.1 mg kg^{-1}, 36.8 mg kg^{-1} and 24.5 mg kg^{-1} respectively).

5.3.1.3. *Biomass*

Biomass of various plant species used in the experiment was estimated after a period of three months in the case of amaranth, and one year in other species. Biomasses of different plant parts in each plant were also found separately (Table 33) to determine the concentration and uptake/accumulation of heavy metals.

Amaranth

Amaranth, being a leafy vegetable, leaves assume more significance, when yield is taken into consideration. Data presented in the Table 33 indicated a significantly higher yield in amaranth leaves due to application of mixed weed compost, compared to control and other treatments. But no significant variation in yield was observed with increase in the quantity of compost applied. On the contrary, higher rate of application of the urban waste compost produced higher yield. Same trend was observed when urban waste compost was mixed with weed compost. The data in general revealed that combined application of urban waste compost with weed compost @2kg per pot was almost equally effective with mixed weed compost @ 2kg/pot when the yield of amaranth leaves were considered. Significantly higher yield of both root and shoot were also observed due to the combined application of both composts @2kg/pot.

Vetiver

In the case of vetiver, roots are the main economic part. Among the treatments, application of weed compost @ 2kg/pot produced significantly higher yield. Yield of roots was found increasing with increase in the quantity of urban waste composts.

Table 33. Influence of different levels of composts on biomass of various plant species (gkg^{-1} dry weight)

Treatment	Amaranth			Vetiver			Teak			Bamboo		
	Root	Stem	Leaf	Root	Stem	Leaves	Root	Stem	Leaf	Root	Stem	Leaf
Control	1.32± 0.26^{a}	1.07± 0.26^{a}	0.59± 0.22^{a}	45.90± 1.84^{a}	71.35± 2.44^{a}	14.83± 0.57^{a}	5.58± 0.48^{a}	11.28± 0.47^{a}	1.21± 0.39^{a}	14.30± 1.24^{a}	7.20± 2.05^{a}	4.49± 1.73^{a}
WC-1kg	9.50± 1.75^{bc}	67.10± 3.46^{d}	14.09± 0.73^{e}	452.18± 10.96^{c}	350.35± 85.98^{cd}	112.05± 1.63^{e}	89.73± 4.01^{d}	339.48± 7.06^{e}	6.92± 0.88^{bc}	195.55± 19.74^{c}	373.54± 36.81^{c}	37.28± 9.60^{c}
WC-2kg	15.42± 2.56^{d}	66.18± 2.81^{b}	13.90± 0.59^{e}	723.10± 25.17^{d}	381.50± 22.99^{d}	158.13± 4.07g	166.33± 3.25^{f}	533.18± 21.37^{b}	14.26± 0.56^{d}	259.20± 3.26^{d}	539.58± 9.86^{e}	45.03± 3.46^{c}
UC-1kg	5.60± 0.62^{b}	36.20± 1.64^{d}	7.60± 0.34^{b}	267.43± 16.08^{b}	147.25± 14.01^{ab}	65.83± 1.11^{c}	56.55± 1.96^{b}	133.48± 7.36^{f}	7.03± 1.55^{bc}	97.60± 2.67^{b}	69.15± 4.58^{a}	18.71± 3.95^{ab}
UC-2kg	7.38± 1.32^{bc}	51.62± 5.70^{c}	10.84± 1.20^{cd}	412.93± 11.44^{c}	293.28± 30.78^{bc}	101.90± 3.62^{d}	87.70± 2.18^{d}	294.60± 17.65^{d}	11.03± 3.47^{bcd}	154.40± 17.24^{bc}	69.30± 6.17^{a}	22.43± 5.92^{b}
WC+ UC-1kg	6.96± 0.61^{b}	48.04± 7.28^{bc}	8.84± 0.74^{bc}	258.95± 55.67^{b}	247.50± 44.47^{cd}	51.33± 1.67^{b}	72.63± 5.64^{c}	207.33± 17.30^{c}	5.65± 1.22^{ab}	139.69± 15.10^{bc}	137.41± 17.19^{b}	21.46± 1.38^{b}
WC+ UC-2kg	11.40± 0.77^{c}	46.70± 2.49^{bc}	13.06± 0.08^{de}	673.25± 10.84^{d}	366.33± 15.43^{cd}	121.08± 1.43f	138.05± 7.33^{e}	348.83± 20.80^{e}	12.20± 2.28^{cd}	362.28± 39.74^{e}	455.15± 33.36^{d}	39.79± 3.44^{c}

WC = Weed compost, UC = Urban compost

Combined application of both urban waste and weed compost @2kg/pot, and weed compost alone @2kg/pot was equally effective in yielding higher root biomass. With respect to the yield of stem and leaves also, combined application at higher doses was more effective than urban waste alone at higher dose.

Teak

Application of weed compost at higher doses (2kg/pot) produced significantly higher biomass yield of stem, root and leaf in teak. As observed in other cases, combined application of urban waste compost and weed compost @2kg/pot was significantly effective in producing higher biomass of stem, root and leaves of teak than urban waste compost alone @2kg/pot.

Bamboo

Influence of weed compost in boosting the biomass yield was observed in bamboo also. Here also, combined application of both urban waste compost and weed compost was more effective in yielding the biomass of various plant parts than urban waste alone.

Thus the results in general revealed that combined application of urban waste with weed compost could produce significantly higher biomass in amaranth, vetiver, teak and bamboo than urban waste compost alone irrespective of the quantity applied. Weed compost, produced out of jeevamrutham, is a very good reserve of all the essential nutrients, diversified microorganisms, enzymes, hormones etc. So, on combining this with urban waste compost, the urban waste compost gets enriched and produces more yield than urban waste alone.

5.3.1.4. *Accumulation of heavy metals in various plant species*

The data on the concentration of heavy metals in various plant species are presented in the appendix 2. Uptake of heavy metals and the values calculated on their percentage reduction due to combined application are presented in the Fig. 16 and appendix 3 respectively.

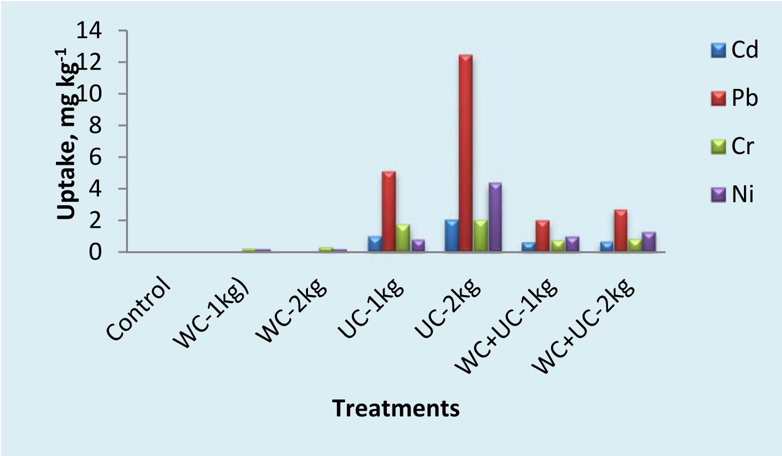
Amaranth

Regarding the concentration and uptake of heavy metals by amaranth, data revealed that application of weed compost alone did not bring any significant difference in the concentration and uptake of heavy metals compared to control.

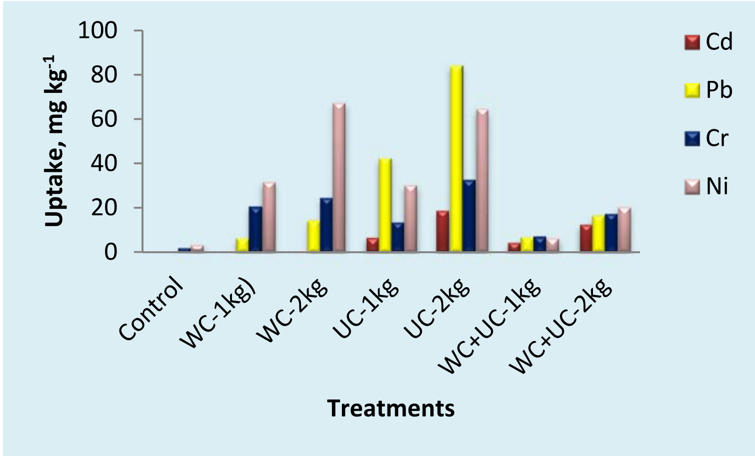
But, there was a significant increase in the concentration and accumulation of heavy metals in various parts of amaranth due to the application of urban waste compost, and significantly higher accumulation was noted with increase in the quantity of compost applied. Data also revealed that combined application of urban waste compost with weed compost significantly reduced the concentration and uptake of heavy metals by various plant parts. In general, this reduction in concentration, at higher doses of combined application (@2kg/ pot) ranged between 55.8-72.2 % , 80.5-85.8 %, 58.6-60 % and 70.2-73.7 % in respect of Cd, Pb, Cr and Ni, when all the plant parts were considered together. Similarly, the reduction in the uptake of Cd, Pb, Cr and Ni ranged between 19.4-34.8 % and, 21 %, 36.9-59.1 % and 26.3-40.5 % respectively, due to the combined application of both composts @ 2kg/ha. When concentration of heavy metals in various plant parts were considered separately, significantly higher content was observed in leaves (33.4 mg kg^{-1}), followed by shoot (30.9 mg kg^{-1}) and roots (23.4 mg kg^{-1}) due to the combined application of both composts @ 2kg/ha. But on the contrary, the data with respect to the uptake was higher in shoot (1.56 $mgkg^{-1}$) followed by leaves (0.36 mg kg^{-1}) and roots (0.17 mg kg^{-1}).

Vetiver

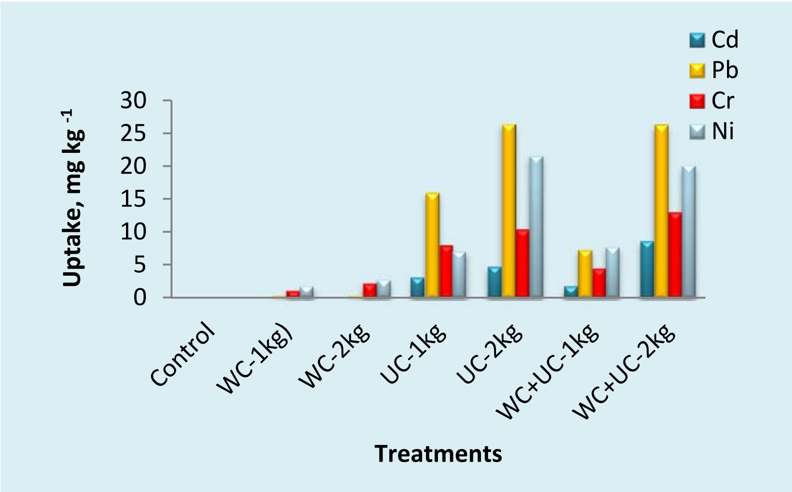
As observed in amaranth, in vetiver also, significantly lower concentration and uptake of heavy metals in various plant parts were observed due to the application of weed compost compared to urban compost. But compared to control, concentration of Pb, Cr and Ni were significantly higher in the treatment with weed compost. Among the treatments, application of urban compost alone triggered significantly higher concentration and uptake of all heavy metals and it was increasing with increase in the quantity of compost applied. But it was noticed that, combined application of urban waste compost with weed compost @2 kg/pot significantly reduced the concentration and uptake of heavy metals in various plant parts, which is definitely due to the dilution effect brought out by the weed compost. In general, the reduction in the concentration ranged between 57.1-57.7 %, 86.4-88.7 %, 56.6-66.2 % and 72.4-80.6 % in respect of Cd, Pb, Cr and Ni, when all the plant parts are considered together. Similarly, the reduction in the uptake of Cd, Pb, Cr and Ni ranged between 30.8-49.4 %, 78-86.5 % , 44.8-48.4 % and 67.1-68.3 % respectively. It was also noticed that in the case of vetiver, concentration and uptake of all heavy metals were higher in root followed by stem and leaves.



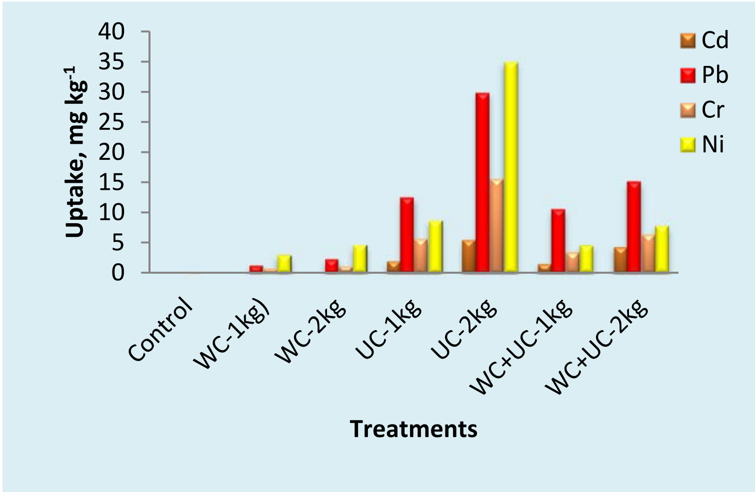
Amaranth



Vetiver



Bamboo



Teak

Fig. 16. Influence of different levels of composts on the uptake of heavy metals by various plant species

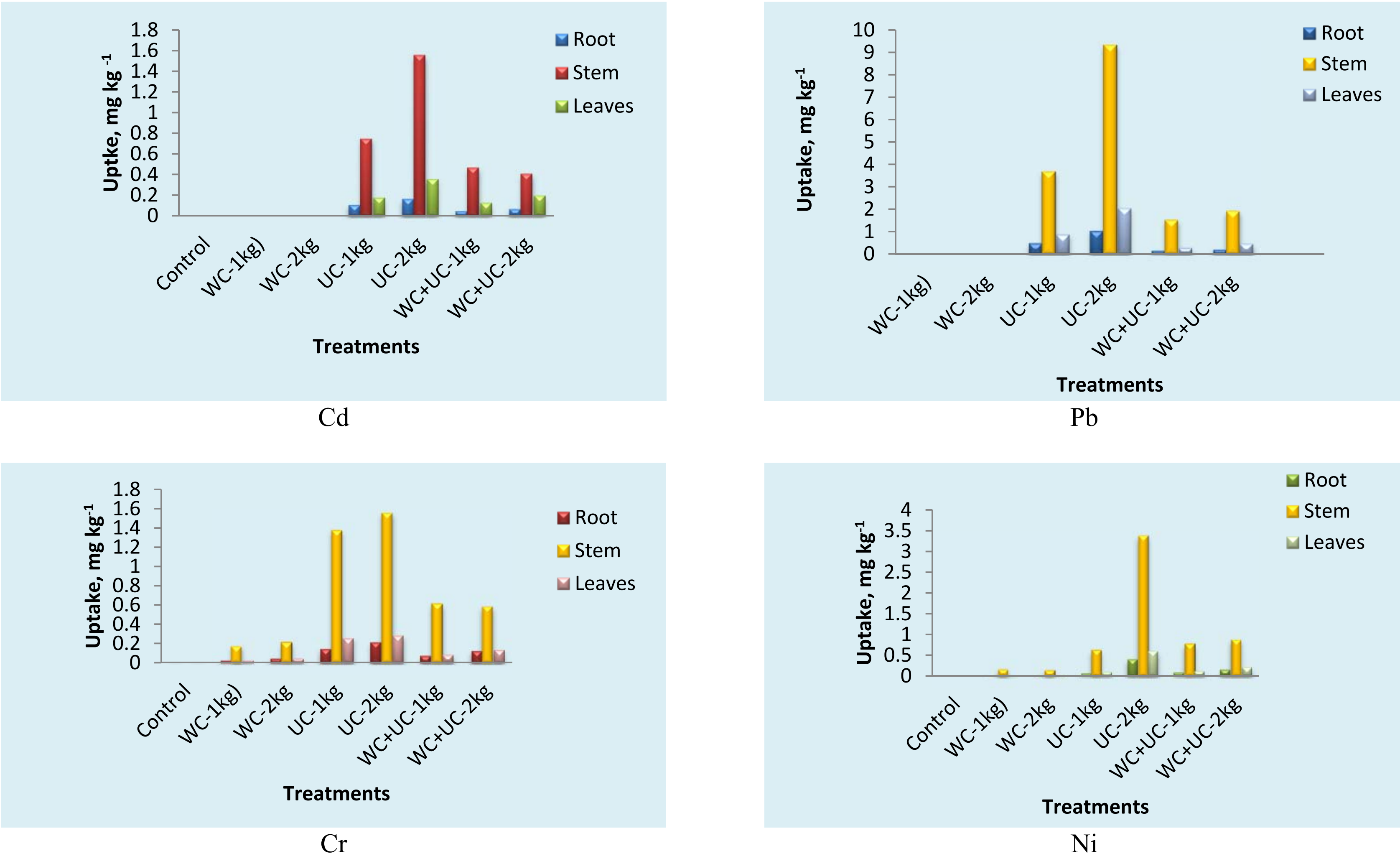
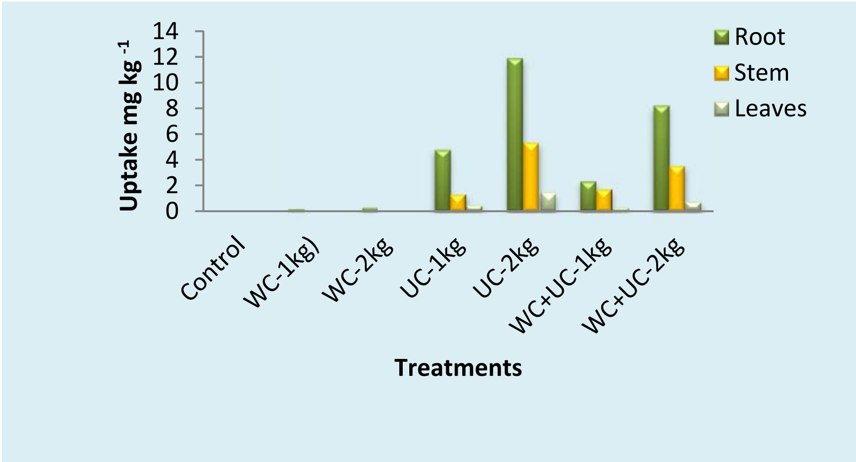
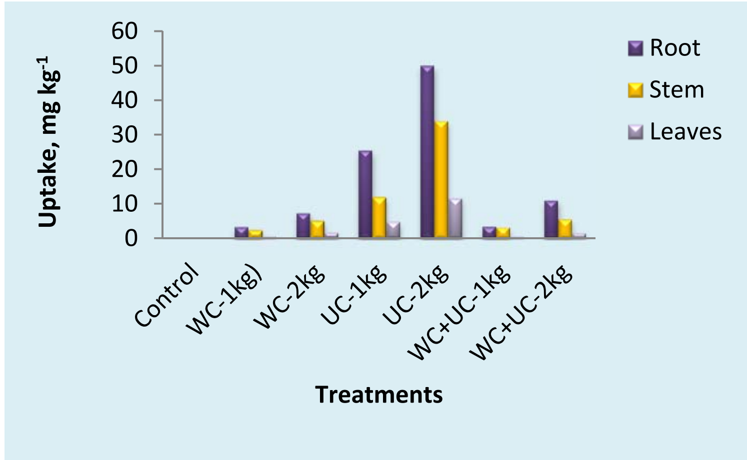


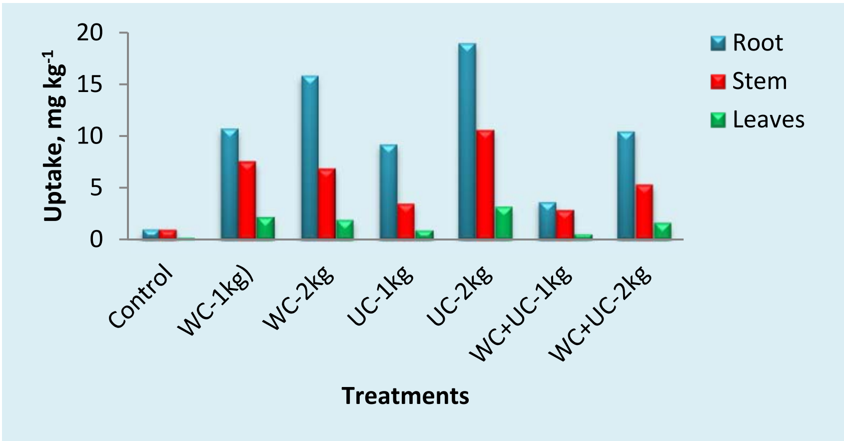
Fig.17. Influence of different levels of composts on the uptake of heavy metals by amaranth



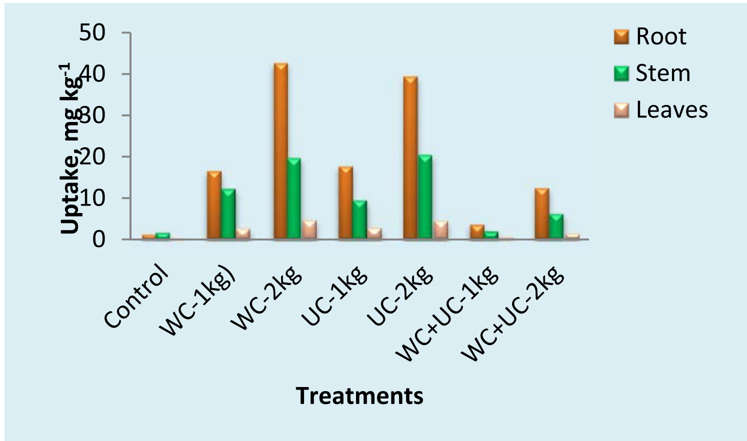
Cd



Pb

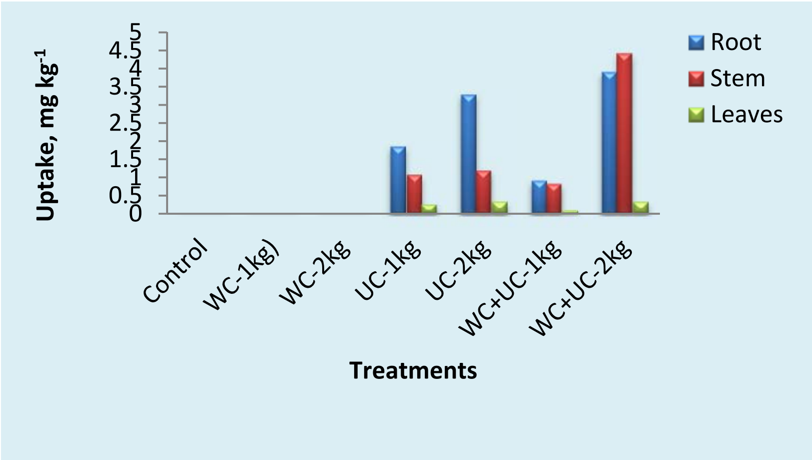


Cr

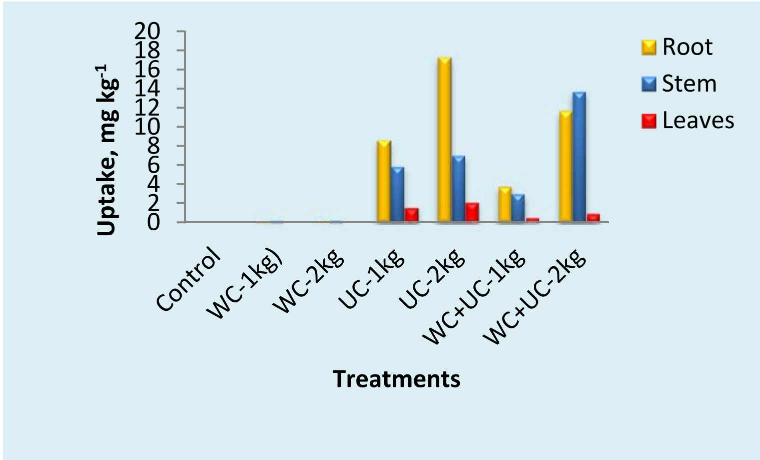


Ni

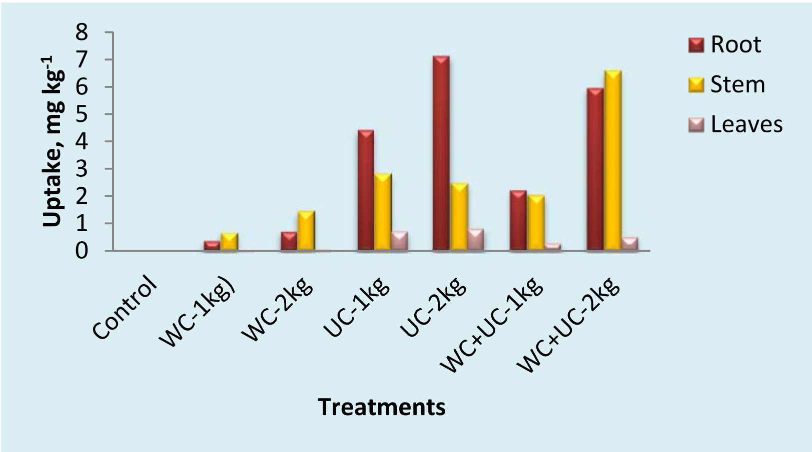
Fig. 18. Influence of different levels of composts on the uptake of heavy metals by vetiver



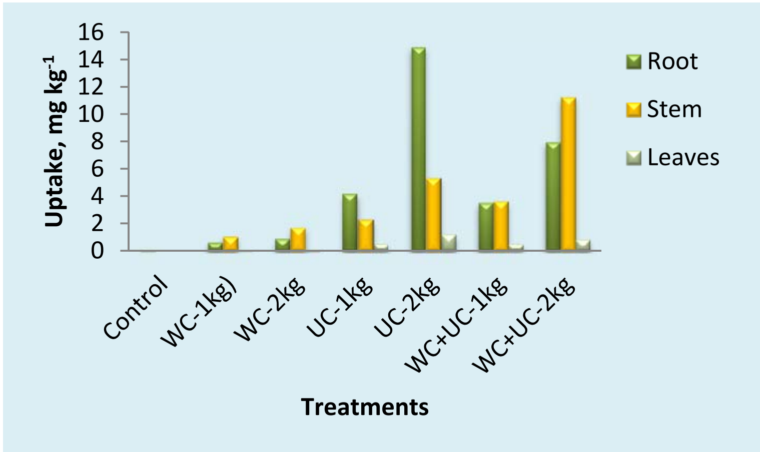
Cd



Pb

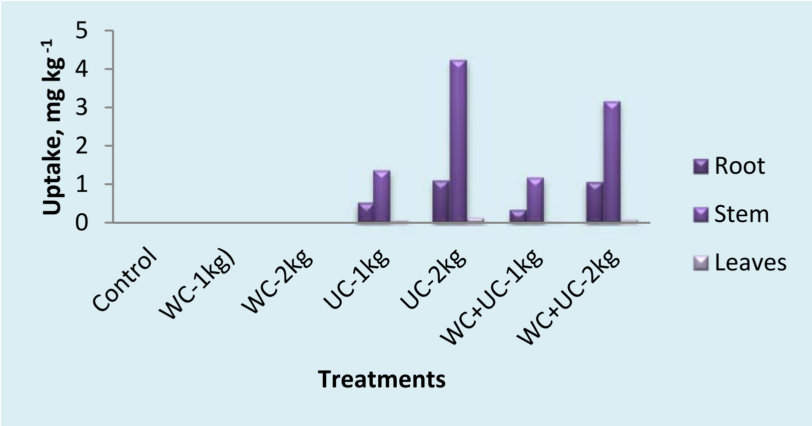


Cr

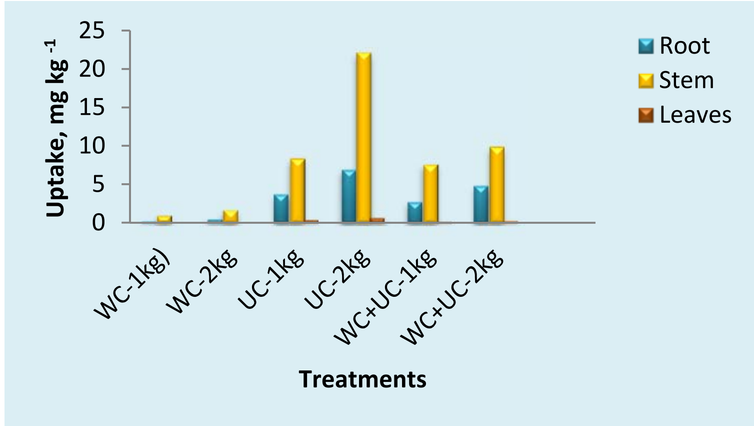


Ni

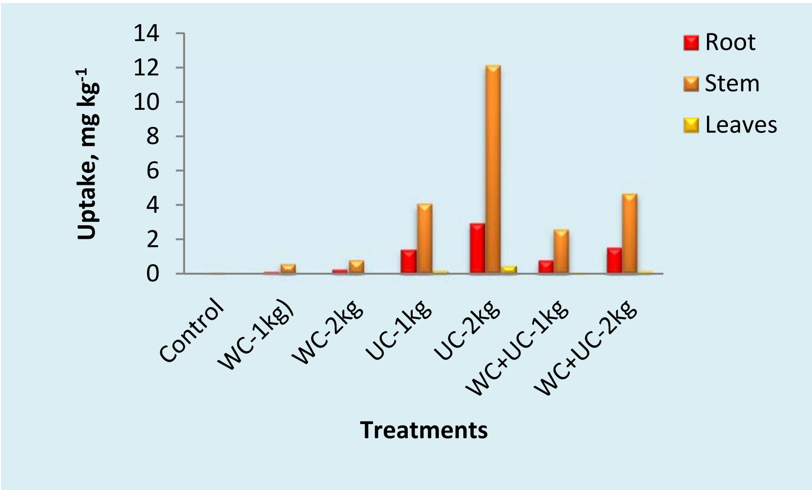
Fig. 19. Influence of different levels of composts on the uptake of heavy metals by bamboo



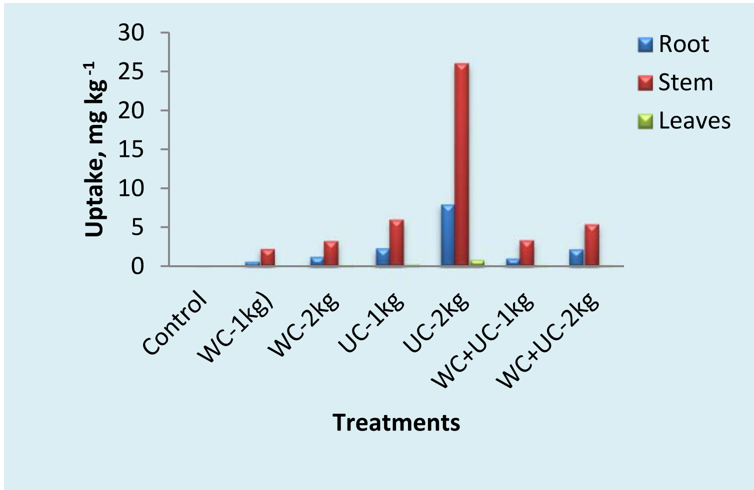
Cd



Pb



Cr



Ni

Fig. 20 Influence of different levels of composts on the uptake of heavy metals by teak

Teak

As observed in other species, in teak also, combined application of urban waste compost with weed compost significantly reduced the concentration and uptake of heavy metals. The reduction in the concentration ranged between 36.6-38.2% , 55.5-56.5%, 66.9-67.5% and (82-84.7% with respect to Cd, Pb, Cr and Ni, when all plant parts are considered together. Similarly, the reduction in the uptake of Cd, Pb, Cr and Ni ranged between 66.7-74.6 %, 52.7-55.3 %, 36.2-38.6 % and 16.7-20.9% respectively.

Regarding the concentration of heavy metals in the specific plant parts, in general, concentration of Cd was higher in roots (12.8 mg kg^{-1}) and Pb (79.8 mg kg^{-1}),Cr (33.9 mg kg^{-1}) and Ni (91.3 mg kg^{-1}) in stem. But when uptake was considered, accumulation of all the metals such as Cd (4.25 mg kg^{-1}), Pb (22.2 mg kg^{-1}), Cr (12.2 mg kg^{-1}) and Ni (26.1 mg kg^{-1}) were high in the stem.

Bamboo

In the case of bamboo also, application of weed compost did not lead to any increase in the concentration of heavy metals. But significant accumulation of these metals in various plant parts were noticed due to the application of urban waste compost and this was increasing with increase in the quantity of compost applied. As expected, combined application of both composts resulted in a reduction in the concentration and uptake of these metals by bamboo. This reduction in concentration varied between 44-48.8 %, 71.2-74.8 %, 62.9-64.6 %, 62.3-74.2 % and uptake between 0 % , 20.8-55.2 %, 7.4-36.9 %, 24.5-31 % in respect of Cd, Pb, Cr and Ni.

Among the various plant parts, concentration of Cd and Pb were almost equal in roots while Cr and Ni higher in stem. But with regard to uptake, significantly higher accumulation of all the metals were observed in roots followed by stem and leaves. Accumulation of heavy metals in amaranth, vetiver have been reported by Chunilall *et* *al*.(2005), Kumar *et al*. (2011), Yang *et al*. (2005), Danh *et al*. (2009) and Pillaia *et al*. (2012).

5.3.2. *Modification of composting technology*

5.3.2.1. *General observations*

Composting of both segregated and non segregated wastes (Table 34) without the application of any microbial consortium resulted in strong foul smell and large number of house flies and maggots were found emerging from the compost piles. But, the intensity of this foul smell and the no. of house flies, maggots *etc*. were comparatively less, in treatments in which cow dung and commercial inocula were applied. But in jeevamrutham applied treatment, there were no foul smell, house flies and maggots. A wide variation in temperature ranging from 35 ^oC to 55 ^oC was observed only in jeevamrutham applied treatments. Jeevamrutham contains relatively higher number of microorganisms (Table 35) and the intense activity of these microorganisms can be the

Table 34. General observations recorded during composting of urban wastes at Chalakkudy

Treatment	Segregation status	Methods of composting	Temperature range (^0C)	No of days taken for composting
Control	NS	Partially aerobic windrow	27-42	180
	CS	Partially aerobic windrow	27-42	180
Cow dung	NS	Partially aerobic windrow	27-46	90
	CS	Partially aerobic windrow	27-46	90
Comercial inoculam	NS	Partially aerobic windrow	30-49	60
	CS	Partially aerobic windrow	30-49	60
Jeevamrutham	NS	Completely aerobic windrow	30-58	35
	CS	Completely aerobic windrow	30-58	35

NS - Non segregated, CS-Completely segregated reason for the high temperature recorded in these treatments. There was a wide variation in the period of composting due to various treatments and it ranged from 35 to 180 days. The jeevamrutham applied treatment resulted in short composting period (35 days) followed by commercial inoculum (60 days), cowdung (90 days) and control (180 days).

Table 35. Number of colony forming unit/g used in different microbial inocula

Microorganisms	Jeevamrutham	Cow dung	Inoculum
Bacteria	$4.64X10^5$	$0.11X10^5$	$1.76X10^5$
Fungi	$0.45X10^5$	$0.05X10^5$	$0.24X10^5$
Actinomycetes	$1.21X10^5$	$1.1X10^5$	$1.45X10^5$

5.3.2.1. *Composting process*

The composting process normally practiced at Chalakkudy was windrow method. Same windrow method was adopted in the treatments with cow dung and commercial inoculum. But in the jeevamrutham applied treatments, the methodology adopted was aerobic windrow, owing to the attainment of high temperature and subsequent turnings needed for aeration. Both segregated and non segregated wastes were spread on the floor and respective microbial consortium was applied @ 10 lr diluted commercial inoculums, 100 kg cow dung and 5 lr jeevamrutham for one ton of waste. The temperature inside the stack was measured every day and turning was done on attainment of high temperature exceeding 45 ^{0}C. Ten aerated turnings were given within 35 days and, there after kept for air drying..

5.3.2.2. *Quality evaluation*

Quality of composts were ascertained with respect to physical characteristics, nutrient composition, pathogenicity and contamination due to heavy metals.

Colour, moisture and nutrient content

The important physical characteristics (Table 36) such as colour and moisture were almost same in all the composting treatments. All the composts were coffee brown in colour with ideal content of moisture (20 %). With regard to the chemical characteristics (Table 36), there was not much variation in the treatments with respect to pH. But the compost produced without the addition of any microbial consortia was with relatively

Table 36. Physical and chemical characteristics of the urban waste compost produced at composting unit, Chalakkudy

Treatment	Segregation status	Color	Moisture (%)	pH	EC(dS/m)	C(%)	C:N
Control	NS	Coffee brown	21.0± 0.19	8.1± 0.03	0.73± 0.03	18.4± 0.43	16.8± 1.03
	CS	Coffee brown	23.9± 0.15	8.0± 0.12	0.80± 0.06	17.9± 0.15	15.8± 0.40
Cow dung	NS	Coffee brown	19.0± 0.32	7.6± 0.15	0.73± 0.03	17.7± 0.34	15.8± 1.07
	CS	Coffee brown	24.4± 0.27	7.5± 0.06	1.33± 0.03	21.2± 0.35	19.5± 1.05
Comercial inoculam	NS	Coffee brown	23.2± 0.39	7.3± 0.03	2.03± 0.07	14.2± 0.30	17.6± 0.40
	CS	Coffee brown	23.7± 0.90	7.3± 0.12	1.67± 0.07	15.9± 0.15	14.2± 0.74
Jeevamrutham	NS	Coffee brown	21.8± 0.15	7.3± 0.03	2.33± 0.15	16.3± 0.12	11.8± 0.21
	CS	Coffee brown	21.5± 0.43	7.4± 0.09	2.77± 0.09	17.7± 0.31	13.4± 0.03

NS - Non segregated, CS-Completely segregated

higher pH (8.1). Higher pH in these samples might be due to improper method of composting and immaturity of the compost. However, considering the acidic nature of the soils of Kerala, the matured composts with pH more than 6.5 are beneficial for improving the chemical condition of the soil. The electrical conductivity was found increased with the addition of microbial consortium. It was maximum in jeevamrutham applied treatments followed by commercial inoculum and cowdung. Since, all the samples were within the prescribed limit of Fertiliser Control (Amendment) Order (2013) ie , ≤ 4 dS/m, they were found suited for organic farming under Kerala condition. In the present study, C:N ratio in the compost samples ranged from 11.8:1 to 19.5 :1. A wider C:N ratio was noted in the cow dung applied treatment and narrow in jeevamrutham applied treatment. Carbon to nitrogen ratio (C:N) is considered as a chemical indicator for compost maturity with respect to organic matter and N cycling.

Table 37. Composition of major nutrients in the urban waste composts produced at composting unit, Chalakkudy

Treatment	Segregation status	Nutrient (%)				
		N	P	K	Ca	Mg
Control	NS	1.09±0.04	0.54±0.03	0.70±0.06	0.55±0.04	0.19±0.01
	CS	1.13±0.02	0.58±0.02	0.61±0.02	0.45±0.04	0.22±0.02
Cow dung	NS	1.12±0.06	0.71±0.01	0.68±0.02	1.39±0.07	0.88±0.05
	CS	1.09±0.04	0.72±0.03	0.66±0.06	1.33±0.15	0.57±0.03
Comercial inoculum	NS	0.81±0.03	1.06±0.01	0.68±0.07	0.76±0.03	0.19±0.03
	CS	1.13±0.07	0.87±0.03	0.75±0.03	0.42±0.07	0.19±0.00
Jeevamrutham	NS	1.38±0.02	1.13±0.02	0.99±0.02	0.68±0.02	0.42±0.05
	CS	1.33±0.02	1.06±0.05	1.05±0.04	0.75±0.03	0.49±0.02

NS - Non segregated, CS-Completely segregated

Ideal compost feedstock mixtures are supposed to have an initial C:N ratio of about 30:1, decreasing to less than 20:1 as composting process proceeds (Sullivan and Miller, 2001).

Nitrogen, phosphorus and potassium, being the major nutrients absorbed by the plants from the soil, these are considered as important quality parameters of composts. Data with respect to the content of N (0.81-1.38 per cent), P (0.54-1.13 per cent), K (0.61-1.07 per cent), Ca (0.42-1.39 per cent) and Mg (0.19- 0.88 per cent) in the composts are given in Table 37. Content of these major nutrients were comparatively high in jeevamrutham applied treatments. However, all the samples were with the minimum requirement of nutrients suggested by Fertiliser Control (Amendment) Order (2013).

Heavy metal contamination

Presence of heavy metals such as Cd (0.72-6.63 *mg* kg^{-1}), Pb (91.8-360.4 mg kg^{-1}), Cr (17.5-82.13mg kg^{-1}) and Ni (18.7-53.7mg kg^{-1}) were seen in all the compost (Table 38).

Table 38. Content of heavy metals in the urban waste composts produced at composting unit, Chalakkudy

Treatment	Segregation status	Heavy metal, mg kg^{-1}			
		Cd	Pb	Cr	Ni
Control	NS	6.63±0.12	314.8±15.29	82.13±3.30	53.67±2.83
	CS	4.47±0.28	107.6±4.22	40.87±5.19	33.77±0.44
Cow dung	NS	5.40±0.40	305.6±6.53	49.97±4.94	52.77±0.55
	CS	2.43±0.27	92.0±2.06	35.70±4.38	22.87±1.05
Commercial inoculam	NS	3.20±0.23	360.4±8.63	48.03±0.92	45.50±2.11
	CS	0.80±0.02	91.8±2.34	22.13±1.13	19.17±1.07
Jeevamrutham	NS	4.43±0.12	262.9±12.89	42.03±1.16	32.07±1.30
	CS	0.70±0.13	93.3±3.00	17.50±1.14	18.67±1.79

NS - Non segregated, CS-Completely segregated

But their content was significantly less in the compost produced out of segregated waste, applied with jeevamrutham.

Pathogenic contamination

Presence of salmonella ($2.17x10^3$ cfu/g) and *E. Coli* (1.8 $x10^3$ $-2.5x10^3$) were seen only in the compost produced without microbial consortium. In the other samples heat generated during composting might have killed all the pathogenic organisms.

Quality indices

Quality evaluation of composts produced through different treatments was carried out based on the values generated for clean and quality indices (Table 39).

Table 39. Quality and clean indices of urban waste composts produced at composting unit, Chalakkudy

Treatment	Segregation status	Quality index	Clean index
Control	NS	2.9	1.4
	CS	2.9	3.0
Cow dung	NS	3.3	2.0
	CS	3.9	3.5
Commercial inoculam	NS	3.1	2.5
	CS	3.4	4.1
Jeevamrutham	NS	3.9	2.5
	CS	4.1	4.1

NS- Non segregated, CS- Completely segregated

The data indicated that the composts prepared out of completely segregated urban wastes with jeevamrutham as inoculum was with higher values for quality index(4.1) and clean index (4.1). Normally the compost with quality index >3.5 and clean index > 4.0 is best suited for organic farming (Saha *et al.,* 2010). This reveals the fact that urban waste, completely segregated at two levels (at source of waste generation and composting unit) and composted using jeevamrutham as inoculum, through aerobic windrow method, lead to the production of good quality compost with adequate nutrients, minimum contamination of heavy metals and absence of pathogenic organisms.

Summary and conclusion

CHAPTER 6

SUMMARY AND CONCLUSION

This study was conducted at Kerala Forest Research Institute, Peechi, during 2011-2016. The study aimed mainly to evaluate the possibility of using the compost produced out of different types of urban wastes at various composting centres in Kerala. The study was launched in the context of probing an alternate option for the continuous supply of organic amendments for the recent organic farming drive in the State. This was achieved mainly through three different objectives. The first objective, mainly focused on the quality of urban and rural waste composts commonly available in Kerala and to categorize them based on their quality and fertilising potential. The second objective was designed in such a way to find out the effect of urban waste dumping on soil characteristics, accumulation of toxic heavy metals in plants, and the effect of dumpyard leachate on soil and water bodies in the surrounding areas. The third objective tried to explore the remedial measures to minimize the contamination in the urban waste composts. The important findings obtained under each objective and the conclusions drawn are given in the following paragraphs.

1. **Nutrient composition, heavy metal content, pesticide residue and pathogenicity of urban and rural waste composts commonly available in Kerala**

    - Most of the urban waste composting units in Kerala were not following proper segregation and scientific method of composting.
    - All the rural composting units under study, were following composting on a small scale by adopting proper method of composting.
    - Most of the urban waste composts (except those from Vilappinsala for colour ; Laloor, Kodungallur and Perinthalmanna for moisture) and all the rural waste composts were with desirable colour and moisture.
    - The pH of urban waste composts varied between 7.0 to 9.4, and those of rural waste composts between 5.0-7.3. The coir pith compost, which was acid in nature, was not suitable for acidic soils of Kerala.

- In general, most of the urban waste composts were with adequate levels of macronutrients and high reserves of micronutrients.
- Even though , there were some exceptions, most of the rural waste composts were also with adequate levels of macronutrients and high reserve of micronutrients.
- Presence of toxic levels of heavy metals were observed in most of the urban waste composts, while they were at minimum levels in rural composts.
- Residues of pesticides were not detected in any of the urban or rural waste composts, while the presence of salmonella and total coliform were detected in some samples of urban waste composts
- Based on the values for quality index, the urban waste composts in the decreasing order of their quality were Sakthan > Chalakkudy > Attingal, Perinthalmanna > Adat >Kongad>Laloor, Vilappinsala> Palakkad, Kozhikkod >Kodungallur. The rual waste composts in the decreasing order of their quality were mixed weed > vegetable waste> ayurvedic medicinal waste>mushroom waste > agricultural waste > market waste > coir pith>paper waste.
- In the case of clean index, the urban waste composts from Sakthan, and rural waste composts made out of weeds and vegetable wastes were found to have the desired values.
- Based on the values for quality and clean indices, the composts from Sakthan was with high fertilising potential, and grouped under the category of " best quality". None of the urban waste composts were qualified to be under "very good and good" category. The composts produced at Attingal, Adat and Kongad belonged to the category "medium quality". But the composts from Laloor, Kodungallur, Vilappinsala, Chalakkudy, Palakkad, Kozhikkod and Perinthalmanna were not suited for organic farming.
- In the case of rural composts, mixed weed and vegetable waste composts were grouped under the category of "best quality". The compost produced from mushroom waste was in the category " good quality" and those from market waste, paper waste, coir pith, ayurvedic medicinal waste and agricultural waste were not qualified for organic farming owing to the low value for clean index.

2. **Effect of urban waste dumping on accumulation of heavy metals and other contaminants in soils and plants**

- Continuous application of urban waste dumping in general resulted in the improvement of pH, enrichment of organic carbon and higher reserves of essential plant nutrients and toxic heavy metals.
- Among the fractions of heavy metals, plant available forms (exchangeable + Fe and Mn oxides) were found dominant with respect to Cd and Pb and residual fractions in the case of Ni and Cr.
- Among the various heavy metals, intensity of pollution in the soil was very high due to Cd followed by Pb, Cr and Ni.
- Among the various heavy metals, plants absorb larger quantity of Pb followed by Cd, Ni and Cr irrespective of the nature of plant species.
- Absorption of heavy metals by various plant species differed at various stages of growth. Higher absorption of metals at three, six, twelve and twenty four months was noticed in amaranth, vetiver, bamboo and teak respectively. This point out the fact that shorter the lifecycle of plants, greater will be the absorption of metals during the initial stages of growth.
- Amaranth was a hyper accumulator with respect to Cd, Pb and Ni at three months after planting. But in the case of vetiver, translocation of all the heavy metals from roots to other plant parts started only at 12 months after planting. In teak, during three months period, only Cd got translocated, while after six months, Cd, Pb and Cr also got translocated. Translocation of all the metals from roots to aerial parts took place only at 12 months after planting. In the case of bamboo also, translocation of heavy metals from roots to other plant parts was operational only at 12 months after planting.
- Amaranth and vetiver should not be grown on soils contaminated with heavy metals
- Bamboo and teak, being non edible and long duration plants, and translocate heavy metals at 12 months after planting, are suited for phyto remediation of soils, contaminated with heavy metals.

- The content of all the nutrients and heavy metals were decreasing with increase in the distance from the dumpyard site and this disclose the profound influence of urban waste leachate on the soil characteristics of the surrounding area.
- Important water quality parameters such as colour, odour, taste, pH, hardness, $NO_{3,}$ Fe, coliform etc. were significantly affected due to the discharge of urban waste leachate to the surrounding well, while the influence on other parameters were relatively less.
- Contamination of well water due to the urban waste leachate was relatively less during post monsoon compared to pre monsoon period.

3. Appropriate remedial measures to minimize soil and plant health hazards caused by the application of urban waste composts

- Combined application of urban waste compost with good quality weed compost could produce significantly higher biomass in amaranth, vetiver, teak and bamboo than urban waste compost alone irrespective of the quantity applied.
- Concentration and uptake of heavy metals by various plants were decreasing on diluting the urban waste compost with good quality weed compost and this reduction was very high at higher dose.
- Urban waste, completely segregated at two levels (at source of waste generation and composting unit) and composted using jeevamrutham as inoculum, through aerobic windrow method, lead to the production of good quality compost in a shorter period, with adequate nutrients, minimum contamination of heavy metals and absence of pathogenic organisms.

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Appendix

Appendix 1

Table 1. Pesticide residues of urban waste composts produced at different composting units in Kerala

Pesticide residues, mg kg^{-1}		Laloor	Kodungallur	Wilappinsala	Chalakkudy	Palakkad	Adat	Kongad	Kozhikkod	Perinthalmanna	Attingal	Sakthan
Organo chlorides	Alpha HCH	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
	Gama HCH/Lindane	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
	Delta HCH	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
	Endosulfan-I	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
	Endosulfan-II	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
	Endosulfan Sulphate	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
	P,P'-DDE	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
	P,P'-DDD	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
	P,P'-DDT	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
Organo phosphorus	Phorate	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
	Chlorpyriphos	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
	Malathion	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
	Parathion-Methyl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
	Quinolphos	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
	Profenophos	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
	Ethion	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl

Table 2. Pesticide residues of rural waste composts produced at different composting units in Kerala

Pesticide residues, mg kg^{-1}		Market waste	Paper waste	Mushroom waste	Coir pith	Ayurvedic medicinal waste	Agriculture waste	Vegetable waste	Mixed weeds
Organo chlorides	Alpha HCH	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
	Gama HCH/Lindane	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
	Delta HCH	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
	Endosulfan-I	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
	Endosulfan-II	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
	Endosulfan Sulphate	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
	P,P'-DDE	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
	P,P'-DDD	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
	P,P'-DDT	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
Organo phosphorus	Phorate	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
	Chlorpyriphos	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
	Malathion	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
	Parathion-Methyl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
	Quinolphos	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
	Profenophos	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl
	Ethion	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl	Bdl

Appendix 2

Table 1. Effect of urban waste dumping on concentration of heavy metals in amaranth

Metal (mg kg^{-1})	plant parts	Laloor	Palakkad
Cd	Root	11.73 ± 0.74^{a}	13.33 ± 2.34^{a}
	Shoot	40.73 ± 2.63^{c}	44.07 ± 3.10^{c}
	Leaf	24.73 ± 1.74^{b}	29.23 ± 1.55^{b}
Pb	Root	67.80 ± 2.55^{a}	67.80 ± 2.55^{a}
	Shoot	86.07 ± 2.71^{b}	86.07 ± 2.71^{b}
	Leaf	62.60 ± 1.59^{a}	75.53 ± 1.67^{a}
Cr	Root	40.67 ± 2.31^{b}	27.53 ± 0.57^{c}
	Shoot	31.00 ± 5.15^{ab}	20.47 ± 1.16^{b}
	Leaf	24.93 ± 2.98^{a}	17.23 ± 0.69^{a}
Ni	Root	68.60 ± 7.57^{ab}	62.73 ± 3.41^{a}
	Shoot	82.13 ± 3.66^{b}	85.60 ± 0.31^{b}
	Leaf	55.13 ± 1.10^{a}	56.33 ± 2.07^{a}

Table 2. Effect of urban waste dumping on concentration of heavy metals in Vetiver

Metals l (mg kg^{-1})	Plant parts	Laloor			Palakkad		
		3months	6months	12months	3months	6months	12months
Cd	Root	16.73±0.34[b]	38.07±0.96[c]	61.87±4.21[b]	16.87±0.78[b]	44.30±2.00[b]	62.07±2.21[b]
	Shoot	10.00±0.55[a]	17.20±1.25[b]	24.40±2.36[a]	8.53±0.28[a]	16.87±1.76[a]	28.80±1.51[a]
Pb	Root	43.60±2.31[b]	106.07±4.84[b]	103.53±7.00[c]	46.63±0.71[b]	113.23±2.23[b]	153.33±3.71[b]
	Shoot	15.83±0.79[a]	52.73±2.24[a]	53.20±10.63[b]	16.87±0.23[a]	49.87±0.76[a]	76.67±4.67[a]
Cr	Root	20.40±0.46[b]	60.13±0.67[b]	83.33±5.77[b]	20.40±0.46[b]	59.50±1.07[c]	86.60±1.74[b]
	Shoot	12.33±1.40[a]	27.90±1.80[a]	49.60±2.55[a]	12.33±1.40[a]	29.83±0.73[b]	33.20±1.67[a]
Ni	Root	41.43±2.98[b]	118.93±5.78[c]	164.27±2.40[b]	48.80±1.39[c]	127.77±2.46[b]	174.20±0.83[b]
	Shoot	32.07±2.07[a]	76.20±1.18[b]	70.47±1.71[a]	32.43±1.52[b]	61.57±11.42[a]	80.80±9.80[a]

Table 3. Effect of urban waste dumping on concentration of heavy metals in Bamboo

Metals l (mg kg^{-1})	Plant parts	Laloor				Palakkad			
		3months	6months	12months	24 months	3months	6months	12months	24 months
Cd	Root	13.83±0.54^{b}	21.80±1.08^{b}	40.9±0.88^{b}	40.50±1.6^{a}	13.57±0.67^{b}	21.23±1.52^{b}	37.80±0.7^{b}	84.40±1.07^{c}
	Shoot	10.53±0.18^{a}	12.77±0.60^{a}	23.27±0.81^{a}	81.27±2.2^{ab}	10.27±0.29^{a}	11.97±0.33^{a}	23.67±0.18^{a}	47.77±1.72^{b}
	Leaf	11.37±0.88^{a}	10.73±0.58^{a}	21.33±1.58^{a}	29.60±1.6^{a}	9.70±0.32^{a}	11.47±0.6^{a}	22.00±0.80^{a}	34.50±1.37^{a}
Pb	Root	34.20±0.81^{c}	84.17±2.38^{c}	168.6±11.3^{b}	83.70±1.3^{ab}	36.70±1.37^{b}	74.4±1.95^{c}	144.6±17.6^{b}	165.63±3.81^{c}
	Shoot	17.43±0.35^{b}	38.93±1.45^{b}	70.40±6.86^{a}	166.40±1.6^{b}	13.07±1.71^{a}	33.57±2.0^{b}	62.00±3.06^{a}	95.90±3.61^{b}
	Leaf	11.00±0.56^{a}	18.13±1.25^{a}	65.27±1.67^{a}	74.40±2.3^{a}	9.27±0.52^{a}	18.2±2.04^{a}	28.87±5.57^{a}	51.43±0.98^{a}
Cr	Root	14.67±0.33^{b}	40.53±0.48^{c}	62.33±6.20^{b}	74.27±2.8^{a}	14.67±0.33^{b}	38.3±1.43^{c}	58.40±2.44^{b}	148.43±7.78^{c}
	Shoot	11.13±0.58^{a}	25.40±0.59^{b}	45.00±2.48^{a}	113.83±2.3^{b}	11.40±0.90^{a}	28.8±0.93^{b}	60.13±1.33^{b}	69.93±2.92^{b}
	Leaf	10.5±0.85^{a}	20.33±1.10^{a}	39.27±1.56^{a}	58.87±1.6^{a}	10.5±0.85^{a}	23.3±1.18^{a}	36.07±6.16^{a}	49.20±4.00^{a}
Ni	Root	30.5±0.43^{c}	89.4±1.07^{b}	146.53±2.4^{b}	105.37±2.8^{b}	33.37±1.47^{b}	83.93±3.2^{b}	138.1±5.24^{c}	163.13±5.07^{c}
	Shoot	21.47±0.55^{b}	39.67±0.58^{a}	93.13±1.47^{a}	181.17±3.1^{b}	24.30±1.41^{a}	43.57±1.8^{a}	84.87±4.64^{a}	113.57±2.62^{a}
	Leaf	14.17±0.81^{a}	38.87±1.23^{a}	102.4±4.98^{a}	109.53±1.8^{b}	21.93±2.03^{a}	41.2±0.74^{a}	120.8±1.68^{b}	136.73±4.59^{b}

Table 3. Effect of urban waste dumping on concentration of heavy metals in Teak

Metals l (mg kg^{-1})	Plant parts	Laloor				Palakkad			
		3months	6months	12months	24months	3months	6months	12months	24months
Cd	Root	6.10±0.12^{b}	7.67±0.39^{a}	26.13±1.88^{b}	38.20±1.62^{a}	5.00±0.26^{a}	10.07±0.73^{a}	25.73±2.42^{b}	39.43±1.62^{b}
	Shoot	6.80±0.10^{c}	12.50±1.07^{b}	32.27±0.96^{c}	60.80±2.4^{b}	6.80±0.26^{b}	14.63±1.20^{b}	35.27±3.54^{c}	62.33±2.34^{c}
	Leaf	4.20±0.17^{a}	7.87±0.15^{a}	14.07±0.24^{a}	30.30±1.3^{a}	4.37±0.18^{a}	8.10±0.75^{a}	13.73±1.76^{a}	28.97±2.32^{a}
Pb	Root	17.53±1.16^{b}	27.50±2.63^{a}	96.40±3.58^{b}	97.60±1.8^{ab}	24.60±0.95^{c}	10.93±1.07^{a}	93.33±9.40^{ab}	125.77±19.18^{ab}
	Shoot	20.53±1.04^{b}	39.93±1.28^{b}	77.07±4.62^{ab}	144.37±2.1^{b}	20.67±1.22^{b}	27.67±2.48^{c}	130.67±8.19^{b}	157.57±3.37^{b}
	Leaf	13.27±0.29^{a}	33.23±1.39^{a}	62.00±8.08^{a}	78.07±2.3^{a}	14.53±0.55^{a}	47.37±0.91^{b}	75.33±17.98^{a}	102.87±9.03^{a}
Cr	Root	8.10±0.12^{a}	15.97±0.17^{b}	25.87±0.71^{a}	48.07±0.81^{a}	8.10±0.12^{a}	36.87±2.04^{b}	27.80±1.56^{a}	105.37±3.98^{b}
	Shoot	7.87±0.65^{a}	21.17±0.75^{c}	32.33±1.76^{b}	76.70±1.12^{b}	7.87±0.65^{a}	37.30±3.00^{b}	31.13±1.80^{a}	75.07±9.86^{a}
	Leaf	8.33±0.46^{a}	11.70±0.76^{a}	27.73±0.35^{a}	43.43±0.56^{a}	8.33±0.46^{a}	15.93±0.71^{a}	24.67±2.53^{a}	49.33±7.72^{a}
Ni	Root	12.67±0.23^{c}	36.87±0.35^{b}	92.93±5.04^{b}	143.30±1.16^{b}	16.57±0.54^{c}	16.40±1.12^{a}	100.33±3.12^{a}	153.80±5.20^{b}
	Shoot	9.97±0.12^{b}	43.17±1.32^{c}	111.20±3.10^{c}	176.77±2.12^{b}	13.77±0.61^{b}	11.93±0.86^{b}	97.33±8.73^{a}	169.20±9.64^{b}
	Leaf	8.07±0.52^{a}	24.10±2.27^{a}	76.73±4.51^{a}	80.10±1.32^{a}	9.20±0.06^{a}	14.76±0.84^{a}	84.67±11.38^{a}	83.47±18.27^{a}

Appendix 3

Table 1. Influence of different levels of composts on concentration of amaranth, mg kg^{-1} dry weight

Treatments	Cd			Pb			Cr			Ni		
	Root	Stem	Leaves	Root	Stem	Leaves	Root	Stem	Leaves	Root	Stem	Leaves
Control	0.02± 0.00^{a}	0.02± 0.00^{a}	0.02± 0.00^{a}	0.15± 0.04^{a}	0.29± 0.05^{a}	0.15± 0.01^{a}	2.16± 0.06^{a}	1.70± 0.04^{a}	1.51± 0.08^{a}	0.84± 0.03^{a}	1.43± 0.03^{a}	1.12± 0.09^{a}
WC -*1*kg	0.01± 0.00^{a}	0.01± 0.00^{a}	0.01± 0.00^{a}	0.22± 0.04^{a}	0.32± 0.10^{a}	0.23± 0.04^{a}	2.85± 0.10^{a}	2.68± 0.03^{a}	2.41± 0.14^{ab}	1.08± 0.03^{a}	2.56± 0.03^{a}	1.37± .23^{a}
WC – 2kg	0.00± 0.00^{a}	0.00± 0.00^{a}	0.00± 0.00^{a}	0.27± 0.01^{a}	0.30± 0.02^{a}	0.24± 0.01^{a}	3.52± 0.10^{a}	3.30± 0.10^{a}	3.20± 0.04^{b}	1.26± 0.15^{a}	2.32± 0.15^{a}	2.08± 0.02^{a}
UC -*1*kg	18.50± 1.44^{c}	20.75± 2.13^{c}	23.55± 0.73^{c}	93.30± 1.97^{d}	102.35± 0.77^{d}	118.80± 3.19^{c}	27.00± 1.34^{c}	38.25± 0.85^{d}	33.25± 0.95^{e}	15.10± 0.19^{b}	17.85± 1.02^{b}	14.55± 0.10^{b}
UC – 2kg	23.35± 1.11^{d}	30.85± 2.32^{d}	33.40± 1.13^{d}	143.95± 1.70^{e}	181.15± 0.31^{e}	192.08± 0.58^{d}	30.18± 0.20^{d}	30.35± 0.46^{c}	26.75± 0.56^{d}	56.85± 1.58^{c}	64.43± 5.02^{c}	55.40± 1.44^{d}
WC+UC – 1kg	7.35± 0.10^{b}	9.60± 1.71^{b}	14.23± 0.15^{b}	26.70± 0.78^{c}	32.30± 0.50^{b}	35.00± 0.82^{b}	11.18± 0.92^{b}	13.25± 1.21^{b}	10.10± 0.49^{c}	14.34± 0.58^{b}	16.53± 1.11^{b}	14.63± 0.43^{b}
WC+UC – 2kg	6.50± 0.11^{b}	8.75± 0.16^{b}	14.75± 0.37^{b}	20.48± 0.36^{b}	42.03± 0.57^{c}	37.43± 0.53^{b}	11.69± 0.67^{b}	12.58± 0.71^{b}	10.70± 0.35^{c}	14.58± 0.75^{b}	19.20± 1.52^{b}	17.38± 0.55^{c}

WC = Weed compost, UC = Urban compost

Table 2. Influence of different levels of composts on concentration of vetiver, mg kg^{-1} dry weight

Treatments	Cd			Pb			Cr			Ni		
	Root	Stem	Leaves	Root	Stem	Leaves	Root	Stem	Leaves	Root	Stem	Leaves
Control	0.02± 0.01^{a}	0.00± 0.00^{a}	0.00± 0.00^{a}	2.22± 0.06^{a}	2.70± 0.11^{a}	2.39± 0.12^{a}	22.30± 1.19^{b}	17.88± 0.18^{b}	14.13± 0.11^{b}	28.48± 0.59^{c}	30.33± 0.25^{c}	22.30± 0.77^{b}
WC-*1*kg)	0.45± 0.03^{a}	0.16± 0.04^{a}	0.15± 0.04^{a}	7.58± 0.24^{b}	6.86± 0.04^{b}	5.74± 0.06^{ab}	23.80± 0.18^{b}	21.36± 0.34^{c}	19.65± 0.50^{c}	36.77± 0.60^{d}	34.85± 0.41^{d}	24.86± 0.39^{c}
WC-2kg	0.46± 0.03^{a}	0.04± 0.01^{a}	0.02± 0.01^{a}	10.21± 0.29^{bc}	13.53± 0.33^{cd}	11.43± 0.08^{bc}	21.85± 1.10^{b}	18.15± 2.18^{b}	12.38± 0.69^{ab}	59.15± 0.71^{e}	51.93± 0.43^{e}	30.25± 0.48^{d}
UC-*1*kg	18.07± 0.86^{d}	9.23± 0.51^{bc}	7.58± 0.21^{c}	95.34± 3.07^{e}	81.04± 0.63^{e}	75.81± 5.66^{d}	34.43± 0.59^{c}	23.90± 0.41^{c}	14.15± 0.26^{b}	66.68± 1.34f	65.40± 1.31f	44.40± 0.69^{e}
UC-2kg	29.03± 1.65^{e}	17.75± 2.19^{d}	15.05± 0.23^{d}	121.38± 2.32f	116.08± 0.90f	114.53± 0.84^{e}	46.05± 1.24^{d}	36.50± 1.27^{d}	31.50± 2.03^{d}	95.85± 2.15g	70.65± 1.83g	45.33± 0.35^{e}
WC+UC-*1*kg	9.18± 0.26^{b}	6.94± 0.17^{b}	6.29± 0.10^{b}	13.81± 0.39^{cd}	13.00± 0.19^{c}	11.64± 0.63^{bc}	14.10± 0.37^{a}	11.94± 0.74^{a}	10.80± 0.19^{a}	14.33± 0.43^{a}	8.07± 0.07^{a}	12.11± 0.26^{a}
WC+UC-2kg	12.29± 0.69^{c}	9.70± 0.47^{c}	6.45± 0.08^{b}	16.50± 0.63^{d}	15.32± .26^{d}	12.92± 0.25^{c}	15.55± 0.39^{a}	14.68± 0.63^{a}	13.68± 0.50^{b}	18.58± 0.31^{b}	17.33± 0.49^{b}	12.53± 0.77^{a}

WC = Weed compost, UC = Urban compost

Table 3. Influence of different levels of composts on concentration of bamboo, mg kg^{-1} dry weight

Treatments	Cd			Pb			Cr			Ni		
	Root	Stem	Leaves	Root	Stem	Leaves	Root	Stem	Leaves	Root	Stem	Leaves
Control	0.00± 0.00^{a}	0.00± 0.00 ^{a}	0.00± 0.00^{a}	0.88± 0.03^{a}	1.12± 0.10^{a}	1.03± 0.02^{a}	0.92± 0.01^{a}	1.07± 0.02^{a}	0.92± 0.02 ^{a}	2.97± 0.04^{a}	2.32± 0.18^{a}	1.81± 0.15 ^{a}
WC-*1*kg)	0.01± 0.00^{a}	0.01± 0.00^{a}	0.01± 0.00^{a}	0.49± 0.01^{a}	0.51± 0.00^{a}	0.45± 0.04^{a}	2.00± 0.09^{ab}	1.83± 0.04^{a}	1.03± 0.00 ^{a}	3.45± 0.09^{a}	2.82± 0.23^{a}	2.29± 0.05 ^{a}
WC-2kg	0.01± 0.00^{a}	0.01± 0.00^{a}	0.00± 0.00^{a}	0.42± 0.01^{a}	0.42± 0.01^{a}	0.37± 0.02^{a}	2.83± 0.05^{b}	2.75± 0.05^{a}	1.67± 0.08 ^{a}	3.65± 0.10^{a}	3.24± 0.29^{a}	2.36± 0.13 ^{a}
UC-*1*kg	19.08± 0.82^{d}	15.90± 0.66^{d}	14.40± 0.12^{d}	88.15± 0.68^{d}	84.73± 1.03^{d}	81.78± 0.75^{c}	45.53± 1.16^{d}	40.70± 2.30^{d}	39.10± 1.08 ^{d}	43.40± 0.84^{d}	33.40± 0.84^{c}	29.60± 0.41 ^{d}
UC-2kg	21.60± 1.67^{e}	17.50± 0.16^{e}	15.63± 0.09^{e}	110.70± 3.90^{e}	101.28± 1.61^{e}	94.68± 1.68^{d}	46.15± 0.46^{d}	35.93± 0.49^{c}	36.95± 0.72 ^{c}	96.73± 0.76^{e}	77.75± 1.94^{d}	57.53± 1.77 ^{e}
WC+UC-*1*kg	6.60± 0.38^{b}	6.10± 0.27^{b}	4.85± 0.27^{b}	26.75± 0.63^{b}	21.70± 0.69^{b}	23.48± 0.35^{b}	16.08± 0.52^{c}	15.33± 0.98^{b}	13.73± 0.55 ^{b}	25.68± 1.05^{c}	26.98± 0.95^{b}	24.28± 0.42 ^{c}
WC+UC-2kg	11.05± 0.68^{c}	9.63± 0.77^{c}	8.75± 0.29^{c}	31.90± 1.74^{c}	29.48± 3.05^{c}	23.90± 0.54^{b}	16.35± 0.76^{c}	14.70± 1.32^{b}	13.35± 0.22 ^{b}	22.15± 0.54^{b}	24.93± 1.44^{b}	21.68± 0.44 ^{b}

WC = Weed compost, UC = Urban compost

Table 4. Influence of different levels of composts on concentration of teak, mg kg^{-1} dry weight

Treatments	Cd			Pb			Cr			Ni		
	Root	Stem	Leaves	Root	Stem	Leaves	Root	Stem	Leaves	Root	Stem	Leaves
Control	0.00± 0.00^{a}	0.00± 0.00^{a}	0.00± 0.00^{a}	1.13± 0.03^{a}	1.05± 0.01^{a}	0.94± 0.04^{a}	1.26± 0.05^{a}	5.95± 0.33^{b}	5.25± 0.56^{b}	5.38± 0.03^{a}	4.30± 0.71^{a}	3.09± 0.07^{a}
WC-*1*kg)	0.01± 0.00^{a}	0.00± 0.00^{a}	0.00± 0.00^{a}	3.11± 0.03^{ab}	2.85± 0.07^{a}	2.50± 0.05^{a}	1.81± 0.02^{a}	1.76± 0.03^{a}	0.79± 0.05^{a}	7.31± 0.22^{b}	6.68± 0.46^{a}	5.57± 0.41^{b}
WC-2kg	0.00± 0.00^{a}	0.00± 0.00^{a}	0.00± 0.00^{a}	3.33± 0.04^{b}	3.27± 0.06^{a}	2.69± 0.07^{a}	1.73± 0.11^{a}	1.55± 0.12^{a}	1.31± 0.04^{a}	7.78± 0.11^{b}	6.27± 0.45^{a}	5.62± 0.22^{b}
UC-*1*kg	9.55± 0.24^{d}	10.35± 0.62^{d}	11.08± 0.37^{d}	67.05± 0.62^{e}	62.80± 1.77^{d}	52.35± 0.58^{d}	25.25± 1.14^{c}	30.80± 0.96^{d}	23.00± 1.48^{e}	41.95± 0.62^{e}	45.25± 2.46^{c}	40.80± 0.35^{d}
UC-2kg	12.78± 0.26^{e}	14.35± 0.64^{e}	14.10± 0.65^{e}	79.78± 1.45f	75.38± 1.40^{e}	65.98± 1.43^{e}	33.93± 0.88^{d}	41.43± 1.97^{e}	43.35± 0.61f	91.25± 0.41f	88.33± 2.35^{d}	81.25± 0.66^{e}
WC+UC-*1*kg	4.78± 0.21^{b}	5.78± 0.44^{b}	5.28± 0.19^{b}	38.40± 0.75^{d}	36.83± 0.72^{c}	35.43± 0.40^{c}	11.28± 0.56^{b}	12.53± 0.29^{c}	11.28± 0.56^{c}	14.75± 0.66^{c}	16.15± 1.37^{b}	12.93± 0.17^{c}
WC+UC-2kg	7.90± 0.37^{c}	9.10± 0.35^{c}	8.05± 0.26^{c}	35.50± 0.60^{c}	28.68± 1.63^{b}	29.03± 1.96^{b}	11.23± 0.25^{b}	13.48± 0.06^{c}	14.10± 0.35^{d}	16.38± 0.23^{d}	15.48± 1.10^{b}	12.43± 0.09^{c}

WC = Weed compost, UC = Urban compost

Appendix 4

Table 1. Percentage reduction in the concentration heavy metals in amaranth

Treatment	Cd (mg/kg)	Pb (mg/kg)	Cr (mg/kg)	Ni (mg/kg)
WC-*1*kg)	0-0.001	0.22-0.32	2.42 -2.85	1.08 -2.56
WC-2kg	0-0.001	0.24 -0.3	3.2 -3.5	1.26 -2.32
UC-*1*kg	18.5-23.55	93.3 -118.8	27 -38.25	14.55 -17.85
UC-2kg	23.35 -33.40	143.95 -192.08	26.75 -30.35	55.40 -64.43
WC+UC-*1*kg	7.35 -14.23 **(60.3-39.6%)**	26.7 -35 **(71.4-70.5%)**	10.1 -13.25 **(62.6-65.4%)**	14.34 -16.53 **(1.4-7.4%)**
WC+UC-2kg	6.5 -14.75 **(72.2-55.8%)**	20.48 -37.43 **(85.8-80.5%)**	10.70 -12.58 **(60-58.6%)**	14.58 -19.20 **(73.7-70.2%)**
Plant parts	Leaf>Stem>Root >Stem>Root	Leaf>Stem>Root	Stem>Root>Leaf	Stem>Leaf>Root

WC = Weed compost, UC = Urban compost

Table 2. Percentage reduction in the uptake of heavy metals in amaranth

Treatment	Cd, mg kg^{-1}	Pb, mg kg^{-1}	Cr, mg kg^{-1}	Ni, mg kg^{-1}
WC-*1*kg)	BDL	0.00 - 0.02	0.03 - 0.18	0.01 - 0.17
WC-2kg	BDL	0.0 - 0.02	0.5 - 0.22	0.02 - 0.15
UC-*1*kg	0.11-0.75	0.52 - 3.7	0.15 - 0.26	0.08 - 0.64
UC-2kg	0.36 -1.15	1.07 - 9.35	0.22 - 1.56	0.42 - 3.39
WC+UC-*1*kg	0.05 - 0.47 **(50-62.7%)**	0.18 - 1.55 **(34.6-41.9%)**	0.08 - 0.6 **(53.3%)**	0.10 - 0.79
WC+UC-2kg	0.07 - 0.4 **(19.4-34.8%)**	0.23 - 1.96 **(21%)**	0.13 - 0.59 **(59.1-36.9%)**	0.17 - 0.89 **(40.5-26.3%)**
Plant parts	Stem>Leaf>Root	Stem>Leaf>Root	Stem>Leaf>Root	Stem>Leaf>Root

WC = Weed compost, UC = Urban compost

Table 3. Percentage reduction in the concentration heavy metals in vetiver

Treatment	Cd, mg kg^{-1}	Pb, mg kg^{-1}	Cr, mg kg^{-1}	Ni, mg kg^{-1}
WC-1kg)	0.15 -0.45	5.74 -7.58	19.65 -23.8	24.86 -36.77
WC-2kg	0.02 -0.46	10.21 -13.53	12.38 -21.85	30.25 -59.15
UC-1kg	7.58 -18.07	75.81 -95.34	14.15 -34.43	44.40 -66.68
UC-2kg	15.05 -29.03	114.53 -121.38	31.50 -46.05	45.33 -95.85
WC+UC-1kg	6.29 -9.18 **(17-49.2%)**	11.64 -13.81 **(84.6-99.9%)**	10.80 -14.10 **(23.7-59%)**	8.07 -14.33 **(78.5-81.8%)**
WC+UC-2kg	6.45 -12.29 **(57.1-57.7%)**	12.922 -16.5 **(86.4-88.7%)**	13.68 -15.55 **(56.6-66.2%)**	12.53 -18.58 **(72.4-80.6%)**
Plant parts	Root>Stem>Leaf	Root>Stem>Leaf	Root>Stem>Leaf	Root>Stem>Leaf

WC = Weed compost, UC = Urban compost

Table 4. Percentage reduction in the uptake of heavy metals in vetiver

Treatment	Cd, mg kg^{-1}	Pb, mg kg^{-1}	Cr, mg kg^{-1}	Ni, mg kg^{-1}
WC-1kg)	0.02 -0.20	0.64 -3.42	2.20 -10.76	2.78 -16.64
WC-2kg	0.00 -0.33	1.81 -7.39	1.96 -15.87	4.79 -42.75
UC-1kg	0.50 -4.83	4.97 -25.58	0.93 -9.23	2.93 -17.79
UC-2kg	1.54 -11.94	11.67 – 50.12	3.22 -18.99	4.62 -39.52
WC+UC-1kg	0.33 -2.39 **(34-50.5%)**	0.60 -3.53 **(86.2-88%)**	0.56 -3.66 **(39.8-60.3%)**	0.62 -3.74 **(78.8-79%)**
WC+UC-2kg	0.78 -8.26 **(30.8-49.4%)**	1.57 -11.09 **(78-86.5%)**	1.66 -10.48 **(44.8-48.4%)**	1.52 -12.52 **(67.1-68.3%)**
Plant parts	Root>Stem>Leaf	Root>Stem>Leaf	Root>Stem>Leaf	Root>Stem>Leaf

WC = Weed compost, UC = Urban compost

Table 5. Percentage reduction in the concentration heavy metals in bamboo

Treatment	Cd, mg kg^{-1}	Pb, mg kg^{-1}	Cr, mg kg^{-1}	Ni, mg kg^{-1}
WC-*1*kg)	BDL	0.45 -0.51	1.03 -2.0	2.29 -3.45
WC-2kg	BDL	0.37 -0.42	1.67 -2.83	2.36 -3.65
UC-*1*kg	14.40 -19.08	81.7-88.1	39.1 -45.52	29.6 -43.4
UC-2kg	15.63 -21.60	94.68 -110.70	35.93 -46.15	57.53 -96.7
WC+UC-*1*kg	4.85 -6.65 **(65.1-66.7%)**	21.72 -26.75 **(69.6-79.4%)**	13.73 -16.08 **(64.4-64.9%)**	24.28 -26.98 **(18-37.8%)**
WC+UC-2kg	8.75 -11.05 **(44-48.8%)**	23.9 -31.9 **(71.2-74.8%)**	13.35 -16.35 **(62.9-64.6%)**	21.68 -24.93 **(62.3-74.2%)**
Plant parts	Root>Stem>Leaf	Root>Stem>Leaf	Root>Stem>Leaf	Root>Stem>Leaf

WC = Weed compost, UC = Urban compost

Table 6. Percentage reduction in the uptake of heavy metals in bamboo

Treatment	Cd, mg kg^{-1}	Pb, mg kg^{-1}	Cr, mg kg^{-1}	Ni, mg kg^{-1}
WC-1kg)	BDL	0.10 -0.19	0.04 -0.68	0.09 -1.08
WC-2kg	BDL	0.11 -0.22	0.08 -1.48	0.11 -1.75
UC-1kg	0.27 -1.09	1.54 -8.61	0.74 -4.44	0.56 -4.24
UC-2kg	0.35-3.3	2.12 -17.29	0.84 -7.14	1.26 -14.95
WC+UC-1kg	0.11 0.93 **(14.7-59.3%)**	0.51 -3.76 **(56.3-66.9%)**	0.30 -2.24 **(49.5-59.5%)**	0.53 -3.67 **(5.4-13.4%)**
WC+UC-2kg	0.35 -4.44 **(-)**	0.95 -13.69 **(20.8-55.2%)**	0.53 -6.61 **(7.4-36.9%)**	0.87 -11.28 **(24.5-31%)**
Plant parts	Root>Stem>Leaf	Root>Stem>Leaf	Root>Stem>Leaf	Root>Stem>Leaf

WC = Weed compost, UC = Urban compost

Table 7. Percentage reduction in the concentration heavy metals in teak

Treatment	Cd, mg kg^{-1}	Pb, mg kg^{-1}	Cr, mg kg^{-1}	Ni, mg kg^{-1}
WC-1kg)	0.00 -0.01	2.50 -3.11	0.79 -1.81	5.57 -7.31
WC-2kg	0	2.69 -3.33	1.31 -1.73	5.62 -7.78
UC-1kg	9.55 -11.08	52.35 -67.05	23.00 -30.80	40.80 -45.25
UC-2kg	12.78 -14.35	65.98 -79.78	33.93 -43.35	81.25 -91.25
WC+UC-1kg	4.78 -5.78 **(47.8-49.9%)**	35.43 -38.40 **(32.3-42.7%)**	11.28 -12.53 **(51-59.3%)**	12.93 -16.15 **(64.3-68.3%)**
WC+UC-2kg	7.90 -9.10 **(36.6-38.2%)**	28.68 -35.50 **(55.5-56.5%)**	11.23 -14.10 **(66.9-67.5%)**	12.43 -16.38 **(82-84.7%)**
Plant parts	Stem>Root>Leaf	Root>Stem>Leaf	Stem>Leaf>Root	Stem>Root>Leaf

WC = Weed compost, UC = Urban compost

Table 8. Percentage reduction in the uptake of heavy metals in teak

Treatment	Cd, mg kg^{-1}	Pb, mg kg^{-1}	Cr, mg kg^{-1}	Ni, mg kg^{-1}
WC-1kg)	0.0	0.02 -0.97	0.01 -0.60	0.04 -2.27
WC-2kg	0	0.04 -1.74	0.02 -0.83	0.08 -3.31
UC-1kg	0.08 -1.37	0.37 -8.41	0.16 -4.12	0.29 -6.03
UC-2kg	0.15 -4.25	0.74 -22.19	0.47 -12.18	0.90 -26.10
WC+UC-1kg	0.03 -1.18 **(13.9-62.5%)**	0.20 -7.64 **(9.2-45.9%)**	0.06 -2.61 **(36.7-62.5%)**	0.07 -3.41 **(43.4-75.9%)**
WC+UC-2kg	0.10 -3.17 **(66.7-74.6%)**	0.35 -9.93 **(52.7-55.3%)**	0.17 -4.70 **(36.2-38.6%)**	0.15 -5.46 **(16.7-20.9%)**
Plant parts	Stem>Root>Leaf	Stem>Root>Leaf	Stem>Root>Leaf	Stem>Root>Leaf

WC = Weed compost, UC = Urban compost

Publications