7. Discussion

7.1. MSW sources

Municipal solid waste consists of household waste, construction and demolition debris, sanitation residue, and waste from streets. This garbage is generated mainly from residential and commercial complexes. Main Sources of Municipal Waste are

- Household waste
- Commercials:
  - Street sweeping
  - Hotels and restaurants
- Clinics and dispensaries
- Construction and demolition
- Horticulture
- Sludge

Sharholy et al. (2008) categorized MSW sources as food waste, rubbish, commercial waste, institutional waste, street sweeping waste, industrial waste, construction and demolition waste, and sanitation waste. Presently, about 90 million t of solid waste are generated annually as byproducts of industrial, mining, municipal, agricultural and other processes. The amount of MSW generated per capita is estimated to increase at a rate of 1–1.33% annually (Pappu et al., 2007; Shekdar, 1999; Bhide and Shekdar, 1998).

7.2. MSW generation

The increase in waste generation is strongly correlated with the increase in population growth (Alamgir et al., 2005; Kumar et al., 2009). The MSW generation showed relationships between waste quantity and a broad set of individual characteristics or habits of the household, which are further related to factors like income, living standards and education level (Beigl, 2008; Kumar et al., 2009). The increase in waste generation was also strongly correlated with time. It is supported by earlier report (Xiao et al., 2007) that discussed about the slow increase trend of organic and recycling waste from 1991 to 2003 in Beijing. Our findings are also in consistent with the findings of Yousuf and Rahman (2007) where the total waste generation included business waste, street waste and domestic waste increased with time. Moreover, the general trend of MSW generation in Thailand is increasing each year (Chiemchaisri et al., 2007). The increase in waste generation is strongly correlated with the increase in population growth (Alamgir et al., 2005; Kumar et al., 2009).

7.3. Composition of MSW

It is essential to know the composition and characterization of MSW for implementing proper waste disposal and management plans and practices for recovery of resource and energy potentials before deciding on the appropriate method of its disposal (Nilanthi et al., 2007; Yousuf & Rahman, 2007). Appropriate selection of waste processing technologies can be selected based on composition and characterization of MSW. The characteristics of MSW collected from any area depends on various factors such as consumer patterns, food
habits, cultural traditions of inhabitants, life-styles, climate, economic status etc. Composition of urban waste is changing with increasing use of packaging material and plastics (CPCB, 2003).

The findings are in consistence with those of Visvanathan et al. (2004) that the solid waste composition in most Asian countries is highly biodegradable, mainly composed of an organic fraction comprising mostly of food waste, and the remaining of paper, rubber/leather, wood/grass, metal, plastic/foam, glass and textiles. In India the biodegradable portion dominates the bulk of Municipal Solid Waste. Generally the biodegradable portion is mainly due to food and yard waste (Kumar et al., 2009). Xiao et al. (2007) showed that food waste comprises the highest proportion followed by plastic and paper in Beijing. Yousef and Rahman (2007) also showed food and vegetable wastes as the dominant portion in waste mostly coming from residential and commercial areas, while the quantity of paper, plastics, rubber and wood were comparatively very low due to the daily recycling. Chanakya et al. (2007) showed fermentable fraction (fruit and vegetable waste) (72 %) occupied a highest portion in waste followed by paper (11 %), dust and sweepings (6.5 %) and plastics and polythene (6.2 %) in Bangalore. The organic (biodegradable) portion was high in waste stream of Srilanka, followed by paper, plastic, glass and metal (Nilanthi et al., 2007). MSW contains recyclables (paper, plastic, glass, metals, etc.), toxic substances (paints, pesticides, used batteries, medicines), compostable organic matter (fruit and vegetable peels, food waste) and soiled waste (blood stained cotton, sanitary napkins, disposable syringes) (Jha et al., 2003; Reddy and Galab, 1998; Khan, 1994; Sharholy et al., 2008). Its average moisture content, pH, electric conductivity and temperature were respectively 45 %, 6.5, 268.1 mho/cm and 31°C. Moisture content of 50–60% of the total weight of waste is considered ideal for the developing countries, which is contradictory to our study (Diaz et al., 1993; Yousef, 2005). Moisture content of waste was around 55-70 % in Thialand (Chiemchaisri et al., 2007). Higher moisture content indicates the possibility of the development of anaerobic conditions in the disposal site, which causes obnoxious odor and quicker rotting. For cities having population < 0.1million and between 0.11–0.5 million (19 cities), the C/N ratio was 18–37, the compostable fraction was 29–63%, and total recyclables were observed to be 13.68–36.64% (Kumar et al., 2009). A higher moisture content in the MSW was observed at Shillong, Kohima (65%), Simla, and Agartala due to heavy rains. High calorific value on a dry weight basis was observed to vary from 591 to 3766 kcal/kg.

7.4. Segregation and Primary Collection

Waste segregation at the source is minimal. Segregation of MSW into dry and wet wastes is carried out only in limited areas of a few cities, and in these areas, separate containers are used for collection of dry and wet wastes. In Puducherry, collection methods are based mostly on manual labour, which is less costly than the mechanized collection systems adopted in developed countries. The primary collection of MSW in Puducherry is the community bin collection system. In India, the community bin collection system is the main practice used for waste collection. In this system, residents deposit their waste into the nearest community bins located at street corners at specific intervals (NEERI Report, 2005). Various types of community bins, such as RCC bins, masonry bins, metallic containers, and plastic containers, are used in India, although RCC and masonry bins are being gradually phased out.

House-to-house collection is practiced now in Ouducherry It is becoming common in India, except for in a few cities. Recent legislation emphasizes the house-to-house collection system, and it is expected that this collection
method will be promoted as an improvement to the existing system in various cities and towns. Street sweepings are also collected in the community bins along with domestic waste. Corporate staff sweep the road and collect the waste in handcarts and baskets, which are emptied into the community bins.

7.5. Transportation of MSW

The average collection efficiency for MSW in Indian cities is about 72.5% and 70% of the cities lack adequate waste transport capacities (TERI, 1998; Kumar et al., 2009). Different types of vehicles, varying from bullock carts to compactors, ordinary trucks, tractor and trailers, dumper placers, and tippers, are used for waste transportation. In Puducherry, transportation is commonly carried out by the vehicles like tractors and trucks. The waste is transported mostly by municipal vehicles, although, in some large towns, private vehicles are also hired to augment the fleet. However, general-purpose open body trucks of 5–9 ton capacity are in common use. In smaller towns, tractor–trailers are used despite being noisy and inefficient. In a few cities, compactor vehicles are also being used. In those cities that use house-to-house collection, handcarts and tricycles are used for waste collection from individual houses at a specific time in the morning, when residents deposit the stored waste into the handcarts. Sometimes a bell is attached to the handcarts to alert the citizens. The waste in the hand-carts is either transferred to community bins or directly transferred to vehicles going to the disposal site.

7.6. Waste Disposal

In developing economies in Asia, the status of solid waste management is characterized by unsafe practices of open dumping and inefficient administration due to heavy governmental subsidies. Very little progress has been made in upgrading waste disposal operations, and open dumping remained as the dominant solid waste disposal system. The MSW is disposed in the open dumping yards is without any specific treatment. The cities are therefore looking for a system of disposing the solid wastes that could be free from the hazards mentioned above and should as well be cost effective. Concerns for environmental risks have driven some of the cites to adopting newer ways of waste disposal that are neither hazardous nor unaffordable. The two leading innovative mechanisms of waste disposal being adopted in India include composting (aerobic composting, anaerobic, vermi-composting, etc.) and waste-to-energy (bio-methanation, pelletisation, incineration, and pyrolysis/gasification).

According to schedule IV of ‘the rules’, the waste processing or disposal facilities shall include composting, incineration, pelletisation, energy recovery or any other facility based on state-of-the-art technology duly approved by the Central Pollution Control Board. According to schedule II of ‘the rules’, the biodegradable wastes shall be processed by composting, vermicomposting, anaerobic digestion or any other appropriate biological processing for stabilization of wastes. Mixed waste containing recoverable resources shall follow the route of recycling. Incineration with or without energy recovery including pelletisation can also be used for processing wastes in specific cases. In our study we have selected the vermicomposting and composting methods for urban waste management. As per ‘the rules’ (schedule II), "composting" means a controlled process involving microbial decomposition of organic matter; and "vermicomposting" is a process of using earthworms for conversion of bio-degradable wastes into compost. The organic component of the urban waste constitutes
about 45-60% of the total waste and can be used as a potential resource by recycling and reusing in the form of high quality compost.

Puducherry, where a lot of solid organic waste is available, the environmentally acceptable vermicomposting technology using earthworms can very well be adopted for converting waste into wealth. The viability of using earthworms as a treatment or management technique for numerous organic waste streams has been investigated by a number of workers (Hand, 1988; Singh, 2002).

7.7. Drawbacks in present SWM Management in Puducherry

- Sweeping and collection bins, vehicles used for transportation and other implements are poorly designed.
- Dustbins are not emptied regularly.
- Scattered waste causes choking of drains.
- The number of bins is inadequate.
- There are no separate bins for collection of litter.
- However, unless these community storage arrangements are conveniently located, householders tend to throw their waste into the roadside gutters for clearance by street sweeping crews.
- Even where storage arrangements are conveniently located, waste tends to be strewn around the storage area, partly due to lack of discipline and partly as a result of scavenging by rag pickers and stray animals. Due to the absence of adequate storage capacity for generated refuse and poor discipline among the generators, waste is also continually dumped on the road.
- The collected waste from the municipality is either burnt or just dumped in the low-lying areas and open landfills without processing and taking any precautions.
- Solid waste workers handle the waste without any protective equipment and are prone to infection.
- Lack of co-operation from the public is also noticed.

7.8. Suggestions for MSW management

To improve conservancy operations, authorities feel that a lack of civic awareness among city residents is proving to be a major hurdle in maintaining the cleanliness of the city. It will be nearly impossible for the civic body to provide better surroundings if residents do not make an effort to deposit waste into the bins and stop the practice of throwing garbage onto the road (Joseph, 2002). Because of the poor conditions for temporary storage of wastes, non-government organizations (NGOs) have been involved in some areas to make arrangements for household waste collection, which has led to improvement in local street cleanliness (Shekdar, 1999).

Systematic planning and implementation are needed for satisfactory and a sustainable management of MSW in Puducherry. The Reduction, Reuse and Recovery/Recycle (3Rs) strategy can be used for waste minimization. Reduction activities should be carried out at the source, which include backyard composting of yard trimmings, or reuse of products and materials that reduce the amount of waste before they enter the MSW management system. Recovery of materials, the process of removing MSW from the waste stream can be done for recycling (including composting and vermin-composting). Materials of MSW such as glass, paper, plastic, and metals can
be recycled and reused commercially in various manufacturing and industrial processes, which reduces burden on natural resources (NEERI, 1995). Proper segregation of the waste shows the way to better options and opportunities for scientific disposal of waste. The waste should be segregated mainly into biodegradable and non-biodegradable components at three different stages of the collection process, i.e., at source prior to collection, by the crews of the collection vehicle and by the rag-pickers at the dumpsite (Chiemchaisri et al., 2007). Non-biodegradable and recyclables waste could be transported to recycling units, which in turn, may be of economic value to the municipality; it may generate employment and income. Door to door collection by containerized handcart/tricycle as suggested by MSW (Management and Handling) Rules, 2000 should be initiated in more residential areas and supported by public awareness campaigns (Kumar et al., 2009). Separate collection of wet and dry components of waste should be encouraged. One of the immediate measures to revamp the existing collection service structure is to provide community waste bins conveniently placed for the people to deposit their domestic waste. It would ensure that people do not throw their garbage on the roads. The waste needs to be transported in covered vehicles. The biomedical waste including hazardous waste should be carried strictly in separate vehicles. Such waste consisting of human body parts, body fluids, etc. has to be incinerated, but for other categories of such waste, methods like microwaving and autoclaving may be applied. The current practices of dumping the waste in low-lying areas need to be discontinued. A proper plan should be developed for sanitary landfilling.

Increases in allocation of funds for better MSWM activities in Puducherry would be appreciable. Municipalities in Puducherry have started implementing the National policy and legislation for MSW management - the ‘Municipal Solid Waste (Management and Handling) Rules’ issued by the Government of India in exercise of its power under the Environment (Protection) Act (EPA), 1986 notified in 2000 with an implementation schedule (MoEF, 2000). As per The Rules, the garbage should be stored in houses in three bins – the green one for biodegradable waste, the white bin for recyclable waste and the black bin for other waste. However, people showed little interest in buying separate bins; thus the municipality has sought sponsorship by banks and private industries. Some of the branches of different banks = State Bank of India, Indian Bank and Canara Bank have agreed to supply the bins. These efforts may avoid littering of streets and deliver waste in accordance with the delivery system notified by the respective Civic body and that of ‘The Rules’.

7.9. Growth and Productivity of earthworms

The mean individual length and live weight, mean growth rate of an individual (mg/day), individual and total biomass gain, reproduction rate (cocoon worm\(^{-1}\) day\(^{-1}\)) and fecundity rate (worm cocoon\(^{-1}\) day\(^{-1}\)) total cocoon, juveniles and adult numbers in the present study varied across different treatments. The increase in body weight of all three earthworm species was noted in three substrates during vermicomposting process, which could be due to the readily available nutrients enhancing the feeding activity of the worms, showing their increase in biomass. Interestingly, cocoon production rate was higher in *P. excavatus*, whereas the number of worms per cocoon was higher in *E. fetida* compared to other species. The indigenous species, *P. excavatus* exhibited better growth and reproduction performance compared to the other two exotic species. The higher numbers of cocoons, juveniles and adults collected from the vermicompost processed by *P. excavatus*, was probably because its indigenous nature being acclimatized to the abiotic environmental conditions extremely well compared to other species. The difference in worm mortality among the three species could be related to the
species-specific composting behavior or to specific tolerance nature of earthworm according to the changing micro-environmental conditions in composting sub-system. Moreover, the growth rate difference between the three species was probably due to the species-specific growth patterns or could be related to the feed quality and preferences by individual species of earthworm.

The mean individual length and live weight, mean growth rate of an individual (mg/day), individual and total biomass gain, reproduction rate (cocoon worm\(^{-1}\) day\(^{-1}\)) and fecundity rate (worm cocoon \(^{-1}\) day\(^{-1}\)) total cocoon, juveniles and adult numbers, in the present study varied across different treatments. The increase in body weight of all three earthworm species was noted during vermicomposting process, which could be due to the substrate quality (Reinecke et al., 1992; Edwards et al., 1998; Suthar, 2007). The worms when introduced into wastes showed an increased growth rate and reproduction activities (Suthar and Singh, 2008). The increase in body weight of all three earthworm species was noted in both the substrates during vermicomposting process, which could be due to the substrate quality or could be related to fluctuating environmental conditions (Edwards et al., 1998; Garg et al., 2007; Suthar, 2007). The readily available nutrients in MW and FW enhanced the feeding activity of the worms, showing their increase in biomass (Suthar and Singh, 2008). Interestingly, cocoon production rate was higher in \textit{P. excavatus}, whereas the number of worms per cocoon was higher in \textit{E. fetida} compared to other species. The indigenous species, \textit{P. excavatus} exhibited better growth and reproduction performance compared to the other two exotic species (Nair et al., 2006). The higher numbers of cocoons, juveniles and adults collected from the vermicompost processed by \textit{P. excavatus}, was probably because its indigenous nature being acclimatized to the abiotic environmental conditions extremely well compared to other species. The difference in worm mortality among the three species could be related to the species-specific composting behavior or to specific tolerance nature of earthworm according to the changing micro-environmental conditions in composting sub-system (Suthar and Singh, 2008). Moreover, the growth rate difference between the three species was probably due to the species-specific growth patterns or could be related to the feed quality and preferences by individual species of earthworm (Suthar and Singh, 2008).

7.10. Waste stabilization

The pre-composting because of its thermophilic nature prior to vermicomposting helped in mass reduction and pathogen reduction (Wang et al., 2007). It was found that the bulk (dry) mass reduction and stabilization of both the wastes during present study through vermicomposting process was significant (Venkatesh and Eivera, 2008; Wang et al., 2007); the vermicomposting may also be known as vermistabilization (Pramanik et al., 2007). The marked stabilization of both the substrates due to vermicomposting process was higher in the vermicompost of \textit{E. eugeniae} followed by that of \textit{E. fetida} and of \textit{P. excavatus} compared to that of compost. FW and its vermicomposts and composts were found to be more stabilized than that of MW and MSW. A marked reduction in the bulk mass of organic fraction of MSW was recorded due to the composting and vermicomposting; it was higher in the later ranging from 40% to 65% compared to that of compost, which was only 20% (Pattnaik and Reddy, 2009). It clearly showed the marked stabilization of MSW due to vermicomposting (Bhatia, 2007). The cow dung used as the inoculant in the vermicomposting process enhanced the quality of feeding resource attracting the earthworms and accelerated the breakdown of wastes resulting in the reduction of C:N ratio by increasing certain nutrients (Edwards and Dominguez, 2000; Gupta and Garg, 2009; Kitturmath et al., 2007; Suthar and Singh, 2008).
7.11. Physico-chemical state of urban waste during vermicomposting and composting processes

The physical conditions during the present study were found to be conducive to earthworm activity during the vermicomposting process (Lee, 1985; Dominguez et al., 2000).

Temperature: At the start of the experiment, the temperature of the substrate was high and then decreases gradually as the composting process progressed. The heat released by the oxidative action of intensive microbial activity on the organic matter resulted in the rise in temperature during the first mesophilic phase of composting process (Peigne and Girardin, 2004). The temperature of the following thermophilic phase rose up above 40°C reaching at about 60 °C when most of the organic matter was degraded with the help of thermophilic bacteria and fungi, consequently consuming most of the oxygen. The thermophilic phase was followed by cooling phase, when compost maturation stage occurred and compost temperature dropped to that of the ambient (Zibilske, 1999). Then, the decreasing trend of temperature with the progress of composting process occurred, which was probably due to the decreased bacterial activity. It may also be attributable to regular sprinkling of water.

Moisture Content: The vermicomposting process requires a moisture content of 70 to 90% (Tognetti et al., 2005). In composting, the optimum moisture content varied from 50 to 70% (Nagavallemma et al., 2006). Edwards and Bater (1992) reported that optimum moisture content for growth of earthworms - E. fetida, E. eugeniae and P. excavatus was 85% in organic waste management. The rate of mineralization and decomposition becomes faster with the optimum moisture content (Singh et al., 2004). According to Liang et al. (2003), the moisture content of 60-70% was proved having maximal microbial activity while 50% moisture content as minimal requirement for rapid rise in microbial activity. The low percentage of moisture content reduces microbial biodegradation (Ahn et al., 2007) while at higher percentage, the water displaces much of the air in the pore of composting bed leading to anaerobic condition (Rynk, 2000). Vermicompost samples during the present study showed higher moisture content than the compost and substrate, which may be due to high absorption capacity, and may also because of assimilation rate by microbial population indicating the higher rate of degradation of waste by earthworms. Relatively highest moisture content of vermicompost produced by E. eugeniae followed by that of E. fetida and P. excavatus implied greater palatability of the substrate by the species. Decline in the moisture content percentage during the thermophilic phase of composting due to high evaporating rates has been recorded by Larney and Blackshow (2003).

pH: It was neutral being around 7 and increased gradually from substrate to compost to vermicompost (Mitchell and Alter, 1993; Nagavallemma et al., 2006). The near-neutral pH of vermicompost may be attributed by the secretion of NH₄⁺ ions that reduce the pool of H⁺ ions and the activity of calciferous glands in earthworms containing carbonic anhydrase that catalyze the fixation of CO₂ as CaCO₃, thereby preventing the fall in pH (Kale et al 1982). The increased trend of pH in the vermicompost and compost samples is in consistency with the findings of Tripathi and Bhardwaj (2004), which was due to higher mineralization whereas the present findings are in contradiction to the that of Suthar and Singh (2008), Chan and Griffiths (1988) and Elvira et al. (1998), who reported lower pH. The increased pH during the process was probably due to the degradation of short-chained fatty acids and amonification of organic N (Tognetti et al., 2005). Fares et al. (2005) found the increase
pH at the end of the composting process, which was attributed to progressive utilization of organic acids and increase in mineral constituents of waste.

EC: It was found that the electrical conductivity (EC) increases during the period of the composting and vermicomposting process. It was in consistence with that of earlier workers (Kaviraj and Sharma, 2003; Jadia and Fulekar, 2008), which was probably due to the degradation of organic matter releasing minerals such as exchangeable Ca, Mg, K and P in the available forms, i.e., in the form of cations in the vermicompost and compost (Guoxuo et al., 2001; Tognetti et al., 2005). Guoxue et al. (2001) found that the EC of compost increased slightly which may be due to the degradation of organic matter to release cations. These results are in contradiction with Warma and AngLopez (2002), which have reported an eventual decrease in EC, and supporting the earlier findings of Elvira et al. (1998). Electrical conductivity (EC) of vermicompost was higher than compost which may be attributed due to the loss of organic matter and freely available ions and minerals that are generated during ingestion and excretion by the earthworms (Garg et al., 2005). Similar kinds of results were also reported by Kaviraj and Sharma (2003).

7.12. Plant nutrients of the urban wastes and their vermicomposts and composts

Vermicomposts prepared from respective organic wastes possessed considerably higher levels of major nutrients - N, P, K, Ca and Mg compared to that of the wastes; these findings are in consistence with those of earlier authors (Edwards, 2004; Reddy and Ohkura, 2004; Garg et al., 2006; Suthar, 2007; Kitturmath et al., 2007; Pattnaik and Reddy, 2009). The decrease in organic carbon content, C:N ratio, and increase in ash content, EC, NPK content in all the vermicomposting samples was noticed in the present study, which was in consistence with the findings of many workers (Yadav and Garg, 2009; Banu et al., 2008; Suthar and Singh, 2009). The present investigation is also supported by few findings (Ananthakrishnasam et al., 2007; Manimegala et al., 2008), which had reported increased NPK content in the vermicompost than the original feed material. The waste materials ingested by the earthworms endured physical decomposition and bio-chemical changes due to the enzymatic and enteric microbial activities while passing through the worm’s gut. The muscular gizzard and intestine masticated the ingested substrates and released nutrients in the form of microbial metabolites enriching the digested substrate in the alimentary canal with plant nutrients and growth promoter-like substances in an assimilated form, which is excreted in the form of vermicast (Kitturmath et al., 2007).

Total N: The total nitrogen content of vermicompost of the three earthworm species was higher than that of compost and substrate. The increasing trend of N in the vermicompost of the three species of earthworms in the present study corroborated the findings of earlier researchers (Balamurugan et al., 1999; Warma and AngLopez, 2002). This finding was supported by the observation of Bhattacharya and Chattopathey (2004) where they have reported N availability was more during vermicomposting in the combination with higher quantity of compost. The enhancement of N in vermicompost was probably due to mineralization of the organic matter (Ravindran et al., 2008; Elvira et al., 1998) and increased rates of conversion of ammonium-N into nitrate (Atiyeh et al., 2000; Suthar and Singh, 2008). Earthworms can boost the nitrogen levels of the substrate during digestion in their gut adding their nitrogenous excretory products, and secretion of mucus, body fluid and even through the decaying dead tissues of worms in vermicomposting sub-system (Suthar, 2007; Kaushik and Garg, 2003; Tripathi and Bhardwaj, 2004; Padmavathiamma et al., 2008). The vermicompost prepared by all the three
Earthworm species showed a substantial difference in total N content (P<0.01), which could be attributed directly to the species-specific feeding preference of individual earthworm species and indirectly to mutualistic relationship between ingested microorganisms and intestinal mucus (Suthar and Singh, 2008). The observed difference could be attributed directly to the feeding preferences of individual earthworm species and indirectly to mutualistic relationship between ingested microorganisms and intestinal mucus which might be species-specific (Suthar and Singh, 2008).

**OC:** Total organic carbon decreased with the passage of time during vermicomposting and composting processes in both the substrates. The reduction of OC during vermicomposting process has been reported by earlier studies (Kale et al., 1982; Garg and Kaushik, 2005; Tognetti et al., 2005; Suthar, 2007; Ananthakrishnasamy, 2009). The decrease in OC was probably due to digestion of waste by enzymatic action in the worms gut. Suthar (2006) has reported that earthworms promote such microclimatic conditions in the vermineactors that increase the loss of organic carbon from substrate through microbial respiration. The earthworms utilized the organic matter as food and released carbon in the form of carbon dioxide during respiration (Elvira et al., 1998; Tajbakhsh et al., 2008). Part of the carbon in the decomposing residues released as CO₂ and a part was assimilated by the microbial biomass as a source of energy decomposing the organic matter (Fang et al., 2001; Cabrera et al., 2005; Jadia and Fulekar, 2008).

The organic carbon was decreased during the composting process by the microbial biomass present in the compost (Fares et al., 2005). The reduction was higher in vermicomposting compared to the ordinary composting process, which may be due to the fact that earthworms have higher assimilating capacity. Similar kinds of results were also reported by some workers (Suthar, 2006; Gupta and Garg, 2007; Ravindran et al., 2008). The ingested waste would be homogenized through muscular action of their foregut leading to an increase in surface area for microbial action (Suthar and Singh, 2008). The microorganisms by biochemical mechanism degrade and provide some extracellular enzymes for waste decomposition within the worm gut leading to the loss of OC content. The difference between the carbon loss of the vermicompost processed by *E. eugeniae, E. fetida* and *P. excavatus*, could be due to the species-specific differences in their mineralization efficiency of OC.

**C/N Ratio:** The C/N ratio decreased during the composting and vermicomposting process. These results are in agreement with the findings of many workers (Guoxue et al., 2001; Garg et al., 2006; Suthar, 2007; Jadia and Fulekar, 2008). The C/N ratios of vermicomposts of three earthworm species were around 20:1; such ratios make nutrients easily available to the plants. Plants cannot assimilate mineral N unless the C/N ratio is of about 20:1; and this ratio is also an indicative of acceptable maturity of compost (Senesi, 1989; Tajbakhsh et al., 2008). In the present study, the decreasing trend of the C/N ratio in vermicompost and that of simple compost reflected the organic waste mineralization during the progress of vermicomposting and composting processes (Gajalakshmi et al., 2005; Suthar and Singh, 2008; Ravindran et al., 2008; Tajbakhsh et al., 2008). Such a decrease is attributable to the feeding of waste by earthworms, which reflected the remarkable reduction in C and significant increase in the total N in the vermicompost (Dash and Senapati, 1986; Suthar, 2007). The loss of carbon through microbial respiration and mineralization and simultaneous addition of nitrogen by worms in the form of mucus and nitrogenous excretory material lowered the C/N ratio of the substrate (Christry and Ramalingam, 2005; Garg et al., 2006; Manna et al., 2003). Higher C/N ratio indicates slow degradation of substrate, and lower the C/N ratio, higher is the efficiency level of mineralization by the species. Lower C/N ratio in vermicompost produced
by *E. eugeniae* implied that this species enhanced the organic matter mineralization more efficiently than *E. fetida* and *P. excavatus* (Padmavathiamma et al., 2008; Suthar and Singh, 2008).

**P:** The P was higher in the vermicompost harvested at the end of the experiment compared to that of initial substrate. The results are in agreement with the findings of other workers (Kaushik and Garg, 2003; Manna et al., 2003; Garg et al., 2006; Suthar 2007; Banu et al., 2008; Tajbakhsh et al., 2008; Suthar, 2008; Sarojni et al., 2009; Ananthakrishnasamy, 2009). The enhanced P level in vermicompost suggests phosphorous mineralization during the process. Ghosh *et al.* (1998) also reported rapid mineralization of P in worm treatments of five organic wastes. The magnitude of transformation of P from the organic to inorganic state was due to P solubilising acids such as carbonic acid, nitric acid and sulphuric acid secreted by the micro-organisms present in the worm’s gut and thereby changing to available forms (Padmavathiamma *et al*., 2008). The vermicompost increased P availability by P solubilisation through phosphatases of earthworms’ gut (Suthar and Singh, 2008). This was supported by increased trend of EC showing enhancement of exchangeable soluble salts in vermicompost of all the three earthworm species. The total phosphorus content value was higher than that of compost. The increase in TP during vermicomposting is probably due to higher phosphatase activity of earthworms contributing to mineralization and mobilization of phosphorous (Elvira *et al*., 1998; Ghosh, *et al*., 1998; Chowdappa *et al*., 1999; Garg *et al*., 2006; Ravindran *et al*., 2008).

**K:** Vermicomposting proved to be an efficient process for recovering higher K from organic waste compared to that of compost. The present findings corroborated to those of (Garg *et al*., 2006; Manna *et al*., 2003; Suthar and Singh, 2008). The increase in K of the vermicompost in relation to that of the simple compost and substrate was probably because of physical decomposition of organic matter of waste due to biological grinding during passage through the gut, coupled with enzymatic activity in worm’s gut, which may have caused its increase (Kaviraj and Sharma, 2003). Mineralization of K was more in vermicompost, which indicates the role of earthworm and microorganisms in mineralization process (Suthar, 2007; Ananthakrishnasamy, 2009). The microorganisms present in the worm’s gut probably converted insoluble K into the soluble form by producing the microbial enzymes.

However, Orozco *et al.* (1996) reported a lower K in coffee pulp waste after vermicomposting. Total potassium slightly decreased from 0.169% to 0.143% in the final product compared to that of the initial product (Ravindran *et al*., 2008), which can be attributed to the leaching of soluble elements by excess water that drained through mass. By the end of the vermicomposting period total potassium significantly (P<0.05) decreased from 10% to 77% (Tajbakhsh *et al*., 2008). Elvira *et al.* (1998) have reported significant reduction of total K by the end of the vermicomposting process which they attributed to its high water solubility and leaching of the windrows. These differences in the observation can be attributed to the differences in the chemical nature of the initial raw materials.

**Ca and Mg:** Exchangeable Ca and Mg contents were also higher in the vermicompost than in the initial substrate. These results were in agreement with the findings of Elvira *et al.* (1998) and Gratelly *et al.* (1996); (Suthar, 2008). When organic waste passes through the gut of worm the nutrients can be converted from unavailable forms to available forms, which consequently enrich the worm casts with higher quality plant materials.
metabolites. Garg and Kaushik (2005) found a significant increase in Ca and Mg content in substrate material, after the completion of vermicomposting process.

The higher Ca content in vermicompost compared to that of compost and substrate is attributable to the catalytic activity of carbonic anhydrase present in calciferous glands of earthworms generating \( \text{CaCO}_3 \) on the fixation of \( \text{CO}_2 \) (Padmavathiamma et al., 2008). The higher concentration of Mg in vermicompost reported in present study was also in consistence with the findings of earlier workers (Padmavathiamma et al., 2008).

Orozco et al. (1996) have reported an increase in Ca after ingestion of coffee pulp waste by earthworms. By the end of the vermicomposting period, total Ca significantly (P<0.05) increased from 1.68 to 3.08-fold; whereas total Mg significantly (P<0.05) increased from 1.29 to 2.67-fold (Tajbakhsh et al., 2008). These results are in agreement with the findings of Gratelly et al. (1996).

However, Elvira et al. (1998) have reported a decrease in Ca in vermicompost after bioconversion of paper–pulp–mill sludge by E. andrei. Hartenstein and Hartenstein (1981) reported a 11.5% and 7.1% loss in the amount of exchangeable Ca and Mg, respectively, in sewage sludge to with earthworms. Similarly Mitchell (1997) reported a decrease in the amount of Ca and Mg in feed-lot cattle manure after the manure was inoculated with E. fetida.

7.12.1. **Comparison between different vermicompost and compost on the basis of nutrients**

Moreover, vermicomposts possessed significantly higher concentrations of nutrients than that of the respective composts (P<0.05), which was probably due to the coupled effect of earthworm gut enzymatic activity as well as addition of microbial metabolites (Tognetti et al., 2007), making the excreta i.e., vermicast containing nutrients of more plant-available nature compared to that of composts (Short et al., 1999; Bansal and Kapoor, 2000). The considerably enrichment of nutrients of the vermicomposts of the three species of earthworms - *E. eugeniae*, *E. fetida* and *P. excavatus* compared to that of composts of substrates, i.e., MSW, MW and FW (P<0.01) were in consistence with the findings of earlier reports (Kitturmath et al., 2003; Garg et al., 2006; Nair et al., 2006; Venkatesh and Eevera, 2008). It was found that the vermicompost of MW possessed significantly higher concentrations of the nutrients followed by MSW and FW and the sole compost, which indicated that the there is a difference due to nutrient content of the waste substrate, and the more efficiency of species of earthworms in recovering nutrients from the waste through vermicomposting process (Padmavathiamma et al., 2008; Venkatesh and Eevera, 2008). These findings reflected that the three species of earthworms showed rapid metabolism and higher mineralization of waste while passing through their gut compared to that of the simple compost (Albanell et al., 1988). It also indicated that the efficiency of bioconversion of the organic waste into vermicompost was relatively higher in case of *E. eugeniae*. These findings are in agreement with those of Padmavathiamma et al. (2008) that *E. eugeniae* as an efficient species of earthworm for converting the organic wastes to nutritious compost. The nutrient contents of simple compost were found many times lower than that of vermicompost of the three species of earthworms (P<0.05). In consistence, Tognetti et al. (2005) reported that the vermicompost of municipal organic waste was richer in organic matter, total N and available nutrients compared to that traditional compost, and they attributed the same to the release of the nutrients due to earthworm grazing upon microflora during the process. However, the findings of Sangwan et al. (2008) in contrast to the present findings,
reported decrease in potassium content in the vermicompost produced by *E. fetida* compared to that of the substrate. Khwairakpam and Bhargava (2009) compared the vermicompost of sewage sludge processed by these three earthworm species in order to report the suitability of worm species for composting. Reddy and Okhura (2004) has assessed the vermicomposts produced by different earthworm species - *Perionyx excavatus, Octoohaetona philotti* and *Octonachaeta rosea* using the rice straw as substrate and found that vermicompost produced by *Perionyx excavatus* possessed higher concentration of nutrients than that of *Octonachaeta rosea* and *Octoahaetona philotti*.

7.12.2. Temporal variation in nutrients

The nutrients and OC were found higher in MW compared to that of MSW and FW, respectively, which was most probably because of mosaic nature of the MW. In all the vermicompost and compost of the present study the nutrients increased and OC, C/N ratio and C/P ratio decreased significantly with the passage of time (from 0 to 15, 30, 45 and 60 days), from the substrate (organic waste) to compost and vermicompost, respectively (Venkatesh and Eevira, 2008). The present findings are in agreement with the findings of earlier workers- (Nagavallemma *et al.*., 2006; Khwairakpam and Bhargava, 2009). The waste materials ingested by the earthworms undergo physical decomposition and bio-chemical changes contributed by the enzymatic and enteric microbial activity while passing through the earthworm gut due to the grinding action of the muscular gizzard releasing the nutrients in the form of microbial metabolites enriching the feed residue with plant nutrients and growth promoting substances in an assimilated form, which is excreted in the form of vermin-cast (Nagavallemma *et al.*, 2006).

7.13. Heavy metals in vermicompost and compost

Of the three types of urban wastes, FW contained lower concentrations of the heavy metals than that of MSW and MW. The concentrations of Cd, Cu and Zn were higher in MSW compared than that of MW, whereas it was vice-versa in case of Pb and Mn. The higher concentration of Pb in MW was attributable to the frequent movement of vehicles, particularly the two-wheelers inside the vegetable market and its adjacent roads. The presence of higher concentration of Cd, Cu and Zn in MSW was probably due to its non-biodegradable constituent materials such as rejected batteries, tin cans, bottles caps, plastics and street dust etc.

The vermicompost produced by *E. eugeniae, E. fetida,* and *P. excavatus* and the compost harvested after different intervals (15, 30, 45 and 60 days) of processing showed significant temporal variations in concentrations of the heavy metals; their concentrations were significantly lower in the vermicomposts than that of the respective substrates across different intervals of vermicomposting and composting process with progress of time (P<0.05). The present findings are in consistence with those of Leonard and Dolfing (2001), Kaushik and Garg (2003) and Shahmansouri *et al.* (2005) that the heavy metal concentrations (Zn and Cu) in the vermicompost decreased compared to that of the initial substrate with increase of time period of composting process. Suthar and Singh (2008) found that in vermicomposted sludge, the reduction in metal content was significantly higher than experimental controls.

The vermicomposts in the present study remediated the heavy metals from their respective substrates, which may be attributable to binding of organic molecules with metals and their enhanced uptake (Jordao *et al.*, 2007; Jadia
and Fulekar, 2008). The significant decrease in heavy metal concentration in the vermicompost was probably due to the accumulation of heavy metals in the body tissue of earthworms (Morgan and Morgan, 1988; Shahmansouri et al., 2005; Suthar and Singh, 2008). However, in contrast to the present findings, Ciavatta et al. (1993) and Barrera and Andres (2001) reported higher concentration of heavy metals in final vermicomposting product than that of the initial substrate, and Garcia et al. (1990) reported composting and its maturation increased the concentration of heavy metals in the vermicompost due to the loss of weight of the substrate material during the composting process. On the contrary Hayawin et al. (2010) found the heavy metal (Cu, Fe, Zn and Mn) content higher in the vermicompost than in the initial substrate. Deolalikar et al. (2005) suggested that weight and volume reduction due to breakdown of organic matter during vermicomposting may be responsible for the increase in heavy metal concentrations in vermicompost.

In the present study, the removal efficiency of Pb, Cd, Cu, Zn and Mn of the vermicompost produced by the E. eugeniae were significantly higher than that of E. fetida followed by P. excavatus and sole compost (P<0.05). It indicated that E. eugeniae is efficient in removing relatively higher concentrations of the heavy metals - Pb, Zn, Cd, Cu and Mn from the substrate through the process of vermicomposting compared to the other two earthworm species, and the sole composting process. Dominguez (2004) in corroboration to the present findings, reported the decrease in total amount of heavy metals by 35 to 55 per cent in the vermicompost, and attributed the same to the chemical binding of the metals with metal binding proteins present in worm’s gut.

The findings showed that vermicomposting is the best technology for heavy metal remediation (Jadia and Fulekar, 2008; Suthar, 2010). The potential of vermicomposting as a tool to remediate heavy metal contamination in solid waste was investigated and proved by Jamaludin and Mahmood (2010). It is proved that heavy metal concentration in vermicompost obtained from sewage sludge composting decreases from three to 10 times (Neshina et al., 2002). Urdaneta et al. (2008) observed the highest adsorption and removal of the metals was for a vermicompost. Hobbelen et al. (2006) reported that after 54 days of vermicomposting durations, in spite of high availability of heavy metal concentrations in earthworms, Cu and Zn concentrations in vermicompost decreased. This is supported by Dominguez et al. (1997) who found that the amounts of bioavailability of heavy metals (Zn and Cu) in vermicomposting of pig manure tend to decrease. Vermicompost residues obtained from this process were used for lettuce cultivation. The vermicompost was found to be efficient in removing metals from the electroplating wastes, as well as in the increase of its pH values (Jardao et al., 2007). It is clear that reduction in metal content was directly related to earthworm activity in the waste decomposition system (Suthar and Singh 2008). Organic matter ingested by earthworms undergoes chemical and microbial changes when it passes through the gut: part of the organic matter is digested, and pH and microbial activity of the gut contents increases (Edwards and Bohlen, 1996). As a result, the possibility for metals to be bound to ions and carbonates (i.e., more soluble fractions) increases in ingested material. As a result, the possibility for metals to be bound to ions and carbonates (i.e. in more soluble fractions) increases in ingested material (Morgan and Morgan, 1999) and the metal content reduces in digested organic material due to bioaccumulations of more soluble fractions of metals in an earthworm’s gut or cutaneous tissues (Suthar and Singh 2008). These soluble fractions can be accumulated in earthworm tissues during transit of waste though worm’s gut, which results in metal reduction in vermicompost during the vermicomposting process and increase in worm tissue (Gupta et al., 2005; Suthar et al., 2008). Dia et al. (2004) suggested that bioaccumulation of metals in earthworms is their ability to eliminate the excess of metals. The organic amendments like
vermicompost and compost have low metal concentration; thus can be used as a sink for reducing the bioavailability of metal(loid)s in contaminated soils and sediments through their effect on the adsorption, complexation, reduction and volatilization of metal(loid)s (Park et al., 2010).

In general, earthworms consume a great amount of organic waste to achieve appropriate nutrition, and during this process metals are liberated in free forms due to the enzymatic actions in their gut (Suthar, 2007). Bioaccumulation of high concentration of metals is well documented (Hsu et al., 2006). According to Suthar et al. (2008), earthworms accumulate a considerable content of metal in their tissues and could serve as useful biological indicator of contamination. Lukkari et al. (2006) stated that bound of metals to organic matter (more tightly bound fractions) partly reduced the availability of metals for earthworms.

The heavy metals are normally present in complex aggregates bound with humic substances in the form of organo-metallic complexes and the polymerized organic fractions of solid waste. These toxic complex aggregates while passing through earthworm gut probably split into simple molecules of less toxic nature due to action of various digestive enzymes. These protein granules are characterized by the low molecular weight and peak absorption of 250 nm, and are capable of binding with the toxic heavy metals converting them to less toxic forms. The earthworm chloragosomes consisting of modified epithelial cells, the eleocytes of the gut containing constituents of ion exchange compounds - phosphoric acid, carboxyl, phenolic hydroxyl and sulphonic acid groups acted as a cation exchange system capable of taking up and accumulating heavy metals, thus probably reducing their concentrations in the worm castings and vermicompost (Ireland, 1979, Morgan and Morgan, 1988; Cooper, 1996; Sinha et al., 2010). Non-enzymatic metalloproteins granules or metallothioneins present in the earthworms gut also probably played a significant role in the remediation of heavy metal pollutants from the substrate (Sinha et al., 2010).

7.14. Microbial characteristics

A large majority of the total number of isolates in the vermicompost and compost were thermophilic bacteria, the members of the genus Bacillus (87% of the randomly picked colonies). Strom (1985) also found more number of thermophilic bacteria, especially Bacillus spp. in solid waste composting.

7.14.1. Contrast between bacterial and fungal count

Comparing the fungi biomass with that of bacteria, vermicompost at 15 days interval showed the important contribution of fungi in decomposition process during initial stage followed by the active role of actinomycetes alone and along with bacteria in the later stage of vermicomposting at 60 days of interval. Such microbial succession is consistent with the findings of Aira et al. (2006); Saito et al. (1990), but contrary to those of Hu and van Bruggen (1997) who reported that the bacteria were active during a first stage before fungi flourished. In initial stage of vermicompost, fungi played an important role in breaking down tough debris including cellulose. They can attack organic residues that are too dry, acidic, or low in nitrogen for bacterial decomposition. Most fungi secrete digestive enzymes onto the food, and then they absorb the products of extracellular digestion. Further decomposition of organic matter was carried out dominantly by bacteria. But at the later stage (at 60
days of processing) as the temperature declines, the actinomycetes and fungi become dominant over the bacteria (Storm, 1985; Jiarg et al., 2003; Jadia and Fulekar, 2008).

Microbiological quantitative studies done by Wierzba and Nabrdalik (2005) indicated distinctive tendency in the increase of general bacteria count (GBC), during biodegradation. There was a significant increase in the inoculated bacterial count in the vermicompost (Kaushik et al., 2007).

Air et al (2007) tested the general hypothesis that microbial populations, and especially fungi, are enhanced by earthworm activity. The presence of earthworms was related with increases in overall microbial biomass and activity, which decreased when earthworms left the substrate; the same pattern was observed for fungi. It should be noted that fungi are also important contributors in the generation of finished composts (Anastasi et al., 2005). The total fungal load was up to 8.2 3 10^5 CFU/g dwt in compost and 4.0 3 10^5 CFU/g dwt in vermicompost. A total of 194 entities were isolated: 118 from green compost, 142 from vermicompost; 66 were common to both (Anastasi et al., 2005). In another study, a total of 193 entities were isolated: 54 from green compost, 77 from vermicompost; 62 were common to both (Anastasi et al., 2005). The ability of fungi to break down complex carbon sources makes them of vital importance in both the generation and application of compost as well as vermicompost (Anastasi et al., 2005).

Comparing the count of microorganisms, vermicompost at 15 days interval showed the highest fungal count during initial stage whereas at the later stage of vermicomposting, i.e., at 60 days of interval, actinomycetes count was higher than that of fungi and bacteria, respectively. Such microbial succession is in consistent with the findings of other workers (Saito et al., 1990; Aira et al., 2006), but contrary to those of Hu and van Bruggen (1997) who reported that the bacteria were active during a first stage before fungi flourished. In initial stage of vermicompost, fungi probably played an important role in breaking down tough debris including cellulose. They can attack organic residues that are too dry, acidic, or low in nitrogen for bacterial decomposition. Most fungi secrete digestive enzymes onto the food, and then they absorb the products of extracellular digestion. Further decomposition of organic matter was carried out dominantly by bacteria. But at the later stage (at 60 days of processing) as the temperature declines, the actinomycetes and fungi become dominant over the bacteria (Storm, 1985; Jiarg et al., 2003; Jadia and Fulekar, 2008). Appearance of actinomycetes towards the end of the experiment implied the maturity of composting process.

### 7.14.2. Temporal variation of microorganisms

In the present study, the density of fungi was higher in vermicompost than in fresh substrate, which was in consistence with the findings of Moody et al. (1995), Pil and Novakova (2003) and Aira et al. (2006). Fungal growth decreased towards end of the experiment. It has been reported that earthworms feed on fungi for their protein/nitrogen requirement (Moody et al., 1995; Ranganathan and Parthasarathi, 2000; Edwards, 2004). This may be the reason for the less diversity of fungal counts at the end of the vermicomposting process (Alauzet et al., 2001; Nagavallemma et al., 2006). Bacterial count decreased gradually from the substrate to 15 days and further to 60 days of processing. However, actinomycetes was not detected in the substrates and in the initial stage of compost and vermicompost; and appeared only after 60 days of composting and vermicomposting process. As the temperature declines towards end of the experiment, the actinomycetes and fungi become
dominant over bacteria during the composting (Jiarg et al., 2003) and vermicomposting process. However, bacterial count along with actinomycetes was more than that of fungi at the end of the experiment. The increase was contributed by actinomycetes. It is in consistence with the findings of Kausik et al. (2008) that the maximum bacterial count between 45 to 60 days. Sen and Chandra (2009) also reported similar findings of less bacterial count at the initial stage of vermicomposting followed by its increasing trend towards the latter stage. Maximum numbers of microbes were found by Kaushik et al. (2007) between 45 and 60 days. This could be attributed to depletion in the available carbon in the substrate. Jadia and Fulekar (2008) found that the thermophilic bacteria played an important role in organic matter degradation during the thermophilic phase of the composting process (Zibilske, 1999). As the temperature declines, the actinomycetes and fungi become dominant during the composting (Jiarg et al., 2003) and vermicomposting process (Jadia and Fulekar, 2008).

In the present study, the abundance of fungi was higher in vermicompost than in fresh substrate, which was in consistence with the findings of other workers (Moody et al., 1995; Pizˇl and Novakova, 2003; Aira et al., 2006). However, fungal growth decreased towards end of the experiment. It has been reported that earthworms feed on fungi for their protein/nitrogen requirement (Moody et al., 1995; Ranganathan and Parthasarathi, 2000; Edwards, 2004), which was probably the reason for the less diversity of fungal counts at the end of the vermicomposting process (Alauzet et al., 2001; Nagavallemma et al., 2006). Bacterial count decreased gradually from the 0 to 15 days and further to 60 days of processing. It was contradictory to some workers. Kausik et al. (2008) found the maximum bacterial count between 45 to 60 days. Sen and Chandra (2009) reported similar findings of less bacterial count at the initial stage of vermicomposting followed by its increasing trend towards the latter stage. But in those cases the highest bacterial count towards end of the experiment was due to presence of actinomycetes, which they considered as bacteria. In the present study, actinomycetes was not detected in the substrates and in the initial stage of compost and vermicompost and appeared only at 60 days of composting and vermicomposting process. As the temperature declined towards end of the experiment, the actinomycetes and fungi become dominant over bacteria at the latter stage of the composting (Jiarg et al., 2003) and vermicomposting process. However, actinomycetes count was more than that of fungi and that of bacterial count at the end of the experiment. It is in consistence with the findings of Kausik et al. (2008) and Sen and Chandra (2009).

7.14.3. Comparison of micro organisms in vermicompost with that of compost

In composting processes, the self-heating phase with its subsequent maturation is the major biological conversion step, whereas in vermicomposting, the gut passage through worms can be considered as being selective (Tognetti et al., 2005). Comparing the vermicompost produced by E. eugeniae, E. fetida and P. excavatus with sole compost, it was found that microbial biomass (bacteria, actinomycetes and fungi) was higher in the vermicompost than compost in all three wastes (Subler et al., 1998; Edwards, 2004). The high levels of ammonia and partially decomposed organic matter in casts and mucus of earthworms that excreted along with the casts, stimulates microbial growth and activity in the vermicompost (Aira et al., 2006).

The highest levels of microbial biomass were observed in layers with highest numbers of earthworms (2 and 4 week-old layers) where these processes were more intense (Aira et al., 2007). This stimulatory effect of
earthworms on microbial biomass could be explained by mucus and casts production; mucus is a source of easy assimilable carbon for microorganisms (Doube and Brown, 1998) and casts are structures enriched in available forms of C, N and P (Scheu, 1987; Aira et al., 2003). Aira et al. (2007) suggested that during the first stages of organic matter decomposition the relationships established between earthworms and microorganisms are close to some kind of mutualism, although in this case would take place outside earthworm gut. This mechanism could be similar to nutrient enrichment process as described by Devliegher and Verstraete (1997), but in the study conducted by Aira et al. (2007), E. fetida modified the structure of substrate and released new nutrient pools due to its feeding and casting activities which stimulated microbial metabolism.

Comparing the vermicompost produced by E. eugeniae, E. fetida and P. excavatus with sole compost, it was found that microbial biomass (bacteria, actinomycetes and fungi) was higher in the vermicompost than compost in all three wastes (Subler et al., 1998; Edwards, 2004). The high levels of ammonia and partially decomposed organic matter in casts and mucus of earthworms that was excreted along with the casts, stimulates microbial growth and activity in the vermicompost (Aira et al., 2006).

7.14.4. Species composition

A total of 59 bacterial entities and 25 actinomycete entities were identified from MSW and its compost and vermicompost. Haruta et al. (2005) isolated similar type of groups of actinomycetes from garbage in Japan. A total of 62 bacterial entities and 29 actinomycete entities were seen in MW and its compost and vermicompost. Jadia and Fulekar (2008) found similar type of bacterial composition in vegetable waste. A total of 55 bacterial entities and 22 actinomycete entities were isolated from FW and its compost and vermicompost. Lu et al. (2005) found some of the bacteria in flower waste.

The biodiversity index values for species of bacteria and actinomycetes in all the samples were calculated. All diversity indexes were higher in vermicomposts than that of compost, showing greater species richness (Hill’s number) and a greater evenness (Berger-Parker, Shannon, Simpson indexes. All the diversity indices showed greater number of species in vermicompost than that of compost. The higher value may be due to a favorable action of earthworms (Brown, 1995; Tiunov and Scheu, 2000). The decrease of microbial diversity in the compost could be due to the high temperature (Fang and Wong, 2000). Moreover, this may be due to disappearance of certain harmful species of bacteria from the vermicompost of 60 days those were present in vermicompost of 15 days.

7.14.5. Species richness and distribution

Presence of these harmful bacteria contributed to highest diversity in MSW (Eastman et al., 2001; Ghazifard et al., 2001; Hassen et al., 2001). Bacillus had highest number of species in all the three wastes and was dominant during the entire composting process in all the three wastes. The present findings were in conformity with those obtained by other workers (Storm, 1985; Jadia and Fulekar, 2008; Fang and Wong, 2000; Ghazifard et al., 2001; Gestel et al., 2003; Pedro et al., 2003). Among the Bacillus species found, some were previously reported in composts, e.g., B. subtilis, B. licheniformis, and B. pumilus (Storm, 1985; Fang and Wong, 2000; Hassen et al.,
The dominant species of actinomycetes was *Rhodococcus* (8) in MSW *Mycobacterium* (6) in MW and *Brevibacterium* (6) in FW (Haruta et al., 2005; Lu et al., 2005; Jadia and Fulekar, 2008).

Ghazifard (2001) examined the thermophilic and mesophilic microbiota in compost produced from Esfahan municipal solid waste at different stages of composting process from day zero to 28 days. Some of the mesophilic bacteria observed in initial stages of composting process were gram negative *Escherichia*, *Klebsiella*, *Aeromonas* and *Alcaligenes*, and gram positive *Enterococcus* and *Bacillus* species. After 20 days of the composting process i.e., at later stages of the process, lower species diversity of mesophiles (only *Bacillus* species) were isolated, which was most likely due to the high temperature (60-68°C) condition. The importance of *Bacillus* and relatives for the hot composting stage, or Actinobacteria during compost maturation, which was already indicated by cultivation, was confirmed (Ryckeboer et al., 2003). The dominant species of actinomycetes was *Rhodococcus* (8) in MSW *Mycobacterium* (6) in MW and *Brevibacterium* (6) in FW (Haruta et al., 2005; Lu et al., 2005; Jadia and Fulekar, 2008).

The distribution pattern of bacterial and actinomycetes species, respectively, among all the nine samples in three wastes was aggregated or clumped type. Bacterial species were aggregated at the effective sample sizes. They clumped together to get the crucial resources for survival. The condition available might be conducive for their growth, which allowed them to clump together.

### 7.14.6. Similarity of different treatments in terms of microbial count

Cluster analysis implied that the bacterial composition of all the vermicompost samples at 15 days were similar. The similar composition found in all the three vermicomposts of 60 days. Compost of 15 and 60 days was not similar with those of vermicompost samples. The actinomycetes composition was similar with all the three vermicomposts separated by compost. The different composition in bacterial and actinomycetes species in compost and vermicomposts may be due to presence of many thermophilic bacterial species in compost samples whereas mesophilic bacteria were dominated in vermicompost samples (Zibilske, 1999; Jadia and Fulekar, 2008). Moreover, earthworms stabilize organic residues and reduce pathogenic bacteria and other human pathogens (Eastman et al., 2001).

### 7.14.7. Relationship between bacterial community and physico-chemical parameters

The significant correlations found between microbial biomass and physico-chemical activity. This hypothesis is supported by stimulatory effect of earthworms on microbial biomass could be explained by mucus and casts production (Aira et al., 2007); mucus is a source of easy assimilable carbon for microorganisms (Doube and Brown, 1998) and casts are structures enriched in available forms of C, N and P (Scheu, 1987; Aira et al., 2003). The highest levels of microbial biomass were observed in layers with highest numbers of earthworms.

The parameters (EC, MC, pH, N, P, K, Ca and Mg) except temperature were positively correlated with the bacterial community (P<0.01). The negative correlation (P<0.05) between temperature and bacterial community was due to the maintained constant temperature. It is contradictory to the study done by Sen et al. (2008), where the physico-chemical variables (carbon, C/N ratio, soluble substances and cellulose) were not significantly
related to the variations in the bacterial community structure dynamics. Schloss et al. (2003) showed the possible correlation of variables like pH and temperature with changes in community structure during the initial stages of composting.

It is contradictory to the study done by Sen et al. (2008), where the physico-chemical variables (carbon, C/N ratio, soluble substances and cellulose) were not significantly related to the variations in the bacterial community structure dynamics. Schloss et al. (2003) showed the possible correlation of variables like pH and temperature with changes in community structure during the initial stages of composting.

7.15. **Micro arthropods characteristics**

7.15.1. **Analysis of micro arthropods' diversity**

In the present study, Acarina and Collembola were found in higher abundance compared to the miscellaneous groups of arthropods. Interestingly it was found across all the composts and vermiomposts that the Mesostigmata was present in higher abundance compared to that of prostigmata and cryptostigmata in the vermicompost process microcosm, which was attributable to their predatory activity and availability of abundant prey and well being and multiplication.

The present findings clearly indicated the dominance of Isotomidae over Entomobryidae and Sminthuridae in all the composts and vermicomposts, which is probably because of their body size with a small forcula in the vermicompost microcosm. Similar to Mesostigmata, the Hymenoptera being predatory taxa represented maximum among the miscellaneous groups, probably because of availability of sufficient prey in the vermicompost microcosm. Mites and collembola are the most abundant arthropods in temperate soil ecosystems (Harding and Stuttard, 1974; Seastedt, 1984; Minor and Cianciolo, 2007). Most mites, and collembola have well-developed mouthparts capable of fragmenting organic matter while feeding on the microflora adhering to this detritus (Seastedt, 1984; Reddy, 1995). Fragmentation i. e. the reduction to small, fine particles have very important consequences in decomposition and mineralization processes, particularly by creating new surface area for microbial colonization (Webb, 1977; Elkins and Whitford, 1982; Seastedt, 1984).

7.15.2. **Spatio-temporal variation of microarthropods**

The present findings indicated the niche preference of these microarthropods across the compost and vermicompost microcosms. Close relationship between the microarthropods like Acarina, Collembola and microorganisms like bacteria, fungi was reported by many earlier workers (Ausmus and Witkamp, 1974; Drift and Jansen, 1977; Hanlon and Anderson, 1979; Ineson et al., 1982; Parker et al., 1984; Seastedt, 1984, Reddy, 1995). It was reported that the respiration rates of micro organisms especially bacteria generally increase in the presence of microarthropods (Drift and Jansen, 1977; Addison and Parkinson, 1978; Santos, et al., 1981; Reddy, 1995). Microarthropods, like Symphyla, Pauropoda and Protura, are typical to well-structured soil like that of woodland or grassland (Wallwork, 1970). Symphyla, Protura and Diplura particularly were absent in the disposal site and were present in the woodland and grassland areas (Menta et al., 2008).
7.15.3. Species composition

The species composition was higher in vermicompost than that of compost. The higher value may be due to availability of microorganisms and nutrient soft materials favorable action of earthworms which formed the food for the microarthropods (Subler et al., 1998).

7.15.4. Relationship between microarthropod densities and nutrients

These microarthropods are considered to play an important role in the nutrient dynamics (Seastedt, 1984; Reddy, 1995; Kautz et al., 2006). It is assumed that microarthropods have an indirect effect on nutrients due to their ability to fragment decaying organic material and thereby increase the surface area and its availability for microorganisms (Petersen and Luxton, 1982). Furthermore, Petersen (2002) emphasizes catalytic effects of soil microarthropods on nutrient turnover. Cole et al. (2004) reported from a microcosm experiment, that nutrient release from a mixture of plant litter fragments and soil increased with increasing microarthropod density. Nitrogen can potentially be mineralized by the grazing and excretory activities of microarthropods (Seastedt, 1984). Microarthropod feeding activities on microflora probably result in rapid recycling of most nitrogen within the system (i.e. within vermicomposting microcosm). Microarthropods probably speed up mineralization of phosphorus (Seastedt and Crossley, 1980). Other studies, however, have reported increased concentrations of phosphorus in system containing microarthropods (Seastedt and Crossley, 1983). Fragmentation and increase of potassium are due to microarthropod activities (Gosz et al., 1973; Seastedt and Crossley, 1980). This element appears to be poorly regulated by microarthropod activities (McBrayer, 1977; Ineson et al., 1982; Reddy, 1995). The amount of calcium was found in living and dead microarthropod exoskeletons which increase the calcium content in vermicompost (Seastedt and Tate, 1984; Reddy, 1995). Calcium is also concentrated in the exoskeletons of micro arthropods (Cromack et al., 1977; Crossley, 1977). Two, relatively short-term studies reported no microarthropod effect on absolute increases in magnesium (Ward and Wilson, 1973; Pokarzhevsky, 1979). The remaining studies reported the positive effect on Mg concentrations and amounts. These inconsistencies probably reflect differences in microflora composition and abundance among sites, and may also reflect differences in feeding preferences of the respective microarthropod fauna as well (Parkinson, 1980).

7.15.5. Relationship between predatory microarthropods with other groups of microarthropods

Relationships were established through regression analyses between predators like Prostigmata and Mesostigmata (Acarina) and other groups of micro arthropods through regression analysis. Regression analysis clearly showed that predators (Prostigmata and Mesostigmata) have positive relationship with all the groups of Collembola and no effect on other group of micro arthropods, i.e., the miscellaneous group. It showed that the densities of Prostigmata and Mesostigmata increased with the increase of Collembola, but not other microarthropods in the microcosm. The microarthropod taxa, the Prostigmatid and Mesostigmatid mites include species that are predaceous (Seastedt, 1984; Moore et al., 1988, Reddy, 1995). Mesostigmata was identified as the predators of other microarthropods by many workers (Wallwork, 1976; Norton, 1990; Koehler, 1997). Prostigmata mites have been reported to regulate densities of micro arthropods’ groups (Edwards et al., 1967), whose densities in turn may also affect organic matter decomposition rates.
7.16. Effect of nutrient contents of the inputs on the growth of plants

Growth of both tomato and fenugreek was significantly higher with the application of urban wastes and their respective vermicomposts and composts compared to that the plants grown in sole soil (P<0.001), which is in consistence with the findings of Azarmi et al. (2008). They found that vermicompost has significant effects on growth traits like plantshoot, dry weight being higher than those of plants grown in sole soil.

Vermicompost increased plant growth, shoot and root lengths and shoot biomass significantly (Atiyeh et al., 2000). There is ample evidence that vermicompost added to horticultural container mixtures stimulates growth and fruit quality of a variety of crop species, including tomatoes (Atiyeh et al.,2000; Arancon et al., 2003; Zaller, 2006). Arancon et al. (2004) reported positive effects of vermicompost on the growth and yield in strawberry, especially increases leaf area, shoot dry weight and fruit weight in field conditions. The available nutrient status of soil was greatly enhanced by the application of vermicompost as an organic source (Prabha et al., 2007). Similar studies were conducted to examine the effect of vermicompost on growth and yield of vegetables in container growth media are in consistence to the present findings, with vermicompost of poultry droppings increasing shoot biomass and seed yield of cowpea (Mba, 1996), that of grape mare enhancing the grape yield up to 55%, and that of food waste and paper waste rising the growth, flowering and yields of field strawberries (Arancon et al., 2004). These authors are of the view that large amount of microbial population in vermicompost, and their build up and activity in the soil treated with vermicompost probably increased the plant growth. Experiments conducted by Azarmi et al. (2008) revealed that growth and yield parameters such as leaf area, dry shoot weights and weight of fruits were significantly affected by applying vermicompost. They showed that vermicompost had significantly effect on shoot dry weights (p < 0.05). Shoot dry weights of plants at the rate of 15 t ha\(^{-1}\) sheep-manure vermicompost were 27% greater than those obtained in control plants. These studies showed that increases in growth and yield at low amounts of vermicompost in the potting medium could probably be due to improvement in the physicochemical properties of the container medium, increase in enzymatic activity, increases in microbial diversity and activity, nutritional factors and plant growth regulators (Arancon et al., 2004; Tomati and Galli, 1995; Atiyeh et al., 2000). Mishra et al. (2008) showed that vermicompost had beneficial effects on growth and yield of rice, especially caused significant increase of many growth parameters, seeds germination, chlorophyll concentration and yield. Similar results were noted by Maynard (1995), who reported that tomato yields in field soils amended with compost were significantly greater than those in the untreated plots. Similar findings of increased plant growth with application of compost and vermicompost were also reported by other researchers (Atiyeh et al., 2001; Samantha and Reddy, 2009; Phasa et al., 2009). Perez- Murcia et al. (2006) showed the significant increases in the dry and fresh weights of broccoli aerial parts with the application of compost, attributing the effects on the growth mainly to the great contribution of nutrients, especially N and P, of composts. These findings have been supported by other researchers (Atiyeh et al., 2001; Garcia-Gomez et al., 2002). Goswani et al. (2001) reported that the addition of vermicompost at rates of 0, 20, 30 and 40 t ha\(^{-1}\) to tomatoes cultivated in the field produced tomato yields of 114, 138, 163 and 192 t ha\(^{-1}\) respectively compared to 56 t ha\(^{-1}\) for inorganically fertilized plants.

Our findings further showed clearly that tomato and fenugreek plants grown with application of vermicompost especially that produced by E. eugeniae are significantly higher than that of E. fetida and of P. excavatus in leaf and branch numbers, plant height and dry biomass compared to that of compost, in the order of vermicompost.
of E. Eugeniae > that of E. fetida > that of P. excavatus > compost (P<0.001), mainly because of vermicompost possessed not only higher concentrations of the macro-nutrients but also the plant growth promoting hormone like substances that boosted the plant growth (Edwards, 1998; Reddy and Ohkura, 2004; Pattnaik and Reddy, 2009). Further, Arancon et al. (2004) found similar results with maize, and tomato and cucumber and explained that auxin groups in humic acids that has been found to increase the stem growth in these plants significantly. The decreased root length with vermicompost was probably due to the availability of readily absorbable nutrients in the vermicompost and their supply to the root system from the near surface whereas larger root length in the plants grown in sole soil was probably due to penetration of roots to deeper soil layers in search of nutrients because of the absence of readily available nutrients on surface and sub surface; similar results were reported in an earlier study by Samantara and Reddy (2009).

The positive correlation between the nutrients present in the treatments of urban wastes and their respective vermicomposts and compost applied to the plants and their growth traits clearly indicated that the growth of tomato and fenugreek increased with addition of organic inputs – organic fraction of waste to composts and vermicomposts and were associated with greater uptake nutrients (P<0.001). The nutrient contents present in the organic inputs applied to the plants increased growth traits of the plants, as nutritional factor being one of the important medium of plant growth (Atiyeh et al., 2000; Arancon et al., 2004).

The significant positive correlation found between number of leaves and dry biomass of both the plants (P<0.001) indicated that based on simple counting the number of leaves followed by the increase in leaf number with the progress of the growth of the plants, the increase in the dry biomass of the plants can be predicted.

### 7.17. Heavy metal accumulation in earthworms’ tissue

#### 7.17.1. Comparison of earthworms on the basis of heavy metal accumulation

The concentrations for all the metals were found higher in the tissue of E. eugeniae than that of E. fetida and P. excavatus. These three species showed a considerable difference in metal concentrations in their tissue’s mainly due to variation in their food selectivity and metabolism (Morgan and Morgan, 1992), which could be probably a species-specific feature. The variation in dietary intake of the metals could be an important factor contributing to differences in the availability of metals in the processed product i.e. vermicompost. Hopkin (1989) stated that the earthworms have a specific capacity to regulate metals, particularly trace metals such as Cu and Zn in their bodies and the accumulation and regulation mechanisms could be species-specific. It is also suggested here that exposure duration could be main determinant for observed differences in metal concentration in tissue. Recently, Suthar et al. (2008) had summarized that species-specific metal physiology in earthworms may alter the concentration of metals in earthworm tissues. The amount of organic fractions in ingesting material denotes the availability of soluble forms of metals in a worm’s gut. Lukkari et al. (2006) stated that binding of metals to organic matter particularly more tightly bound fractions, partly reduced the availability of metals for earthworms. The earthworm gut could modify the mobility of metals due to pH changes and favor their assimilation. They reported a considerable concentration of metals in vermin-composting earthworms.

In previous reports a considerable concentration of metals in vermicomposting earthworms has been reported. Graff (1982) reported the accumulation of heavy metals in Eisenia fetida and Eudrilus eugeniae after feeding on compost made from municipal garbage. He suggested that earthworms extracted the heavy metal from the
compost and concentrated them in their tissues. Gupta et al. (2005) reported 26.5–79.3 mg kg\(^{-1}\) Cr, 7.5–21.1 mg kg\(^{-1}\) Cu, 11.7–43.4 mg kg\(^{-1}\) Ni, 21.1–55.7 mg kg\(^{-1}\) Pb, and 70.1–140.1 mg kg\(^{-1}\) Zn in _Eisenia fetida_ collected from different vermibeds of fly ash. They concluded that earthworm tissue-metal level was directly related to the proportion of waste, e.g. fly ash, in vermibeds. Heavy metal accumulation by _Perionyx excavatus_ was also reported by some workers (Maboeta et al., 1999; Suthar and Singh, 2008).

### 7.17.2. Comparison of substrates on the basis of heavy metal accumulation

The data clearly indicated that concentrations of Pb, Zn and Mn in tissue was highest in earthworms cultured in MW, and that of Cu and Cd were highest in the worms cultured in MSW; while earthworms cultured in FW showed the lowest concentrations of all the metals in worms. The concentrations of metals in earthworms were directly dependent on the metal concentrations of substrate waste in which the worms were cultured (Lukkari et al., 2006). Heikens et al. (2001), who studied the concentrations of heavy metals in earthworms, found that the increased accumulation in the tissues of earthworms was in line with the increased contamination in substrate. It was observed that the metal burden in the earthworm tissue increased with the increase in metal treatment (Maity et al., 2008). Gupta et al. (2005) reported that earthworm tissue metal level was directly related to the proportion of waste, e.g. fly ash, in vermibeds. The similar pattern of metal bioaccumulation was observed by Suthar et al. (2008), which further supports the hypothesis that tissue-metal level reflects the metal availability in the substrates.

### 7.17.3. Comparison with substrates on the basis of heavy metal accumulation

The inoculated earthworms showed the greater concentrations of Cd in their tissues, than that of substrates; whereas the other heavy metals –Pb, Zn, Cu and Mn were more in substrate than that in body tissue at the end of the vermicomposting process. Cd and Zn were accumulated to levels greater than that in soil (Van Hook, 1974; Pietz et al., 1984). Tissue level of Cu was lower than soil levels (Yeates et al., 1994). Numerous authors have suggested that _E. fetida_ is able to regulate Zn, by binding Zn in their chloragogenous tissue (Cotter-Howells et al., 2005; Morgan and Morris, 1982; Morgan and Winters, 1982). Since the binding of Zn to metallothioneins is reversible, it is likely that Zn-thioneins may regulate the concentrations of the metal in the body tissue by allowing rapid elimination of Zn (van Gestel et al., 1993). Malley et al. (2006) reported that copper accumulated within worm tissues. A similar trend was observed in the experiment conducted by Hayawin et al. (2010).

Earthworms are able to accumulate heavy metals in their bodies from the substrate and complex those by other compounds so might be having less toxicity (Jain and Singh, 2004). The present study clearly showed the earthworms accumulated metals from the substrate wastes. The observed difference for tissue-metal concentrations could be related to the amount of metals in ingested waste materials. Graff (1982) reported that earthworms (_E. fetida_ and _E. eugeniae_) accumulated the heavy metal from the municipal garbage compost and concentrated them in their tissues.

The relationship determined by this study between the level of contamination in the substrate and the accumulation of heavy metals in the tissues of earthworms, is supported by many other field and laboratory studies (Mariño et al., 1992, Spurgeon and Hopkin, 1999). The concentrations of the Cd in the tissues of _E. fetida_ exceeded many times the concentrations in the substrate. These results confirmed the data from literature
A similar relationship as was found in this study for cadmium accumulation in earthworms was obtained by Brewer and Barret (1995). In their study, with the concentration of heavy metal like cadmium in the tissues of earthworms was almost 40 times higher than that in the soil. Lapinski and Rosciszewska (2008) showed that the correlation between the concentration of the heavy metal (Cd) in the substrate and its accumulation in the bodies of earthworms was statistically significant.

Kagi and Kojima (1987) in their study revealed that accumulation of metals, especially Cd, Cu and Zn, in earthworms is mainly due to the binding of metals by metallothioneins (MTs). According to Andersen and Laursen (1982) the earthworm in general uses three ways to handle the metals: (1) immobilization in fatty (chloragogen) cells of gut wall, (2) storage in waste nodules (or ‘brown bodies’) formed within the body cavity, and (3) excretion through the calciferous glands. The gut-related processes in earthworm may also increase metal availability. The earthworm chloragosomes consisting of modified epithelial cells, the eleocytes of the gut containing constituents of ion exchange compounds - phosphoric acid, carboxyl, phenolic hydroxyl and sulphonic acid groups acted as a cation exchange system capable of taking up and accumulating heavy metals, (Ireland, 1979, Morgan and Morgan, 1988; Cooper, 1996). It has been reported that, the distribution of heavy metals in substrate/soil changed significantly after inoculating earthworms, presumably by increasing their bioavailability (Cheng and Wong, 2002; Ma et al., 2002).

7.17.4. Temporal Variation on the basis of heavy metal accumulation

The higher metal concentrations in earthworm tissue at 60 days of vermi-composting and low concentration in 15 days of vermi-composting showed that there was a consistent trend of higher metals accumulation in tissues of earthworms as the time progressed. It is probably that the metal levels in earthworm tissue were directly related to the availability of metals over different time intervals. The lower tissues metal concentration in earthworms with shorter time intervals, i.e., at 15 days and 30 days further supports the hypothesis strongly. As the time passes, earthworms consume a great amount of organic waste to acquire required nutrition, and during this process metals are liberated in free forms due to the enzymatic actions in their gut (Suthar, 2007). When the composting process progressed from 15 to 60 days, the available forms of metals were absorbed by the epithelial layer of gut and incorporated in the body tissue while the wastes transited of through it.

7.17.5. Bioaccumulation Factor

It is clear from the present results that BAF was low in 15 days of interval and was higher at 60 days of interval in the tissue of earthworms grown in the substrates. The BAF was higher for E. eugeniae than that of E. fetida and P. excavatus. The range of bioaccumulation factor was higher for Cd and accordingly the other metals ranked in the order of Cd >Zn>Pb>Cu>Mn. The BAFs for all the heavy metals showed positive correlation with each other in all the three substrates, i.e., MSW (range of r - 0.906 to 0.980, P<0.001), MW (r - 0.956 to 0.989, P<0.001), FW(r - 0.924 to 0.993, P<0.001).

In the present study the range of Cd, Pb, Zn, Cu and Mn was 1.05 to 3.39, 0.49 to 0.93, 0.44 to 0.95, 0.28 to 0.88 and 0.31 to 0.85, respectively. The ranges of BCFs for total metals studied by Suthar and Singh (2008) were
between the following ranges (mg kg\(^{-1}\)): 0.43 to 0.58 for total Cu, 0.19 to 0.31 for total Zn, and 0.35 to 0.60 for total Pb. The BCF ranges calculated in this study, however, were higher than those reported by earlier workers (Dia et al., 2004; Hsu et al., 2006). The observed difference for BAF in present and past studies could be related to the level of metals contamination and exposure duration or earthworm species type. According to Morgan and Morgan (1992), difference species can show a considerable difference for tissue’s metal contents mainly due to difference in their food selectivity and metabolic physiology (Suthar and Singh, 2008). The observed differences for BAFs could be related to the specific metabolism of organic fractions of metal compounds in the earthworm body (Suthar and Singh, 2008; Suthar et al., 2008; Lukkari et al., 2006).

Higher BAF for Cd in all the samples clearly implied that the Cd concentrations in the tissues of earthworms exceeded many times the concentrations in the substrate. Earthworms easily accumulate Cd and retain it in their body tissue. These results confirmed the data earlier studies (Lapinski et al., 2002; Brewer and Barret, 1995; Audrone and Irena, 2005). Cd was accumulated to levels greater than that in soil (Van Hook, 1974; Pietz et al., 1984). Cd accumulation in earthworm tissues can occur in two ways: 1) the element is bound to inorganic particles or 2) it is bound to proteins named metallothioneins (Tessier et al., 1994).

The value of BAF was directly related to the amount of waste assimilated by inoculated worms. The degree of BAFs mainly depended upon level of contamination and characteristics of waste, earthworm species used. Suthar and Singh (2009) suggested that BAFs could be an important indicator of metal bioconcentration during the process of vermicomposting. Some earlier workers have demonstrated higher ranges of BAFs for earthworms collected from contaminated sites (Suthar et al., 2008; Hsu et al., 2006). BAF range increased as the time of vermicomposting process progressed from 15 to 60 days. The BAFs were higher in wastes in which earthworm showed relatively better mineralization. Thus, the BAF values were directly related to the amount of waste assimilated by the worms (Suthar et al., 2008). The observed differences for BAFs could be related to the specific metabolism of organic fractions of metal compounds in the earthworm body (Lukkari et al., 2006; Suthar and Singh, 2009; Suthar et al., 2008). It could be related to the difference in specific metal regulating mechanism in earthworms. Recent studies revealed that accumulation of metals, especially Cd, Cu and Zn, in earthworms is mainly due to the binding of metals by metallothioneins (MTs) (Kagi and Kojima, 1987). Earlier workers have demonstrated higher ranges of BCFs for earthworms collected from contaminated sites (Hsu et al., 2006; Suthar et al., 2008). Some other studies reported considerable ranges of BCFs for metals in earthworms (Dia et al., 2004; Hsu et al., 2006).

The amount of bioavailability of metals during the vermicomposting process could be calculated effectively using BAF, i.e., Bioaccumulation Factor (Suthar and Singh, 2009). The bioconcentration factors (BCFs) or bioaccumulation factors (BAFs) have been used widely to quantify the bioaccumulation of environmental pollutants in aquatic and terrestrial biota with assumption that organism achieve a chemical equilibrium with respect to a particular medium or route of exposure (Mountouris et al., 2002; Hsu et al., 2006).

7.18. Heavy metal accumulation in plants

Plants absorb and translocate both essential and non-essential elements from soils and soils applied with different organic amendments. The accumulation of metals in different plant parts is known to depend upon the
amount of heavy metals present in the soil and its inputs. It was indicated by significant positive correlation between the heavy metal concentrations of different plant parts of both the plants and their respective inputs – substrate wastes and their composts and vermicomposts. The level of heavy metal accumulation differed between and within species of plants (McGrath et al., 2002). Such accumulations cause stress in plants resulting a number of biochemical reactions. Most of these reactions are produced by the displacement of protein cationic centers or increase of reactive oxygen species. Further, the metal translocation in plants showed strong relationship with their chemical characteristics and influenced the metal absorption (Peijnenburg and Jager, 2003).

The range of heavy metal accumulation in tomato and fenugreek in the present study were respectively 0.001 to 0.20 and 0.001 to 0.15 ppm for Cd, 0.008 to 5.75 and 0.001 to 4.74 ppm for Pb, 0.07 to 12.17 and 0.035 to 8.61 ppm for Zn, 0.021 to 3.72 and 0.063 to 4.034 ppm for Cu, 1.32 to 16.56 and 1.514 to 18.018 ppm for Mn. It clearly indicated tomato plant accumulating higher concentration of the heavy metals compared to fenugreek. These concentrations of heavy metals - Cd, Zn, Cu and Mn are lower compared to the recommended tolerable levels proposed by Joint FAO/WHO Expert Committee on Food Additives (Codex Alimentarius Commission, 1984) for different vegetables - 0.3, 5.0, 60.0, and 40.0 mg kg\(^{-1}\) in Cd, Pb, Zn, and Cu, respectively (Farooq et al., 2008). The Pb concentration in the plant parts of both plants were below permissible limits except in the root of tomato grown in soil applied with MW. This was probably because of high concentration of Pb present in MW and accumulated in its roots. World Health Organization (WHO) (1996) recommended maximum level of Cd - 0.10, Pb - 0.30, Mn - 500.00, Zn -100.00, and Cu - 73.00 mg kg\(^{-1}\) in vegetables (Bigdeli and Seilsepour, 2008). These guidelines used for maximum levels of metals in soils was adopted from the reference by Ewers et al. (1991) and for Mn as given in Pendias et al. (1992). The permissible limit of Cu and Zn are 200 and 500 mg kg\(^{-1}\) dry wt (Food Standards Committee, 1950). Oyelola et al. (2009) found that levels of heavy metals in the dumpsite soil were Pb (127.50 ppm), Zn (157.60 ppm), Cu (27.60 ppm); whereas the concentration of heavy metal in tomato plant were Pb (46.75ppm), Zn (85.64ppm), and Cu (13.35 ppm), which were higher compared to those of the present study.

The concentration of Cd in vegetables ranged from 0.049 to 0.068 mg kg\(^{-1}\) (Murtaza et al., 2003), where its maximum concentration was found in leaves of spinach. The concentration of Cd was above the critical limit (0.01mg kg\(^{-1}\)) in leaves of the plants (WHO, 1996). In a similar study, Adhikari et al. (1998) observed that available Cd in soils was below permissible limits but plants grown there showed Cd levels in high concentration which could be attributable to the bioaccumulation characteristic of the plant. The range of Cd was 0.001 to 0.196 ppm noted in the present study, was also below the permissible limit. The Mn concentration in different plant parts varied from 5.10 to 162.40 mg kg\(^{-1}\) (Adhikari et al., 1998; Murtaza et al., 2003). Maximum value of Mn was found in spinach leaves (115.77 mg kg\(^{-1}\)). The concentration Mn was above permissible limit of 6.61 mg kg\(^{-1}\) in almost all samples of fruits and leaves (WHO, 1996). The Mn accumulation in the present study was lower than the above levels, and was below the permissible limit.

The mean concentrations of Cd, Pb, Zn and Cu in leaves stem and roots of vegetables were quite variable such as 0.011–0.073 mg kg\(^{-1}\), 1.121–2.652 mg kg\(^{-1}\), 0.361–1.893 mg kg\(^{-1}\) and 0.161–0.923 mg kg\(^{-1}\), respectively (Farooq et al., 2008). They reported that the magnitude of heavy metals detected in different kinds of vegetables was in the ranking order - Cd < Cu < Zn < Pb. The cabbage showed higher levels of Cd (0.073 mg kg\(^{-1}\)) than the other