DISCUSSION

Solid waste management is a complex problem and it demands creative solutions from many disciplines. It requires knowledge of quantity and category of waste generated, the physico-chemical nature of the waste, the manpower involved in collection, transportation and dumping, the possibility of recycling and resource recovery, the measures for reducing waste production, the impact of solid waste on human and environmental health, the involvement of the community and the government in solid waste management and the creation of awareness on waste reduction, recycling and reusing. Though it
is not possible to cover all the foresaid aspects in a single study, an attempt has been made in the present study to give a complete view of the solid waste management system as it is, what should be done in the future and what options are available.

The purpose of this study is to find out the quantity of solid waste generated in Dindigul Town which is a Class-I Town and its characteristics in order to suggest proper management strategies so that a foundation can be provided to interested people to understand the solid waste management problem and find ways for a better disposal system. The study has been organized in five sections to reflect the major categories of the solid waste science of a Class-I Town and they are: waste generation in Dindigul Town, characterization of the municipal solid waste, microbial activity, vermicomposting and management. Each category has its value in finding a solution to the solid waste problem.

Studies on municipal solid waste management have been carried out by many workers in various cities and towns: Nanda et al. (2000-a and b) in Burla Town, Orissa, India; Goswami et al. (2001) in Gauhati, Assam, India; Saxena and Joshi (2002) in Hardwar, Uttranchal, India; and Daniel and Paul (2004) in Dindigul, Tamil Nadu, India. But, so far, no in depth work has been carried out anywhere and no one has so far standardized
the procedure for sub-sampling of municipal solid waste for characterization study.

The quantity of waste produced in the developing countries like India is lesser than that in the developed countries and is normally observed to vary between 0.2 to 0.5 kg/head/d (CPHERI, 1973; Ahsan, 1999 and Palnitkar, 2000). The present study has shown that the average per capita waste production of Dindigul Town is 0.352 kg/d and it varied in the various sanitary divisions. It was 1.099 and 0.792 kg/head/d in sanitary divisions 8 and 3 respectively. It was high in these two sanitary divisions because they are located in the commercial area where markets are located and people from the town and also the floating population from the villages around the town regularly visit this area on all days for various commercial purposes (Table 1). Munnoli and Bhosale (2002) also reported that the quantity of solid waste generation shoots up because of the floating population in Goa.

According to the environmental protection agency United States produces 11 billion tonnes of solid waste each year and nearly half of that consists of agricultural wastes. The municipal wastes amounts to about 180 million metric tonnes per year in the United States i.e., approximately two thirds of a tonne for each individual and it is twice as much per capita as Europe of Japan and 5 to 10 times as much as most developing countries.
India produces 210 million tonnes of municipal solid waste each year (Abbasi and Ramasamy, 2001).

The per capita waste generation positively correlated with the number of families and the size of the population/ha (fig. 2). Similar type of results were observed by Cailas et al. (1996) and Beede and Bloom (1995) in their studies on the rate of waste production with reference to the population size. The wards covered under the thickly populated domestic area, i.e., sanitary division 1 is a slum area and hence the population is dense in this division when compared with the other areas and the total waste production is also high in this area. In the less populated area i.e., sanitary divisions 2, 12 and 13, the houses are scattered over a larger geographical area and, in the thickly populated mixed area, i.e., sanitary divisions 4, 6, 11 and 15, which is a mixture of domestic and commercial sectors, the per capita waste generation is lesser than in the commercial area but more than in the domestic area (figs. 3 and 4).

The residential household waste dominated the non-residential sector because of the large population, but the non-residential source contained more quantity of organic fractions and that was due to the presence of the vegetable wastes and large quantities of leaves in the wastes, i.e., the wastes produced by the markets, hotels and wedding halls (fig. 5). Some of the waste produced by the wedding halls and the hotels
are collected and used as hog feed by those who rear them around the Dindigul municipal limits.

As given in Table 2, the sanitary division 4 has a large number of big and small hotels and a big flower market because the bus stand is located in this division and many people visit this area. The organic waste production is also high in this division.

Most of the people dispose of wastes by simply dropping them somewhere. Open and unregulated dumping is the predominant method of waste disposal in Dindigul Town. The waste piles are exposed to wind and rain and also to rats, flies, insects, pigs and other animals. In some places the people set fire to the wastes. The rag pickers spend their days sorting through the garbage for reusable and recyclable materials. The trash gets accumulated along the road sides, in vacant places, particularly in the poorer sections of the town.

The floating population simply dump the wastes in any convenient place when they visit the town. Quite close to the major roads within the town limits unsightly, unhealthy and unregulated dumps of all sorts of human wastes can be seen. They are abundant in areas with more vegetation. Many people do not see the dumping of garbage as an environment problem. Awareness, education and alternatives only can solve the problem of unsanitary dumping.
Placing dust bins may reduce the problem of waste accumulation along the roadsides, but only 122 cement bins have been placed in the whole of Dindigul Town with a 14.01 sq.k.m. area.

Some people argue that continued economic growth and population growth certainly will cause more waste generation and some others argue that it will be feasible to reduce waste generation with increase in the level of education and development, but, practically speaking, nothing seems to work out on reducing the waste generation and it is the responsibility of the individuals and collectively of the community to find out measures to protect and improve the environment around their houses and in the streets.

The municipal solid waste generated in the fifteen sanitary divisions is transported to the dumping yard by different mode (Table 3). Park (1997) has explained the advantage of house to house collection and it has resulted in a simultaneous reduction in the number of public bins (Kawata, 1963). Nearly 43.29 percent of the total wastes of Dindigul Town are transported to the dumping yard by bullock cart, 0.53 percent by tricycle and the rest (56.18 %) by motorized vehicles such as mini truck, minidior, tractor trailer, truck, tipper truck, power tiller and sullage truck. Bullock carts should be suspended from the transportation of wastes, for it is not energy efficient and also increases the manpower requirement.
Vast amounts of unwanted stuff are generated every year and places to dispose of these wastes are becoming more and more scarce, the contents of the wastes are becoming increasingly unpleasant and no one wants it in their neighbourhood. Many cities dump the municipal refuse and sewage sludge in the ocean.

In most countries the solid wastes are used as landfills. Many European and American cities and industries are sending their wastes abroad to less developed countries. Sometimes even toxic wastes are exported illegally and dumped in the less developed countries. Radioactive wastes and hazardous chemicals have been transported to other countries and sometimes ashes have been dumped in oceans.

The dumping yard of Dindigul Municipality located in sanitary division 13 (fig. 1) was once a low lying area and over the years the land fills have occupied the whole area i.e., 11.4 acres and raised it to the ground level. The municipality is badly in need of a new site for disposing of the solid waste. Several times in a year the workers set fire to the dump, causing the smoke to rise up and pollute the atmosphere. One such occasion has been photographed and depicted in plate 1. An alternative site is also proposed and recommended for future use in the present study.

Too much wastes are produced and there is too little acceptable space for their permanent disposal. In several cities
people spend 50 - 75 dollars to dispose of one metric tonne of urban refuse in different cities all over the world.

No one wants to live near a waste disposal site whether it is a sanitary landfill for municipal solid waste or an incinerator that burns urban wastes or a hazardous chemical wastes disposal operation site. In some places the refuse pile has reached several tens of meters above sea level. New York is an example of such waste piles.

Fig. 6 indicates the annual expenditure of Dindigul Municipality on the salary of the sanitary manpower: 95.15 percent of the expenditure on waste management staff is shelled out to meet the salary of the sanitary staff because the majority of them are sanitary workers (the salary of the health officer is not included in this count because waste management alone is not his work). India spends about Rs. 230 million per year on waste disposal alone. This expenditure includes the cost of collection, transportation and disposal of municipal wastes (Abbasi and Ramasamy, 1999). Municipal agencies spend 5-25 percent of their budget on solid waste management (Bhide, 1996). It is time that the people are asked to pay for the waste generated by them based on the quantity and quality of the waste, so that proper disposal measures can be adopted.

Human beings produce waste in nearly everything they do. The wastes we discard contain organic materials such as food wastes, garden wastes, sewage sludge, wood, rags, worn out
furniture, newspapers and recyclable metals, glass, plastics and dust and rubble.

Though everyone knows that the municipal solid waste consists of domestic garbage, commercial waste and construction waste, no attempt so far has been made to standardize a sampling technique for the characterization of the municipal solid waste.

The components of the municipal solid waste was identified by several workers (Tchobanoglous et al., 1977; Ladhar, 2000; and Munnoli and Bhosale, 2002). The various components present in the municipal solid waste of Dindigul Town are listed in Table 4.

The determination of the sample size of the municipal solid waste for physical characterization is very important. Some workers followed randomized sampling technique (Nanda et al., 2000-b; Deepa et al., 2002; Jeenger and Mathur, 2002; Rampal and Sharma, 2003; and Paul et al., 2003) and have used 10 to 10000 kg of the wastes as samples to observe all the components of the municipal solid wastes in their studies. If the sample size is too small it can not hold all the components of the municipal solid waste and if it is too large it will need more time and energy for segregation. Hence the proper sample size will have to be identified.

The reducing square method followed in the present study is the first attempt to standardize the sample size in India for the
observation of various components of the municipal solid waste. The percent availability of the same components in the subsequent smaller squares varied depending on the bulk density of the total waste in the square. At the seventh square, one or more components were absent and hence the sixth square was thought to be suitable for the sampling study. However, the standardization of the sampling error through mean, deviation percentage of the physical characterization of municipal solid waste (Table 5 and fig. 7) indicated 13.19 to 49.2 percent mean deviation for 42.625 kg of wastes and hence 81.25 kg of well mixed waste, which will contain all the 13 components, is recommended as the minimum acceptable sample size for the physical characterization study for Dindigul Town. This sample size can be adopted for studying the waste characterization in other Class - I Towns also provided the wastes are thoroughly mixed before sampling. In all the squares observed i.e., 1 to 6, the food wastes and the plant residues were high indicating the presence of wastes from hotels, markets and houses.

The physical composition of the municipal solid waste in the fifteen sanitary divisions showed a high proportion of food wastes and plant residues. It reflects the practice of eating fresh vegetables and fruits. Due to the presence of vegetable markets, the plant residues are high in the sanitary divisions 3 and 4. Low amounts of glass, plastic, metal and rubber items
were essentially due to their reclamation at the source. Plastics are the major compounds that pollute the environment, but comparatively its presence was very less (Tables 6 and 7). The same type of observation has been made by Munnoli and Bhosale (2002) in Goa, India, and Reddy et al. (2002) in Bangalore, India.

Study on the physical composition of the municipal solid waste in different months observed over a period of three years (fig. 8) showed a high percentage of food waste in April to June and that was because these months are the holiday season for all educational institutions and so draw more visitors from other major cities of the country for holidaying or weddings and other social gatherings. Deepa et al. (2002) observed an increase in the organic wastes during non-working days than working days in Mysore City, India. The generation of plant residues was high during December and that was because of the availability of agricultural residues and byproducts during October to December all over India (Agarwal, 1998).

As shown in fig. 9, in the domestic area the organic matter content is low when compared to the commercial area but the rags, inert materials and miscellaneous items were high and that is because the people have the habit of throwing away old cloth and unwanted rugs in the street. They also sweep the front part of their houses, the streets and the backyards and collect the sand/earth and dump it along with municipal solid wastes.
Similar findings were observed by Kumar and Singh (1999) in Ghazipur City, India. The shopping area produces more amount of papers and plastics and the mixed area generates all types of wastes, i.e., organic wastes, papers, plastics, rubber, metals, construction wastes and road sweepings. On an average, the biodegradable wastes dominated the rest in all the three areas studied, i.e., domestic, commercial and mixed areas. Rampal and Sharma (2003) also found a similar observation in Jammu, India.

The physico-chemical analysis of the municipal solid waste of Dindigul Town has shown that it is slightly alkaline and the organic carbon and the organic matter content are high (Table 8). It is also quite rich in macro and micronutrients and hence it can be composted further. If the municipal solid waste of Dindigul Town is dumped in the dumping yard, 64.25 tonnes of nitrogen, 32.13 tonnes of phosphorus, 58.01 tonnes of potassium, 2247.13 tonnes of cellulose and 2498.79 tonnes of lignin get wasted every year. The high cellulose and lignin contents can be utilized as the carbon source for the production of microbial biomass protein (Paul and Daniel, 2004-a).

The composition of the bio-medical wastes of Dindigul Town showed 79.84 percent of non-infectious wastes and 20.16 percent of infectious wastes. Of this 3.73 percent was highly infectious and it contained tissue wastes like uterus, umbilical chord, muscles and blood (Table 9). These wastes should be
disinfected, incinerated and then buried. The WHO (2002) also has observed the presence of 20 percent of hazardous materials and 80 percent of benign materials in bio-medical wastes (plate 2).

The enumeration of the colony forming units of bacteria, fungi and actinomycetes present in the municipal solid waste of Dindigul Town has shown the presence of a heavy load of microorganisms in the wastes (Table 10). The presence of heavy organic matter in the municipal solid waste, i.e., 72.61 percent, is the cause for such a heavy load of microorganisms. Researchers who have worked on municipal solid waste and human wastes (Obeng and Wright, 1987) and vegetable market and hotel wastes (Balamurugan, 2002) have also identified the presence of a heavy load of colony forming units in their studies.

Since fungi are known to degrade the organic material, they are considered important in the biodegradation of solid wastes. A large number of fungi can degrade cellulose by producing enzymes of the cellulase complex. Hence experiments were carried out to identify the dominant species present in the municipal solid waste of Dindigul (plate 3). *Aspergillus* was the well established species (Table 11) and the same has been reported by Weinrich et al. (1999) in four cities in Germany and these species were further screened for celulolytic, lignolytic and phosphate solubilizing activities.
Earlier workers have used different concentrations of carboxy methyl cellulose (CMC) to determine the cellulolytic activity of microorganisms (Mogal and Dube, 1994; Hossain and Anwar, 1996 a and b; and Naha et al., 1998). The concentration of CMC plays a vital role in the fungal mycelial growth. If the concentration is very high, the fungal isolates are not able to utilize the carbon source (Table 12).

The results of the production of extracellular protein indicate that *T. viride* has a high potential to produce extracellular protein from municipal solid waste and *A.niger* (strain-2) has the ability to produce enzymes for saccharification of municipal solid waste. The biomass yield and the cellulase activity had no direct correlation (Singh et al., 1986 and Anwar and Zaman, 1994). The holocellulose of municipal solid waste was also reduced by the fungal species and hence these isolates can be employed for the production of extracellular proteins.

Eight fungal species were found efficient in reducing the cellulose present in the municipal solid waste which got reflected through the production of extracellular protein, the reducing sugar level, the percentage of saccharification and the biomass yield as given in Tables 13 and 14. Similar results were found in *A.niger* (Hossain and Anwar, 1996), *T. viride* (Mandels and Stenberg, 1976) and *Trichoderma* spp. and *Aspergillus* spp. (Shewale and Sadana, 1981).
The concentration of the substrate required for enzyme production varied, but 1-2 percent CMC proved to be optimal (Anandapandian et al., 2002). The optimum concentration of CMC for CMC\textsubscript{ase} activity of the crude enzymes extracted from the selected eight fungal cultures was found to be 1.5 percent. Further increase in the substrate concentration reduced the enzyme activity, which is probably due to increased levels of reducing sugar accumulated through saccharification and responsible for the repression of cellulase synthesis (Anandapandian et al., 2002). The rate of cellulolytic activity was high at the minimum enzyme concentration. The highest CMC\textsubscript{ase} activity was recorded with *T. viride*, followed by *A.niger* (strain-1) and the lowest with *F.solani* i.e., 175 pg/ml/h, 150 fjg/ml/h and 115 jjg/ml/h (figs. 10 to 14).

From this study it is suggested that *T. viride* can be effectively used for the production of microbial biomass protein (MBP) from the municipal solid waste and also for biodegradation of the cellulose present in the municipal solid waste. Lignin and tannic acid are closely related substances and therefore the evidence for tannic acid degradation can be taken for lignin degradation (Bavendamm, 1927). Tannic acid degradation was shown by the formation of a brown zone around the fungal colony due to the decomposition products of tannic acid (Table 15) (plate 4).
The zone of clearance was high in *A. erythrocephalus* (Table 16) (plate 5) and was formed due to the solubilization of insoluble phosphates by acidification associated with either proton extrusion or organic acid secretion (Bardiya and Gaur, 1974 and Darmal *et al.*, 1989). The solubilization of phosphates in a liquid medium depends on the nature of the phosphate source, the organic incubation period and the nature and quantity of the organic acids secreted into the medium (Sujatha *et al.*, 2004). The number of days taken for the maximum activity varied for various species (Table 17). Fourteen days of incubation period was favourable for maximum phosphate solubilization by microorganisms in a liquid medium. Narsian *et al.* (1995) observed that the phosphate solubilizing activity of *Aspergillus aculeatus* was the highest after 48 h of fungal growth and that the fungal biomass production was more in the case of tricalcium phosphate than other phosphate sources.

The fall in the pH during the initial days was due to the production of organic acids like citric, acetic, fumaric and malic in the growth (fig. 15). The mechanisms used by microorganisms for inorganic phosphate solubilization have been attributed mainly to acidification, chelation and exchange reactions in the growth environment (Molla and Chowdhry, 1984 and Cunningham and Kuiack, 1992).

The aeromicrobial survey was carried out in the present study to assess the impact of the dumping yard on the
surrounding atmosphere. A higher microbial load was observed in the dumping yard than in the nearby sites (Tables 18 to 20). The extent and the types of aeromicrobes over the dumping yard can be the actual spot wherefrom it will be disseminated to nearby zones causing the prevalence of microbes in the air, which can slowly cause epidemic and endemic diseases and infect crops and finally pollute the atmosphere to a great extent (Lacey and Dutkiewicz, 1994). The disposal sites cause significant air pollution problems. The untreated sewage dumped along with other wastes also causes air pollution and some are even carcinogenic.

The prevalence of optimum temperature and wind velocity favored higher aeromicrobial population in and around the dumping yard. Chopra and Sharma (1998) correlated the humidity and the number of fungal colonies and found positive results on many fungal species. As the fungal spores may cause allergy and diseases (Gupta et al., 1960; Agrawal et al., 1969 and Maurice, 1995), the dumping yard should be properly maintained and controlling methods should be employed in order to maintain good hygienic conditions.

The microbial load in the leachate showed a very high population of bacteria, fungi, actinomycetes and coliforms than in the ground water collected from the dumping yard and from 100 feet away from the dumping yard (Table 21). The density of the coliform group is the criterion for the degree of contamination
and has been the basis for bacteriological water quality standards. The presence of coliforms in water is an indicator of contamination by human or animal excrement. The indiscriminate disposal of domestic waste on land surface, the improper disposal of solid waste, the leaching of waste water from landfill areas further aggravate the chances of bacterial contamination of ground water (Jain, 2004). The MPN of coliforms shall not be more than 10 per 100 ml as per BIS (1991), but in the present study, it was too high and this was due to the dumping of 1800 kg of sullage in the dumping yard as a layer over the municipal solid waste in the pit. Royee and Prakasam (2002) found that the coliforms were higher in number during the rainy season than in the non-rainy season. In some places, in the name of waste management programmes, many of the wastes are simply moved from one site to another site and are not really managed. Ultimately methane gas and obnoxious liquids leak from the dumping site and contaminate the surrounding area.

The leachate is the most significant hazard from a landfill, which pollutes the surface and ground water. The noxious mineralized liquid is capable of transporting bacterial pollutants to the water by moving literally through the refuse. The pollutants can be moved by the water several kilometers from the disposal site, depending on the amount of water that infiltrates or moves through the waste and the length of time that
the infiltrated water is in contact with the refuse. The topography of the site, the location of the ground water table, the amount of precipitation and type of soil are the important factors to be considered before dumping and sanitary landfilling. Arid regions are much favored for such operations.

The ground water abstraction sources and their surroundings should be properly maintained to ensure hygienic conditions and the leachate should not be allowed to percolate directly to the ground water aquifer. Samples showing bacterial contamination should be properly disinfected before being used for domestic purposes. Some of the older urban landfills are now being considered hazardous waste sites and will require costly clean up. Hence proper planning is essential for separating different types of wastes at the origin, i.e., houses, food shops, grocery, markets and hospitals.

The results of all the physico-chemical characteristics of the water samples collected from the leachate and the ground water from the dumping yard exceeded the standards (WHO, 1971 and BIS, 1991) except in the case of pH (Table 36). But the ground water samples collected from 100 feet away from the dumping yard were well within the recommended limits except for alkalinity. The exceeding of the physico-chemical parameters was due to the discharge of salts and minerals from the domestic waste which is landfilled in the dumping yard. However the physico-chemical characteristics of the ground
water in the dumping yard does not conform to the drinking water standards. Similar observation was made by several other workers (Aurangabadkar et al., 2000 and Kumar and King, 2004).

Composting is an age old technology traditionally followed by the farming community to enrich the agrosoil after each harvest. The coming of chemical fertilizers has replaced manures and caused soil sickness. However, in the recent past, agriculturists have realized their mistake and have once again resorted to composting activities. Vermicomposting technology, particularly, has become an important activity in several parts of the world and a few earthworm species are being employed for the preparation of vermicompost. *Eudrilus eugeniae* and *E.fetida* (Karmegam and Daniel, 2001), *P.excavatus* (Karmegam and Daniel, 2001), *P.ceylanensis* (Karmegam and Daniel, 2003), *D.chlorina*, *D. circumpapiliata*, *D.paradoxa*, *D.pellucid pallid*, *L.mauritii* and *P.ceylanensis* (Karmegam et al., 2003) are some of the species utilized and tested for vermicomposting operations in the Department of Biology, Gandhigram Rural Institute, Gandhigiram.

If the available 49.896 tonnes per day of organic matter of the municipal solid waste of Dindigul Town can be properly composted either by the traditional method or by vermicomposting technology, that will produce 18212.04 tonnes/annum of organic manure, which can be sold
to the farmers who live around the town and the money earned can be used to maintain the sanitary status of the town. Dindigul can be made a refuse free Class-I Town if the three R's, i.e., reduce, reuse and recycle can be followed.

In the present study, a native earthworm, *P.ceylanensis* (plates 6 and 7) and an exotic earthworm, *E.fetida* (plates 8 and 9), were employed for vermicomposting of the municipal solid waste. Studies carried out by other workers have also indicated the usefulness of *E.fetida* for vermicomposting technology (Reinecke et al., 1992; Shinde et al., 1992; Orazco et al., 1996; Karmegam and Daniel, 2000-d). But so far only a few works have been reported about the efficiency of *P.ceylanensis* for vermicomposting of plant residues (Karmegam et al., 2003 and Karmegam and Daniel, 2003). This is the first work on the possibility of using *P.ceylanensis* for vermicomposting of municipal solid waste.

Pre-digestion or half digestion of municipal solid waste should be effected before feeding the earthworms and hence the municipal solid waste was pre-decomposed for a period of 24 days to reduce the heat produced during the initial decomposition of organic materials and also to ensure a favourable C/N ratio for the action of earthworms and microorganisms (figs. 16 to 18 and Table 22). On the fourth day of pre-decomposition the bacterial and fungal count was reduced due to the generation of excess heat and then it was
stabilized (Davis et al., 1992 and Bhiday, 1995). Changes in the microbial load and C/N ratio showed optimum conditions for vermicomposting at the 16th day. Hence 16 days of pre-decomposition of municipal solid waste was selected as the suitable period for pre-decomposition.

Since the C/N ratio of the pre-decomposed municipal solid waste was high, an attempt was made in the present study to reduce the C/N ratio by incorporating cowdung, which is a good source of nitrogen, in order to make the waste mixture suitable for decomposition using earthworms.

Several researchers have used different ratios of organic wastes and cowdung mixture for vermicomposting studies. Leaf litter and cowdung (1:1) (Karmegam and Daniel, 2000-a), Sugar cane trash and cowdung (1:4) (Ramalingam and Thilagar, 2000) and vegetable waste and cowdung (3:1) (Padma et al., 2002) are some of the combinations used by these authors for vermicomposting. The generation of compostable organic material in Dindigul Town is 49.896 tonnes/day and it requires a minimum of 16.632 tonnes of cowdung/day to prepare a 3:1 ratio mixture. It is very difficult to collect 16.632 tonnes of cowdung/day. Hence a minimum incorporation of cowdung in the form of slurry with municipal solid waste has been worked out in the current study (plate 12).

The 50 day vermicomposting results presented in Table 23 show that with increase in the incorporation of cowdung the
percentage decomposition of the municipal solid waste also increased. It increased from 58.09±4.57 in the 100:2 combination to 70.48±5.66 in the 100:10 combination of municipal solid waste and cowdung in the treatment with *P. ceylanensis*, and it increased from 61.72±4.55 to 75.67±3.75 in the treatment with *E. fetida*. The percentage increase of decomposition was 63.27 and 65.79 in the 100:10 combination treated with *P. ceylanensis* and *E. fetida* respectively. Hence it is recommended that cowdung may be incorporated in 10:1 ratio in order to induce effective decomposition of the municipal solid waste. The two-way ANOVA results showed significant difference between the percentage decomposition of various combinations of municipal solid waste and cowdung slurry and also between the earthworm species (Table 24).

The total biomass and the number of worms (*P. ceylanensis* and *E. fetida*) recovered at the end of the experiment were high in the treatments incorporated with a high proportion of cowdung (Tables 25 and 27). Reinecke and Viljoen (1990) explained the requirement of cowdung to maintain earthworms’ growth and reproduction. The biomass of the worms recovered was more or less equal for both the species tested (Table 26). The recovery of a high number of earthworms in the treatment inoculated with *P. ceylanensis* showed the short life cycle of this earthworm species (Karmegam, 2002). The
number of cocoons was high in the treatment inoculated with *E. fetida*.

As indicated in Table 28, a significant difference was observed between the number of worms recovered in various combinations of municipal solid waste and cowdung slurry and also between the earthworm species. As shown in fig. 27, with the increase in the worm biomass the number of cocoons recovered also increased for both the species tested. Hence a positive correlation was observed between the worm biomass and the number of cocoons recovered (plates 10 and 11).

The pH values showed a slight reduction in the worm worked vermicompost when compared to the worm-unworked compost (fig. 19). The decrease in pH value was due to the formation of humic acids in the vermicompost during microbial metabolism (Hartenstein and Hartenstein, 1981 and Haimi and Huhta, 1986) and to the presence of gut microflora and special enzyme system in earthworms (Salisbury, 1925). A decrease in pH is an important factor in nitrogen retention, as this element is lost as volatile ammonia at high pH values (Hartenstein, 1981). Similar results were observed in various organic materials composted using *E. eugeniae* and *E. fetida* (Daniel and Karmegam, 1999 and Karmegam and Daniel, 2000-c and 2000-d).

Electrical conductivity is an indicator of concentrations of soluble salts. After the composting it was found to have
increased in all the treatments (fig. 19). The electrical conductivity of vermicompost increases from its initial value because the earthworms convert the unavailable form of nutrients to more available forms (Bhiday, 1994) and also due to the presence of more exchangeable calcium, magnesium and potassium in the worm cast than in the soil (Bhatnagar and Palta, 1996).

The worm-worked vermicompost of both the species of earthworms, *P. ceylanensis* and *E. fetida*, showed a more significant reduction of organic carbon, organic matter content and C/N and C/P ratio than in the worm-unworked composts (figs. 20 to 22 and fig. 24). Because of the combined action of the microorganisms and the earthworms, a large fraction of the organic matter in the initial substrates was lost as CO$_2$ by the end of the vermicomposting period. Edwards (1988) found that worm activity in animal waste changed most of the nitrogen from ammonium to the nitrate form and this helped in bringing down the ratio of carbon to nitrogen, which is essential in the humification process. Lavelle *et al.* (1983) found that a significant proportion of carbon assimilated by earthworms is secreted as intestinal and cutaneous mucus with greater C/N ratio than those of the resource used.

In the decomposing materials, microorganisms used carbon for energy and nitrogen for growth. During the vermicomposting process, carbon was released as CO$_2$ and,
consequently, the C/N ratio was reduced. Hence it can be concluded that the organic carbon in the vermicompost is the main source of energy for microorganisms, plants and soil aggregates. The C/N and C/p ratio is of importance because the plants can not assimilate mineral nitrogen and phosphorus unless the ratio is between 20:1 and 15:1 or lower (Edwards and Bohlen, 1996).

The higher percentage increase of N, P and K in the worm-worked vermicompost produced by *P. ceylanensis* and *E. fetida* than in the worm-unworked compost in the present study (figs. 20 and 23) could be attributed to the excretion of CaCO$_3$ by earthworms which solubilized the nutrients (Robertson, 1934) and to the mineralization process caused by the action of earthworms, and microorganisms on organic materials.

The increased level of phosphorus during vermicomposting is due to earthworm gut derived phosphatases activity and increased microbial activity in the cast (Lee, 1991). Lee (1985) stated that only very small quantities of phosphorus are excreted by earthworms in liquid wastes, but considerable quantities are ingested with organic matter, passed through the intestine and excreted in casts.

The value of potassium in the final composts was more than in the control (fig. 23). Coleman *et al.* (1983) observed that the uptake of potassium by bacteria, fungi, grazing
microorganisms and earthworms, their excretion and decomposition result in the release of potassium components that can be cycled through plants and back again to the soil biota. Jambhekar (1992) observed a considerable increase in the available potassium compared to that in the initial stage and in the control treatment in different animal residues and agricultural wastes. Several workers have reported considerable increase in the nitrogen, phosphorus and potassium content after vermicomposting (Graff, 1971; Watanabe, 1975; Buchanan et al., 1988; Ramalingam, 1997 and Karmegam et al., 2003). The present study also confirms the above findings.

The calcium content in the worm-worked vermicompost was higher than that in the worm-unworked compost (fig. 23). The increase of calcium in the vermicompost may be due to the excretion calcium from the calciferous glands. In earthworms, enough of calcium is available in the calciferous glands, which have the primary role of secreting calcium and secondary excrete wastes (Jamieson, 1981). The reduction of sodium may be due to the increased utilization of this element from the ingested organic waste by the worms and the microbes for their growth and reproduction. The ionic regulatory mechanism in earthworms involves uptake of Fe, Mn and sodium from ingesta and its excretion via the calciferous glands (Bouche, 1983). The increased/decreased levels of macro and micronutrients in the
vermicomposts were in conformity with the results of earlier works (Kale et al., 1994; Ramalingam, 1997 and Daniel and Karmegam, 1999).

The cellulose and lignin contents were found to be reduced in the municipal solid waste and cowdung mixture treated with earthworms (fig. 25). Degradation of the ligno-cellulosic compounds is very difficult for earthworms, but this was made easy due to the enzymes secreted by the microorganisms present in the gut of the earthworms and in the substrates. Kale (1998) stated that there was an increase in cellulolytic, hemi cellulolytic and nitrifying bacteria in the earthworm cast compared to the surrounding soil. Akpa and Loquet (1997) observed that composting and vermicomposting of ligno-cellulosic wastes showed an increased mineralization as indicated by weight loss, organic matter loss, total carbon loss, and loss of total aliphatic carbon and lignin. In the present study the percent decrease of cellulose was high and this was due to the cellulolytic microorganisms present in the cowdung. Cellulose/lignin ratio and lignin/nitrogen ratio were reduced in the municipal solid waste and cowdung mixture treated with earthworms, which indicates the biodegradation of lignin (fig. 26).

In the present study, the population of the microorganisms was found to be higher in the worm-worked vermicompost over the worm-unworked compost (Tables 29 and 30). This clearly
indicated that the organic substrates used in the present study could initiate the proliferation of the microorganisms and the two different species of earthworms used in the present study also acted as a medium for the rapid microbial colonization. Several workers studied the microbial load in the casts and surrounding environment and found that the casts increased the number of the microbial population (Bassalik, 1913; Ramalingam and Thilagar, 2000 and Nagarathnam et al., 2000). Edwards and Lofty (1977) suggested that the size of the microbial population in casts depends on the quality and type of the food. Microorganisms constitute an important component of the earthworm diet (Lee, 1985). A faster growth of actinomycetes in the advanced stages of composting was reported by Mun et al. (1988). The inter-relationship of microorganisms with macroorganisms by their presence inside or outside the body of the macroorganism and in their environment has been established already by Tiwari and Mishra (1993) and Lavelle et al. (1995).

Based on the observations of percentage incorporation, worm biomass, number of worms recovered, physico-chemical characteristics of vermicompost and microbial load of vermicompost, it is suggested that *P. ceylanensis* is equivalent in its efficiency to *E. fetida* for the biodegradation of municipal solid waste and the percentage incorporation of cowdung to municipal
solid waste could be 10:1. This ratio can be used for large scale vermicomposting of municipal solid waste.

The advantages of using native worms are many and notable among them is that they preserve the native diversity of the earthworms. Abbott (1980) reported that when the indigenous earthworm, *P. excavatus*, was introduced in a mixed culture along with the exotic earthworm *E. eugeniae*, the population of *P. excavatus* was gradually replaced, and it indicates the competition among the earthworm species, probably for food.

The results of the vermicomposting studies with *P. ceylanensis* and *E. fetida* in various combinations of municipal solid waste and cowdung slurry indicate that both the species can be successfully utilized for vermicomposting of municipal solid waste in Dindigul Town.

All types of society produce wastes but industrialization and urbanization have caused an ever increasing affluence that has greatly compounded the problems of waste management. Hence, before a crisis occurs, newer and innovative programmes need to be worked out in addition to the already existing waste disposal options. In the innovative method, the waste will have to be considered as resources, but out of place. In the future, the increasing cost of raw materials, energy, transportation and land will make it feasible to reuse and recycle more resources from the municipal solid waste.
For planning an effective solid waste management by Dindigul Municipality, a newly modified profile of the sanitary manpower is recommended for the future (figs. 28 and 29). As per the profile, administrative staff consisting of one Junior Assistant, one Office Assistant and a Writer will be sufficient to attend to the paper work. One Junior Assistant and two Office Assistants can be dropped or may be transferred to other sections of the municipality. For the compost yard, one Biologist should be newly appointed for analyzing the compost quality and managing the composting activity. Bullock carts should be removed from the transportation task and the salary paid to 29 cart drivers and 8 cattle depot workers can be saved (Daniel and Paul, 2004).

In the modified profile of the sanitary manpower, the energy to be expended on collection, transportation, dumping and composting of municipal solid waste of Dindigul Town has been worked out (Tables 31 and 32). The energy spent can be reduced from 7126.82 mJ/d to 7017.96 mJ/d i.e., 39733.9 mJ/y. Though the reduction of energy expenditure looks meager, it should be noted that the new calculation involves the energy expenditure for one more new section i.e., composting section. In this new profile, animal power used for transportation has been replaced by motorized vehicles in order to improve the solid waste management system and also to eliminate the
manpower required for driving the bullock carts and the maintenance of bullocks.

The number of sanitary workers to be involved in the waste management, the quantum of municipal solid waste to be collected/h/d and the area to be covered by each sanitary worker/d are suggested based on the quantum of wastes generated in the given area of the respective sanitary divisions of Dindigul Town (Table 34). For example, the area covered in sanitary division 3 is less, but the waste production is comparatively very high because of the commercial profile. Hence changes are recommended in the existing pattern.

The air required for composting and for combustion was calculated for the wastes drawn from all the fifteen sanitary divisions (Table 33). If the wastes are composted, 6532.91 m$^3$ of air per day can be saved and also the carbon monoxide production from the combustion can be avoided and, in turn, air pollution can be reduced. The organic fraction of the municipal solid waste can be utilized for methane production and, after that, the slurry can be subjected to vermicomposting. Due to higher moisture and nutrient content the option of incineration process for energy recovery is reduced and the refuse is more suitable for composting than for energy recovery (Jeenger and Mathur, 2002). Hence the municipal solid waste is recommended for composting and vermicomposting.
Nowadays, due to the shortage of traditional organic fertilizers, new resources of organic matter are coming up. The current waste philosophy is to treat all wastes as resource material: some for recycling, some for conversion to fertilizer, some as a source of energy and the rest for land reclamation (Rampal and Salaria, 2001). In waste utilization, the separation of municipal solid waste should be carried out at the sub-depot.

Recycling is a major player in municipal solid waste reduction. Glass, aluminium cans, plastics, newspapers and organic materials can be recycled, the construction waste can be used for landfills and the hospital waste can be incinerated. It is essential to get public support for a sound waste management programme. Business people also should come forward to support the waste management programme.

The non-degradable components should be transported to the dumping yard and the recyclable components such as plastics, metals and papers should be recycled through industry. Some components like wood wastes and rubber can be pelletized for use as refuse derived fuel. The infectious wastes from hospitals and toxic chemical containers should be disinfected and then landfilled or incinerated. The degradable wastes should be transported to the composting yard. The total compostable components be composted by trench or pit method of composting, vermicomposting and composting using microbial
cultures. To this compost some biofertilizers may be added and a mixed manure can be prepared and sold to farmers (fig. 30).

The location of the proposed compost yard, the location of the proposed sub-depots and the possible route to the compost yard and the dumping yard from the fifteen sanitary divisions of Dindigul Municipality are given in fig. 31. The present dumping yard is located within the municipal limits, but the location of the proposed dumping yard is 5 km away from the Dindigul bus stand, i.e., outside the municipal limits. Within the limits of the fifteen sanitary divisions, four new sub-depots will have to be constructed following suitable safety measures. The total wastes produced from each household should be separated into degradable organic wastes, non-degradable but recyclable wastes and non-degradable landfill wastes at the house level and these wastes should be taken to the sub-depots where they can be separated further. The degradable organic wastes and non-degradable wastes can be transferred to the compost yard and the dumping yard respectively through the proposed new routes. The proposed route is drawn in such a way as not to cross the main roads so that the pollution caused by the refuse transport can be reduced and there will be no interference with the movement of other vehicles.

For constructing the recommended composting yard with 110 pits, a land area of 4.64 acres is needed. In addition to that 30 percent (1.39 acre) extra working space is needed for
separation and shredding and also for road and pathways. Six to seven (6 to 7) acres will be sufficient to compost all the waste generated by the people of Dindigul Town (Table 35).

The old concept of waste management was “dilute and disperse” and the new concept is “concentrate and contain”. This is possible only through integrated waste management. The expansion of townships and urban areas has increased the waste output. Waste management can be made simple by several ways. Fast food outlets such as small hotels and roadside tea shops should provide on site bins for recycling the used papers and polythene bags. The grocery stores should use paper bags in the place of plastics and polythenes. Some grocery stores and food stores nowadays offer inexpensive canvass shopping bags. There are people who prefer degradable plastic and paper bags. Some small hotels, tea shops and institutions offer paper cups and paper plates in the place of plastic ones. Several parts used for automobiles are recycled rather than left to become rusting eyesores in junk yards. In some communities recycled plastics, metallic appliances, glass and rubber articles are sold at very cheap prices thereby proving the importance of integrated waste management.

In conclusion, listing of wastes produced by different agencies, prescribing the type and size of bin to be used for collecting the waste at the source by different agencies,
standardization of the method of disposal of different categories of waste, collection of charges for the quantity of wastes produced depending on the type of waste, increasing the budget for waste management, fixing responsibilities for maintaining the sanitary condition of different areas and creation of awareness among the public on waste management will improve sanitary conditions and the scenic beauty of towns.