Chapter 6.
Summary

Over the past few years disposal and management of organic solid wastes has become more problematic and rigorous due to rapidly increasing population, intensive agriculture and industrialization. In fact municipal authorities in India as well as in other developing countries of the world lack appropriate, infrastructure and resources for organized and sustainable biosolid waste management strategies. The normally practiced and predominant mode of disposal has been open dumping and land filling (94%), and only a very small proportion (6%) is recycled in an eco-friendly manner. Decrease in the available space and enactment of legislation for protection of environment along with public awareness has drawn the attention of concerned authorities and researchers towards searching and employing alternative strategies for recycling the nutrients locked in the organic wastes.

Stabilization of organic wastes with vermicomposting is being considered as the best option for management of a wide variety of organic wastes. In this technology, joint action of earthworms and microbes leads to degradation and recovery of nutrients from wastes in a relatively shorter span of time. Earthworms act as crucial promoters of this process by aerating and conditioning the organic matter to enhance the activity of biological microbes. Out of the various species of earthworms, *Eisenia fetida* is the most preferred species as it is hardy, prolific breeder and accepts a wide variety of food.

Present work envisaged biosafe disposal of the biosludges and effluents of three industries (Beverage, Distillery and Paper mill) situated in the District Amritsar of Punjab, India. The biosludges of these industries are rich in organic matter highly imbalanced with respect to nutrient content and are generally dumped by the industries in landfills or open fields where these toxify and pollute the soil for a long time. The effluents are also being released in water bodies after preliminary oxidation in settling tanks and make the water unfit for consumption by human beings and other animals, as well as have deleterious influence on vegetation and other aquatic life. Therefore, it was planned to improve quality of the solid and liquid wastes of these industries before their disposal. For bioremediation the bio-solid wastes were fed to *Ei. fetida*
and the liquid wastes (effluents) of these industries were filtered through vermicompost biofilter. The biosludges of all the three industries were so toxic to earthworms that heavy mortality occurred in them, rather they were not accepted as feed even after pre-composting of two weeks. Co-composting with a complementary waste the cattle dung helped to improve their acceptability for *Ei. fetida* and in turn led to fast recycling of nutrients locked in them. Thus sludges were mixed with cattle dung in various proportions and subjected to traditional aerobic composting (without *Ei. fetida*) and vermicomposting (with *Ei. fetida*) for the purpose of efficiency comparison of the two techniques.

The experiments for solid wastes were performed in rectangular plastic trays (28 x 23 x 6 cm) in triplicate under the sheds of the Vermifarm, Department of Zoology, Guru Nanak Dev University, Amritsar in two phases. In the first phase of the experiment, growth rate, onset of maturity (clitellum development), rate of reproduction (cocoon production) and population buildup were recorded as the indices of suitability of a particular mixture for the worms. Physico-chemical characterization of the products of traditional aerobic composting and vermicomposting was done to evaluate the efficiency of *Ei. fetida* over microbes for changing the sludge in to a soil conditioner. In the second phase of the experiment two best suitable mixtures of each sludge with cattle dung were taken and experiment was run with a variation in weight of worms (7.5, 12.5 and 25 g/kg feed mixture) to find out the optimum weight of worms /kg mixture for fastest conversion of the waste to a quality product. Worm biomass, time taken for degradation and nutrient content of the final product were taken as indices for the best quality product in shortest possible time.

The effluents were passed through 38.0 x 3.2 cm glass columns with vermicompost for detoxification and improvement of quality. Efficiency of vermicompost as a biofilter was determined with respect to physico-chemical characteristics of the effluent before and after filtration.

Electrical Conductivity (EC) and pH for biosludges were determined in double distilled water suspension of each mixture in the ratio of 1:10 (w/v) using HM digital meter-COM-100 and Equip-tronics EQ-614-A, respectively. For effluents EC and pH was determined directly. Organic Carbon (OC) was measured after igniting the sample in a Muffle furnace at 550 °C for 60 minutes by employing the method of Nelson and Sommers (1996). Method of John (1970) was used for measuring phosphorus with UV-Visible Spectrophotometer. Potassium and Sodium
were measured with the help of Sytronics Flame photometer-117. Transition metals (Cu, Fe, Mn and Zn) were analysed by Varian 20 model of Atomic Absorption Spectrophotometer after digesting the samples in a diacid mixture (HNO\textsubscript{3}: HClO\textsubscript{4} in 4:1 ratio). Micro-Kjeldhal method (Bremner and Mulvaney, 1982) was used for measuring Nitrogen after digesting the sample in digestion mixture (H\textsubscript{2}SO\textsubscript{4} + K\textsubscript{2}SO\textsubscript{4}: CuSO\textsubscript{4}: SeO\textsubscript{2} in 10:4:1).

Statistical analysis was done with the help of Minitab 14 programme/software. One-way ANOVA was used to calculate differences among various mixtures. The data for numbers of worm, cocoons and hatchlings were subjected to square root transformation prior to analysis of variance. Two-way ANOVA was used to find the effect of interaction between the proportion of sludge and weight of earthworms in the mixtures on the selected physico-chemical parameters of the products. Pearson’s correlation coefficient and regression analysis was used to calculate the relationship between concentrations and chemical parameters. Student’s t-test was used to evaluate differences between initial and final values of various chemical parameters. Response surface design was used for finding out the best expected ratio of a biosludge and cattle dung giving maximum number of worms, cocoons and hatchlings.

Beverage industry biosludge was mixed with cattle dung in the ratio of 0:100 (BV\textsubscript{1}, BT\textsubscript{1}) 25:75 (BV\textsubscript{2}, BT\textsubscript{2}), 50:50 (BV\textsubscript{3}, BT\textsubscript{3}), 75:25 (BV\textsubscript{4}, BT\textsubscript{4}) and 100:0 (BV\textsubscript{5}, BT\textsubscript{5}) on dry weight basis, and subjected to vermicomposting (BV) and traditional aerobic composting (BT). Population built up in the form of number of worms, cocoons, hatchlings and biomass as a measure of suitability of a particular feed mixture for *Ei. fetida* was significantly different (p<0.01). Minimum mortality and maximum population build up were observed in BV\textsubscript{3} (50:50). On the basis of response surface curve the best proportion of biosludge and cattle dung giving highest number of worms came to be 48.24:51.76. Cocoon production started between 25\textsuperscript{th} and 30\textsuperscript{th} day of the release of worms in all the mixtures except for BV\textsubscript{5}, where the cocoons were observed on 45\textsuperscript{th} day. The concentration of biosludge giving highest number of cocoons came to be 44.25:55.75 with response surface design. The response surface curve showed that a negative correlation was present in the number of hatchlings with the concentration of biosludge in the mixtures, further it indicated that for highest number of hatchlings beverage industry sludge and cattle dung should be mixed in the ratio of 47.45:52.55. The worm biomass started declining in all the mixtures after 90\textsuperscript{th} day but it was highest in BV\textsubscript{3} on all the durations. According to response surface curve 50.11:49.89 proportion of the bio sludge and cattle dung would give
maximum biomass. A negative correlation \( r = -0.89 \) was observed in the worm biomass and concentration of the bio sludge in the mixture.

In the first phase of experiment in beverage biosludge, nitrogen, phosphorus, sodium and pH increased, while electrical conductivity, organic carbon and potassium declined in all the products of vermicomposting, however, an opposite trend was observed in the products of traditional aerobic composting (except for a small decline in OC). Percent increase in pH was maximum in BV\(_5\) (19.04\%) and minimum in BV\(_1\) (4.69\%). With both vermicomposting and traditional aerobic composting, EC declined in the products and the decline was maximum in BV\(_1\) (28.59\%) and BT\(_1\) (8.94\%) and minimum in BV\(_5\) (20.5\%) and BT\(_5\) (3.75\%). Increase in nitrogen was maximum in BV\(_2\) (15.82\%) and minimum in BV\(_5\) mixture (3.59\%). Decline in OC was maximum in BV\(_1\) (37.52\%) and minimum in BV\(_2\) (27.50\%) and the decline in C: N ratio was observed to be maximum in BV\(_1\) (55.77\%) and minimum in BV\(_4\) (35.57\%). Highest decline in C: N ratio of the products of traditional aerobic composting was only 0.75\% in BT\(_1\) feed mixture. Percent increase over initial in phosphorus was maximum in BV\(_1\) (52.98\%) and minimum in BV\(_5\) (1.63\%). While in the products of traditional aerobic composting BT\(_5\) showed minimum increase in phosphorus (0.54\%), which was less than even half of the value in BV\(_5\). Potassium declined in the products of vermicomposting but showed an increase in the products of traditional aerobic composting. Maximum percentage decline in potassium was noticed in BV\(_5\) (58.13\%) and it was minimum in BV\(_2\) (16.42\%). Content of potassium increased in the range of 5.7\% to 12.5\% over initial in the products of traditional aerobic composting. Increase in Na was maximum in BV\(_3\) (92.80\%) and minimum in BV\(_1\) mixture (30.53\%). In the products of traditional aerobic composting the increase in sodium was maximum in BT\(_5\) (34.5\%) and minimum in BT\(_2\) (5.3\%). Increase in the contents of selected transition metals in the products of both the techniques was proportional to the concentration of sludge in the mixture but it was much less in the products of traditional aerobic composting. It ranged from 15.7\% to 28.47\% for Mn, 10.71\% to 20.51\% for Cu, 17.95\% to 127.95\% for Fe and 11.51\% to 26.61\% for Zn in the products of vermicomposting while in the products of traditional aerobic composting the range was 1.39\% to 4.01\% for Mn, 2.39\% to 3.89\% for Cu, 10.40\% to 17.29\% for Fe and 2.64\% to 6.94\% for Zn.

The second set of experiment indicated that decline in pH, organic carbon, potassium, transition metals and rate of degradation was directly correlated to the weight of worms/kg feed mixture. Feed mixture was composted in 95 days with 25g worms/kg feed mixture and 110 days
with 7.5 g worms/kg feed mixture but the physico-chemical properties of the products were best with 12.5 g worms/kg waste which was converted into compost after 105 days. Worm biomass, however showed an opposite correlation and was always highest in the feed mixtures with 7.5 g worms/Kg feed mixture. The mean values at 95% confidence intervals showed that the maximum decrease of Cu (28.3% and 42.7%), Fe (19.9% and 23.4%), Mn (12.1% and 16.8%), Zn (37.6% and 31.4%) was in BE3 and B’E3 respectively. In the products of traditional aerobic composting the increase was 3.2% and 3.8% for Cu, 3.5% and 2.1% for Fe, 2.9% and 5.8% for Mn, 9.3% and 5.2% for Zn in BE0 and B’E0 respectively.

Pulp and paper mill sludge was co-composted with (PV) and without (PT) *Ei. fetida* after mixing with cattle dung in the ratio of 0:100 (PV1, PT1), 25:75 (PV2, PT2), 50:50 (PV3, PT3), 75:25 (PV4, PT4) and 100:0 (PV5, PT5) on dry weight basis. Population buildup of *Ei. fetida* in different mixtures was significantly different (p< 0.01) and negatively correlated (r = -0.89) with the ratio of paper mill sludge in the feed mixture. Population of worms was highest in PV2 and minimum in PV5. Clitellates and cocoons were observed on 45th day in all the feed mixtures except PV5, where these were noticed on 65th day. In PV1, PV2, PV3 and PV4 mixtures number of cocoons increased continuously up to 105th day whereas in PV5 number of cocoons increased till 135th day but the numbers remained lowest in this mixture. The number of hatchlings came to be maximum in PV2 (427.0) and minimum in PV5 (1.15) at the end of the experiment. Maximum worm biomass was observed in PV5 on 135th day, which was followed by PV4, PV3, PV2 and PV1. It was observed that the paper mill sludge negatively affected reproduction and population buildup of *Ei. fetida* but it enhanced earthworm biomass.

The physico-chemical parameters showed significant changes when paper mill sludge was co-composted with and without *Ei. fetida*. There was an increase in pH of the products of vermicomposting and it was maximum in PV1 (18.37%) and minimum in PV5 (10.67%) while there was a significant decrease in the pH of the products of traditional aerobic composting over initial (p< 0.01, r = -0.94). EC declined in the products of vermicomposting and the decline was maximum in PV2 (41.53%) and minimum in PV3 (34.30%). Whereas in the products of traditional aerobic composting EC increased in the range of 1.45 to 10.43 % over initial. Increase in nitrogen was 68.95% (highest) in PV1 and 49.02% (lowest) in PV5, on the other hand the decline in nitrogen (p< 0.01, r = -0.94) in the products of traditional aerobic composting ranged from 6.09 to 15.96% over initial. Data showed that the products of vermicomposting had
approximately double the content of nitrogen in comparison to the products of traditional aerobic composting. Decline in OC with vermicomposting was maximum in PV₂ (44.62%) and minimum in PV₅ (22.85%). Traditional aerobic composting brought only a slight decline in organic carbon of the mixtures ranging from 5.0% (PT₂) to 13.72% (PT₃). Highest C: N was 43.97 (PV₃) for the products of vermicomposting and 78.05 (PT₅) for the products of traditional aerobic composting. Phosphorus increased over initial with vermicomposting (18.18% in PV₅ to 43.55% in PV₁) but declined with traditional aerobic composting (2.72% in PT₃ to 10.02% in PT₁). Potassium, however, declined (p < 0.05) in the products of vermicomposting except for PV₅ while it increased significantly (p < 0.05) in the products of traditional aerobic composting. Except for PV₅ and PT₅ amount of sodium decreased over initial in the products of both vermicomposting (3.1- 17.7%) and traditional aerobic composting (4.0-9.1%). There was a significant (p < 0.01) increase in the contents of transition metals in the products of vermicomposting as well as traditional aerobic composting but the increase was more with vermicomposting in comparison to traditional aerobic composting.

During second phase of the study it was noticed that decline in worm biomass, pH, organic carbon, potassium and transition metals over initial was directly correlated with the weight of *Ei. fetida* /kg feed mixture. But the rate of degradation increased in correlation with the weight of earthworms (g) /kg feed. Feed mixture was composted in 77 days with 25g worms/kg feed mixture and in 98 days with 7.5 g worms/kg feed mixture but best quality products were obtained with 12.5g *Ei. fetida* /kg mixture. Mean values at 95% confidence intervals indicated that the contents of transition metals decreased with an increase in the weight of earthworms. Maximum decrease in transition metal was observed in PE₃ and P'E₃, which was 78.0% and 63.6% for Cu, 10.8% and 3.6% for Fe, 11.3% and 18.4% for Mn, 9.8% and 19.2% for Zn. On the other hand there was an increase over initial in the contents of transition metals in the products of traditional aerobic composting and it was to the tune of 25.4% and 3.4% for Cu, 3.0% and 1.4% for Fe, 6.6% and 4.7% for Mn and 10.4% and 5.3% for Zn in PE₀ and P'E₀ respectively.

The dark brown sludge produced from the spent wash of distillery caused heavy mortality of *Ei. fetida* as it had a high BOD, COD and nutrient imbalance. So it was mixed with cattle dung in the ratio of 0:100 (DV₁, DT₁) 10:90 (DV₂, DT₂), 25:75 (DV₃, DT₃), 50:50 (DV₄, DT₄), 75:25 (DV₅, DT₅) and 100:0 (DV₆, DT₆) w/w on dry weight basis. Survival, growth, onset of maturity, cocoon production and population buildup increased with increasing ratio of cattle
dung in the mixture. Highest population was observed in DV2 while maximum cocoons and hatchlings were observed in DV2 and DV3 respectively. The number of worms started to increase after 75th day in DV1, DV2 and DV3 mixtures and continued up to 105th day and then there was a decrease till the end of the experiment. In DV4, DV5 and DV6 mixture, the number of worms declined continuously till 105th day, after this although there was an increase in the number of worms but the number always remained less than even the initial number of worms inoculated in the feed mixtures. Clitellum appeared between 45th to 60th day in all the feed mixtures except for DV5 and DV6 where it appeared between 75th and 90th day respectively. Maximum number of cocoons was observed in DV2 (200.0) followed by DV3 (160.0) and DV1 (120.0) on 120th day. Hatchlings were observed for the first time between 75th and 90th day in DV1, DV2 and DV3 mixtures and between 105th and 120th day in DV4, DV5 and DV6 mixture. The number of hatchlings increased continuously and came to be maximum in DV3 (295 ± 12.0) and minimum in DV6 (2 ± 0.1) on 150th day. Worm biomass showed significant differences (p< 0.05) and had a positive correlation (r = 0.95) with the concentration of sludge in the mixtures. On the basis of response surface design the concentrations giving highest number of worms, cocoons and hatchlings came out to be 21.11%, 24.51% and 17.19% respectively, which were very near the observed values for these parameters.

Percent increase in pH of the products of vermicomposting ranged from 5.63% (DV6) to 14.38 % (DV1) over initial, while in the products of traditional aerobic composting the increase in pH ranged from 0.85% (DT3) to 6.62% (DT1) over initial. EC of the products was found to decline significantly over initial with vermicomposting, however, it increased over initial with traditional aerobic composting. In the products of vermicomposting an increase in nitrogen was observed and percent increase over initial was maximum in DV1 (34.86%) and minimum in DV6 (12.78 %) while, in the products of traditional aerobic composting there was a significant decline in nitrogen in all the mixtures (10.0 to 15.1%). With vermicomposting decline in OC was maximum in DV1 (24.71%) and minimum in DV6 (11.21%). In the products of traditional aerobic composting there was a less but significant decline in organic carbon and it was in the range of 3.80% to 13.32% over initial. Higher decline in C: N ratio was observed with vermicomposting and it was maximum in DV1 (44.20 %) minimum in DV6 (21.28%). In the products of traditional composting there was a smaller but significant decline in C: N ratio and it ranged from 1.02 to 0.37 % over initial. Vermicomposting brought an increase in phosphorus over the initial (4.51%–
13.83%), while traditional aerobic composting brought a significant decrease over initial (2.69% to 8.85%). Decline in potassium in the products of vermicomposting was significant and it ranged from 20.27% (DV6) to 40.07% (DV3). On the other hand an increase in the content of potassium ranging from 1.78% (DT3) to 7.62% (DT1) was observed in the products of traditional aerobic composting. Increase in sodium was much more in the products of vermicomposting and it was maximum in DV1 (30.83%) and minimum in DV6 (6.30%). An increase was observed in the contents of transition metals in the products of both the techniques but it was higher in the products of vermicomposting. Increase in Mn was maximum in DV6 (28.09%) and minimum in DV5 (12.42%), increase in Cu was however, maximum in DV1 (20.51%) and minimum in DV5 (8.0%). Fe was observed to be maximum in DV6 (11.43%) and minimum in DV2 (4.75%), while Zn was maximum in DV4 (19.72%) and minimum in DV2 (11.55%).

In the second phase of the experiment it was noticed that worm biomass, pH, organic carbon, potassium and transition metals decreased over initial in a direct correlation with the weight of worms/kg feed mixture. However, rate of degradation was positively correlated with earthworm density/kg feed as the feed mixture was composted in 98 days with 25 g worms/kg feed mixture and in 120 days with 7.5 g worms/kg feed mixture. But the physico-chemical properties were observed to be best in the mixtures inoculated with 12.5g worms/Kg feed. Cu, Fe, Mn and Zn showed maximum decline in DE3 and D’E3, which was 40.0% and 39.1% for Cu, 34.0% and 47.2% for Fe, 26.3% and 41.2% for Mn, 25.1% and 32.4% for Zn. However, the transition metals increased significantly (p< 0.05) in the products of traditional aerobic composting and the increase was 2.9% and 4.1% for Cu, 0.6% and 3.3% for Fe, 10.9% and 2.2% for Mn and 3.2% and 2.24% for Zn in DE0 and D’E0 respectively.

Vermicompost was observed to be an efficient biofilter as it had an appreciable buffering and adsorption capacity. Glass columns (38 cm high, 3.2 cm wide) were loaded with 20g, 50g and 100g vermicompost (0.23mm particle size) to evaluate the rate of adsorption of transition metals and changes in pH, EC, BOD, COD, TDS and TSS of the effluents after filtration through 50g vermicompost. Rate of adsorption for the transition metals of these effluents was significant and fitted Langmuir isotherm equation. Initial COD, BOD, pH and EC of beverage industry effluent was 1000 mg/l, 387.5 mg/l, 9.97 and 2.0 mS/cm respectively, on passage through vermicompost the filtrate COD came down to 440.0 mg/l and BOD declined to 174.0 mg/l, pH 7.8, its EC increased to 4.0 mS/cm. TDS and TSS declined significantly over initial and came to
be 72.0 mg/l and 246.0 mg/l respectively. High adsorption was noticed for transition metals and it was positively correlated with weight of vermicompost in the column and adsorption was 87.8% for Cu, 71.7% for Mn, 54.0% for Fe and 33.3% for Zn with 100g of vermicompost.

Initial COD, BOD, pH and EC of paper mill effluent was 1240.0 mg/l, 440.0 mg/l, 7.1 and 4.8 mS/cm respectively, on passage through vermicompost filters COD and BOD was reduced to 530.0 mg/l and 260.0 mg/l respectively. pH of the filtrate ranged between 7.8 and EC came to be 6.1 mS/cm. TDS and TSS declined significantly over initial and their amounts came to be in the range of 210.0 mg/l and 230.0 mg/l respectively. Adsorption of transition metals was in the order of Cu (69.2%) > Mn (58.3%) > Fe (58.8%) > Zn (18.4%) with 100g of vermicompost.

Initial COD, BOD, pH and EC of distillery effluent was 42,200 mg/l, 17200, 4.5 and 6.9 mS/cm respectively. On passage through vermicompost COD of the filtrate came to 18,000 mg/l and BOD 5806 mg/l. pH ranged from to 5.8 and EC came to 8.1 mS/cm. TDS and TSS declined significantly over initial and came to be 206.7 mg/l and 105.7 mg/l respectively. Adsorption for transition metals was highest with 100g vermicompost for Mn (88.7%), Zn (78.0%) and Fe (37.3%) with 100g vermicompost for Mn, Zn, Fe and 50g vermicompost for Cu (68.8%).

The present study evidently demonstrated that vermicomposting can be and should be employed as a fast and low cost technology for the biosafe disposal of the nutritionally imbalanced bio solids of beverage, paper and distillery industries. However, these biosludges need to be premixed with cattle dung in the ratios of 25:75, 30:70 and 50:50 for distillery, paper and beverage industries, respectively, and pre-composted for 15 days for reducing the proportion of their toxic elements and for making the biosludges congenial for the growth and activity of *Ei. fetida*. Cattle dung not only enhances the rate of degradation by increasing the acceptability of the wastes for *Ei. fetida* but it also enhances nutritional status of the products. The results also indicated that vermicomposting is a better option over traditional aerobic composting as the lowest C: N ratio of the final products was 14.9 (BV1) and 26.2 (BT4) for beverage, 6.89 (PV2) and 17.7 (PT2) for paper mill and 7.1(DV1) and 12.4(DT1) for distillery respectively. *Ei. fetida* should be inoculated at 12.5 g/Kg 25:75, 30:70 and 50:50 mixtures of distillery, paper mill and beverage biosludges, respectively, for obtaining the best quality products. This study further indicated that vermicompost proved to be an efficient biofilter by inducing a decline in BOD, COD, TDS and TSS of the effluent and changed its pH to neutral. Therefore, by adopting this
combined technology for management of their solid and liquid wastes industries will not only save money but will also be instrumental in saving the environment.