Chapter 4

Results

In the present study an attempt has been made for bioremediation of the solid (biosludge) and liquid (effluent) wastes of beverage, paper and distillery industries. For the solids, experiments were conducted in two phases in triplicates. In the first phase the biosludges from the three industries were mixed with cattle dung and inoculated with twenty non-clitellated worms to find out the proportion of a particular sludge in the feed mixture supporting highest population buildup of worms (Plate 5). Variation in the quality of the products due to the proportion of sludge in the mixture was adjudged by physico-chemical characterization of the products (Plate 6). In the second phase, two best mixtures of each sludge from phase one were inoculated with a variable weight of *Ei. fetida* for finding out the appropriate weight of worms/kg feed mixture for fastest production of a quality product from these wastes. Physico-chemical analysis was done to know the effect of worm density on the quality of a product. For remediation of the effluents of these industries vermicompost was used as a biofilter. The effluent was passed through glass columns with 50g vermicompost for pH, EC, BOD, COD, TDS and TSS. For transition metals column with a variable weight of vermicompost were used. Physico-chemical characteristics of the effluent before and after passage through the columns were analysed to estimate the adsorption capacity of vermicompost.

4.1 First Phase

The experiments were conducted to find out two mixtures of each sludge with highest population buildup of *Ei. fetida*.

4.1.1 Beverage biosludge

Proportion of beverage biosludge and cattle dung in the feed mixtures and physico-chemical characteristics of biosludge and cattle dung are given in Table 1 and Table 2.
4.1.1.1 Population buildup of worms

Population buildup in the form of number of worms, cocoons, hatchlings and biomass as a measure of acceptance of a particular feed mixture by *Ei. fetida* was significantly different.

4.1.1.1.1 Number of worms:

The numbers of worms at different time intervals in various feed mixtures were statistically different (p< 0.01). The number started to increase on 30th day in BV2, BV3 and BV4 mixtures and on 45th day in BV1 feed mixture and continued till the end of the experiment. In BV5 mixture, however, a decrease in numbers up to 75th day was followed by an increase up to 120th day. At the end of experiment maximum increase was observed in BV3 (8.2 folds) followed by BV2 (6.8 folds) and BV4 mixture (6.5 fold) (Figure 1A). On the basis of response surface curve the best concentration of biosludge giving highest number of worms came to be 48.24 %. A negative correlation (r = -0.97) was observed in the increase in number of worms and the concentration of biosludge in the feed mixture (Figure 1B).

4.1.1.1.2 Number of cocoons:

Clitellum appeared between 15th to 30th days in all the feed mixtures except BV5 where the clitellates were noticed between 30th to 45th day. The numbers of cocoons with varying biosludge concentration were significantly different (p< 0.01). Cocoon production started between 25th to 30th day of the release of worms in all the mixtures except for BV5, where the cocoons were observed on 45th day. In BV2, BV3 and BV4 mixtures number of cocoons increased continuously up to 75th day whereas, the numbers increased up to 105th day in BV1 and BV5 mixtures and then declined. Maximum number of cocoons was observed on 75th day in BV2 (Figure 2A) and there was a significant decline in the number of cocoons with respect to increasing concentration of biosludge (r = -0.94) in the feed mixtures. The concentration of biosludge giving highest number of cocoons came to be 44.2% with response surface curve (Figure 2B).

4.1.1.1.3 Number of hatchlings:

There was a significant difference (p< 0.01) in the numbers of hatchlings with varying biosludge concentration. Hatchlings were observed for the first time on 30th day in BV2, BV3 and BV4, on 75th day in BV1 and on 90th day in BV5 mixture. The
number of hatchlings increased continuously after this and on 120th day it was maximum in BV3 (155.5 ± 18.5) and minimum in BV5 (93.0 ± 5.0) mixture (Figure 3A). The response surface curve showed a negative correlation in the number of hatchlings with respect to increasing concentration of biosludge (r = -0.97), further it indicated that for highest number of hatchlings beverage industry sludge should be mixed in cattle dung at 47.4% (Figure 3B).

4.1.1.4 Worm biomass:

Worm biomass showed significant differences (p< 0.01) with variation in the concentration of biosludge in the mixtures. The worm biomass started declining in all the mixtures after 90th day (Figure 4A) and feed mixture was composted in 120 days. Maximum worm biomass was observed in BV3 mixture on all the durations and according to response surface curve also 50.1% bio sludge in cattle dung would give maximum worm biomass. A negative correlation (r = -0.89) was observed in the worm biomass and concentration of the biosludge in the mixture (Figure 4B).

4.1.1.2 Physico-chemical parameters

The physico-chemical parameters also showed significant changes with varying concentration of biosludge in the mixtures (Table 3 and Figure 5 and 6).

4.1.1.2.1 Appearance:

Beverage biosludge was light brown in colour and its texture was compact and solid. The products of vermicomposting were granular and dark brown in comparison to the products of traditional aerobic composting.

4.1.1.2.2 pH:

There was a significant increase in pH of the products over initial (p< 0.05) but the correlation of pH with the concentration of biosludge was negative for both vermicomposting (r = -0.88) and traditional aerobic composting (r = -0.97). Maximum percentage increase in pH during vermicomposting was noticed in BV5 (18.9%) and it was minimum in BV1 mixture (4.5%). For the products of traditional aerobic composting increase in pH was maximum in BT5 (8.7%) and minimum in BT1 (1.2%). The order of increase in pH of the products of vermicomposting and traditional aerobic composting was in the order of BV5> BV4 > BV2 > BV3 > BV1 and BT5> BT4> BT3> BT2> BT1 respectively.
4.1.1.2.3 Electrical conductivity (EC):

EC was found to decline significantly over initial in the products of both vermicomposting and traditional aerobic composting (p < 0.01) and it showed a negative correlation with the concentration of biosludge in the mixtures (r = -0.98). Maximum percentage decline was noticed in BV1 (28.5%) and it was minimum in BV5 (20.5%). In the products of traditional aerobic composting the decline was maximum in BT1 (8.9%) and minimum in BT5 (3.7%). The trend of decline in EC in the products of vermicomposting and traditional aerobic composting was in the order of BV1 > BV2 > BV3 > BV4 > BV5 and BT1 > BT2 > BT3 > BT4 > BT5.

4.1.1.2.4 Nitrogen:

Nitrogen increased significantly over initial in the products of vermicomposting only (p < 0.05) and its content showed a positive correlation with the concentration of biosludge in the feed mixtures (r = 0.93). The increase was 15.7% in BV1 and 3.5% in BV5 mixture and the trend of nitrogen in the products of vermicomposting was in the order of BV1 > BV2 > BV3 > BV4 > BV5. In the products of traditional aerobic composting nitrogen decreased significantly (r = 0.97, p < 0.05) over initial. Decline was maximum in BT5 (10.1%) and minimum in BT1 (4.4%). The order of percent decrease in nitrogen in the products of traditional aerobic composting was BT5 > BT4 > BT3 > BT2 > BT1.

4.1.1.2.5 Organic Carbon (OC) and C: N ratio:

There was a significant decline (p < 0.01) in organic carbon (OC) of the products of both vermicomposting (r = 0.94) and traditional aerobic composting (r = 0.89) and it showed a positive correlation with the concentration of biosludge in the mixtures. Decline over initial in OC with vermicomposting was maximum in BV5 (35.9%) and minimum in BV2 (27.5%). In the products of traditional aerobic composting the decline was much less and it was 5.2% in BT1 (maximum) and 2.8% in BT5 (minimum). The percent decrease in OC in the products of vermicomposting was in the order of BV5 > BV1 > BV3 > BV4 > BV2. Whereas the percent decrease in OC of the products of traditional aerobic composting was in the order of BT1 > BT2 > BT3 > BT4 > BT5.

The products of vermicomposting as well as traditional aerobic composting had lower C: N ratio as compared to the initial mixtures. Maximum decline in C: N
ratio was observed in BV1 (46.0%) and it was minimum in BV2 (34.0%). However, the decline in C: N ratio over initial in the products of traditional aerobic composting was in the range of 0.75% to 8.07% only. The percent decrease in C: N ratio of the products of vermicomposting was in the order of BV1 > BV5 > BV3 > BV4 > BV2. Whereas C: N ratio of the products of traditional aerobic composting was in the order of BT5 > BT4 > BT3 > BT2 > BT1.

4.1.1.2.6 Phosphorus:

Phosphorus increased significantly {over initial (p< 0.05)} in the products of both vermicomposting and traditional aerobic composting and showed a positive correlation with increase in biosludge concentration in the mixtures (r = 0.90 and 0.89 respectively). Percent increase over initial was maximum in BV1 (52.7%) and minimum in BV5 (1.5%) during vermicomposting. However, in the products of traditional aerobic composting there was only a small increase in phosphorus over initial (0.54% to 2.7%). Phosphorus in the products was in the order of BV1 > BV2 > BV3 > BV4 > BV5 and BT1 > BT2 > BT3 > BT4 > BT5.

4.1.1.2.7 Potassium:

Potassium in the products of vermicomposting was significantly less than the initial feed mixtures (p< 0.05). On the other hand, an increase in the content of potassium was observed in the products of traditional aerobic composting. The content of potassium showed a negative correlation with the concentration of biosludge in the mixtures of both vermicomposting and traditional aerobic composting (r = -0.98). Percent decline in potassium was maximum in BV5 (58.1%) and minimum in BV2 (16.4%). Increase over initial in potassium was maximum in BT1 (12.5%) and minimum in BT5 (5.7%). Potassium in the products of vermicomposting and traditional aerobic composting was in the order of BV5 > BV4 > BV3 > BV1 > BV2 and BT1 > BT2 > BT3 > BT4 > BT5.

4.1.1.2.8 Sodium:

Sodium in the products of vermicomposting and traditional aerobic composting increased significantly (p< 0.05) from initial and showed a positive correlation with the concentration of biosludge in the mixtures (r = 0.90 and 0.96 respectively). Increase in Na was maximum in BV3 (92.8%) and minimum in BV1 (30.4%) for vermicomposting and for traditional aerobic composting the increase was
maximum in BT$_5$ (34.5%) and minimum in BT$_2$ (5.3%). The trend of increase in sodium in the products of vermicomposting and traditional aerobic composting was in the order of BV$_3$ $>$ BV$_2$ $>$ BV$_4$ $>$ BV$_5$ $>$ BV$_1$ and BT$_3$ $>$ BT$_4$ $>$ BT$_5$ $>$ BT$_1$ $>$ BT$_2$.

4.1.1.2.9 Transition metals:

The transition metals increased significantly over initial in the products of vermicomposting as well as traditional aerobic composting ($p<0.01$) (Table 4 and Figure 7). Mn, Cu, Fe and Zn showed a positive correlation ($r = 0.96, 0.99, 0.89$ and $0.95$ respectively) with the increasing concentration of sludge in the feed mixtures and the increase ranged from $15.7\%$ to $28.4\%$ for Mn, $10.7\%$ to $20.4\%$ for Cu, $17.9\%$ to $127.9\%$ for Fe and $11.5\%$ to $26.6\%$ for Zn. In the products of traditional aerobic composting also Mn, Cu, Fe and Zn showed a positive correlation ($r = 0.98, 0.99, 0.80$, and $0.91$ respectively) with the increasing concentration of sludge in the feed mixtures and the increase ranged from $1.3\%$ to $4.0\%$ for Mn, $2.3\%$ to $3.8\%$ for Cu, $2.6\%$ to $6.9\%$ for Zn and $10.4\%$ to $17.2\%$ for Fe.

4.1.2 Paper mill sludge

Proportion of paper sludge and cattle dung in the feed mixtures and their physico-chemical characteristics have been given in Table 5 and 6.

4.1.2.1 Population buildup of worms

Population buildup in the form of number of worms, cocoons, hatchlings and worm biomass as a measure of acceptance of a particular feed mixture by *Ei. fetida* was significantly different. (Plate 11 and 12)

4.1.2.1.1 Number of worms:

Number of worms in different mixtures was significantly different ($p<0.01$) and negatively correlated ($r = -0.89$) with concentration of paper mill sludge in the feed mixture. The number started increasing on $60^{th}$ day in PV$_1$, PV$_2$ and PV$_3$ and continued till $120^{th}$ day followed by a decline thereafter. Increase in number of worms was maximum in PV$_2$ and it was $19.4\%$ more than PV$_1$ (only cattle dung). In PV$_4$ and PV$_5$ a lot of mortality was observed and at the end of the experiment there were respectively 19 and 18 worms in these mixtures (Figure 8A and 8B).
4.1.2.1.2 Number of cocoons:

Clitellates and cocoons were observed on 45th day in all the feed mixtures except PV5 where these were noticed on 65th day. The numbers of cocoons declined significantly with increasing paper mill sludge concentration in the feed mixtures ($r = -0.98$, $p<0.01$). In PV1, PV2, PV3 and PV4 mixtures number of cocoons increased continuously up to 105th day and then there was a decline till the end of the experiment. In PV5 although the number of cocoons increased till 135th day but the numbers were too less (14.5 maximum) in comparison to other feed mixtures as PV1 supported maximum cocoon production (252.5) followed by PV2 (225.0), PV3 (80.0) and PV4 (55.5) (Figure 9A and 9B).

4.1.2.1.3 Number of hatchlings:

Hatchlings were observed for the first time on 60th day in all the feed mixtures except in PV5, where these were observed on 75th day. The number of hatchlings increased continuously and came to be maximum in PV2 (427.0) and minimum in PV5 (11.5) at the end of the experiment (Figure 10 A). Hatchling production was significantly different ($p<0.01$) and negatively correlated ($r = -0.92$) with the proportion of paper mill sludge in the feed mixtures (Figure 10 B).

4.1.2.1.4 Worm biomass:

Maximum worm biomass was observed on 135th day in PV5 (29.8 g/10 worms) and it was minimum in PV1 (9.25 g/10 worms). The worm biomass started declining in PV1 and PV2 mixtures after 90th day, however, in PV5 it declined (last of all) after 135th day (Figure 11 A) feed mixture was composted in 135 days. Earthworm biomass showed a significant positive correlation ($p<0.01$, $r = 0.97$) with the concentration of paper mill sludge in the feed mixture (Figure 11 B).

4.1.2.2. Physico-chemical parameters

The physico-chemical parameters showed significant changes when paper mill sludge was composted with and without *Ei. fetida* (Table 7, Figure 12 and 13).

4.1.2.2.1 Appearance:

Paper mill sludge was light grey in colour with a solid fibrous texture. At the end of the experiment the colour of the products of both vermicomposting and traditional aerobic composting ranged from dark grey to black with a granular texture.
4.1.2.2.2 pH:

There was a significant increase in pH of the products of vermicomposting (p < 0.05) but the correlation of pH with the concentration of sludge was negative (r = -0.99) as percent increase in pH was maximum in PV1 (18.3%) and minimum in PV5 (10.6%). With traditional aerobic composting, however, pH decreased over initial (p < 0.01) and had a negative correlation (r = -0.91) with the proportion of paper mill sludge in the mixture. Percent decrease over initial in pH was maximum in PT1 (4.1%) and minimum in PT2 (1.1%). The order of increase in pH of the products of vermicomposting was PV1 > PV2 > PV3 > PV4 > PV5 and order of decrease in pH of the products of traditional aerobic composting was PT1 > PT5 > PT4 > PT3 > PT2.

4.1.2.2.3 EC:

EC in the products of vermicomposting was found to decline significantly (r = 0.97, p ≤ 0.01) from initial except for PV5. Decline in EC was maximum in PV2 (41.5%) and minimum in PV3 (34.3%). Whereas, in the products of traditional aerobic composting EC increased significantly (p < 0.01) and came to be 1.4 to 10.4% more over initial but was negatively correlated (r = -0.95) with the proportion of paper mill sludge in the mixtures. The trend of EC for vermicomposting and traditional aerobic composting was PV5 > PV2 > PV1 > PV4 > PV3 and PT5 > PT1 > PT2 > PT4 > PT3 respectively.

4.1.2.2.4 Nitrogen:

Nitrogen in the products of vermicomposting increased significantly from initial (p < 0.01) and showed a negative correlation with the concentration of paper mill sludge (r = -0.97) in the mixture. Maximum increase in nitrogen was noticed in PV1 (68.9%) and it was minimum (49.0%) in PV5. On the other hand, nitrogen declined significantly from initial (p < 0.01, r = -0.96) in the products of traditional aerobic composting and the percent decline ranged from 6.0 to 15.9%. Comparison shows that the products of vermicomposting had approximately double content of nitrogen than the products of traditional aerobic composting. Percent increase in nitrogen in the products of vermicomposting was in the order of PV1 > PV2 > PV3 > PV4 > PV5, whereas the order of percent decrease in nitrogen of the products of traditional aerobic composting was PT2 > PT4 > PT1 > PT3 > PT5.
4.1.2.2.5 Organic carbon (OC) and C: N ratio:

Vermi-degradation brought a significant decline in OC (p< 0.01) and there was a positive correlation (r = 0.95) in OC content of the products with the concentration of paper mill sludge in the mixture. Decline in OC was maximum in PV_2 (44.6%) and minimum in PV_5 (22.8%). In the products of traditional aerobic composting a significant but much less decline in organic carbon was noticed (r = 0.89, p< 0.05) and it was maximum over initial (13.7%) in PT_5 and minimum (5.0%) in PT_2. These values were 9.2 and 39.62 times less than the values for the respective products of vermicomposting. Percent decrease in organic carbon in the products of vermicomposting and traditional aerobic composting was in the order of PV_2> PV_3> PV_4> PV_1> PV_5 and PT_3> PT_4> PT_3> PT_1> PT_2 respectively. Correspondingly C: N ratio of the products of vermicomposting was lower as compared to the products of traditional aerobic composting. Highest C: N was 43.9 in PV_5 after vermicomposting and 78.05 in PT_5 after traditional aerobic composting, whereas it was lowest in PV_2 (6.8) and PT_1 (17.7) at the end of the experiment.

4.1.2.2.6 Phosphorus:

Phosphorus increased significantly (p< 0.05) in the products of vermicomposting and showed a negative correlation (r = -0.97) with the proportion of paper mill sludge in the mixture. Percent increase over initial was maximum in PV_1 (43.5%) and minimum in PV_5 (18.1%). However, in the products of traditional aerobic composting there was 2.72-10.0% decrease over initial in the content of phosphorus and it was also significant and negatively correlated (r = -0.97, p< 0.01) with the concentration of paper mill sludge in the feed mixture. Percent increase in phosphorus of the products of vermicomposting was in the order of PV_1> PV_2> PV_3> PV_4> PV_5. The order of decline in phosphorus content of the products of traditional aerobic composting was PT_1> PT_2> PT_3> PT_4> PT_5.

4.1.2.2.7 Potassium:

Potassium in the products of vermicomposting declined significantly (p< 0.05) except for PV_5 while, it increased significantly (p< 0.05) in the products of traditional aerobic composting. Content of potassium in the products showed a negative correlation with the concentration of paper mill sludge in the mixture of vermicomposting (r = -0.95) as well as traditional aerobic composting (r = -0.99).
Percent decline was maximum in PV₃ (31.8%) and minimum in PV₁ (25.3%). Increase in potassium was maximum in PT₁ (12.9%) and minimum in PT₂ (0.9%). Percent decline in potassium in the products of vermicomposting and increase in potassium in the products of traditional aerobic composting was in the order of PV₃> PV₅> PV₄> PV₂> PV₁ and PT₁> PT₄> PT₅> PT₃> PT₂ respectively.

4.1.2.2.8 Sodium:

Sodium decreased significantly over initial in the products of both vermicomposting and traditional aerobic composting except for PV₅ and PT₅ but the content showed a positive correlation with the concentration of paper mill sludge in the feed mixture (r = 0.80, r = 0.85 respectively, p< 0.05). Decrease in Na was maximum in PV₁ (17.7%) and minimum in PV₄ (3.1%) with vermicomposting. In the products of traditional aerobic composting decline in sodium was much less (4.0-9.1%) as compared to the products of vermicomposting (3.1-17.7%). The trend of percent decrease in sodium of the products was in the order of PV₁> PV₂> PV₃> PV₄> PV₅ and PT₁> PT₄> PT₃> PT₂> PT₅.

4.1.2.2.9 Transition metals:

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. Mn showed a significantly negative (r = -0.99), while Cu, Fe and Zn showed a significantly positive (r = 0.97, 0.98 and 0.96 respectively) correlation with the increasing concentration of sludge in the feed mixtures subjected to vermicomposting. Increase in the concentration of metals in the products of vermicomposting ranged from 5.7% to 28.0% for Mn, 8.0% to 18.4% for Cu, 5.9% to 14.5% for Fe and 10.4% to 27.4% for Zn. In the products of traditional aerobic composting also, Mn showed a significantly negative (r = -0.98), while Cu, Fe and Zn showed a significantly positive (r = 0.98, 0.96 and 0.92 respectively) correlation with the increasing concentration of sludge in the feed mixtures. Increase in transition metals was less in the products of traditional aerobic composting and it was 1.5% to 8.7% for Mn, 2.1% to 6.3% for Cu, 0.3% to 13.8% for Fe and 0.9% to 5.5% for Zn (Table 8, Figure 14).
4.1.3 Distillery sludge

Proportion of paper sludge and cattle dung in the feed mixtures and physico-chemical characteristics of paper sludge and cattle dung are given in Table 9 and 10.

4.1.3.1 Population buildup of worms

Survival and population buildup in the form of number of worms, number of cocoons, number of hatchlings and worm biomass as a measure of suitability of various mixtures for *Ei. fetida* were significantly different.

4.1.3.1.1 Number of worms:

The numbers of worms after different time intervals in various mixtures were significantly different (p< 0.01). A negative correlation was observed in the rate of population buildup and the ratio of distillery sludge in the feed mixture (r = -0.78). The number started to increase after 75th day in DV1, DV2 and DV3 mixtures and continued up to 105th day and then it decreased till the end of the experiment. In DV4, DV5 and DV6 mixture, the number of worms declined continuously till 105th day, although after this 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. After 150th day maximum increase was observed in DV3 (1.24 folds) followed by DV2 (1.03 fold) and DV1 (1.0 fold) (Figure 15A and 15B). On the basis of response surface design the proportion of distillery sludge giving highest number of worms came to be 21.1%.

4.1.3.1.2 Number of cocoons:

Clitellum appeared between 45th to 60th day in all the feed mixtures except for DV3 and DV6 where it appeared between 75th and 90th day. Cocoon production started between 60th to 75th day of the release of worms in DV1 and DV2, between 75th to 90th day in DV3 and DV4 and between 90th and 105th day in DV5 and DV6. Number and production of cocoons varied significantly with the concentration of distillery sludge in the feed mixture. (p< 0.05, r = -0.95). In DV1 the number of cocoons increased continuously up to 105th day, whereas it increased up to 120th day in DV2, DV3 and DV4 and then there was a decline till the end of the experiment. Very few cocoons were produced by the worms in DV5 and DV6 mixture, between 120th-150th days of the study. On 120th day maximum number of cocoons was observed in DV2 (200.0)
followed by $DV_3$ (160.0), $DV_1$ (120.0) and $DV_4$ (111.0) (Figure 16A). The response surface curve showed that 24.5% distillery sludge in the feed mixture would give highest number of cocoons (Figure 16B).

4.1.3.1.3 Number of hatchlings:

There was a significant difference ($p < 0.05$) and a negative correlation ($r = -0.92$) in the numbers of hatchlings with varying concentration of distillery sludge in the feed mixture. Hatchlings were observed for the first time between 75th - 90th day in $DV_1$, $DV_2$, $DV_3$ and between 105th and 120th day in $DV_4$, $DV_5$ and $DV_6$ feed mixtures. The number of hatchlings was maximum in $DV_3$ ($295 \pm 12.0$) and minimum in $DV_6$ ($2 \pm 0.1$) on 150th day (Figure 17A). The response surface curve indicated that 17.1% distillery sludge in the mixture would give highest number of hatchlings (Figure 17B).

4.1.3.1.4 Worm biomass:

Worm biomass showed significant differences ($p < 0.05$) and a positive correlation ($r = 0.95$) with the concentration of sludge in the mixtures. The biomass started declining after 105th day in all the feed mixtures except $DV_6$ where it declined after 90th day (Figure 18A) feed mixture was composted in 150 days. According to response surface curve 81.8 % proportion of the distillery sludge in cattle dung would give maximum worm biomass (Figure 18B)

4.1.3.2 Physico-chemical parameters

Significant changes were observed in the physico-chemical characteristics of the products of both vermicomposting and traditional aerobic composting (Table 11, Figure 19 and 20).

4.1.3.2.1 Appearance:

Colour of distillery sludge was dark brown and it had a solid and compact texture. The products of vermicomposting were more granular, soft and black in colour in comparison to the products of traditional aerobic composting.

4.1.3.2.2 pH:

There was a significant increase over initial in the pH of the products of both vermicomposting ($p < 0.05$) and traditional aerobic composting ($p < 0.05$) and it had a positive correlation with the concentration of distillery sludge in the mixtures ($r = 0.99$). Percent increase over initial in pH was maximum in $DV_1$ (14.3%) and
minimum in DV₆ (5.6%) with vermicomposting, while highest increase in pH (only 6.6% in DT₁) due to traditional aerobic composting was almost equal to the least increase due to vermicomposting. The order of increase in pH of the products was DV₁ > DV₂ > DV₃ > DV₄ > DV₅ > DV₆ and DT₁ > DT₂ > DT₃ > DT₄ > DT₅ > DT₆.

4.1.3.2.3 Electrical Conductivity (EC):

EC of the products of vermicomposting was found to decline significantly over initial (p< 0.01) and showed a positive correlation with increase in the concentration of distillery sludge (r = 0.98). Percent decline over initial was maximum in DV₁ (11.1%) and minimum in DV₆ (0.9%). However, in the products of traditional aerobic composting there was a significant increase over initial (p< 0.01) and a positive correlation (r = 0.93) of EC with the proportion of distillery sludge in the mixture. Percent increase was maximum (16.1%) in DT₁ and minimum (1.8%) in DT₆. The trend of EC in the products was in the order of DV₁ > DV₂ > DV₃ > DV₄ > DV₅ > DV₆ and DT₁ > DT₂ > DT₃ > DT₄ > DT₅ > DT₆.

4.1.3.2.4 Nitrogen:

Nitrogen increased significantly over initial in the products (p< 0.01) of vermicomposting only and showed a negative correlation with the concentration of distillery sludge in the feed mixtures (r = -0.99). Increase was maximum in DV₁ (34.8%) and minimum in DV₆ (12.7%). In the products of traditional aerobic composting a significant (p< 0.01) decline having a negative correlation (r = -0.99) with the proportion of distillery sludge in the mixture was noticed. Nitrogen content in the products of traditional aerobic composting ranged from 10.0 (DT₆) to 15.1 (DT₁) g/kg mixture. The trend of increase and decline of nitrogen in the products of vermicomposting and traditional aerobic composting was in the order of DV₁ > DV₂ > DV₄ > DV₅ > DV₃ > DV₆ and DT₁ > DT₂ > DT₃ > DT₄ > DT₅ > DT₆ respectively.

4.1.3.2.5 Organic carbon (OC) and C: N ratio:

Both vermi degradation and traditional aerobic composting brought a significant decline in OC of the products (p< 0.01) and the decline showed a positive correlation (r = 0.99, r = 0.98 respectively) with the proportion of distillery sludge in the mixtures. Decline in OC was more in the products of vermicomposting and it was maximum in DV₁ (24.7%) and minimum in DV₆ (11.2%). With traditional aerobic composting there was a much less decline in organic carbon (3.8%-13.3%) in the
products. The trend of decline in organic carbon due to vermicomposting and traditional composting was in the order of $DV_1 > DV_3 > DV_2 > DV_4 > DV_5 > DV_6$ and $DT_1 > DT_2 > DT_3 > DT_4 > DT_5 > DT_6$, respectively.

The products from both the techniques had low C: N ratio as compared to the initial mixtures but the decline in C: N ratio was much more due to vermicomposting ($p< 0.05$, $r = 0.98$). Maximum decline in C: N ratio was observed in $DV_1$ (44.2 %) whereas it was minimum in $DV_6$ (21.2%). In the products of traditional aerobic composting there was a significantly different ($p< 0.01$, $r = 0.99$) but smaller decline in C: N ratio which ranged from 1.0 to 0.3 % over initial. The percent decrease in C: N ratio of the products was in the order of $DV_1 > DV_2 > DV_3 > DV_4 > DV_5 > DV_6$ and $DT_5 > DT_4 > DT_3 > DT_1 > DT_6 > DT_3 > DT_2$.

4.1.3.2.6 Phosphorus:

Phosphorus increased significantly over initial in the products of vermicomposting and had a positive correlation with the proportion of distillery sludge ($p< 0.05$, $r = 0.99$) in the mixture. Percent increase over initial was maximum in $DV_4$ (13.8%) and minimum in $DV_1$ (4.5%). In the products of traditional aerobic composting, there was a significant decrease over initial in phosphorus having a positive correlation with the proportion of sludge in the mixture ($p< 0.01$, $r = 0.98$) and ranged from 2.6% ($DT_6$) to 8.8% ($DT_1$). The increase and decrease of phosphorus in the products of vermicomposting and traditional aerobic composting was respectively in the order of $DV_4 > DV_6 > DV_5 > DV_3 > DV_2 > DV_1$ and $DT_1 > DT_2 > DT_4 > DT_5 > DT_3 > DT_6$.

4.1.3.2.7 Potassium:

Potassium in the products of vermicomposting was significantly less than initial ($p< 0.05$) and had a negative correlation with the proportion of distillery sludge ($r = -0.88$) in the feed mixture. Percent decline was maximum in $DV_3$ (40.0%) and minimum in $DV_6$ (20.2%). On the other hand, content of potassium increased over initial in the products of traditional aerobic composting and showed a positive correlation with the concentration of the sludge in the mixtures ($p< 0.01$, $r = 0.98$). Increase in potassium in the products ranged from 1.7% ($DT_6$) to 7.6% ($DT_1$). The trend for decline and increase in potassium in the products of the two techniques was
in the order of DV3 > DV2 > DV5 > DV4 > DV1 > DV6 and DT1 > DT3 > DT4 > DT2 > DT5 > DT6.

4.1.3.2.8 Sodium:

Sodium in the products of vermicomposting increased significantly (p < 0.05) from initial and showed a negative correlation (r = -0.94) with the concentration of distillery sludge in the feed mixture and ranged from 6.3% (DV6) to 30.8% (DV1) more over initial. In the products of traditional aerobic composting content of sodium increased significantly (p < 0.01, r = 0.94) but was much less (2.6% in DT5 to 6.5% in DT1) in comparison to the products of vermicomposting. The trend of increase in sodium was in the order of DV1 > DV2 > DV3 > DV4 > DV5 > DV6 and DT1 > DT2 > DT4 > DT6 > DT3 > DT5.

4.1.3.2.9 Transition metals:

Transition metals (Mn, Cu, Fe and Zn) increased significantly over initial (p < 0.05) in the products of both vermicomposting and traditional aerobic composting (Table 12, Figure 21). Mn showed a significantly negative correlation (r = -0.99), while Cu, Fe and Zn showed a significantly positive correlation (r = 0.97, 0.99 and 0.97 respectively) with the increasing concentration of sludge in the feed mixtures. Mn was maximum in DV6 (28.0%) and minimum in DV5 (12.4%). Increase in Cu was maximum in DV1 (20.5%) and minimum in DV5 (8.0 %), Fe on the other hand was observed to be maximum in DV6 (11.4%) and minimum in DV2 (4.7%), while Zn was maximum in DV4 (19.7%) and minimum in DV2 (11.5%). In the products of traditional aerobic composting a little less increase in transition metals was noticed with the increasing proportion of the sludge (p < 0.05) in the mixtures. Mn showed a significant negative correlation (r = -0.99), while Cu, Fe and Zn showed a significantly positive correlation (r = 0.97, 0.96 and 0.96 respectively) with the increasing concentration of sludge in the feed mixtures. Increase in the contents of transition metals in the products of traditional aerobic composting was in the range of 4.7 to 14.7% for Mn, 3.2 to 8.4% for Cu, 0.2 to 11.4% for Fe and 3.6 to 6.5% for Zn.

4.2 Second phase

For this phase two mixtures of each biosludge (40% and 60% for beverage and paper mill and 20% and 40% for distillery industry) with cattle dung were selected on
the basis of the results of the first phase and inoculated with 7.5g, 12.5g and 25g Ei. fetida/kg mixture (Table 13). Worm biomass and nutrient content of the mixture were estimated to find out the optimum weight of Ei. fetida per kg mixture for obtaining a quality product in the shortest possible time. The same feed mixtures were subjected to traditional aerobic composting (without earthworms), and a comparison was made between rate of degradation and physico-chemical characteristics of the products of the two technologies. Table 14 shows the initial characteristics of the sludges and cattle dung.

### 4.2.1 Beverage Biosludge

**4.2.1.1 Worm biomass:**

Worm biomass increased up to 90th day in all the feed mixtures and was maximum in these feed mixtures with 7.5 g worms/kg feed mixture. Worm biomass decreased significantly ($r = 0.88$ and $r' = 0.98$) with increasing the number of earthworms in all the mixtures and it was minimum in the feed mixture with 25g worms/kg feed mixture. On 90th it was maximum day in BE$_1$ and minimum in B’E$_3$. Feed mixture was composted in 95 days with 25g worms/kg feed mixture and 110 days with 7.5 g worms/ kg feed mixture (Figure 22).

**4.2.1.2 Physico-chemical parameters**

Physico-chemical parameters showed significant changes with varying concentration of sludge and weight of earthworms in the feed mixtures (Table 15, Figure 23 and 24).

**4.2.1.2.1 pH:**

pH decreased significantly ($p< 0.01$) over initial due to a significant interaction ($p< 0.01$) between the weight of earthworms and concentration of bio sludge in the feed mixture. The mean values at 95% confidence intervals showed highest decrease over initial in pH (15.1% in BE$_3$ and 13.4% in B’E$_3$) with 25g worms/kg waste. Traditional aerobic composting also brought significant ($p< 0.05$) decline in pH over initial and the highest value was 4.7% in BE$_0$ and 1.4% in B’E$_0$. The decrease in pH in the products was in the order of BE$_3$> BE$_2$>BE$_1$> BE$_0$ and B’E$_3$> B’E$_2$>B’E$_1$> B’E$_0$. 
4.2.1.2.2 Electrical Conductivity (EC):

A significant interaction (p< 0.01) between the weight of earthworms and concentration of biosludge in the feed mixture brought a significant increase in the electrical conductivity over initial (p<0.05). The increase was maximum in BE_1 (55.2%) and B’E_1 (65.5%) and minimum in BE_3 (31.0%) and B’E_3 (27.1%). In the products of traditional aerobic composting 6.3% (BE_0) and 10.9% (B’E_0) increase over initial was noticed (p< 0.05), but it was much less as compared to the products of vermicomposting. EC in the products was in the order of BE_1> BE_2> BE_3> BE_0 and B’E_1> B’E_2> B’E_3> B’E_0.

4.2.1.2.3 Nitrogen:

There was a significant increase in the nitrogen content of the products of vermicomposting (p< 0.01) due to a significant (p< 0.01) interaction between the proportion of the biosludge and weight of _Ei. fetida_. Mean values at 95% confidence intervals showed that nitrogen content increased best in the feed mixtures with 12.5 g worms/kg waste and the increase came to be 25.0% and 17.1% more over initial in BE_2 and B’E_2 respectively. Nitrogen decreased significantly (p< 0.05) over initial during traditional aerobic composting in both BE_0 (6.0%) and B’E_0 (4.7%). The content of nitrogen in the products was in the order of BE_2> BE_1> BE_3> BE_0 and B’E_2> B’E_1> B’E_3> B’E_0.

4.2.1.2.4 Organic carbon (OC) and C: N ratio:

Organic carbon decreased significantly (p< 0.05) from initial in correspondence with an increase in the weight of earthworms/kg feed mixture (p< 0.01). Maximum decrease in organic carbon in the products of vermicomposting was in BE_3 (23.8%) and B’E_3 (18.2%). Decline in organic carbon was very less with traditional aerobic composting (p< 0.05) and it was only 2.6% (BE_0) and 3.5% (B’E_0). Organic carbon in the products was in the order of BE_3> BE_2 > BE_1> BE_0 and B’E_3> B’E_2> B’E_1> B’E_0.

The products from both the techniques had significantly low C: N ratio as compared to the initial mixtures (p< 0.05) but the decline was much more in the products of vermicomposting. Decline in C:N ratio was maximum in BE_2 (32.51%) and B’E_2 (26.16%) whereas it was minimum in BE_1 (18.70%) and B’E_1 (13.21%).
the products of traditional aerobic composting significant decline (p< 0.05) in C: N ratio over initial was 3.69% in BE\textsubscript{0} and 1.24% in BE\textsubscript{0}. The percent decrease in C: N ratio of the products was in the order of BE\textsubscript{2} > BE\textsubscript{3} > BE\textsubscript{1} > BE\textsubscript{0} and B'E\textsubscript{2} > B'E\textsubscript{3} > B'E\textsubscript{1} > BE\textsubscript{0}.

4.2.1.2.5 Phosphorus:

Vermidegradation brought a significant increase in phosphorus (p< 0.05) over initial and the interaction between the proportion of the biosludge and weight of \textit{Ei. fetida} was also significant (p< 0.01). The mean values at 95% confidence intervals showed that phosphorus content increased best in the feed mixtures with 12.5 g worms/kg feed and it came to be 38.6% and 12.3% more over initial in BE\textsubscript{2} and B'E\textsubscript{2} respectively. In the products of traditional aerobic composting (p< 0.05) there was a decrease in phosphorus in both BE\textsubscript{0} (6.8%) and B'E\textsubscript{0} (3.9%). Phosphorus in the products was in the order of BE\textsubscript{2} > BE\textsubscript{1} > BE\textsubscript{3} > BE\textsubscript{0} and B’E\textsubscript{2} > B’E\textsubscript{1} > B’E\textsubscript{3} > B’E\textsubscript{0}.

4.2.1.2.6 Potassium:

The content of potassium decreased significantly (p<0.05) over initial in the products and came to be maximum in BE\textsubscript{3} (32.9%) and B’E\textsubscript{3} (44.4%) and minimum in BE\textsubscript{1} (17.6%) and B’E\textsubscript{1} (16.9%). The interaction between the proportion of the biosludge and weight of \textit{Ei. fetida} was also significant (p< 0.01). In the products of traditional aerobic composting potassium (p< 0.05) increased over initial and the increase was 6.7% and 6.6% respectively in BE\textsubscript{0} and B’E\textsubscript{0}. Potassium content of the products was in the order of BE\textsubscript{3} > BE\textsubscript{2} > BE\textsubscript{1} > BE\textsubscript{0} and B’E\textsubscript{3} > B’E\textsubscript{2} > B’E\textsubscript{1} > B’E\textsubscript{0}.

4.2.1.2.7 Sodium:

There was a significant increase in the content of sodium in the products of vermicomposting (p< 0.01) and the interaction between the proportion of the biosludge and weight of \textit{Ei. fetida} was also significant (p< 0.01). The mean values at 95% confidence intervals showed that sodium content increased best in the feed mixtures with 12.5 g worms/kg waste and it came to be 61.4% and 34.4% more over initial in BE\textsubscript{2} and B’E\textsubscript{2} respectively. In the products of traditional aerobic composting (p< 0.05) increase in sodium was 15.5% and 3.5% more over initial in BE\textsubscript{0} and B’E\textsubscript{0} respectively. Sodium in the products was in the order of BE\textsubscript{2} > BE\textsubscript{1} > BE\textsubscript{3} > BE\textsubscript{0} and B’E\textsubscript{2} > B’E\textsubscript{1} > B’E\textsubscript{3} > B’E\textsubscript{0}.
4.2.1.2.8 Transition metals:

Transition metals decreased significantly (p< 0.05) over initial corresponding to the weight of earthworms/kg feed mixture (Table 16, Figure 25). 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%) and Zn (37.6% and 31.4%) was in BE₃ and B’E₃ respectively. In the products of traditional aerobic composting the increase (p< 0.05) was 3.2% and 3.8% for Cu, 3.5% and 2.1% for Fe, 2.9% and 5.8% for Mn and 9.3% and 5.2% for Zn in BE₀ and B’E₀ respectively.

4.2.2 Paper mill sludge

4.2.2.1 Worm biomass:

Worm biomass increased up to 60th day in all the feed mixtures and the gain was more in these feed mixtures which has 7.5 g worms/kg mixture. Worm biomass decreased significantly (r = 0.99 and r’ = 0.97) with increasing earthworms density and it was less in these feed mixtures which with 25g worms/kg mixture. It was maximum in P’E₁ and minimum in P’E₃ on 60th day. Feed mixture was composted in 77 days with 25g worms/kg feed mixture and 98 days with 7.5 g worms/ kg feed mixture (Figure 26).

4.2.2.2 Physico-chemical parameters

Physico-chemical parameters showed significant changes with varying concentration of paper mill sludge and weight of earthworms in the mixtures (Table 17 and Figure 27 and 28).

4.2.2.2.1 pH:

pH decreased significantly (p< 0.01) over initial and the interaction between the weight of earthworms and concentration of sludge in the feed mixture was also significant (p< 0.01). The mean values at 95% confidence intervals showed highest decrease in pH over initial (10.8% and 8.3% in PE₃ and P’E₃ respectively) with 25g worms/kg waste. In the products of traditional aerobic composting, (p< 0.05) the decrease in pH was much less in comparison to the products of vermicomposting (2.1% in PE₀ and 1.3% in P’E₀). pH of the products was in the order of PE₃> PE₂> PE₁> PE₀ and P’E₃> P’E₂> P’E₁> P’E₀.
4.2.2.2.2 Electrical Conductivity (EC):

Electrical conductivity increased significantly ($P < 0.01$) from initial and the interaction ($p < 0.01$) between weight of earthworms and concentration of sludge in the feed mixture was also significant. The mean values at 95% confidence intervals indicated highest increase over initial in EC (26.1% in PE$_2$ and 57.5% in P'E$_2$) with 12.5 g worms/kg feed. There was an increase in EC of the products of traditional aerobic composting ($p < 0.05$) also (1.4% in PE$_0$ and 16.7% in P'E$_0$) but it was less as compared to the products of vermicomposting. EC of the products was in the order of PE$_2$> PE$_3$> PE$_1$> PE$_0$ and P'E$_2$> P'E$_3$> P'E$_1$> P'E$_0$.

4.2.2.2.3 Nitrogen:

Nitrogen increased significantly ($p < 0.05$) from initial during vermicomposting and the interaction between the proportion of the sludge and weight of *E. fetida* was also significant ($p < 0.01$). The mean values at 95% confidence intervals showed that nitrogen content increased best in the feed mixtures with 12.5 g worms/kg feed and it came to be 82.0% and 134.3% more over initial in PE$_2$ and P'E$_2$ respectively. However, nitrogen decreased significantly ($p < 0.05$) during traditional aerobic composting and it came to be 16.0% and 12.5% less than initial in PE$_0$ and P'E$_0$ respectively. Nitrogen content of the products was in the order of PE$_2$> PE$_1$> PE$_3$> PE$_0$ and P'E$_2$> P'E$_3$> P'E$_1$> P'E$_0$.

4.2.2.2.4 Organic carbon and C: N ratio:

Weight of earthworms and proportion of sludge showed a significant interaction ($p < 0.01$) for bringing a significant decline in organic carbon of the products ($p < 0.01$). The mean values at 95% confidence intervals showed that maximum decline in organic carbon occurred with 25.0 g worms/kg feed mixture but it was more (32.1%) in PE$_3$ than P'E$_3$ (25.2%). Organic carbon decreased significantly ($p < 0.05$) over initial in the products of traditional aerobic composting ($p < 0.05$) also but the decline was only 4.8% and 7.6% in PE$_0$ and P'E$_0$ respectively. Organic carbon in the products was in the order of PE$_3$> PE$_2$> PE$_1$> PE$_0$ and P'E$_3$> P'E$_2$> P'E$_1$> P'E$_0$.

The products of both vermicomposting and traditional aerobic composting had significantly ($p < 0.05$) lower C: N ratios. Decline in C: N ratio was maximum in PE$_2$ (59.9%) and P'E$_2$ (65.7%) whereas it was minimum in PE$_1$ (52.18%) and P'E$_3$.
(58.7%). In the products of traditional aerobic composting there was a smaller decline (p< 0.05) over initial in C: N ratio and it was only 13.26% in PE0 and 5.52% in P’E0. Percent decrease in C: N ratio of the products was in the order of PE2> PE3> PE1> PE0 and P’E2> P’E1> P’E3> P’E0.

4.2.2.2.5 Phosphorus:

Only vermidigestion brought a significant increase in phosphorus of the products (p< 0.01) as there was a significant (p< 0.01) interaction between the weight of earthworms and concentration of the sludge. The mean values at 95% confidence intervals indicated that 12.5 g worms brought maximum increase in the content of phosphorus (59.1% in PE2 and 55.7% in P’E2). In the products of traditional aerobic composting, however, there was 23.6% (PE0) and 11.3% (P’E0) decrease (p< 0.05) in phosphorus over initial. Phosphorus content of the products was in the order of PE2> PE1> PE3> PE0 and P’E2> P’E1> P’E3> P’E0.

4.2.2.2.6 Potassium:

Content of potassium decreased significantly (p< 0.01) over initial due to a significant interaction between the weight of earthworms and concentration of sludge in the mixtures (p< 0.01). The mean values at 95% confidence intervals showed maximum decline of 14.0% (PE3) and 9.17% (P’E3) with 25.0 g Ent. fetida/kg feed. Minimum decline in potassium was in PE1 (1.9%) and P’E1 (2.6%). In the products of traditional aerobic composting (p< 0.05) potassium increased by 0.50% and 1.23% over initial in PE0 and P’E0 respectively. Potassium in the products was in the order of PE3> PE2> PE1> PE0 and P’E3> P’E2> P’E1> P’E0.

4.2.2.2.7 Sodium:

During vermicomposting sodium increased significantly (p< 0.01) over initial and interaction between the weight of earthworms and concentration of sludge was also significant (p< 0.01). The mean values at 95% confidence intervals showed that 12.5 g worms/kg feed mixture brought 33.7% (PE2) and 55.7% (P’E2) increase in sodium over initial. In the products of traditional aerobic composting, sodium decreased significantly (p< 0.05) over initial in both PE0 (30.5%) and P’E0 (26.3%). Sodium in the products was in the order of PE2> PE1> PE3> PE0 and P’E2> P’E1> P’E3> P’E0.
4.2.2.8 Transition metals:

Transition metals decreased significantly (p< 0.05) over initial because of a significant interaction (p< 0.01) between the weight of earthworms and concentration of sludge in the feed mixture (Table 18 and Figure 29). 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 Cu, Fe, Mn and Zn was 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 respectively. On the other hand there was an increase (p< 0.05) 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.

4.2.3 Distillery sludge

4.2.3.1 Worm biomass:

Worm biomass increased up to 90th day in all the feed mixtures and the gain was more in these feed mixtures with 7.5 g worms/kg feed mixture. Worm biomass decreased significantly (r = 0.79 and r’ = 0.94) with increasing earthworm density and it was less in the feed mixtures with 25 g worms/kg mixture. On 90th day worm biomass was maximum in DE1 and minimum in DE3. Feed mixture was composted in 98 days with 25g worms/kg feed mixture and 120 days with 7.5 g worms/kg feed mixture (Figure 30).

4.2.3.2 Physico-chemical parameters:

Physico-chemical parameters showed significant changes with varying concentration of sludge and weight of earthworms in the mixtures (Table 19 and Figure 31 and 32).

4.2.3.2.1 pH:

pH decreased significantly (p< 0.01) from its initial value due to a significant interaction (p< 0.01) in the weight of earthworms and concentration of distillery sludge in the feed mixture. The mean values at 95% confidence intervals showed highest decrease in pH in DE3 (12.6%) and D’E3 (8.4%). With traditional aerobic composting, significant decline (p< 0.05) over initial in pH was 4.4% in DE0 and
0.2% in D’E₀. pH in the products was in the order of DE₃> DE₂> DE₁> DE₀ and D’E₃> D’E₂> D’E₁> D’E₀.

4.2.3.2.2 Electrical Conductivity (EC):

Electrical conductivity increased significantly (P< 0.01) as a result of a significant interaction (p< 0.01) between weight of earthworms and concentration of distillery sludge in the feed mixture. The mean values at 95% confidence intervals indicated that 25 g worms/kg feed mixture brought maximum increase in EC (18.6% in DE₃ and 27.9% in D’E₃). Increase in EC within traditional aerobic composting (p< 0.05) was 2.4% in DE₀ and 8.2% in D’E₀. EC in the products was in the order of DE₃> DE₂> DE₁> DE₀ and D’E₃> D’E₂> D’E₁> D’E₀.

4.2.3.2.3 Nitrogen:

Nitrogen increased significantly (p< 0.05) over initial during vermicomposting and there was a significant interaction between weight of earthworms and content of distillery sludge (p< 0.01) in the mixtures. The mean values at 95% confidence intervals indicated that nitrogen content increased best with 12.5 g worms/kg feed mixture (42.6% in DE₂ and 38.7% in D’E₂). However, DE₀ (7.8%) and D’E₀ (8.1%) showed a decline (p< 0.05) in the content of nitrogen over initial with traditional aerobic composting. Nitrogen in the products was in the order of DE₂> DE₁> DE₃> DE₀ and D’E₂> D’E₁> D’E₃> D’E₀.

4.2.3.2.4 Organic carbon (OC) and C: N ratio:

Organic carbon decreased significantly (p< 0.01) over initial in the products and weight of earthworms showed a significant interaction with the proportion of distillery sludge (p< 0.01). It was observed that 25.0 g worms/kg feed brought maximum decline (40.9% in DE₃ and 29.4% in D’E₃) in organic carbon. Minimum decline (p< 0.05) in organic carbon was noticed in the products of traditional aerobic composting and it was 5.5% and 3.6% over initial in DE₀ and D’E₀ respectively. Organic carbon in the products was in the order of DE₃> DE₂> DE₁> DE₀ and D’E₃> D’E₂> D’E₁> D’E₀.

The products of both the technologies had significantly (p< 0.05) low C: N ratio but the decline was much more in the products of vermicomposting. Decline in C: N ratio was maximum in DE₂ (49.9%) and D’E₂ (47.4%) whereas it was minimum in DE₁ (33.3%) and D’E₃ (31.2%). In the products of traditional aerobic composting
there was only 2.5% (DE₀) and 4.8% (D’E₀) decline (p < 0.05) in C: N ratio over initial. The percent decrease in C: N ratio of the products was in the order of DE₂ > DE₁ > DE₀ and D’E₂ > D’E₁ > D’E₀ > D’E₀.

4.2.3.2.5 Phosphorus:

Vermidegradation brought a significant increase in the phosphorus content (p< 0.05) of the products and the interaction between weight of earthworms and concentration of distillery sludge was also significant (p < 0.01). The mean values at 95% confidence intervals showed that highest increase in phosphorus was in the mixtures with 12.5 g worms/kg feed and it was 55.7% in DE₂ and 42.6% in D’E₂. Traditional aerobic composting, on the other hand brought 8.8% and 3.8% decline (p < 0.05) in the content of phosphorus in DE₀ and D’E₀ respectively. Phosphorus in the products was in the order of DE₂ > DE₁ > DE₀ and D’E₂ > D’E₁ > D’E₃ > D’E₀.

4.2.3.2.6 Potassium:

Content of potassium decreased significantly (p< 0.05) over initial due to a significant interaction (p< 0.01) between the weight of earthworms and concentration of the distillery sludge. The mean values at 95% confidence intervals indicated that maximum decline in potassium was in the feed mixture containing 25.0 g worms/kg mixture as it was 13.6% in DE₃ and 14.1% in D’E₃ and 1.0% in DE₁ and 6.0% in D’E₁. With traditional aerobic composting there was 8.3% and 4.2% increase over initial (p < 0.05) in the content of potassium in DE₀ and D’E₀ respectively. Potassium content in the products was in the order of DE₂ > DE₁ > DE₀ and D’E₂ > D’E₁ > D’E₃ > D’E₀.

4.2.3.2.7 Sodium:

During vermicomposting sodium increased significantly (p< 0.01) over initial due to a significant interaction (p< 0.01) between the weight of earthworms and concentration of sludge. The mean values at 95% confidence intervals showed that 12.5 g worms brought highest increase over initial in the content of sodium (27.8% in DE₂ and 38.7% in D’E₂). In the products of traditional aerobic composting sodium decreased significantly (p< 0.05) over initial and came to be 3.1% and 10.0% less than initial in DE₀ and D’E₀ respectively. Sodium in the products was in the order of DE₂ > DE₁ > DE₀ and D’E₂ > D’E₁ > D’E₃ > D’E₀.
4.2.3.2.8 Transition metals:

Transition metals decreased significantly over their initial values and the decline was directly correlated with the weight of earthworms/kg feed mixture (Table 20 and Figure 33). All the transition metals 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 respectively. 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.

4.3 Industrial effluents

Vermicompost was used as a bio-filter for remediation of the industrial effluents of the three selected industries. The industrial effluents were passed through 50g vermicompost filled glass columns filled with 50g vermicompost and physico-chemical properties (like pH, EC, TDS, TSS, TS, BOD and COD) of the filterate and effluents were compared for determining the efficiency of vermicompost as a biofilter. Physico-chemical properties of the industrial effluents and filterates are given in Table 21. For removal of transition metals the effluents were passed through glass columns filled with 20g, 50g and 100g vermicompost. Rate of adsorption for the transition metals of was significant and fitted Langmuir isotherm equation for the effluents of the three selected industries (Plate 7).

4.3.1 Beverage industry effluent:

4.3.1.1 pH, EC, BOD, COD and solids (TDS and TSS):

Vermicompost acted as a strong buffer and when the beverage industry effluent (pH 9.97) was passed through the glass columns loaded with vermicompost, pH of the filtrate came to be 7.8. EC of the filtrate increased to 4.0 mS/cm from its initial value of 2.0 mS/cm. Vermicompost brought a decline in BOD and COD of the beverage industry effluent and these came down to 174.0 mg/l and 440.0 mg/l from their respective initial value of 387.5 mg/l and 1,000 mg/l. There was a significant decline (p < 0.05) in the contents of Total Dissolved Solids (TDS) and Total Suspended Solids (TSS) and these came down to 72.0 mg/l and 246.0 mg/l from their initial values of 360.0 mg/l and 1230.0 mg/l respectively (Table 21).
4.3.1.2 Transition metals:

Transition metals declined significantly (p< 0.05) over initial after vermicompost column (Table 22). Adsorption of transition metals increased with increasing amount of vermicompost in the column. Maximum adsorption was noticed for Cu (87.8%, R = 0.89 Figure 34A), which was followed by rate of Mn 71.7% (R = 0.80 Figure 35A), Fe (54.0%, R = 0.80 Figure 36A) and Zn (33.3%, R = 0.56 Figure 37A).

4.3.2 Paper mill effluent:

4.3.2.1 pH, BOD, COD and solids (TDS and TSS):

When the paper industry effluent (pH 7.1) was passed through the glass column loaded with vermicompost, the filtrate had a pH 7.8 and its EC increased to 6.1 from an initial value of 4.8 mS/cm. COD of paper mill effluent (1240 mg/l) was reduced to 530.0 mg/l while BOD (440.0 mg/l) came down to 260.0 mg/l. Initial content of TDS and TSS in the paper mill effluent was 780 mg/l and 1300 mg/l respectively, vermicompost brought a decline in the contents to 210.0 mg/l and 230.0 mg/l respectively (Table 21).

4.3.2.2 Transition metals:

Transition metals in the paper mill effluent declined significantly (p< 0.05) over initial on passage through vermicompost column (Table 22). Adsorption of transition metals increased with increasing amount of vermicompost in the columns. Maximum adsorption was noticed for Cu (69.2%, R = 0.96 Figure 34B) and was followed by Mn (58.3%, R = 0.80 Figure 35B), Fe (58.8%, R = 0.85 Figure 36B) and Zn (18.4%, R = 0.59 Figure 37B).

4.3.3 Distillery effluent:

4.3.3.1 pH, BOD, COD and solids (TDS and TSS):

Vermicompost brought an increase in the pH of the filtrate of distillery effluent from 4.5 to 5.8. Initial EC of the effluent was 6.9 mS/cm, after passing through the vermicompost column it came down to 8.1 mS/cm. COD came down to 18,000 mg/l from an initial value of 42,200 mg/l. Vermicompost removed the high BOD of the distillery effluent and brought it down to 5806 mg/l from 17200 mg/l.
TDS (1140.0 mg/l) and TSS (2220.0 mg/l) of the effluent also declined significantly and came down to 206.7 mg/l and 105.7 mg/l respectively (Table 21).

4.3.3.2 Transition metals:

The transition metals declined significantly (p< 0.05) from initial after filtration (Table 22). The adsorption of transition metals increased with increasing amount of adsorption material i.e vermicompost in the column. Maximum adsorption was noticed for Cu (68.8%, R = 0.96 Figure 34C) followed by Mn (88.70%, R = 0.85 Figure 35C), Fe (37.35%, R = 0.80 Figure 36C) and Zn (78.03%, R = 0.83 Figure 37C).
Figure 1
Figure 2
Figure 3

(A) Graph showing the number of hatchlings over days for different treatments (BV1 to BV5).

(B) Graph showing the number of hatchlings over biosludge concentration, with the equation $y = -0.011x^2 + 1.119x + 19.48$ and $R^2 = 0.974$. 

Figure 3
Figure 4

(A) Average worm biomass (g) over Days

(B) Average worm biomass (g) vs. Biosludge concentration with the equation:

\[ y = -0.001x^2 + 0.170x + 6.293 \]

\[ R^2 = 0.798 \]
Figure 6
Figure 8
Figure 9

(A) Graph showing the number of cocoons over days with different concentrations labeled PV1 to PV5.

(B) Graph showing the linear relationship between the number of cocoons and paper mill sludge concentrations.

Equation: $y = -0.562x + 57.97$

$R^2 = 0.969$
Figure 10

(A) Number of hatchlings over days for different paper mill sludge concentrations.

(B) Scatter plot showing the relationship between paper mill sludge concentrations and number of hatchlings. The equation is $y = -1.22x + 127.5$ with $R^2 = 0.847$.
Figure 11
Figure 12

Graphs showing the effects of paper mill sludge concentrations on pH, EC, Nitrogen, and Phosphorus levels.
Figure 14
Figure 15
Figure 16

(A) Graph showing the number of cocoons over days with different lines for DV1 to DV8.

(B) Graph showing the number of cocoons versus sludge concentration with the equation $y = -0.003x^2 - 0.156x + 45.17$ and $R^2 = 0.915$. 

Figure 16
Figure 17
Figure 18

(A) Graph showing the average worm biomass (g) over days with different lines representing different conditions labeled DV1 to DV6.

(B) Graph showing the relationship between sludge concentration and average worm biomass (g) with the equation $\gamma = -0.000x^2 + 0.068x + 4.700$ and $R^2 = 0.915$. 
Figure 21
Figure 22
Figure 23
Figure 25

Concentrations of beverage biosludge

Figure 25

Concentrations of beverage biosludge

Figure 25

Concentrations of beverage biosludge

Figure 25

Concentrations of beverage biosludge
Figure 26
Figure 27

Graphs showing the pH, EC, Nitrogen, and Phosphorus levels at different concentrations of paper mill sludge.
Figure 28
Figure 29
Figure 33
Figure 34
Figure 35

(A) 

\[ y = 3234x - 616.66 \]
\[ R = 0.80 \]

(B) 

\[ y = 20842x - 531.46 \]
\[ R = 0.80 \]

(C) 

\[ y = -64.32x + 1599. \]
\[ R = 0.031 \]
Figure 36
Figure 37

(A) 

(B) 

(C) 

Figure 37
Table 1. Proportion of beverage biosludge and cattle dung in various feed mixtures (on dry weight basis) for vermicomposting (BV) and traditional aerobic composting (BT).

<table>
<thead>
<tr>
<th>Set</th>
<th>Feed mixtures</th>
<th>Biosludge (BS)</th>
<th>Cattle Dung (CD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>BV₁ BT₁</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>2</td>
<td>BV₂ BT₂</td>
<td>25</td>
<td>75</td>
</tr>
<tr>
<td>3</td>
<td>BV₃ BT₃</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>4</td>
<td>BV₄ BT₄</td>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td>5</td>
<td>BV₅ BT₅</td>
<td>100</td>
<td>0</td>
</tr>
</tbody>
</table>

Table 2. Initial physico-chemical characteristics of beverage biosludge and cattle dung (Mean ± SE).

<table>
<thead>
<tr>
<th>Physico-chemical parameters</th>
<th>Biosludge</th>
<th>Cattle Dung</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colour</td>
<td>Light brown</td>
<td>Brown</td>
</tr>
<tr>
<td>Nₘ</td>
<td>18.1 ± 0.97</td>
<td>13.4 ± 0.74</td>
</tr>
<tr>
<td>Pₘ</td>
<td>9.1 ± 0.12</td>
<td>3.6 ± 0.68</td>
</tr>
<tr>
<td>Kₘ</td>
<td>17.7 ± 5.15</td>
<td>39.9 ± 4.75</td>
</tr>
<tr>
<td>Naₘ</td>
<td>12.4 ± 0.23</td>
<td>8.4 ± 2.59</td>
</tr>
<tr>
<td>OCₘ</td>
<td>515.8 ± 6.78</td>
<td>371.2 ± 6.98</td>
</tr>
<tr>
<td>pH</td>
<td>6.5 ± 0.01</td>
<td>8.1 ± 0.01</td>
</tr>
<tr>
<td>EC (mS/cm)</td>
<td>4.0 ± 0.68</td>
<td>5.7 ± 4.45</td>
</tr>
<tr>
<td>C:N</td>
<td>28.5: 1</td>
<td>25.7: 1</td>
</tr>
<tr>
<td>Mnₘ</td>
<td>147.5 ± 2.58</td>
<td>107.0 ± 2.59</td>
</tr>
<tr>
<td>Cuₘ</td>
<td>53.5 ± 2.11</td>
<td>20.3 ± 3.56</td>
</tr>
<tr>
<td>Feₘ</td>
<td>2905.0 ± 5.87</td>
<td>3342.5 ± 6.58</td>
</tr>
<tr>
<td>Znₘ</td>
<td>330.0 ± 4.24</td>
<td>157.0 ± 2.31</td>
</tr>
</tbody>
</table>

ₘ weight in g/kg
ₘ weight in mg/kg
Table 3. Initial (I) and Final (F) physico-chemical characteristics of various mixtures of beverage biosludge and cattle dung.

<table>
<thead>
<tr>
<th>Feed mixtures</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Na</th>
<th>OC</th>
<th>EC</th>
<th>pH</th>
<th>C: N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
<td>F</td>
<td>I</td>
<td>F</td>
<td>I</td>
<td>F</td>
<td>I</td>
<td>F</td>
</tr>
<tr>
<td>BV₁</td>
<td>13.4</td>
<td>15.51</td>
<td>3.6</td>
<td>5.50</td>
<td>39.9</td>
<td>33.31</td>
<td>8.4</td>
<td>10.96</td>
</tr>
<tr>
<td></td>
<td>(0.47)*</td>
<td>(0.01)</td>
<td>(0.68)</td>
<td>(0.07)</td>
<td>(4.75)</td>
<td>(1.21)</td>
<td>(2.59)</td>
<td>(0.98)</td>
</tr>
<tr>
<td>BV₂</td>
<td>14.4</td>
<td>15.82</td>
<td>3.8</td>
<td>5.79</td>
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<td>28.08</td>
<td>9.3</td>
<td>16.51</td>
</tr>
<tr>
<td></td>
<td>(0.74)</td>
<td>(0.04)</td>
<td>(0.36)</td>
<td>(0.20)</td>
<td>(2.33)</td>
<td>(0.72)</td>
<td>(2.58)</td>
<td>(0.36)</td>
</tr>
<tr>
<td>BV₃</td>
<td>14.8</td>
<td>15.97</td>
<td>4.8</td>
<td>6.57</td>
<td>29.2</td>
<td>17.64</td>
<td>10.0</td>
<td>19.28</td>
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<td>(0.08)</td>
<td>(0.27)</td>
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<td>(2.91)</td>
<td>(0.17)</td>
<td>(1.41)</td>
<td>(0.37)</td>
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<tr>
<td>BT₁</td>
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<td>4.8</td>
<td>4.9</td>
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<td>31.89</td>
<td>10.0</td>
<td>11.20</td>
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<td>(2.01)</td>
<td>(0.08)</td>
<td>(0.27)</td>
<td>(0.01)</td>
<td>(2.91)</td>
<td>(0.12)</td>
<td>(1.41)</td>
<td>(0.16)</td>
</tr>
<tr>
<td>BV₄</td>
<td>16.6</td>
<td>17.47</td>
<td>5.4</td>
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<td>12.09</td>
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<td>(0.66)</td>
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<td>(0.31)</td>
</tr>
<tr>
<td>BT₄</td>
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<td>5.4</td>
<td>5.5</td>
<td>21.2</td>
<td>22.85</td>
<td>11.1</td>
<td>13.10</td>
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<td>(0.26)</td>
<td>(0.08)</td>
<td>(0.05)</td>
<td>(0.01)</td>
<td>(3.22)</td>
<td>(0.27)</td>
<td>(3.11)</td>
<td>(0.20)</td>
</tr>
<tr>
<td>BV₅</td>
<td>18.1</td>
<td>18.74</td>
<td>9.1</td>
<td>9.24</td>
<td>17.7</td>
<td>7.41</td>
<td>12.4</td>
<td>20.57</td>
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<td>(0.06)</td>
<td>(0.12)</td>
<td>(0.18)</td>
<td>(5.15)</td>
<td>(0.19)</td>
<td>(0.23)</td>
<td>(0.19)</td>
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<tr>
<td>BT₅</td>
<td>18.1</td>
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<td>9.1</td>
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<td>18.72</td>
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<td>(0.01)</td>
<td>(0.12)</td>
<td>(0.01)</td>
<td>(5.15)</td>
<td>(0.56)</td>
<td>(0.23)</td>
<td>(0.21)</td>
</tr>
</tbody>
</table>

*weight in g/kg on dry weight basis
*values of standard error are given in parentheses
Table 4. Content of transition metals (mg/kg) in the Initial (I) and Final (F) mixtures of beverage biosludge and cattle dung.

<table>
<thead>
<tr>
<th>Feed mixtures</th>
<th>Mn</th>
<th>Cu</th>
<th>Fe</th>
<th>Zn</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
<td>F</td>
<td>I</td>
<td>F</td>
</tr>
<tr>
<td>BV₁</td>
<td>107.0</td>
<td>123.79</td>
<td>20.3</td>
<td>24.46</td>
</tr>
<tr>
<td></td>
<td>(2.59)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(1.58)</td>
<td>(3.56)</td>
<td>(2.12)</td>
</tr>
<tr>
<td>BV₂</td>
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<td>135.49</td>
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<td>(3.58)</td>
<td>(0.99)</td>
<td>(4.57)</td>
<td>(1.01)</td>
</tr>
<tr>
<td>BT₁</td>
<td>107.0</td>
<td>111.3</td>
<td>20.3</td>
<td>21.09</td>
</tr>
<tr>
<td></td>
<td>(2.59)</td>
<td>(1.78)</td>
<td>(3.56)</td>
<td>(0.12)</td>
</tr>
<tr>
<td>BV₃</td>
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<td>148.49</td>
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</tr>
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<td>(4.51)</td>
<td>(0.56)</td>
<td>(2.47)</td>
<td>(0.71)</td>
</tr>
<tr>
<td>BT₃</td>
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<td>34.92</td>
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<td>(0.99)</td>
<td>(2.47)</td>
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<tr>
<td>BV₄</td>
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<td>157.49</td>
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<td>(3.56)</td>
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<tr>
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<td>(0.78)</td>
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<td>(0.09)</td>
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<td>(0.54)</td>
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<td>(0.37)</td>
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<tr>
<td>BT₅</td>
<td>147.5</td>
<td>149.56</td>
<td>53.5</td>
<td>54.78</td>
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<td>(2.58)</td>
<td>(0.98)</td>
<td>(2.11)</td>
<td>(0.87)</td>
</tr>
</tbody>
</table>

<sup>a</sup> values of standard error are given in parentheses
Table 5. Proportion of paper mill sludge and cattle dung in various feed mixtures (on dry weight basis) for vermicomposting (PV) and traditional aerobic composting (PT).

<table>
<thead>
<tr>
<th>Feed mixtures</th>
<th>Paper sludge (PS)</th>
<th>Cattle dung (CD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set 1</td>
<td>Set 2</td>
<td></td>
</tr>
<tr>
<td>PV₁</td>
<td>PT₁</td>
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</tr>
<tr>
<td>PV₂</td>
<td>PT₂</td>
<td>25</td>
</tr>
<tr>
<td>PV₃</td>
<td>PT₃</td>
<td>50</td>
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<td>PV₄</td>
<td>PT₄</td>
<td>75</td>
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<tr>
<td>PV₅</td>
<td>PT₅</td>
<td>100</td>
</tr>
</tbody>
</table>

Table 6. Initial physico-chemical characteristics of paper mill sludge and cattle dung (Mean ± SE).

<table>
<thead>
<tr>
<th>Physico-chemical Parameters</th>
<th>Paper sludge</th>
<th>Cattle dung</th>
</tr>
</thead>
<tbody>
<tr>
<td>Colour</td>
<td>Light grey</td>
<td>Brown</td>
</tr>
<tr>
<td>N (weight in g/kg)</td>
<td>4.1 ± 0.18</td>
<td>17.46 ± 0.38</td>
</tr>
<tr>
<td>P (weight in mg/kg)</td>
<td>1.10 ± 0.26</td>
<td>4.89 ± 0.39</td>
</tr>
<tr>
<td>K (weight in g/kg)</td>
<td>2.94 ± 0.42</td>
<td>11.41 ± 0.33</td>
</tr>
<tr>
<td>Na (weight in g/kg)</td>
<td>3.08 ± 0.07</td>
<td>4.28 ± 0.07</td>
</tr>
<tr>
<td>OC (weight in g/kg)</td>
<td>348.3 ± 0.44</td>
<td>295.8 ± 0.60</td>
</tr>
<tr>
<td>pH</td>
<td>6.56 ± 0.09</td>
<td>7.51 ± 0.04</td>
</tr>
<tr>
<td>EC (mS/cm)</td>
<td>1.15 ± 1.44</td>
<td>3.82 ± 1.11</td>
</tr>
<tr>
<td>C:N</td>
<td>84.95:1</td>
<td>16:1</td>
</tr>
<tr>
<td>Mn (weight in mg/kg)</td>
<td>60.5 ± 1.75</td>
<td>112.0 ± 2.59</td>
</tr>
<tr>
<td>Cu (weight in mg/kg)</td>
<td>39.2 ± 0.58</td>
<td>22.3 ± 3.56</td>
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<tr>
<td>Fe (weight in mg/kg)</td>
<td>5292.5 ± 6.87</td>
<td>3442.5 ± 6.58</td>
</tr>
<tr>
<td>Zn (weight in mg/kg)</td>
<td>206.0 ± 0.11</td>
<td>160.0 ± 2.31</td>
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</tbody>
</table>

<sup>a</sup>weight in g/kg
<sup>b</sup>weight in mg/kg
Table 7. Initial (I) and Final (F) physico-chemical characteristics of various mixtures of paper mill sludge and cattle dung.

<table>
<thead>
<tr>
<th>Feed mixtures</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Na</th>
<th>OC</th>
<th>EC</th>
<th>pH</th>
<th>C: N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
<td>F</td>
<td>I</td>
<td>F</td>
<td>I</td>
<td>F</td>
<td>I</td>
<td>F</td>
</tr>
<tr>
<td>PV₁</td>
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<td>29.5</td>
<td>4.89</td>
<td>7.02</td>
<td>11.41</td>
<td>8.52</td>
<td>4.28</td>
<td>3.52</td>
</tr>
<tr>
<td></td>
<td>(0.38)</td>
<td>(0.43)</td>
<td>(0.39)</td>
<td>(0.18)</td>
<td>(0.33)</td>
<td>(0.17)</td>
<td>(0.07)</td>
<td>(0.16)</td>
</tr>
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<td>PT₁</td>
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<td>15.8</td>
<td>4.89</td>
<td>4.40</td>
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<td>12.89</td>
<td>4.28</td>
<td>3.89</td>
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<tr>
<td></td>
<td>(0.38)</td>
<td>(0.02)</td>
<td>(0.39)</td>
<td>(0.01)</td>
<td>(0.33)</td>
<td>(0.35)</td>
<td>(0.07)</td>
<td>(0.42)</td>
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<td>(0.56)</td>
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<td>(0.21)</td>
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*weight in g/kg

*values of standard error are given in parentheses
Table 8. Contents of transition metal (mg/kg) in the Initial (I) and Final (F) mixtures of paper mill sludge and cattle dung.

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<tr>
<th>Feed mixtures</th>
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<th>Fe</th>
<th>Zn</th>
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<td>(3.56)</td>
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<td>(0.99)</td>
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<td>(1.30)</td>
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<td>(0.99)</td>
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<td>(0.79)</td>
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<td>37.5</td>
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<tr>
<td></td>
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<td></td>
<td>(0.88)</td>
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</tr>
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<td></td>
</tr>
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<td>(0.58)</td>
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</tr>
<tr>
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<td>39.2</td>
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</tr>
<tr>
<td></td>
<td>(1.75)</td>
<td></td>
<td>(0.58)</td>
<td></td>
</tr>
</tbody>
</table>

*a values of standard error are given in parentheses.
Table 9. Proportion of distillery sludge and cattle dung in various feed mixtures (on dry weight basis) for vermicomposting (DV) and traditional aerobic composting (DT).

<table>
<thead>
<tr>
<th>Feed mixtures</th>
<th>Distillery sludge (DS)</th>
<th>Cattle Dung (CD)</th>
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<tbody>
<tr>
<td>DV₁</td>
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<tr>
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<td>75</td>
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<td>DV₅</td>
<td>75</td>
<td>25</td>
</tr>
<tr>
<td>DV₆</td>
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<td>0</td>
</tr>
</tbody>
</table>

Table 10. Initial physico-chemical characteristics of distillery sludge and cattle dung of (Mean ± SE).

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<tr>
<th>Physico-chemical Parameters</th>
<th>Distillery sludge</th>
<th>Cattle dung</th>
</tr>
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<tbody>
<tr>
<td>Colour</td>
<td>Dark brown</td>
<td>Brown</td>
</tr>
<tr>
<td>N&lt;sup&gt;a&lt;/sup&gt;</td>
<td>10.25 ± 0.87</td>
<td>16.98 ± 0.32</td>
</tr>
<tr>
<td>P&lt;sup&gt;a&lt;/sup&gt;</td>
<td>8.89 ± 0.35</td>
<td>5.76 ± 0.30</td>
</tr>
<tr>
<td>K&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.03 ± 0.50</td>
<td>12.07 ± 0.69</td>
</tr>
<tr>
<td>Na&lt;sup&gt;a&lt;/sup&gt;</td>
<td>2.22 ± 0.15</td>
<td>3.34 ± 0.01</td>
</tr>
<tr>
<td>OC&lt;sup&gt;a&lt;/sup&gt;</td>
<td>314.0 ± 0.52</td>
<td>216.78 ± 0.32</td>
</tr>
<tr>
<td>pH</td>
<td>8.52 ± 0.35</td>
<td>7.09 ± 0.02</td>
</tr>
<tr>
<td>EC (mS/cm)</td>
<td>4.32 ± 0.24</td>
<td>2.97 ± 0.56</td>
</tr>
<tr>
<td>C:N ratio</td>
<td>30.63 ± 0.31</td>
<td>12.76 ± 0.31</td>
</tr>
<tr>
<td>Cu&lt;sup&gt;b&lt;/sup&gt;</td>
<td>39.2 ± 1.31</td>
<td>20.33 ± 2.89</td>
</tr>
<tr>
<td>Zn&lt;sup&gt;b&lt;/sup&gt;</td>
<td>206.0 ± 1.21</td>
<td>157.0 ± 1.52</td>
</tr>
<tr>
<td>Mn&lt;sup&gt;b&lt;/sup&gt;</td>
<td>60.5 ± 1.31</td>
<td>105.9 ± 1.59</td>
</tr>
<tr>
<td>Fe&lt;sup&gt;b&lt;/sup&gt;</td>
<td>5292.5 ± 3.46</td>
<td>3342.5 ± 7.61</td>
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</table>

<sup>a</sup>weight in g/kg
<sup>b</sup>weight in mg/kg
Table 11. Initial (I) and Final (F) physico-chemical characteristics of various mixtures of distillery sludge and cattle dung.

<table>
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<tr>
<th>Feed mixtures</th>
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<th>N (F)</th>
<th>P (I)</th>
<th>P (F)</th>
<th>K (I)</th>
<th>K (F)</th>
<th>Na⁺ (I)</th>
<th>Na⁺ (F)</th>
<th>OC (I)</th>
<th>OC (F)</th>
<th>pH (I)</th>
<th>pH (F)</th>
<th>EC (I)</th>
<th>EC (F)</th>
<th>C: N (I)</th>
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<td>4.37</td>
<td>216.78</td>
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<td>12.76</td>
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*weight in g/kg
*values of standard error are given in parentheses
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<th>Fe</th>
<th>Zn</th>
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<td>I</td>
<td>F</td>
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<td>110.9 (1.09)</td>
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</table>

ᵃvalues of standard error are given in parentheses
Table 13. Weight of *E. fetida* (g)/kg mixture of each sludge and cattle dung.

<table>
<thead>
<tr>
<th>Industries</th>
<th>Biosludge</th>
<th>Cattle dung</th>
<th>Weight of earthworm g/Kg feed</th>
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</thead>
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<tr>
<td>Beverage</td>
<td>40 : 60</td>
<td></td>
<td>BE₀</td>
</tr>
<tr>
<td></td>
<td>60 : 40</td>
<td></td>
<td>B’E₀</td>
</tr>
<tr>
<td>Paper mill</td>
<td>40 : 60</td>
<td></td>
<td>PE₀</td>
</tr>
<tr>
<td></td>
<td>60 : 40</td>
<td></td>
<td>P’E₀</td>
</tr>
<tr>
<td>Distillery</td>
<td>20 : 80</td>
<td></td>
<td>DE₀</td>
</tr>
<tr>
<td></td>
<td>40 : 60</td>
<td></td>
<td>D’E₀</td>
</tr>
</tbody>
</table>

Table 14. Initial physico-chemical parameters of beverage, paper mill, distillery sludge and cattle dung (mean± S.E).

<table>
<thead>
<tr>
<th>Physico-chemical Parameters</th>
<th>Beverage bio sludge</th>
<th>Paper mill sludge</th>
<th>Distillery sludge</th>
<th>Cattle dung</th>
</tr>
</thead>
<tbody>
<tr>
<td>N&lt;sup&gt;a&lt;/sup&gt;</td>
<td>22.7 ± 0.52</td>
<td>2.50 ± 0.10</td>
<td>12.5 ± 0.15</td>
<td>9.2 ± 0.98</td>
</tr>
<tr>
<td>P&lt;sup&gt;a&lt;/sup&gt;</td>
<td>8.90 ± 0.63</td>
<td>2.65 ± 0.01</td>
<td>6.62 ± 0.03</td>
<td>5.53 ± 0.07</td>
</tr>
<tr>
<td>K&lt;sup&gt;a&lt;/sup&gt;</td>
<td>12.55 ± 0.51</td>
<td>6.98 ± 0.11</td>
<td>10.61 ± 0.01</td>
<td>26.15 ± 1.46</td>
</tr>
<tr>
<td>Na&lt;sup&gt;a&lt;/sup&gt;</td>
<td>5.80 ± 0.34</td>
<td>2.66 ± 0.10</td>
<td>1.26 ± 0.04</td>
<td>3.29 ± 0.14</td>
</tr>
<tr>
<td>OC&lt;sup&gt;a&lt;/sup&gt;</td>
<td>355.0 ± 12.6</td>
<td>397.6 ± 2.55</td>
<td>311.8 ± 1.33</td>
<td>397.8 ± 2.27</td>
</tr>
<tr>
<td>pH</td>
<td>7.55 ± 0.25</td>
<td>7.3 ± 0.10</td>
<td>7.3 ± 0.05</td>
<td>8.92 ± 0.13</td>
</tr>
<tr>
<td>EC (mS/cm)</td>
<td>5.18 ± 0.03</td>
<td>0.79 ± 0.02</td>
<td>5.81 ± 0.01</td>
<td>5.56 ± 0.19</td>
</tr>
<tr>
<td>C:N</td>
<td>15.63 ± 0.23</td>
<td>159.0 ± 0.58</td>
<td>24.94 ± 0.02</td>
<td>43.23 ± 0.40</td>
</tr>
<tr>
<td>Cu&lt;sup&gt;b&lt;/sup&gt;</td>
<td>45.0 ± 0.68</td>
<td>65.0 ± 1.15</td>
<td>60.5 ± 0.92</td>
<td>20.0 ± 1.15</td>
</tr>
<tr>
<td>Fe&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1530 ± 5.77</td>
<td>1963.0 ± 8.66</td>
<td>3308.0 ± 5.77</td>
<td>2185 ± 2.65</td>
</tr>
<tr>
<td>Mn&lt;sup&gt;b&lt;/sup&gt;</td>
<td>43.0 ± 1.53</td>
<td>48.0 ± 1.53</td>
<td>170.5 ± 1.61</td>
<td>92.0 ± 3.61</td>
</tr>
<tr>
<td>Zn&lt;sup&gt;b&lt;/sup&gt;</td>
<td>70.5 ± 0.80</td>
<td>33.6 ± 0.51</td>
<td>60.5 ± 1.85</td>
<td>75.0 ± 1.15</td>
</tr>
</tbody>
</table>

<sup>a</sup>weight in g/kg  
<sup>b</sup>weight in mg/kg
Table 15. Physico-chemical characteristics of the mixtures of beverage biosludge and cattle dung (mean ± SE) with variable weight of *Ei. fetida.*

<table>
<thead>
<tr>
<th>Feed mixtures</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>Na</th>
<th>OC</th>
<th>pH</th>
<th>EC</th>
<th>C:N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
<td>F</td>
<td>I</td>
<td>F</td>
<td>I</td>
<td>F</td>
<td>I</td>
<td>F</td>
</tr>
<tr>
<td>BE&lt;sub&gt;0&lt;/sub&gt;</td>
<td>14.8</td>
<td>13.9</td>
<td>6.44</td>
<td>6.0</td>
<td>18.73</td>
<td>19.98</td>
<td>4.31</td>
<td>4.98</td>
</tr>
<tr>
<td></td>
<td>(0.59)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>(0.40)</td>
<td>(0.35)</td>
<td>(0.11)</td>
<td>(0.68)</td>
<td>(0.28)</td>
<td>(0.06)</td>
<td>(0.39)</td>
</tr>
<tr>
<td>BE&lt;sub&gt;1&lt;/sub&gt;</td>
<td>14.8</td>
<td>16.5</td>
<td>6.44</td>
<td>8.20</td>
<td>18.73</td>
<td>15.42</td>
<td>4.31</td>
<td>5.96</td>
</tr>
<tr>
<td></td>
<td>(0.59)</td>
<td>(0.35)</td>
<td>(0.35)</td>
<td>(0.15)</td>
<td>(0.68)</td>
<td>(0.17)</td>
<td>(0.06)</td>
<td>(0.63)</td>
</tr>
<tr>
<td>BE&lt;sub&gt;2&lt;/sub&gt;</td>
<td>14.8</td>
<td>18.5</td>
<td>6.44</td>
<td>8.93</td>
<td>18.73</td>
<td>13.86</td>
<td>4.31</td>
<td>6.96</td>
</tr>
<tr>
<td></td>
<td>(0.59)</td>
<td>(0.45)</td>
<td>(0.35)</td>
<td>(0.18)</td>
<td>(0.68)</td>
<td>(0.69)</td>
<td>(0.06)</td>
<td>(0.53)</td>
</tr>
<tr>
<td>BE&lt;sub&gt;3&lt;/sub&gt;</td>
<td>14.8</td>
<td>15.8</td>
<td>6.44</td>
<td>7.80</td>
<td>18.73</td>
<td>12.56</td>
<td>4.31</td>
<td>5.16</td>
</tr>
<tr>
<td></td>
<td>(0.59)</td>
<td>(0.55)</td>
<td>(0.35)</td>
<td>(0.25)</td>
<td>(0.68)</td>
<td>(0.28)</td>
<td>(0.06)</td>
<td>(0.03)</td>
</tr>
<tr>
<td>B′E&lt;sub&gt;0&lt;/sub&gt;</td>
<td>16.9</td>
<td>16.1</td>
<td>7.39</td>
<td>7.10</td>
<td>11.65</td>
<td>12.42</td>
<td>3.98</td>
<td>4.12</td>
</tr>
<tr>
<td></td>
<td>(1.14)</td>
<td>(0.20)</td>
<td>(0.14)</td>
<td>(0.05)</td>
<td>(0.50)</td>
<td>(0.21)</td>
<td>(0.20)</td>
<td>(0.07)</td>
</tr>
<tr>
<td>B′E&lt;sub&gt;1&lt;/sub&gt;</td>
<td>16.9</td>
<td>18.1</td>
<td>7.39</td>
<td>7.77</td>
<td>11.65</td>
<td>9.68</td>
<td>3.98</td>
<td>5.08</td>
</tr>
<tr>
<td></td>
<td>(1.14)</td>
<td>(0.15)</td>
<td>(0.14)</td>
<td>(0.42)</td>
<td>(0.50)</td>
<td>(0.60)</td>
<td>(0.20)</td>
<td>(0.11)</td>
</tr>
<tr>
<td>B′E&lt;sub&gt;2&lt;/sub&gt;</td>
<td>16.9</td>
<td>19.8</td>
<td>7.39</td>
<td>8.30</td>
<td>11.65</td>
<td>7.55</td>
<td>3.98</td>
<td>5.35</td>
</tr>
<tr>
<td></td>
<td>(1.14)</td>
<td>(0.37)</td>
<td>(0.14)</td>
<td>(0.07)</td>
<td>(0.50)</td>
<td>(0.30)</td>
<td>(0.20)</td>
<td>(0.30)</td>
</tr>
<tr>
<td>B′E&lt;sub&gt;3&lt;/sub&gt;</td>
<td>16.9</td>
<td>17.6</td>
<td>7.39</td>
<td>7.50</td>
<td>11.65</td>
<td>6.47</td>
<td>3.98</td>
<td>4.72</td>
</tr>
<tr>
<td></td>
<td>(1.14)</td>
<td>(0.40)</td>
<td>(0.14)</td>
<td>(0.25)</td>
<td>(0.50)</td>
<td>(0.20)</td>
<td>(0.20)</td>
<td>(0.57)</td>
</tr>
</tbody>
</table>

<sup>a</sup>weight in g/kg on dry weight basis
<sup>b</sup>values of standard error are given in parentheses
Table 16. Contents of transition metals (mg/kg) in the Initial (I) and Final (F) mixtures of beverage biosludge and cattle dung with variable weight of *Ei. fetida*.

<table>
<thead>
<tr>
<th>Feed Mixtures</th>
<th>Zn</th>
<th>Cu</th>
<th>Fe</th>
<th>Mn</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
<td>F</td>
<td>I</td>
<td>F</td>
</tr>
<tr>
<td>BE₀</td>
<td>101.3</td>
<td>(1.82)²</td>
<td>110.8</td>
<td>(1.74)</td>
</tr>
<tr>
<td>BE₁</td>
<td>101.3</td>
<td>(1.82)</td>
<td>82.0</td>
<td>(3.06)</td>
</tr>
<tr>
<td>BE₂</td>
<td>101.3</td>
<td>(1.82)</td>
<td>68.2</td>
<td>(7.0)</td>
</tr>
<tr>
<td>BE₃</td>
<td>101.3</td>
<td>(1.82)</td>
<td>63.2</td>
<td>(1.70)</td>
</tr>
<tr>
<td>Be₀</td>
<td>121.4</td>
<td>(1.51)</td>
<td>127.8</td>
<td>(6.36)</td>
</tr>
<tr>
<td>Be₁</td>
<td>121.4</td>
<td>(1.51)</td>
<td>108.3</td>
<td>(1.74)</td>
</tr>
<tr>
<td>Be₂</td>
<td>121.4</td>
<td>(1.51)</td>
<td>98.2</td>
<td>(3.72)</td>
</tr>
<tr>
<td>Be₃</td>
<td>121.4</td>
<td>(1.51)</td>
<td>83.2</td>
<td>(2.58)</td>
</tr>
</tbody>
</table>

²Values of standard error are given in parentheses.
Table 17. Physico-chemical characteristics of the mixtures of paper mill sludge and cattle dung (mean ± SE) with variable weight of *Ei. feidia*.

<table>
<thead>
<tr>
<th>Feed mixtures</th>
<th>N</th>
<th>P'</th>
<th>K</th>
<th>Na</th>
<th>OC</th>
<th>EC</th>
<th>pH</th>
<th>C:N</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
<td>F</td>
<td>I</td>
<td>F</td>
<td>I</td>
<td>F</td>
<td>I</td>
<td>F</td>
</tr>
<tr>
<td>PE₀</td>
<td>5.0</td>
<td>4.20</td>
<td>6.85</td>
<td>5.23</td>
<td>19.79</td>
<td>19.8</td>
<td>4.68</td>
<td>3.25</td>
</tr>
<tr>
<td></td>
<td>(0.15)</td>
<td>(0.20)</td>
<td>(0.36)</td>
<td>(0.17)</td>
<td>(0.93)</td>
<td>(0.32)</td>
<td>(0.08)</td>
<td>(0.10)</td>
</tr>
<tr>
<td>PE₁</td>
<td>5.0</td>
<td>8.20</td>
<td>6.85</td>
<td>9.20</td>
<td>19.79</td>
<td>19.4</td>
<td>4.68</td>
<td>5.39</td>
</tr>
<tr>
<td></td>
<td>(0.15)</td>
<td>(0.11)</td>
<td>(0.36)</td>
<td>(0.07)</td>
<td>(0.93)</td>
<td>(0.10)</td>
<td>(0.08)</td>
<td>(0.01)</td>
</tr>
<tr>
<td>PE₂</td>
<td>5.0</td>
<td>9.10</td>
<td>6.85</td>
<td>10.90</td>
<td>19.79</td>
<td>18.2</td>
<td>4.68</td>
<td>6.26</td>
</tr>
<tr>
<td></td>
<td>(0.15)</td>
<td>(0.11)</td>
<td>(0.36)</td>
<td>(0.48)</td>
<td>(0.93)</td>
<td>(0.10)</td>
<td>(0.08)</td>
<td>(0.01)</td>
</tr>
<tr>
<td>PE₃</td>
<td>5.0</td>
<td>7.20</td>
<td>6.85</td>
<td>8.12</td>
<td>19.79</td>
<td>17.0</td>
<td>4.68</td>
<td>5.10</td>
</tr>
<tr>
<td></td>
<td>(0.15)</td>
<td>(0.15)</td>
<td>(0.36)</td>
<td>(0.01)</td>
<td>(0.93)</td>
<td>(0.32)</td>
<td>(0.08)</td>
<td>(0.09)</td>
</tr>
<tr>
<td>P'E₀</td>
<td>3.2</td>
<td>2.80</td>
<td>5.65</td>
<td>5.01</td>
<td>16.23</td>
<td>16.4</td>
<td>3.84</td>
<td>2.83</td>
</tr>
<tr>
<td></td>
<td>(0.30)</td>
<td>(0.11)</td>
<td>(0.08)</td>
<td>(0.02)</td>
<td>(0.39)</td>
<td>(0.11)</td>
<td>(0.32)</td>
<td>(0.02)</td>
</tr>
<tr>
<td>P'E₁</td>
<td>3.2</td>
<td>6.80</td>
<td>5.65</td>
<td>7.80</td>
<td>16.23</td>
<td>15.8</td>
<td>3.84</td>
<td>4.65</td>
</tr>
<tr>
<td></td>
<td>(0.30)</td>
<td>(0.26)</td>
<td>(0.08)</td>
<td>(0.06)</td>
<td>(0.39)</td>
<td>(0.11)</td>
<td>(0.32)</td>
<td>(0.02)</td>
</tr>
<tr>
<td>P'E₂</td>
<td>3.2</td>
<td>7.50</td>
<td>5.65</td>
<td>8.80</td>
<td>16.23</td>
<td>15.0</td>
<td>3.84</td>
<td>5.98</td>
</tr>
<tr>
<td></td>
<td>(0.30)</td>
<td>(0.18)</td>
<td>(0.08)</td>
<td>(0.06)</td>
<td>(0.39)</td>
<td>(0.20)</td>
<td>(0.32)</td>
<td>(0.04)</td>
</tr>
<tr>
<td>P'E₃</td>
<td>3.2</td>
<td>5.80</td>
<td>5.65</td>
<td>6.90</td>
<td>16.23</td>
<td>14.7</td>
<td>3.84</td>
<td>4.23</td>
</tr>
<tr>
<td></td>
<td>(0.30)</td>
<td>(0.17)</td>
<td>(0.08)</td>
<td>(0.05)</td>
<td>(0.39)</td>
<td>(0.15)</td>
<td>(0.32)</td>
<td>(0.01)</td>
</tr>
</tbody>
</table>

* weight in g/kg

* values of standard error are given in parentheses
Table 18. Contents of transition metals (mg/kg) in the Initial (I) and Final (F) mixtures of paper mill sludge and cattle dung with variable weight of *Ei. fetida*.

<table>
<thead>
<tr>
<th>Feed mixtures</th>
<th>Zn</th>
<th>Cu</th>
<th>Fe</th>
<th>Mn</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
<td>F</td>
<td>I</td>
<td>F</td>
</tr>
<tr>
<td>P'E₀</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PE₀</td>
<td>32.4</td>
<td>35.8</td>
<td>50.0</td>
<td>62.7</td>
</tr>
<tr>
<td></td>
<td>(0.70)a</td>
<td>(0.52)</td>
<td>(0.52)</td>
<td>(0.62)</td>
</tr>
<tr>
<td>P'E₁</td>
<td>32.4</td>
<td>31.5</td>
<td>50.0</td>
<td>41.0</td>
</tr>
<tr>
<td></td>
<td>(0.70)</td>
<td>(0.14)</td>
<td>(0.52)</td>
<td>(0.69)</td>
</tr>
<tr>
<td>P'E₂</td>
<td>32.4</td>
<td>30.5</td>
<td>50.0</td>
<td>39.0</td>
</tr>
<tr>
<td></td>
<td>(0.70)</td>
<td>(0.15)</td>
<td>(0.52)</td>
<td>(0.35)</td>
</tr>
<tr>
<td>P'E₃</td>
<td>32.4</td>
<td>29.2</td>
<td>50.0</td>
<td>11.0</td>
</tr>
<tr>
<td></td>
<td>(0.70)</td>
<td>(0.20)</td>
<td>(0.52)</td>
<td>(0.10)</td>
</tr>
<tr>
<td>P'E₀</td>
<td>30.1</td>
<td>31.7</td>
<td>55.0</td>
<td>56.9</td>
</tr>
<tr>
<td></td>
<td>(0.20)</td>
<td>(0.15)</td>
<td>(0.50)</td>
<td>(0.85)</td>
</tr>
<tr>
<td>P'E₁</td>
<td>30.1</td>
<td>28.6</td>
<td>55.0</td>
<td>42.0</td>
</tr>
<tr>
<td></td>
<td>(0.20)</td>
<td>(0.15)</td>
<td>(0.50)</td>
<td>(0.15)</td>
</tr>
<tr>
<td>P'E₂</td>
<td>30.1</td>
<td>26.5</td>
<td>55.0</td>
<td>40.0</td>
</tr>
<tr>
<td></td>
<td>(0.20)</td>
<td>(0.20)</td>
<td>(0.50)</td>
<td>(0.51)</td>
</tr>
<tr>
<td>P'E₃</td>
<td>30.1</td>
<td>24.3</td>
<td>55.0</td>
<td>20.0</td>
</tr>
<tr>
<td></td>
<td>(0.20)</td>
<td>(0.17)</td>
<td>(0.50)</td>
<td>(0.51)</td>
</tr>
</tbody>
</table>

*a*values of standard error are given in parentheses
Table 19. Physico-chemical characteristics of the mixtures of distillery sludge and cattle dung (mean ± SE) with variable weight of Ei. fetida.

<table>
<thead>
<tr>
<th>Feed mixtures</th>
<th>N I F</th>
<th>P I F</th>
<th>K I F</th>
<th>Na I F</th>
<th>OC I F</th>
<th>EC I F</th>
<th>pH I F</th>
<th>C:N I F</th>
</tr>
</thead>
<tbody>
<tr>
<td>DE&lt;sub&gt;0&lt;/sub&gt;</td>
<td>8.90 (0.05)&lt;sup&gt;a&lt;/sup&gt;</td>
<td>8.20 (0.01)</td>
<td>5.56 (0.05)</td>
<td>5.07 (0.03)</td>
<td>18.03 (0.02)</td>
<td>19.54 (0.02)</td>
<td>3.19 (0.01)</td>
<td>3.09 (0.01)</td>
</tr>
<tr>
<td>DE&lt;sub&gt;1&lt;/sub&gt;</td>
<td>8.90 (0.05)</td>
<td>11.10 (0.01)</td>
<td>5.56 (0.05)</td>
<td>7.01 (0.06)</td>
<td>18.03 (0.02)</td>
<td>17.84 (0.02)</td>
<td>3.19 (0.02)</td>
<td>3.47 (0.08)</td>
</tr>
<tr>
<td>DE&lt;sub&gt;2&lt;/sub&gt;</td>
<td>8.90 (0.05)</td>
<td>12.70 (0.01)</td>
<td>5.56 (0.05)</td>
<td>16.89 (0.02)</td>
<td>18.03 (0.02)</td>
<td>15.56 (0.04)</td>
<td>3.19 (0.02)</td>
<td>4.08 (0.03)</td>
</tr>
<tr>
<td>DE&lt;sub&gt;3&lt;/sub&gt;</td>
<td>8.90 (0.05)</td>
<td>9.90 (0.02)</td>
<td>5.56 (0.05)</td>
<td>15.56 (0.04)</td>
<td>18.03 (0.02)</td>
<td>15.15 (0.02)</td>
<td>3.19 (0.02)</td>
<td>3.39 (0.07)</td>
</tr>
<tr>
<td>D'E&lt;sub&gt;0&lt;/sub&gt;</td>
<td>11.10 (0.01)</td>
<td>10.20 (0.06)</td>
<td>6.23 (0.02)</td>
<td>5.99 (0.04)</td>
<td>15.15 (0.02)</td>
<td>15.79 (0.02)</td>
<td>2.48 (0.01)</td>
<td>2.23 (0.01)</td>
</tr>
<tr>
<td>D'E&lt;sub&gt;1&lt;/sub&gt;</td>
<td>11.10 (0.01)</td>
<td>13.40 (0.01)</td>
<td>6.23 (0.02)</td>
<td>7.25 (0.11)</td>
<td>15.15 (0.02)</td>
<td>14.23 (0.02)</td>
<td>2.48 (0.01)</td>
<td>3.23 (0.01)</td>
</tr>
<tr>
<td>D'E&lt;sub&gt;2&lt;/sub&gt;</td>
<td>11.10 (0.01)</td>
<td>15.40 (0.01)</td>
<td>6.23 (0.02)</td>
<td>8.89 (0.06)</td>
<td>15.15 (0.02)</td>
<td>13.89 (0.01)</td>
<td>2.48 (0.01)</td>
<td>3.44 (0.05)</td>
</tr>
<tr>
<td>D'E&lt;sub&gt;3&lt;/sub&gt;</td>
<td>11.10 (0.01)</td>
<td>12.0 (0.28)</td>
<td>6.23 (0.02)</td>
<td>7.09 (0.04)</td>
<td>15.15 (0.02)</td>
<td>13.01 (0.03)</td>
<td>2.48 (0.01)</td>
<td>2.95 (0.02)</td>
</tr>
</tbody>
</table>

weight in g/kg

<sup>a</sup>values of standard error are given in parentheses
Table 20. Contents of transition metal (mg/kg) in the Initial (I) and Final (F) mixtures of paper mill sludge and cattle dung with variable weight of *Ei. fetida*.

<table>
<thead>
<tr>
<th>Feed mixtures</th>
<th>Zn</th>
<th>Cu</th>
<th>Fe</th>
<th>Mn</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
<td>F</td>
<td>I</td>
<td>F</td>
</tr>
<tr>
<td><strong>DE0</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>45.8</td>
<td>47.3</td>
<td>87.2</td>
<td>89.8</td>
</tr>
<tr>
<td>F</td>
<td>(0.76)a</td>
<td>(2.77)</td>
<td>(0.90)</td>
<td>(0.56)</td>
</tr>
<tr>
<td><strong>DE1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>45.8</td>
<td>38.4</td>
<td>87.2</td>
<td>77.0</td>
</tr>
<tr>
<td>F</td>
<td>(0.76)</td>
<td>(0.20)</td>
<td>(0.90)</td>
<td>(0.68)</td>
</tr>
<tr>
<td><strong>DE2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>45.8</td>
<td>35.2</td>
<td>87.2</td>
<td>63.0</td>
</tr>
<tr>
<td>F</td>
<td>(0.76)</td>
<td>(0.26)</td>
<td>(0.90)</td>
<td>(1.68)</td>
</tr>
<tr>
<td><strong>DE3</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>45.8</td>
<td>34.3</td>
<td>87.2</td>
<td>52.3</td>
</tr>
<tr>
<td>F</td>
<td>(0.76)</td>
<td>(0.40)</td>
<td>(0.90)</td>
<td>(1.26)</td>
</tr>
<tr>
<td><strong>D’E0</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>62.3</td>
<td>63.7</td>
<td>95.0</td>
<td>98.9</td>
</tr>
<tr>
<td>F</td>
<td>(0.36)</td>
<td>(0.23)</td>
<td>(1.35)</td>
<td>(0.95)</td>
</tr>
<tr>
<td><strong>D’E1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>62.3</td>
<td>47.6</td>
<td>95.0</td>
<td>86.0</td>
</tr>
<tr>
<td>F</td>
<td>(0.36)</td>
<td>(0.64)</td>
<td>(1.35)</td>
<td>(0.48)</td>
</tr>
<tr>
<td><strong>D’E2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>62.3</td>
<td>43.6</td>
<td>95.0</td>
<td>70.0</td>
</tr>
<tr>
<td>F</td>
<td>(0.36)</td>
<td>(0.73)</td>
<td>(1.35)</td>
<td>(1.00)</td>
</tr>
<tr>
<td><strong>D’E3</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>62.3</td>
<td>42.1</td>
<td>95.0</td>
<td>57.8</td>
</tr>
<tr>
<td>F</td>
<td>(0.36)</td>
<td>(0.45)</td>
<td>(1.35)</td>
<td>(0.89)</td>
</tr>
</tbody>
</table>

aValues of standard error are given in parentheses.
Table 21. Initial and Final physico-chemical parameters of different industrial effluents (mean ± S.E).

<table>
<thead>
<tr>
<th>Physico-chemical parameters</th>
<th>Beverage effluent</th>
<th>Paper mill effluent</th>
<th>Distillery effluent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial</td>
<td>Final</td>
<td>Initial</td>
</tr>
<tr>
<td>pH</td>
<td>9.97 ± 1.2</td>
<td>7.8 ± 0.26</td>
<td>7.1 ± 1.5</td>
</tr>
<tr>
<td>EC (mS/cm)</td>
<td>2.0 ± 1.0</td>
<td>4.0 ± 0.03</td>
<td>4.8 ± 0.9</td>
</tr>
<tr>
<td>TDS(^a)</td>
<td>360.0 ± 12.0</td>
<td>72.0 ± 1.15</td>
<td>780 ± 8.9</td>
</tr>
<tr>
<td>TSS(^a)</td>
<td>1230.0 ± 9.8</td>
<td>246.0 ± 1.0</td>
<td>1300 ± 6.8</td>
</tr>
<tr>
<td>TS(^a)</td>
<td>1590 ± 9.8</td>
<td>318.0 ± 1.0</td>
<td>2080 ± 6.8</td>
</tr>
<tr>
<td>BOD(^a)</td>
<td>387.5 ± 11.9</td>
<td>174.0 ± 1.0</td>
<td>440.0 ± 12.8</td>
</tr>
<tr>
<td>COD(^a)</td>
<td>1000.0 ± 6.8</td>
<td>440.0 ± 2.8</td>
<td>1240.0 ± 8.9</td>
</tr>
</tbody>
</table>

\(^a\) weight in mg/l
Table 22. Initial and Final content of transition metals (mg/kg) in the effluents of beverage, paper and distillery industries.

<table>
<thead>
<tr>
<th>Transition metals</th>
<th>Beverage effluent</th>
<th>Paper mill effluent</th>
<th>Distillery effluent</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial 20 g 50g 100g</td>
<td>Final 20 g 50g 100g</td>
<td>Initial 20 g 50g 100g</td>
</tr>
<tr>
<td>Cu</td>
<td>0.33 ± 0.01</td>
<td>0.28 ± 0.01</td>
<td>0.11 ± 0.02</td>
</tr>
<tr>
<td>Mn</td>
<td>0.78 ± 0.2</td>
<td>0.60 ± 0.08</td>
<td>0.45 ± 0.05</td>
</tr>
<tr>
<td>Fe</td>
<td>16.33 ± 2.1</td>
<td>15.54 ± 0.27</td>
<td>12.09 ± 0.63</td>
</tr>
<tr>
<td>Zn</td>
<td>3.84 ± 1.1</td>
<td>3.60 ± 0.09</td>
<td>3.26 ± 0.09</td>
</tr>
</tbody>
</table>

Figure in parentheses indicates percent change over initial in transition metals.