Due to ever increasing population, exploitive agriculture, growing industrialization over last few decades, the problem of management of wastes through efficient disposal has become a common concern in developing as well as developed nations. Edwards and Bater (1992) emphasized that a sustainable and cost effective approach is required to tackle environmental problems caused due to the disposal of large quantities of organic waste globally. According to Senapati and Julka (1993) this is an important issue to maintain healthy environment.

Vermicomposting offers a tangible solution as an integrated strategy for solid waste management through joint activities of microorganisms and earthworms. Aira et al. (2007) explained that earthworms initiate the process of conditioning the substrate upon which microorganisms act to degrade organic matter through biochemical processes. Singh et al. (2010) suggested that the processing time and quality of the product may vary depending upon the composition of initial material being processed. Various vermicomposted industrial wastes such as paper waste (Elvira et al., 1998; Kaur et al., 2010), guar gum waste (Suthar 2006), sugar industry wastes (Sen and Chandra 2007), distillery sludge and leather industry waste (Ravindran et al., 2008), tannery industries wastes (Ravindran and Sekaran 2011) and beverage industry sludge (Singh et al., 2010) etc. have been turned into nutrient rich manures. Moreover, vermicompost has manifested favorable impact on plant growth when applied in field conditions (Mamta et al., 2012). Although different physical, chemical and microbial methods for disposal of various organic waste are available and being used, yet these are costly and time consuming. This calls for identifying less time consuming and cost effective methods befitting Indian conditions. In this context Hand et al. (1988), Raymond et al. (1988), Harris et al. (1994) and Logsdson (1994) suggested vermicomposting as a befitting strategy for the management of solid organic wastes. This view has been substantiated by several researchers that some species of earthworms have the ability to consume a wide variety of organic wastes including sewage sludge, animal dung, crop residues and industrial refuse (Mitchell et al., 1980; Chan and Griffiths 1988 and Hartenstein and Bisesi 1989; Edwards 1998). The waste substrate is first fragmented by earthworms for an accelerated decomposition process which leads to stabilization of unstabilized organic matter. The vermicompost thus produced has higher quantity of nutrients per kilogram weight
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than the organic substrate from which it is produced (Buchanam et al., 1988). Ismail (2000) opined that biological activity of the earthworms enhances the microbial activity to provide nutrient rich vermicompost which facilitates better plant nutrition through higher uptake and transfer of plant nutrients.

Keeping this in view the present experiment was conducted to assess the potential of earthworm species (*Eisenia fetida*) in composting agricultural waste amended with cow dung in different ratios using mustard crop straw as agro waste material. The results of present investigation are discussed here under:

Changes in physico-chemical characteristics of organic substrate, composts and their vermicomposts

**pH**

The pH of substrate (mustard straw) was acidic i.e. 6.4 and increased gradually from substrate to vermicompost (Table 4; Fig.13a). Haimi and Huhta (1987) suggested that the near neutral pH of the vermicompost may be due to secretion of NH$_4^+$ ions which reduce the pool of H$^+$ ions as well as the fixation of CO$_2$, catalyzed through the activity of calciferous glands in earthworms containing carbonic anhydrase, thus preventing the fall in pH (Kale et al., 1982). The increased trend of pH in the compost and vermicompost from *Brassica* straw is in accordance with the findings of Tripathi and Bhardwaj (2004) and Loh et al. (2005) which may be attributed to higher mineralization. Tognetti et al. (2005) observed that the degradation of short chained fatty acids and ammonification of organic nitrogen increased the pH. Fares et al. (2005) opined that changes in pH are attributable to sequential and continuous utilization of organic acids and persistent increase in mineral constituents of waste. In present studies the percent of response from compost to vermicompost ratios showed lower pH values in vermicomposts as compared to their respective compost ratios. Vermicompost ratios 50:50 (-6.5%) and 60:40 (-6.5%) were significantly lower than the overall mean value (-3.87%). The decrease in mean performance of the vermicompost ratios for pH value from compost control to vermicompost was up to -6.5 % in 50:50 and 60:40 ratios. The pH reduction may be due to mineralization of nitrogen into nitrates /nitrites and
phosphorus into orthophosphates as well as bioconversion of organic waste to organic acids as observed by Ndegwa et al. (2000).

**Electrical conductivity (EC)**

Electrical conductivity in 50:50 compost ratio was 0.47 which increased to 0.56 in corresponding vermicompost ratio. Similar trend was observed in other compost and corresponding vermicompost ratios (Table 4; Fig.14a). Kaviraj and Sharma (2003) and Jadia and Fulekar (2008) also observed increase in EC during vermicomposting processes and suggested that bioconversion of organic matter coupled with release of additional minerals like exchangeable calcium, magnesium, potassium and phosphates in the cations forms accounts for increase in EC (Tognetti et al. 2005). In present investigations the percent response (increase) from compost to vermicompost ratios showed higher values than those of their respective compost ratios. Vermicompost ratios showed up to 138 % increase in 70:30 ratio. Vermicompost ratios 70:30 (138 %) and 60:40 (100 %) were significantly higher than the overall average value which indicated mineralization of Brassica straw and dung as suggested earlier by Neuhauser et al. (1980).

**Nitrogen**

The total nitrogen (N) includes mainly two kinds of inorganic forms of nitrogen such as NH$_4$ -N and NO$_3$ -N. Nitrogen concentration was higher in vermicompost ratio (0.459%) followed by compost (0.394%) and substrate (mustard straw, 0.33%), respectively (Table 5a; Fig.15a). Maximum increase in N concentration was observed in 80:20 compost (0.585 %) ratio, however among vermicompost ratios maximum increase was observed in 70:30 (0.529%) ratio. In the present study an increasing trend for nitrogen concentration in the vermicompost ratios was recorded, except for 80:20 compost ratio. These findings are in agreement with the earlier findings of Tripathi and Bhardwaj (2004); Pattnaik and Reddy (2010). The loss in organic carbon may be a reason for enhancement of N (Viel et al., 1987). According to Atiyeh et al., (2000) earthworms enhance nitrogen mineralization in manure and mineral nitrogen may be retained in the nitrate form due to transformation by earthworms. Crawford (1983) and Gaur and Singh (1995) observed that the final N content of the compost as well as vermicompost depends on the initial content of N in the substrate and the extent of its decomposition. The earthworms can enhance N
levels during vermicomposting through the digestion of substrate in their gut and simultaneous addition of nitrogenous excretory products, mucus, body fluid, enzymes; besides the decay of dead tissues of worms in vermicomposting sub-system (Suthar 2007). In present studies the increase in mean performance of nitrogen concentration from compost to vermicompost ratios was up to 17.29 % in 70:30 ratio followed 50:50 (16.49 %), significantly higher for percent increase over overall mean value(5.90%). A 2.0 to 3.2-fold increase in N during vermicomposting was observed by Garg and Kaushik (2005) using textile mill sludge mixed with wheat straw and cow dung as substrate. As reported by Benitez et al. (1999) earthworms accelerate the decomposition of organic materials as well as N mineralization which lead to changes in the nitrogen content of substrate.

Uptake of nitrogen in mustard straw was 9.90 kg/ha (Table 3b). It varied from 11.82 (50:50 compost) to 17.58 kg/ha (80:20 compost) with overall mean of 14.49 kg/ha among all compost and vermicompost ratios. The increase in mean performance of nitrogen concentration over straw in compost and vermicompost ratios was up to 17.01 % in 80:20 ratio without earthworms. Compost ratios 90:10 (14.77%), 80:20 (17.01%) and vermicompost ratios 80:20 (14.37%), 70:30 (14.57%) and 90:10 (14.67%) were statistically significant for percent increase over overall mean value (13.66%).

**Phosphorus**

The total phosphorus (P) of substrate (mustard straw) was 0.06 % and increased gradually from compost to vermicompost ratios (Table 5a; Fig.16a). Maximum increment in P concentration was observed in 90:10 vermicompost (0.268 %) ratio, among compost also highest P concentration was observed in 90:10 ratio (0.205 %). The increased trend of P in the compost and vermicompost lots in various proportions is in agreement with results reported earlier by Pattnaik and Reddy (2010) and Wani et al. (2013). Mineralization and consequent mobilization of phosphorus by enhanced bacterial and phosphatase activities during vermicomposting leads to increase in P as suggested earlier by Edwards and Lofty (1972). Physical break down of plant litter by earthworms with subsequent digestion leads to increased available phosphorus in the substrate (Mansell et al., 1981). An increase of 25% in paper waste sludge after the activities of earthworms was reported by Satchell and Martein (1984).
They further suggested that the consequent increase in P after the earthworms’ activities may be due to direct action of worm gut enzymes and due to enhanced microbial activity in the vermicompost. Similarly, Edwards and Lofty (1972) opined that increase in P content in vermicompost could be due to enhanced mineralization and mobilization of phosphorus as a result of increased bacterial and fecal phosphatase activity of earthworms.

In present investigation, the increase in mean performance of compost ratios to vermicompost ratios for phosphorus content was up to 56.0% in 70:30 ratio followed by vermicompost ratios 60:40 (53.0%) and 50:50 (46.0%).

Phosphorus uptake of 1.80 kg/ha was observed for mustard straw (Table 3b). P content of 3.21 (50:50 compost) to 8.04 kg/ha (90:10 vermicompost) with a mean of 5.31 kg/ha was recorded among all compost and vermicompost ratios. The increase in mean performance of P concentration over straw in compost and vermicompost ratios was up to 7.25% in 90:10 vermicompost ratio. Compost ratios 90:10 (5.85%), 80:20 (5.25%) and vermicompost ratios 80:20 (5.27%), 60:40 (5.43%) and 90:10 (7.27%) were statistically significant for percent increase over overall mean value (4.73%).

Le Bayon and Binet (2006) suggested that the enzymes, acid phosphatases and alkaline phosphatases released from earthworms gut can partly convert some amount of phosphorus to more available forms. In this context, 1.3 to 1.5-fold increase in P content was reported by Sangwan et al. (2010) in vermicompost made from press mud.

**Potassium**

In mustard straw potassium content was recorded to be 0.08%. The K concentration in compost ratio 50:50 increased to 0.460% in 50:50 vermicompost ratio. Likewise similar trend persisted for 60:40 ratio as the increment in K concentration was observed. Maximum increase in K concentration was observed in 70:30 compost (0.590%) however among vermicompost ratios maximum increase was observed in 60:40 (0.543%) ratio (Table 6a, Fig.17a). It showed that as compared to the crop straw, compost and vermicompost had more K concentration. The available nutrients in vermicompost like K are partly required by earthworms,
although in low concentrations as compared to K content in substrate i.e. mustard straw in present case. Kaviraj and Sharma (2003) and Khwairakpam and Bhargava (2009) suggested that key role in enhanced mineralization rate is played by acids produced by microbial activity in higher quantities during vermicomposting.

Potassium uptake of 2.40 kg/ha was observed for mustard straw (Table 3b). The uptake of K however, varied from 13.08 (50:50 compost) to 17.70 kg/ha (70:30 compost) with a mean of 15.44 kg/ha among all compost and vermicompost ratios. The increase in mean performance of K concentration over straw in compost and vermicompost ratios was up to 17.56 % in 70:30 vermicompost ratio. Compost ratios 70:30 (17.56%), 90:10 (16.59%) and 80:20 (15.93%) were statistically significant for percent increase over overall mean value (14.83 %).

These observations have also been substantiated by Suthar (2007). He opined that vermin-processed organic waste contains higher concentration of exchangeable K mainly due to increased mineralization as a consequence of enhanced microbial activity during vermicomposting. Adi and Noor (2009) reported that solubilization of insoluble total K is achieved through over production of acids mediated by enhanced microbial activity during decomposition of organic material in vermicomposting process. The percent response (increase/decrease) from ratios showed that K concentration of the vermicompost ratios 50:50 (7%) and 60:40 (4%) were higher than those of their respective compost ratios. However, ratio 90:10 with earthworms showed up to 14 % decrease in potassium concentration followed by 80:20 ratio. Vermicompost ratio 50:50 (7 %) was significantly higher than the overall mean value (3.92 %).

Calcium

The total calcium in straw substrate was 0.06 % which increased gradually from compost to vermicompost ratios. Maximum rise in Ca content was observed in 60:40 and 80:20 vermicompost (2.1 %) ratios, however among compost maximum increment was observed in 80:20 (1.7%) ratio (Table 6a; Fig. 18a). Increase in calcium content in various vermicompost ratios as compared to corresponding ratio of compost and substrate i.e. mustard straw may be attributed to the catalytic activity of carbonic anhydrase present in earthworm glands. This enzyme generates CaCO$_3$ on
the fixation of CO₂ (Padmavathiamma et al., 2008). As in present study, the higher concentration of calcium in the vermicompost was also reported by Yadav et al., (2013). The increase in mean performance of compost to vermicompost ratios for calcium content was up to 82.0 % in 50:50 ratio followed by 70:30 (43 %), 60:40 (40 %), 80:20 (23.52 %) and 90:10 (21.42 %) ratio. Vermicompost ratios 50:50 (82%) and 70:30 (43 %) were significantly higher than the overall mean value (41.98 %).

Calcium uptake of 18.00 kg/ha in mustard straw (Table 3b) varied from 33.00 (50:50 compost) to 63.90 kg/ha (80:20 vermicompost). Vermicompost ratios 80:20, 60:40, 70:30 and 50:50 were statistically significant over overall mean value (51.18 Kg/ha) (Table 5b). The increase in mean performance of Ca content over straw in compost and vermicompost ratios was up to 63.10 % in 80:20 vermicompost ratio. Vermicompost ratios, 80:20 (63.10%), 60:40 (62.28%), 70:30 (60.21%) and 50:50 (59.45%) were statistically significant for percent increase over overall mean value (50.57 %).

Spiers et al., (1986) reported that calcium oxalate crystals get converted to calcium bicarbonate in the gut of earthworms which is when egested increases calcium availability in the processed vermicompost. Similarly, increased calcium content in the vermicompost prepared from industrial wastes was reported by Garg and Kaushik (2005). They opined that through earthworm mediated mineralization process during vermicompost process, a fraction of total calcium gets converted to free form from fixed form, which leads to calcium enrichment in the vermicompost/vermicast.

**Organic carbon**

The decrease in total organic carbon (OC), as in present study, may be attributed to consumption of a fraction of available carbon by the earthworms to meet their energy requirements. Also, the microorganisms thriving on organic carbon may deplete it to CO₂ form.

The organic carbon of straw substrate was 13.12%. However, among all compost and vermicompost ratios organic carbon varied from 9.02% (50:50 vermicompost) to 25.72 % (90:10 compost) with overall mean of 16.33 %. Among
compost ratios the highest organic carbon was observed in ratio 90:10 (25.72%) followed by 80:20 (21.13%) and among vermicompost ratios the highest concentration was observed in ratio 90:10 (18.82 %). As compared to 15.18% organic carbon in 50:50 compost ratio, the concentration reduced to 9.02% in 50:50 ratio in vermicompost. Likewise similar trend persisted for 60:40, 70:30, 80:20 and 90:10 ratios (Table 7; Fig 19a). During vermicomposting total organic carbon gets depleted with the passage of time. These findings are in agreement with the earlier reports of Garg and Kaushik (2005) and Pattnaik and Reddy (2010).

The reduction in organic carbon content and increase in CO₂ in municipal or industrial waste has been reported by Kaviraj and Sharma (2003). According to Crawford (1983) due to microbial respiration and mineralization of organic matter, the organic carbon is lost as CO₂ and total N is increased in vermicompost. This observation was subsequently substantiated by Fang et al. (2001) and Cabrera et al. (2005) that a part of the organic carbon in the residues is released as CO₂ and a part is assimilated by the microbial biomass. Carbon is used as source of energy by the microorganisms while decomposing the organic matter. In vermicompost higher amount of organic carbon is used as compared to normal compost as the earthworms have higher additional assimilating capacity besides microorganisms. Earthworms modify conditions which subsequently lead to increased carbon losses as CO₂ due to microbial respiration in organic matter being converted to vermicompost (Aira et al., 2007).

In present study also, the percent response (change) from compost to vermicompost ratios showed that organic carbon content in all the vermicompost ratios was lower as compared to their corresponding compost ratios. Vermicompost ratios showed up to 40.58 % decrease in 50:50 ratio followed by 60:40 and 80:20 (33.61 %) ratios. Vermicompost ratios 50:50 (-40.58 %), 60:40 (-34 %) and 80:20 (33.61 %) were significant over overall mean value (-32.60 %).

Moisture Content

Moisture content of 9.43% was recorded in mustard straw. However, among all vermicompost ratios and compost ratios moisture content ranged from 32 (60:40 vermicompost) to 59 % (90:10 compost) with overall mean of 47.6 %
(Table 7; Fig.20a). Highest moisture content was observed in 90:10 compost (59%) ratio. Also among vermicompost ratios maximum increment of 53% was observed in this ratio. Edwards and Bater (1992) observed that the optimum moisture content for earthworms was 85% for management of organic waste. Singh et al. (2004) observed that with optimum moisture the rate of decomposition and mineralization becomes faster. Liang et al. (2003) observed that 60-70% moisture content supported maximum microbial activity and this was the minimal requirement for rapid rise in microbial activity.

In present study also, compost and vermicompost in various ratios showed higher moisture content as compared to mustard straw (substrate) from which compost and vermicompost were prepared. Higher moisture content in compost and vermicompost could be attributed to their higher absorption capacity. This leads to higher assimilation by microbial population which would support higher rate of degradation of organic waste by earthworms. The percent response from compost to vermicompost ratios, in general, showed lower moisture content in vermicompost ratios than their respective compost ratios. Vermicompost ratios showed up to 42.86 % decreases in 60:40 ratio followed 70:30 (-34.49 %) and 50:50 (-34 %) ratios over respective compost ratios. Vermicompost ratios 60:40 (-42.86% %) 70:30 (-34.49 %) and 50:50 (-34 %) were statistically significant over overall mean value (28.27%).

Association studies

The mustard compost having high pH also had more moisture content, high calcium content, low EC, low organic carbon and high potassium. The compost having high EC also had low potassium, low moisture content and low calcium content. Wani et al. (2013) showed that moisture content, total organic carbon, total phosphorus and potassium were significantly and positively associated with pH content of vermicompost made out of kitchen waste in field conditions. Also, the pH content in this vermicompost lot exhibited negative correlation with total nitrogen. In cowdung compost, the pH was found to be significantly positively associated with total organic carbon and potassium while it showed negative association with total nitrogen and total phosphorus. The mustard compost having high total nitrogen also had more phosphorus and more potassium. The calcium content of the mustard compost showed a positive correlation with moisture content. Wani et al. (2013) reported that total phosphorus of garden compost exhibited negative correlation with
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potassium while, total phosphorus of kitchen compost exhibited positive association with potash. However, the potassium in cow dung was negatively correlated with total phosphorus. The total phosphorus and potassium in kitchen compost showed significant negative correlation with total nitrogen. However, total phosphorus in cowdung showed significant positive correlation with total nitrogen while total nitrogen exhibited negative association with potassium.