

Vermiconversion of Paper Mill Sludge for Recycling the Nutrients Using Earthworm *Eudrilus eugeniae*

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Abstract: Pot culture experiments were done to process paper mill sludge mixed with bedding materials (cow dung, pig waste and water hyacinth (*Eichhornia crassipes*) in the ratio of 25:75, 50:50, and 75:25 using earthworm *Eudrilus eugeniae*. Totally there were three treatments (T_1 , T_2 and T_3) with three replicates for each. Before and after treatments physico-chemical parameters such as pH, OC, TN, TP, tot TK, Ca, Zn, Fe and Mn were analysed. There were reduction in pH and OC in all vermibeds. On comparison in T_2 the level of macronutrients such as tot N, tot P, tot K were found to be high. Micronutrients were high in T_2 . Earthworm biomass and cocoon production were also studied.

Keywords: Earthworm, Paper Mill Sludge, Vermicompost, Cocoon, Macronutrients and Micronutrients

I. Introduction

Paper industry of India is the 15th largest industry in the world and contributes 5 million dollars to the government's coffers annually. The world paper industry has been registering a growth rate of 2.8% per annum to meet the growing demand for paper and paperboard which is expected to grow from 300 million tons to 420 million tons by the end of 2010. So much so that the US paper industry the largest in the world recorded 100 million dollars profit in the year 2009 alone. Correspondingly more landfill space will be required or dumping the toxic organic sludge generated by this industry. This will not only severely pollute land and ground water of that area but there will also be a waste of rich carbon resource. Legislation for protection of environment, decreasing landfill space and public awareness have drawn more attention towards alternative strategies for recovery of rich pool of nutrients from such wastes [1].

In India the exotic epigeic species, like *Eudrilus eugeniae* [2], *Perionyx excavatus* [3] and *Eisenia fetida* [4] are being used for vermicomposting. The hazards of using alien species are well known. History is littered with examples of confrontations between indigenous and foreign organisms [5]. The introduction of foreign species has been justified by a few scientists [6, 7], though it is extremely unnecessary and undesirable to tamper with local biodiversity [8]. Keeping this in view *Eudrilus eugeniae* (exotic and local species respectively) were chosen for the comparative study of their potential in vermicomposting of PMS.

Literature clearly indicates that vermicomposting is fast in comparison to traditional aerobic composting (without worms) and gives a product rich in organic matter, N, P, K and other plant nutrients [9, 10]. Vermicomposting is being considered as a potential option in the hierarchy of integrated solid waste management. It involves stabilization of organic material by the joint action of earthworms and microorganisms. Although microbes are responsible for biochemical degradation of organic matter, earthworms are the important drivers of the process by conditioning the substrate and altering the biological activity [11]. However, the processing time and quality of the end product vary according to the composition of the initial mixture being processed [12]. The various industrial wastes which have been vermicomposted and turned into nutrient rich manure include paper waste [1, 13], textile mill sludge [14], guar gum industrial waste [15], sugar industry wastes [16], distillery sludge [17], leather industry [18] and beverage industry sludge [12], agro-industrial sludge [19], primary sewage sludge [20], tannery industries [21].

The aim of the present investigation was to vermicompost solid paper mill sludge (PMS) from a paper mill industry using the earthworm species, *E. eugeniae*. The dried sludge was mixed with bedding materials (cow dung, water hyacinth and pig waste) at different ratios (25:75, 50:50 and 75:25) in order to optimize the waste mixture for better decomposition/mineralization. The changes in physical and chemical parameters of waste materials were measured. Earthworm cocoon production patterns in different waste mixture were also monitored during vermicomposting process.

II. Materials and Methods

2.1. Collection and Culturing of Earthworms

Eudrilus eugeniae was purchased from Periyar Maniammai University, Thanjavur, and were cultured in the vermicomposting unit of the PG and Research Department of Zoology, Periyar E.V.R. College, Tiruchirappalli, India. The Cement tanks using cow dung and leaf litter as culturing material.

2.2. Collection of Paper Mill Sludge

Paper mill sludge (PMS) was collected from the paper mill industry (TNPL, Pugalur, Tamil Nadu, India), containing 67-74% moisture and was collected in 20L plastic containers, dried in the shade on polythene bags to remove excess water while turning daily. Partially dried sludge cake solids were homogenized and shredded.

2.3. Collection of Cow Dung, Pig Waste and Water Hyacinth

The cow dung (CD) was obtained from a Parvathi cowshed located in Khajamalai, Tiruchirappalli, Tamil Nadu, India. The pig waste (PW) was collected from a livestock farm located at Tiruchirappalli, Tamil Nadu. The cow dung and pig waste was partially dried in a shed and stored for further experimentations. The water hyacinth (*Eichhornia crassipes*) plants were collected from infested river Uyyakondan, Tiruchirappalli. The water hyacinth was allowed to dry slightly in sunlight and was chopped into small bits.

2.4. Experimental Setup

The experiment was conducted in earthen pots of capacity 2kg with a small hole at the bottom. Aerobically treated solid paper mill sludge was slightly dried in air and mixed with bedding materials in different ratios to give different combinations. Bedding materials was air dried and mixed with solid paper mill sludge in different ratios. Experimental beddings were kept in triplicates for each treatment, and the control treatment had the same setup without earthworm. These mixtures were turned over manually every day for 20 days in order to eliminate volatile toxic substances. After 20 days, fifteen clitellated, *E.eugeniae* were collected from the stock culture and released into different earthen pot containers. The moisture level of substrates was maintained around 70–73%, throughout the study period by periodic sprinkling of adequate quantity of tap water. Containers were placed in a humid and shady place at an ambient temperature (27-28 °C). The important physical and chemical parameters of substrate were measured in all the treatments before the introduction of earthworms and after 80 days. Biological parameters of composting earthworm biomass and cocoon production were studied in vermicomposting subsystem, following the method of Negi and Suthar [22].

2.5. Chemical Analysis

The pH and electrical conductivity (EC) were determined using a water suspension of the vermicompost in the ratio of 1:10 (w/v) after agitating for 30 min by pH and electrical conductivity meters, respectively. Organic carbon was determined by the partial-oxidation method Walkley and Black [23]. Total nitrogen was measured by micro Kjeldahl method [24]. Extractable phosphorous was determined by following Olson's sodium bicarbonate extraction method [25]. Exchangeable elements (K, Ca and Mg) were determined after extracting the sample using ammonium acetate extractable method [26]. The concentration of micronutrients, i.e. Cu, Fe, Zn, and Mn was determined by following diethylene-triaminepentaacetic acid (DTPA) extraction method, analyzed by Atomic Absorption Spectrophotometer (AAS).

III. Results and Discussion

3.1. Nutrient Quality of Vermicomposted Material

Vermicomposting had a different treatment on the quality of the waste feedstock after eighty days. The end material was more stabilized, odour free, and dark brown with a high level available nutrients for plant growth. The changes in different physicochemical properties over the period of the experiment were described in Table-1. pH is an important parameter in the vermicompost for promoting plant growth. There was a decrease in pH in all the treatments ($T_1 - T_3$) relative to their initial values during vermicomposting (Table-1). Initially pH values in different treatments were in range of 6.93, 7.49, and 7.76 in final vermicompost, ranged from 6.73, 7.40 and 7.61. Maximum reduction was recorded in T_3 , while minimum was recorded in T_2 . Gupta *et al.*, [27] also reported reduction in pH during vermicomposting of water hyacinth. Suthar [28] has reported that 12.3% and 14.7% reduction in pH than initial levels in cattle wastes vermicomposting. Elvira *et al.*, [13] concluded that the production of CO_2 and organic acids by the combined action of earthworms and microbial decomposition during vermicomposting lowers the pH of substrate.

The EC of vermicomposts, which were in range of $0.31 dS m^{-1}$ (T_2), $0.46 dSm^{-1}$ (T_1) was obtained and $0.47 dSm^{-1}$ (T_3) were the highest than those of the initial waste mixtures (Table -1). This increase may be due to mineralization and consequent formation of ions in different waste mixtures in the presence of earthworms. The maximum increase in EC was recorded in Treatment 3 (0.47) and minimum in Treatment 1 (0.46). Deka *et al.*, [29] have reported that earthworms produce organic-mineral compounds by digesting the organic materials as feed and these minerals may accumulate in the final products. It was observed that the organic carbon (OC) decreased from the initial value. Decline in OC was maximum in T_1 (0.51%) feed mixture. The percentage decrease in OC was in the order of $T_1 > T_3 > T_2$. The decrease in OC after vermicomposting indicates organic matter stabilization in the substrate due to combined action of earthworms and soil microorganisms. It has been

reported that earthworms modify the substrate conditions, which subsequently enhances the carbon losses from the substrates through microbial respiration in the form of CO₂ [30, 31]. Garg and kaushik [14] reported 20-15% loss of organic carbon in the form of CO₂ from different industrial sludge during vermicomposting.

Table -1 Physico-chemical characteristics of paper mill sludge (PMS) in different proportions subjected to vermicomposting (80 days) using the earthworm, *Eudrilus eugeniae*

Name of the Parameter	T ₁ (25% PMS)			T ₂ (50% PMS)			T ₃ (75% PMS)		
	Control	Initial	Final	Control	Initial	Final	Control	Initial	Final
pH	7.29	7.76	7.61	6.47	7.49	7.40	6.87	6.93	6.73
EC (dSm ⁻¹)	0.14	0.39	0.46	0.30	0.14	0.31	0.12	0.15	0.47
Organic Carbon (%)	0.52	1.16	0.51	0.76	0.87	0.60	0.65	1.19	0.54
Total Nitrogen (kg/ha)	210	214.6	314	212	248	313	307	205	272
Total Phosphorus (kg/ha)	15.3	16.4	18.4	14.6	18	21.4	13	10.9	23
Total Potassium(kg/ha)	234	290	376	276	216	364	304	300	335.6
Calcium (%)	4.8	8.5	10.7	6.3	6.5	12.9	9.3	7.1	9.8
Megnesium (%)	2.6	4.2	6.0	2.9	4.3	6.4	4.9	3.6	5.1
Iron(ppm)	9.41	9.96	13.47	12.6	8.29	29.4	11.0	11.4	16.31
Zinc (ppm)	0.22	0.49	0.79	0.11	0.16	0.18	0.11	0.05	0.14
Copper (ppm)	0.43	0.47	1.01	0.24	0.23	0.43	0.51	0.29	0.56
Manganese(ppm)	0.16	0.11	0.53	0.32	0.39	0.99	0.51	0.15	0.75

Increase in Total Nitrogen in all the vermibeds were shown in Table -1. The final N content was 314-272 kg/ha (T₁-T₃) in vermicomposted substrate. Maximum total N content (as compared to the initial level) was in observed in T₁ 314 kg/ha followed by T₂ 313 kg/ha, and minimum nitrogen content was recorded in T₃ 272 kg/ha. The increase was higher in the vermibeds than in experimental controls (Table-1). The present data clearly suggested that nitrogen increase in vermicomposted material was directly related to the physico-chemical properties of the initial substrates. N mineralization was more in beddings which contained a higher or equal proportion of bedding materials. Bedding materials modify the physical structure of waste and also accelerate the waste mineralization rate in vermibeds. Benitez *et al.*, [32] suggested that hydrolytic enzyme production plays an important role in C and N cycle in waste decomposition system and was drastically influenced by the availability of easily degradable organic compounds (cattle dung) in vermibeds. Most other reports on vermicomposting [13, 19, 33] have reported a higher N increase at the end.

Phosphorus (P) content in vermicomposted material was higher than in control treatment at the end. The highest P content was recorded in T₃ (23 kg/ha) followed by T₂ (21.4 kg/ha) and T₁ (18.4 kg/ha). The earthworm affects phosphorus mineralization in wastes if reared for longer periods [17]. Phosphorus mineralization varied significantly among different vermibeds possibly due to quality and proportion of bedding materials in feedstock. According to Lee [34], if organic matter passes through the gut of the earthworm, it results in some amount of phosphorus being converted that are highly essential for plants. The release of phosphorus in available form is performed partly by earthworm gut phosphatases, and further release of P might be attributed to the P-solubilizing microorganisms present in worm casts. The difference among vermireactors for P mineralization rate could be due to different chemical structure of substrate material [17].

Exchangeable Potassium (K) content in ready vermicompost was higher in (Table-1) than the initial substrate material. The highest K content was recorded in T₁ (376) and T₂ (364), respectively. Minimum K content was noticed in T₃ 335.5 kg/ha, when compared to initial and control. However, when organic waste passes through the gut of worm the some quantity of organic minerals are then converted into more available forms through the action of enzymes produced by gut associated microflora. Thus vermicomposting plays an important role in microbial-mediated nutrient mineralization in wastes. The results of this study agree with previous reports that the vermicomposting process accelerates the microbial populations in waste and subsequently enriches the end product with more available forms of plant nutrients [28].

The calcium (Ca) and magnesium (Mg) concentration were found to be maximum in 12.9 % (T₂) and 6.4 % (T₂) respectively. The increase in Ca was high in vermibeds that had a higher proportion of bedding materials. Earthworm drives the mineralization process efficiently and transforms a large proportion of Mg from bind to free form which results higher concentration of Mg in the vermicompost. The solid paper mill sludge contained appreciable amounts of micronutrients. The concentration of Fe, Zn, Cu and Mn in sludge recorded were 29.4 ppm, 0.79 ppm, 1.01 ppm and 0.75 ppm respectively. The release of plant available forms of trace elements in vermicompost could be due to mineralization of partially digested worm faecal by detritus communities, such as bacteria and fungi. In general, earthworm fragments and modifies the physical structure of ingested wastes through muscular actions of foregut and consequently increases the surface area for microbial action [28, 35]. Such biological coordination results in high level of extractable or available trace elements in ready vermicompost.

3.2. Biomass and Cocoon Production by *E. eugeniae* in Different Treatments

E. eugeniae showed excellent patterns of biomass gain and cocoon productions in all vermibeds during the vermicomposting experimentation. Paper mill sludge proved to be good for earthworm biomass but it negatively affected reproduction of *E. eugeniae*. Maximum worm biomass was observed in T₃ on 60th day, which was followed by T₂ and T₁. The worm biomass started declining in T₁ and T₂ mixture after 60th day (Fig.2), moreover, compost started granulating on the surface and it also indicated exhaustion of nutrients in the mixture. Neuhauser *et al.* [36] and Edwards *et al.*, [9] reported that population density of worms per unit volume or weight of feed was important in affecting the rate of growth and reproduction.

Worm biomass, however, increased with the increasing proportion of paper mill sludge in the feed mixture but it corresponded with a very low rate of production of cocoons. Seems that the energy otherwise to be used for reproduction was diverted towards weight gain by the worms. This gets corroborated by the findings of that in paper sludge earthworms had more biomass and low reproductive rate. Low level of nitrogen in paper mill sludge is considered a limiting factor for the growth of worms [37].

Cocoon production was started and monitored from second week in 75%BM + 25%PMS, 50%BM + 50%PMS and 25BM + 75%PMS feed mixtures and in fourth week in the rest of the feeds except 50%CD + 50%PMS (fifth week). Cocoon production fluctuated considerably with time. Initially cocoon production rate was high. This rate decreased after eighth week and then approximately constant. Since cocoon production is highly dependent on the food availability, which explains much fluctuation.

Fig.1 Number of cocoons in various paper mill sludge

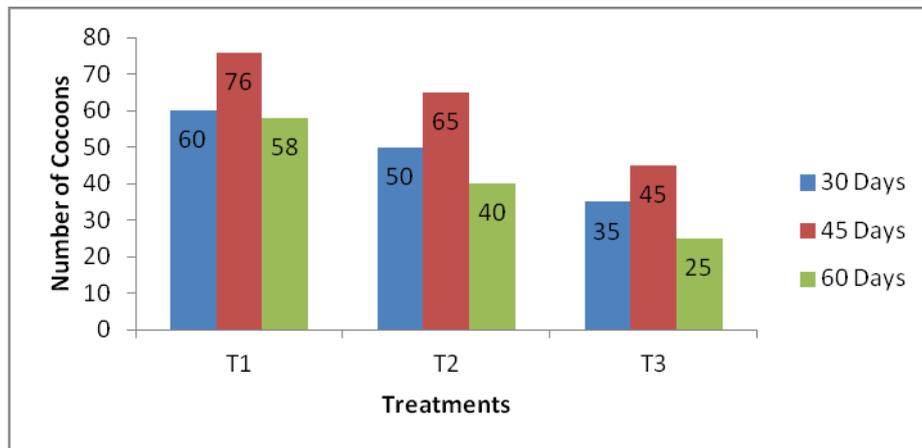
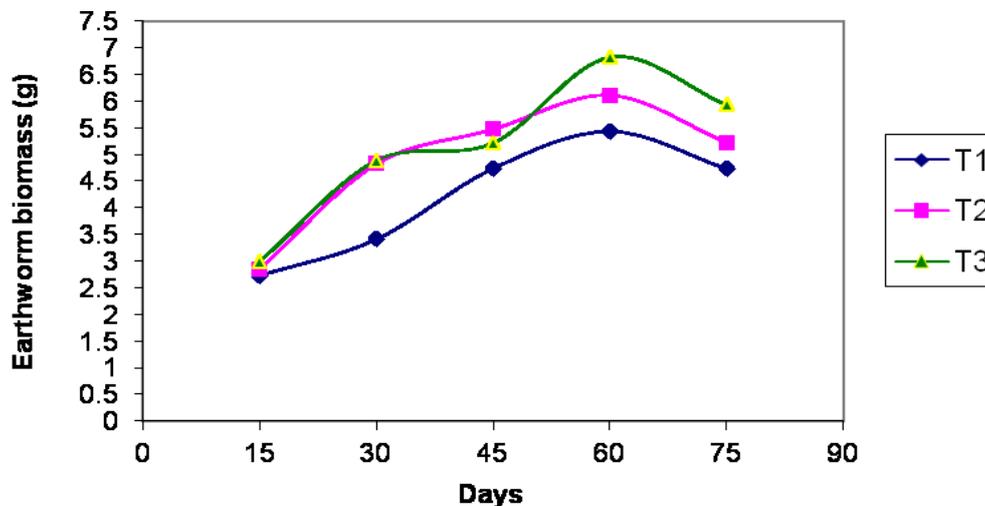


Fig. 2 Earthworm biomass in different treatments during vermicomposting



Total number of cocoons produced was maximum (76) in 25%PMS + 75% BM and minimum (25) in 75% SPMS + 25%BM feed mixture (Fig 1). These results showed that BM amended with 25% and 50%PMS can be a suitable growth medium for *E. eugeniae*. These mixtures probably provide the earthworm with sufficient amount of easily metabolizable organic matter and non-assimilated carbohydrates that favours growth. The results suggested that higher proportions of PMS in bedding materials were not suitable for cocoon production. Production of cocoons in different feed mixtures can be related to the biochemical quality of the feed, which was one of the most important factors [38].

IV. Conclusion

Vermiconversion paper mill sludge with bedding materials (cow dung, pig waste and water hyacinth) and *E.eugeniae* can solve the problem of disposal of this phytotoxic sludge by converting it into a nutrient rich supplement for plants in a short span of time (80 days).The final vermicomposts were homogenous, rich in important plant nutrients N, P, K, Fe, Zn, Cu and Mn which indicated their agricultural value as a soil conditioner. These results also indicated the economic utilization of paper mill sludge mixed with bedding materials which may be very important to achieve sustainable development. Earthworm cocoon production performance was excellent in bedding those contained with lower proportions of paper mill sludge e.g. T₁ and T₂, which suggests that paper mill sludge can retard the potentials of composting earthworms if applied at a higher rate in vermibeds. Thus the present experimental data provides a sound basis that vermicomposting is a suitable technology for the conversion of paper mill sludge into organic fertilizer and clearly demonstrates that the conversion of paper mill sludge with bedding materials into vermicompost may not only reduce the burden of synthetic fertilizers but also acts as a good soil conditioners and a source of plant nutrients in agriculture.

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