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RESEARCH ARTICLE

VERMICOMPOSTING OF PAPER MILL SLUDGE WITH COWDUNG, PIG WASTE AND WATER HAYACINTH IN TO VALUABLE MANURE USING EARTHWORM *PERIONYX EXCAVATUS*

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ABSTRACT

The present study aimed in management of Paper Mill Sludge (PMS) by vermicomposting. PMS was mixed with Bedding Materials (BM), cow dung, pig waste and water hyacinth leaves in three different ratios and pre digested by over turning and sprinkling water at intervals. There were three treatments with three replications for each. The experiments were conducted in small earthen pots. In each pot different combinations of PMS with BM were taken. The experiments were carried out for 75 days. The parameters pH, OC, total N, P, K, Ca and Mg were analyzed and all the values significantly increased in T1 and T3. The cocoon production was found to be high in T1 and T2 were the ratio of PMS was less. This proves that PMS with 25% and 50% were found to be the best for the management of PMS by vermicomposting. The result proved vermicomposting was simple and economical alternative technology for recycling of PMS using *P.excavatus*.

INTRODUCTION

The pulp and paper industry is considered one of the most polluting industries (Thompson *et al.,* 2001). A variety of liquid and solid wastes are produced during different processes of paper manufacturing. In general, pulping and bleaching are the two main steps in production of paper in industry and a huge quantity of fresh water is utilized resulting a large quantity of wastewater, sludge and other solids. The solid wastes from pulp and paper industries are mainly treatment sludges, lime mud, lime slaker grits, boiler and furnace ash, scrubber sludges, and wood processing residuals. The paper production generates around 45% wastewater sludge (0.2–1.2 kg dry matter (DM)/kg of biological oxygen demand (BOD) removed), 25% ash, (Zambrano *et al.,* 2003), 15% wood cuttings and waste, and 15% other solid waste. The sludge from wastewater treatment units (20–60% solid fractions, pH 7) includes wood fibers, biosludge, calcium carbonate, clay and other inorganic materials (Nurmesniemi *et al.,* 2007). Dry sludge amounts to approximately 4.3% of the final product, increasing to 20–40% for recycled paper mills (World Bank, 2007).

The primary methods of disposal for this type of sludge have been land application and landfilling. The unsafe disposal of these solid wastes cause environmental problems because of high organic content, partitioning of chlorinated organic, pathogens, ash and trace amounts of heavy metals. The pulp and paper industry faces a growing solid waste disposal problem as environmental regulations become increasingly stringent and landfill space grows scarcer. The chemical analysis (high organic matter content, pH, buffer capacity, nitrogen and phosphorous level, and low concentrations of heavy metals and organic pollutants) have revealed that pulp mill sludge may be utilized as a soil amendment, improving soil fertility (Zhang *et al.,* 2004) but stabilization involving decomposition of an organic waste to the extent that biological and chemical hazards are eliminated is required (Benito *et al.,* 2003; Suthar, 2010; Gomez-Brandon *et al.,* 2011).

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Vermicomposting, through earthworms, is an ecobiotechnological process that transforms energy rich and complex organic substances in to a stabilized vermicomposts (Bentiez *et al.,* 2000).Vermicomposting is stabilization of organic material, involving the joint action of earthworms and micro organisms. Although microbes are responsible for biochemical degradation of organic matter, earthworms are important derivers of the process, conditioning the substrate and altering the biological activity (Aira *et al.,* 2002). During vermicomposting, nutrients are released and converted in to soluble and available forms for plants (Ndegwa and Thompson, 2001). Vermicomposting through different species of earthworm has been studied (Edwards *et al.,* 1998).

The epigeic earthworm were utilized for organic waste management (Suthar, 2006; Garg and Kaushik, 2005; Benitez *et al.,* 2005). Epigeic forms of earthworms can hasten the composting process to a significant extent with production of better availability of vermicomposts (Ndegwa and Thomson, 2001). The epigeic earthworm, *E.fetida* is a suitable species for management of waste and is utilized successfully in vermicomposting (Chaudhari and Battacharjee, 2002). The various industrial wastes which have been vermicomposted and turned into nutrient rich manure include paper waste (Elvira *et al.,* 1998; Kaur *et al.,* 2010), textilemill sludge (Garg and Kaushik, 2005), guar gum industrial waste (Suthar, 2006), sugar industry wastes (Sen and Chandra, 2007), distillery sludge (Suthar and Singh, 2008), leather industry (Ravindran *et al.,* 2008) and beverage industry sludge (Singh *et al.,* 2010), agroindustrial sludge (Suthar, 2010), primary sewage sludge (Hait and Tare, 2011), tannery industries (Ravindran and Sekaran, 2011).

The aim of the present investigation was to vermicompost Solid Paper Mill Sludge (PMS) from a paper mill industry using the earthworm species, *P.excavatus*. The dried sludge was mixed with Bedding Materials (BM) (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. Cocoon production patterns of earthworm in different waste mixture were also monitored during vermicomposting process.

MATERIALS AND METHODS

Procurement of Earthworms (EWs) and PMS

Periyonyx excavatus was obtained from vermiculture form in the 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. Using cow dung and leaf litter as culturing material, in cement tanks. Paper mill sludge (PMS) was collected from the Paper Mill Industry at TNPL, Pugalur, Tamil Nadu. The sludge was dried in shade prior to use in vermicomposting.

Procurement of cow dung, pig waste and water hyacinth

The cow dung (CD) was obtained from Parvathi cowshed located in Khajamalai, Tiruchirappalli, Tamil Nadu, India. The pig waste (PW) was obtained from a livestock farm located at Tiruchirappalli, Tamil Nadu, India. 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 river Uyyakondan, Tiruchirappalli, India. The water hyacinth was allowed to dry slightly in sunlight and chopped into small bits.

Experimental setup

A pot culture experiment on vermicomposting of PMS and BM with *P.excavatus* was conducted. The experiment was conducted in randomized block design (RBD) with three replications. PMS was sun dried to remove excess moisture and odour. Bedding materials (cow dung, pig waste and water hyacinth leaves) were mixed in the ratio of 1:1:1 and utilized for further studies. The three treatments used in the experiment were T1 with PMS and BM in the ratio of 25:75, T2 with PMS and BM in the ratio of 50:50, T3 with PMS and BM in the ratio of 75:25 and control treatment had the same setup without earthworm. Earthen pots were used for the study. Small hole was made in the bottom of the pot to drain out excess water. The mixture was pre-digested for twenty days by turning over manually and sprinkling water to eliminate volatile toxic substances. After 20 days fifteen clitellated *P.excavatus* were released into each pot. Moisture was maintained by sprinkling water.

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. OC was determined by the partial-oxidation method (Walkey and Black, 1934). Total nitrogen was measured by micro Kjeldahl method (Jackson, 1975). Extractable phosphorous was determined by following Olson's sodium bicarbonate extraction method (Olsen *et al.,* 1954). Exchangeable elements (K, Ca and Mg) were determined after extracting the sample using ammonium acetate extractable method (Simard, 1993). The concentration of micronutrients, i.e. Cu, Fe, Zn, and Mn was determined by following diethylene-triaminepentaacetic acid (DTPA) extraction method, analyzed by Atomoic Absorption Spectrophotometer (AAS)

Statistical analysis

One-way ANOVA was used to analyze the differences between treatments. Duncan multiple ranged test was also performed to identify the homogeneous type of the data sets. Statistical analysis was done with the SPSS computer software program.

RESULTS AND DISCUSSION

Nutrient quality of vermicomposted material

Vermicomposting had a different treatment on the quality of the waste feedstock after 75 days. The end material was more stabilized, odor 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 significantly (P<0.05) 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 7.23, 7.98, and 8.45 and in final vermicompost, ranged from 6.91, 7.45 and 7.64. Maximum reduction was recorded in T_2, while minimum was recorded in T_3. Gupta *et al*., (2007) also reported reduction in pH during vermicomposting of water hyacinth. Suthar (2009) has reported that 12.3% and 14.7% reduction in pH than initial levels in cattle wastes vermicomposting. Elvira *et al*., (1998) 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.

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 CO_2 (Aira *et al*., 2007; Tripathi and Bharadwaj, 2004). Garg and Kaushik (2005) reported 20-15 % loss of OC in the form of CO_2 from different industrial sludge during vermicomposting.

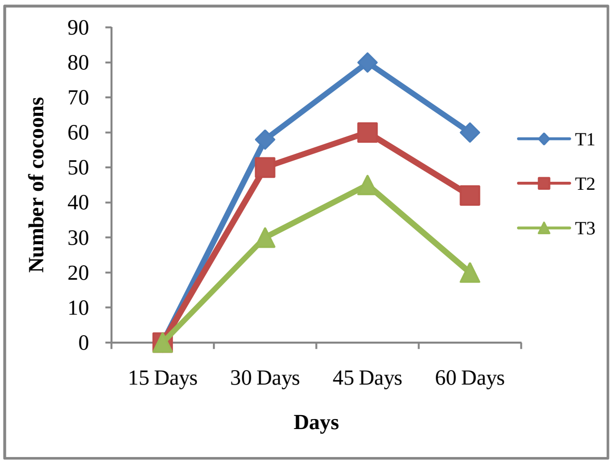

Fig.1. Number of cocoons in various feed mixtures of PMS and BM

Table 1 Physico-chemical characteristics of paper mill sludge (PMS) in different proportions subjected to vermicomposting

Parameters	T_1-25% PMS			T_2-50% PMS			T_3-75% PMS		
	Control	Initial	Final	Control	Initial	Final	Control	Initial	Final
pH	7.62±0.01c	7.98±0.02a	7.45±0.005b	6.49±0.01c	8.45±0.005a	7.64±0.005b	6.47±0.02c	7.23±0.01a	6.91±0.01b
EC(dsm^{-1})	1.28±0.005c	1.43±0.01b	1.48±0.01a	1.31±0.01b	1.33±0.01b	1.35±0.005a	1.16±0.01b	1.12±0.02c	1.31±0.02a
OC (%)	0.56±0.01c	0.65±0.01a	0.54±0.01b	0.74±0.01b	0.89±0.01a	0.61±0.01c	0.67±0.01b	0.78±0.01a	0.53±0.01c
TN (%)	1.28±0.01c	1.30±0.01b	1.68±0.01a	1.25±0.01c	1.27±0.005b	1.88±0.005a	0.80±0.005c	0.80±0.005b	1.20±0.02a
TP (%)	2.50±0.005c	2.58±0.005b	3.19±0.005a	2.23±0.01c	2.38±0.01b	3.42±0.005a	2.26±0.02c	2.48±0.01b	2.94±0.01a
TK (%)	0.80±0.005c	1.15±0.005b	1.35±0.01a	1.17±0.005c	1.25±0.01b	1.61±0.01a	1.01±0.005c	1.17±0.01b	1.48±0.01a
Ca (%)	4.90±0.01c	8.60±0.005b	9.70±0.01a	6.40±0.01b	6.40±0.02b	8.20±0.005a	7.41±0.01b	7.40±0.01b	8.00±0.00a
Mg (%)	3.00±0.00c	4.61±0.01b	5.20±0.005a	2.10±0.005c	2.20±0.01b	2.91±0.01a	3.40±0.01b	3.41±0.005b	5.40±0.01a
Zn(ppm)	0.28±0.01c	0.86±0.005c	0.97±0.01a	0.14±0.005c	0.18±0.01b	0.29±0.01a	0.11±0.01c	0.13± 0.01b	0.16±0.01a
Fe(ppm)	9.90±0.005c	10.01±0.005b	14.01±0.01a	8.31±±0.005c	12.40±0.01b	14.67±0.01a	10.40±0.01c	11.10±0.01b	12.71±0.005a
Cu(ppm)	0.47±0.01b	0.46±0.005b	0.57±0.01a	0.17±0.01b	0.19±0.005a	0.21±0.01a	0.51±0.005c	0.58±0.005b	0.84±0.01a
Mn(ppm)	0.50±0.01c	0.60±0.005b	0.71±0.005a	0.34±0.005c	0.38±0.005b	0.47±0.01a	0.13±0.01b	0.14±0.005b	0.18±0.01a

*Results are the mean value in triplicates ± SD with significant difference at *P<0.05*.

The EC of vermicomposts, which were in range of 1.31 dS m^{-1} (T_3), 1.35 dS m^{-1} (T_2) was obtained and 1.48 dS m^{-1}(T_1) 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 T_1 (1.48) and minimum in T_3 (1.31). There was significant variation (P<0.05) observed for all the treatments.

Deka *et al*. (2011) 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 OC decreased significantly (P<0.05) from the initial value. Decline in OC was maximum in T_2 (0.28%) feed mixture.

The percentage decrease in OC was in the order of T_2>T_3>T_1. The decrease in OC after vermicomposting indicates organic matter stabilization in the substrate due

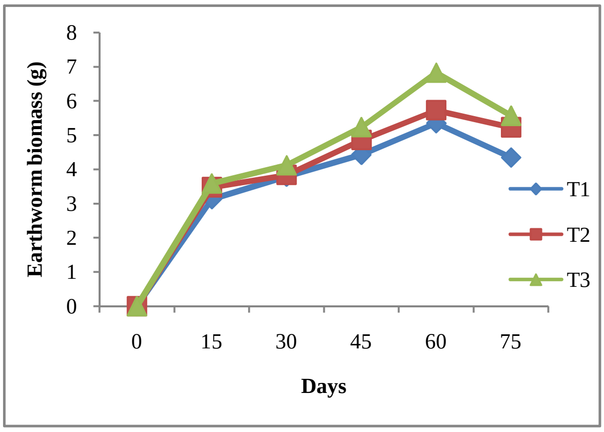

Fig. 2 Earthworm biomass (g) in various feed mixtures of PMS and BM

Increase in Total Nitrogen in all the vermibeds were shown in Table -1. The final N content was 1.68-1.20(%) (T_1-T_3) in vermicomposted substrate. Significant variation (P<0.05) was observed in TN, maximum total N content (as compared to the initial level) was in observed in T_2 (1.88 %) followed by T_1 (1.68 %), and minimum nitrogen content was recorded in T_3 (1.20 %). 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.*, (1999) 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 (Elvira *et al.*, 1998; Bhattacharya *et al.*, 2004; Suthar, 2008) have reported a higher N increase at the end.

Phosphorus (P) content in vermicomposted material was increased significantly ($P<0.05$) than in control and initial treatment at the end. The highest P content was recorded in T_2 (3.42 %) followed by T_1 (3.19 %) and T_3 (2.94 %). The earthworm affects phosphorus mineralization in wastes if reared for longer periods (Suthar and singh 2008). Phosphorus mineralization varied significantly among different vermibeds possibly due to quality and proportion of bedding materials in feedstock. According to Lee (1992), 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 (Suthar and Singh, 2008). Satchell and Martein (1984) reported approximately 25% increase in the level of P after worm activity in paper waste sludge. They attributed this increase in P to direct action of worm gut enzymes and indirectly by stimulating of the microflora. Recently Suthar (2009) claimed higher contents of available P in organic wastes after inoculated with epigeic earthworms. The difference among vermireactors for P mineralization rate could be due to concentration of sludge in bedding material.

Exchangeable Pottasium (K) content in ready vermicompost was a significant increase (Table-1) than the initial substrate material. The highest K content was recorded in T_2 (1.61) and T_3 (1.48), respectively. Minimum K content was noticed in T_1 (1.35), 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. Garg *et al.* (2006) reported higher total potassium contents in the vermicomposted sludge, at the end. They attributed this increase in K content to enhanced microflora in feed substrates, which produces acids for solubilizing the insoluble K. 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 (Suthar, 2009).

The calcium (Ca) and magnesium (Mg) concentration were found to be maximumin 9.70 % (T_1) and 5.40 % (T_3) respectively. Calcium and magnesium increased significantly ($P<0.05$) from initial in different feed mixture of treatments. 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 (Suthar, 2008) which results higher concentration of Mg in the vermicompost (Suthar, 2008; Suthar, 2009). The solid paper mill sludge contained appreciable amounts of micronutrients. The concentration of Fe, Zn, Cu and Mn in sludge recorded were 14.67, 0.97, 0.84 and 0.71 ppm respectively. The iron and zinc variations were significant ($P<0.05$) in all the treatments. 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 (Suthar, 2008, 2010). Such biological coordination results in high level of extractable or available trace elements in ready vermicompost.

Biomass and cocoon production by *P.excavatus* in different treatments

Maximum worm biomass was recorded in T_3 on 60^{th} day, which was followed by T_2 and T_1. The worm biomass started declining in T_1 and T_2 mixture after 60^{th} day (Fig.2), moreover, compost started granulating on the surface and it also indicated exhaustion of nutrients in the mixture. In general, earthworm biomass gain is directly related to the feeding rate, palatability of feedstuff and particle size of feedstock; however, there is a close relationship between feedstock quality and microbial richness of bedding substrates which directly or indirectly affects the earthworm feeding rate, as microbes are the important component of earthworm diets (Gomez-Brandon *et al.*, 2011). Neuhauser *et al.* (1988) and Edwards *et al.* (1998) 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 (Elvira *et al.* 1998) 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 (Butt, 1993).

Cocoon production was started and monitored from second week in PMS 25% + BM 75%, PMS 50% + BM 50% and PMS 75%+ BM 75% feed mixtures and in fourth week in the rest of the feeds except 50%BM +50%PMS (5^{th} week). Cocoon production fluctuated considerably with time. Initially cocoon production rate was high. This rate decreased after 8^{th} week and then approximately constant. Since cocoon production is highly dependent on the food availability, which explains much fluctuation.

Total number of cocoons produced was maximum (80) in 25% PMS+75% BM and minimum (20) 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 *P.excavatus*. These mixtures probably provides 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 (Flack and Hartenstein, 1984). Suthar (2006) emphasized that in addition to the biochemical properties of waste, the microbial biomass and decomposition activities during vermicomposting are also important in determining the worm cocoon production.

CONCLUSION

Vermiconversion paper mill sludge with bedding materials (cow dung, pig waste and water hyacinth) and *P.excavatus* 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 (75 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 PMS mixed with BM which may be very important to achieve sustainable development. Earthworm cocoon production performance was excellent in bedding those contained with lower proportions of PMS *e.g.* T_1 and T_2, 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 PMS in to 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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