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Physico-chemical and Biological Dynamics of Waterhyacinth Biocompost: A Compost Maturity Assessment Scenario

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The present investigation was carried out to explore the possibility of conversion of waterhyacinth into nutrient rich biocompost by using different microorganisms. The composting experiment laid out in a randomized block design (RBD) with five treatments. The treatment consisted of waterhyacinth with cowdung slurry (CS), effective microorganisms (EM), microbial consortium (MC), mixed liquor suspended solids (MLSS) and plain waterhyacinth (as control experiment). The treatment considerably facilitated mineralization in the order: MC > EM > CS > MLSS. The results revealed that the composting with microbial consortium was found to be the best option for converting waterhyacinth into nutrient rich manure through their superior physico-chemical properties *i.e.* lower C:N ratio, higher total N and micronutrients with higher microbial populations. The study has thus indicated that waterhyacinth can be effectively recycled for the production of nutrient rich biomanure through composting using suitable microbial consortia, resulting in greater economic and ecological benefits.

Key words: pulp and paper mill effluent, waterhyacinth, biocompost, microorganisms.

Waterhyacinth (*Eichornia crassipes*), one of the world's worst aquatic weed, is commonly found in effluent treatment plant areas of different industries. This aquatic plant can tolerate substantial variation in highly polluted water, nutrients, temperature, toxic and pH levels. Accordingly, it can hastily grow to very wide densities (over 60 kg m^{-2}), thereby absolutely clogging water bodies, which in turn may have unenthusiastic effects on the surrounding environment, potential threat to human health and economic growth. The waterhyacinth could form mat like structure with abundant growth and potentially block the irrigation canals; interfere with navigation, turbine in power generation leads to consume significant time and money for cleaning and other regular operation. The mat like structure increases the anaerobic circumstance, blocks the light penetration and leads to decreases the dissolved oxygen content. In addition the large dense mat could create favorable conditions for mosquito, encephalitis and filariasis (Mironga, 2004). In fact, this aquatic weed has become a severe problem in different parts of the world owing to its abandoned rapid growth.

A variety of methods have been attempted for the safe disposal of this aquatic weed, including physical removal, application of chemical and biological control agents. It is well known that the physical removal processes are inefficient due to their speedy growth and also require additional cost for repeat operation. The other two technologies also have some limitations for

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practical applications (Guitierrez *et al*., 2000). Many efforts were made to identify different ways to exploit these aquatic weeds to partly reduce operation costs, including its use as an agricultural soil amendment, mushroom cultivation, phytoremediation of contaminated soil and industrial effluent, biogas and power alcohol production, animal fodder, raw materials for rope, basket etc., (Malik, 2007; Gunnarsson and Petersen, 2007). Another possible most effective and eco-friendly method for safe disposal towards reuse of waterhyacinth is aerobic digestion, *i.e.*, biocomposting. Composting is the biological decomposition of organic wastes, under controlled conditions into a clean, humus rich, quite biostable product that improves the land and fertilizes the growing plants. The potential use of waterhyacinth compost as a manure for crop productions has been successfully investigated by Sanjeeva Gandhi, (2010) and the report indicated that the application of waterhyacinth compost in groundnut increased the crop growth, pod yield along with increasing the seed protein and oil content. Gajalakshmi and Abbasi, (2002) documented that the waterhyacinth compost had positive effects on plant growth, shoot-root ratio, and greater biomass per unit time on vegetable and flower crops. It has also been documented that the use of waterhyacinth compost did not produce any adverse effect on the growth of field crops. In fact, the waterhyacinth compost increases the available nitrogen, phosphorous and potassium level in the soil (Gunnarsson and Petersen, 2007).

Microorganisms are playing an important role in the biocomposting process through the generation of enzymes, which help while the degradation of plant based organic waste materials like lignin, hemicelluloses, cellulose etc., (Vargas-García *et al*., 2010). Many microbial agents like *Bacillus subtilis*, *Trichoderma viride*, *Aspergillus niger*, *Pseudomonas* sp and *Streptomyces* sp are known and proved efficient tools for decomposition of waterhyacinth waste materials into nutrient rich biocompost. Keeping the above facts in view detailed investigations were undertaken for the scientific experiment on biocompost of waterhyacinth to assess the efficiency of utilizing the compost.

MATERIALS AND METHODS

Preparation of microbial consortium

The microorganism used to prepare the consortium was obtained from the Department of Environmental Sciences, TNAU, Coimbatore. The microbial consortium was prepared by using the mixture of *Bacillus subtilis*, *Trichoderma viride*, *Aspergillus niger*, *Pseudomonas* sp and *Streptomyces* sp with vermicompost as the carrier materials. About 200 g of microbial consortium was mixed well with 10 liters of water to make a suspension, and then well mixed with 100 kg of chopped water hyacinth.

Preparation of EM solution

Stock solution of EM was obtained from M/s. Maple Organics, TN, India. This solution was activated by mixing water, molasses and EM stock solution @ ratio of 20: 1: 1. The liquid was sealed in air tight polypropylene bottles and kept in dark room at ambient temperature. The product was ready for use on 7th day of incubation, when pH dropped below 4.0. The cowdung, molasses and extended EM were mixed in water in the ratio of 5:1:1:30. About 15 litres of this mixture was mixed with 100 kg water hyacinth.

Experimental methods

The fresh waterhyacinth biomass was collected manually from effluent treatment plant, in Seashasayee Paper and Boards Limited (SPB Ltd.), TN, India, which is an integrated pulp and paper mill established in the year 1960. SPB Ltd. is a pioneer in using bagasse, a solid waste byproduct of sugar industry, for the eco-friendly manufacture of paper. The SPB Ltd. has also launched the lift irrigation scheme on a cooperative basis involving the farmers of thirteen villages surrounding the industry on a tripartite agreement for the utilization of the treated effluent as an irrigation water substitute since 1980.

The collected biomass was cut into small pieces of 5 cm length and then made into small circular heaps. Exactly, 100 kg of fresh waterhyacinth was used for making each heap. These heaps were left for 5 days for moisture reduction and the treatments were applied on 6th day then the heap was covered to generate adequate heat. Turnings were given once in 30 days to enhance aeration in the heaps and regular watering was done to maintain the moisture at 60

%. The biocomposting experiment laid out in a randomized block design (RBD) with five treatments and five replications. The treatment consisted of waterhyacinth with cowdung slurry (CS) (10 % on fresh weight basis), waterhyacinth with microbial consortium (MC), waterhyacinth with effective microorganisms (EM), waterhyacinth with missed liquor suspended solids (MLSS) (10 % on fresh weight basis) and plain waterhyacinth (as control experiment). The composting was done in the Compost yard of SPB Ltd, Erode.

Analysis of compost samples

Physico-chemical and biological properties

The samples taken periodically (30, 60, 90 and 110 days after initiation) from the composting heaps were air-dried and sieved. The sieved samples were analyzed for the physico-chemical properties as per the standard methods given in table 1. The population of different groups of microorganisms was enumerated in the fresh compost samples using the standard serial dilution plating techniques.

Compost maturity test

The compost samples at 110th day of composting were evaluated for their maturity. The humification parameters like per cent humic acid and fulvic acid were determined by using the standard procedure (Sequi *et al*., 1986).

Statistical analysis

The data generated during this investigation for various characters were statistically analysed by the method given by Gomez and Gomez, (1984). The results are presented and discussed at 5% probability level, uniformity.

RESULTS AND DISCUSSION

In order to find out the physico-chemical composition of pulp paper mill effluent and raw water hyacinth, samples were analyzed and results are presented in table 2 and 3, respectively. The treated effluent let out for irrigation from SPB Ltd. was brown in color and had appreciable amount of suspended, dissolved and total solids with phenolic odor. The pH and EC of the treated paper mill effluent was 7.62 and 2.84 dS m^{-1}, respectively, which might be due to the addition of sodium salts for cooking of chipped raw materials in the kraft process. The BOD and COD values of treated effluent were 47.8 and 569 mg L^{-1}, respectively. In general, the vital quality parameters *viz.*, pH, EC, total dissolved solids, BOD, COD, chloride, sulphate and sodium content of treated effluent were within the permissible limits. The treated effluent had considerable amount of essential nutrients *viz.*, ammonical nitrogen, phosphorus and potassium. This might be due to the addition of urea and diammonium phosphate (DAP) during the effluent treatment process and SPB Ltd. is an agro based industry and the final effluent contains appreciable levels of organic carbon. In addition the paper mill effluent had considerable amount of microbial population.

Table 1. Methodologies followed for analysis of compost samples (Jackson, 1958)

S. No.	Parameters	Methodology
1.	pH	Sample - water suspension at 1: 10 ratio by using pH meter
2.	EC	Sample - water suspension at 1: 10 ratio by using Conductivity Bridge
3.	Temperature	Digital thermometer
4.	Organic carbon	Chromic acid wet digestion method
5.	Total N	Diacid extract using kjeldahl distillation
6.	Total P	Triple acid extract using colorimeter
7.	Total K	Triple acid extract using Flame photometer
8.	Total Ca and Mg	Triple acid extract - Versenate method
9.	Total Cu, Mn and Zn	Triple acid extract using atomic absorption spectro-photometer

The waterhyacinth biomass showed a neutral pH of 7.46 and EC of about 0.43 dS m^{-1}. The organic carbon content was 42.9 per cent. The total N content of the waterhyacinth was 1.68 per cent with C: N ratio of 25.5. The total P, K, Ca and Mg contents in the waterhyacinth were 0.22, 0.94, 1.98 and 0.82 per cent, respectively. The micronutrients *viz*., Cu, Mn, Fe and Zn were 14.8, 296, 11869 and

144.9 mg kg^{-1}, respectively. The microbial populations *viz*., bacteria, fungi and actinomycetes were 17.6 x 10^6 CFU g^{-1}, 11.3 x 10^4 CFU g^{-1} and 6.8 x 10^3 CFU g^{-1}, respectively. The waterhyacinth has an admirable capacity to absorb nutrients and other chemicals from its surrounding environment, thus the present chemical composition of the waterhyacinth depends strongly on the composition of pulp and paper mill effluent. This result directly indicated that the SPB Ltd paper mill effluent contains appreciable amount of nutrients and minerals and thus it act as a good sources for the growth of waterhyacinth.

Table 2. Physico-chemical and biological characteristics of the secondary treated paper mill effluent

S.No.	Parameters	Values
I	Physico-chemical characteristics	
1.	Color (CU)	170
2.	Odor	phenolic
3.	pH	7.62
4.	EC (dS m^{-1})	2.84
5.	TSS (mg L^{-1})	190
6.	TDS (mg L^{-1})	1320
7.	BOD (mg L^{-1})	47.8
8.	COD (mg L^{-1})	569
9.	Calcium (mg L^{-1})	230
10.	Magnesium (mg L^{-1})	110
11.	Sodium (mg L^{-1})	192
12.	Potassium (mg L^{-1})	17
13.	Chloride (mg L^{-1})	198
14.	Sulphate (mg L^{-1})	156
15.	Carbonate (mg L^{-1})	-
16.	Bicarbonate (mg L^{-1})	196
17.	Soluble sodium (%)	29
II	Biological characteristics	
18.	Bacteria × 10^6 CFU ml^{-1}	31
19.	Fungi × 10^4 CFU ml^{-1}	12
20.	Actinomycetes × 10^3 CFU ml^{-1}	4

Table 3. Physico-chemical properties of raw waterhyacinth biomass

S.No.	Parameters	Values
I	Physico-chemical properties	
1.	pH	7.46
2.	EC (dS m^{-1})	0.43
3.	Organic Carbon (%)	42.9
4.	C : N ratio	25.5
5.	Total N (%)	1.68
6.	Total K (%)	0.94
7.	Total P (%)	0.22
8.	Total Ca (%)	1.98
9.	Total Mg (%)	0.82
10.	Total Cu (mg kg^{-1})	14.8
11.	Total Mn (mg kg^{-1})	296
12.	Total Fe (mg kg^{-1})	11869
13.	Total Zn (mg kg^{-1})	144.9
II	Biological properties	
14.	Total bacteria x 10^6 CFU g^{-1}	17.6
15.	Total fungi x 10^4 CFU g^{-1}	11.3
16.	Total actinomycetes x 10^3 CFU g^{-1}	06.8

Physico-chemical changes during composting of waterhyacinth

The changes in pH during the composting process are presented in Fig. 1a. The pH of the compost increased significantly during early stages of composting and decreased at maturity stage. At 30th day of bio-composting, significantly higher pH of 7.72 was recorded in microbial consortium and it was statistically on par with EM. The lowest pH was recorded in waterhyacinth alone (7.52).

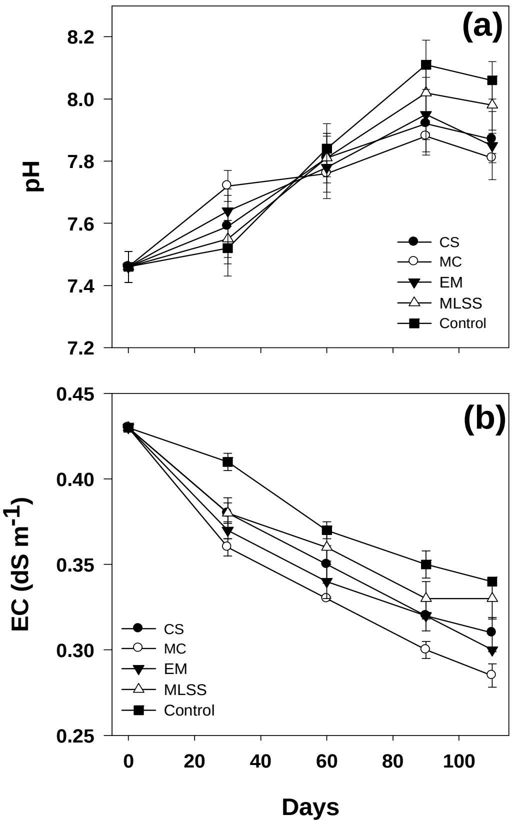

Fig. 1. Changes in (a) pH and (b) EC during biocomposting of water hyacinth

However, at 60, 90 and 110th day of bio-composting, significantly higher pH was recorded in waterhyacinth alone (7.84, 8.11 and 8.06, respectively), whereas the lowest pH was recorded in microbial consortium (7.76, 7.88 and 7.81, respectively). The increase of pH in the initial period of composting might be due to the evolution of ammonia from the nitrogenous sources during composting (Rashad *et al*., 2010). A slight decrease in pH after 90th day in all the treatments might be due to synthesis of organic acids and production of phenolic compounds by microorganisms. These findings are in agreement with results reported by Sundberg and Jonsson, (2005). At maturity stage, pH of the compost in all the treatments was near neutral. This was due to buffering action of humus produced as result of composting process. The changes in EC during composting are recorded and the data are presented in Fig. 1b. The EC content during the period of composting decreased

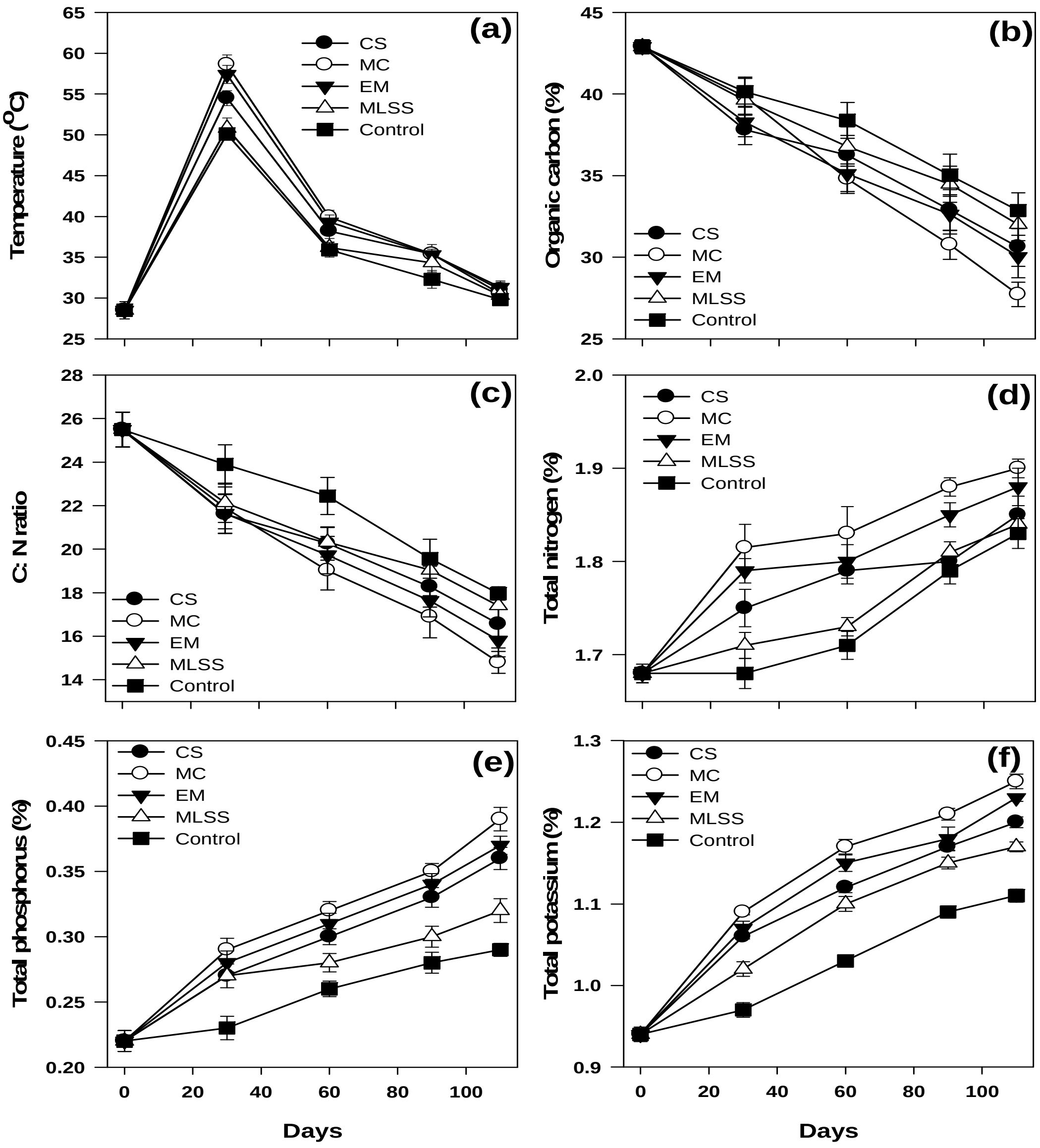

Fig. 2. Changes in (a) temperature, (b) organic carbon content, (c) C: N ratio, (d) total nitrogen, (e) phosphorus and (f) potassium content during biocomposting of waterhyacinth

gradually from beginning to end of the composting process. Invariably, at all the stages of composting waterhyacinth alone exhibited the highest EC (0.41, 0.37, 0.35 and 0.34 dS m^{-1}) and the lowest value was recorded in microbial consortium (0.36, 0.33, 0.31 and 0.29 dS m^{-1}) at 30, 60, 90 and 110th day of bio-composting, respectively**.** The decrease in EC subsequently as the composting progressed is due to the utilization of soluble salts by the microorganisms for the synthesis of their biomass (Tang *et al*., 2007). Significantly lower EC value was observed in the microbial consortium treatment compared to other treatments which might be due to better humification as a result of enhanced microbial activity.

The temperature of the composting process fluctuated significantly with treatment time (Fig. 2a). There was a rapid increase in temperature during the initial stages of composting and then a gradual decrease was observed. Among the treatments, microbial consortium and EM attained the highest temperature of 58.6 and 57.2°C on 30th day, respectively and then the temperature decreased thereafter. The generation of temperature in compost is a direct reflection of microbial activity. The increase in temperature during composting might be due to the release of exothermic energy throughout oxidation of

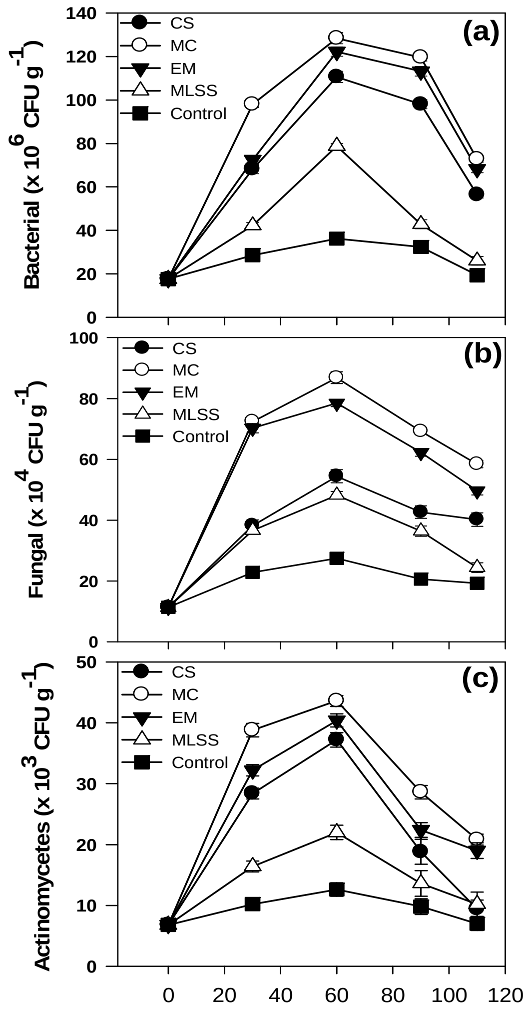

Fig. 3. Changes in microbial population, (a) bacteria, (b) fungi and (c) actinomycetes during biocomposting of waterhyacinth

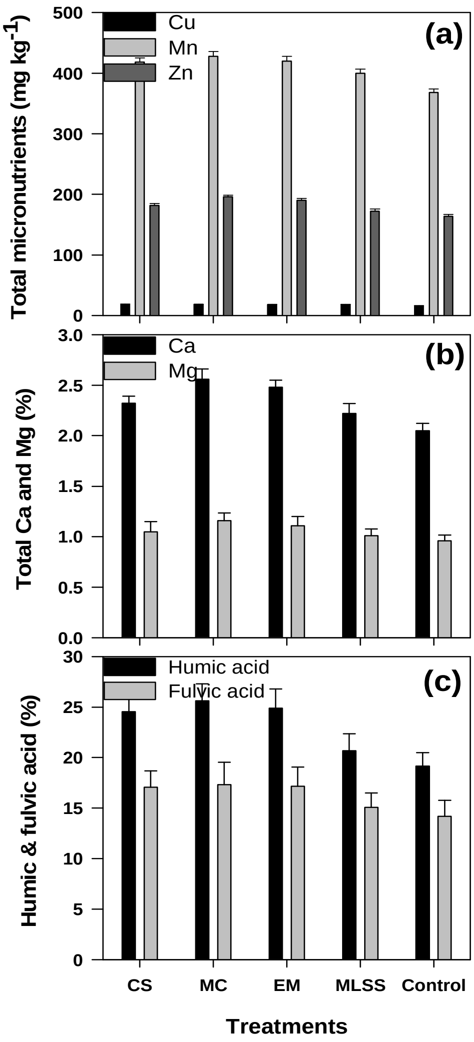

Fig. 4. Total (a) micronutrients, (b) Ca and Mg and (c) Humic and fulvic acid content in compost at maturity stage (110th day)

waterhyacinth biomass by microorganisms. It was also documented that the increases of temperature during the composting process is considered to be a reflection of the metabolic activity of the different groups of microorganisms (Pagans *et al*., 2006).

The changes in organic carbon content of compost during the composting process are given in Fig. 2b. The organic carbon content decreased in all the treatments with increase in the period of composting from 42.90 to 27.72 per cent. At 60, 90 and 110th day of bio-composting, significantly higher organic carbon content was recorded in waterhyacinth alone (control experiment) (38.38, 35.02 and 32.86 %, respectively) whereas the microbial consortium recorded lower organic carbon content of 34.81, 30.76 and 27.72 per cent, respectively. The optimum organic carbon content of microbial consortium was due to more efficient oxidation of organic carbon and high mineralization of waterhyacinth biomass by microorganisms present in microbial consortium due to the augmentation of the composting process over continuous thermophilic condition (Abdelhamid *et al.*, 2004). During this process higher heat, carbon dioxide and water vapor are produced. The organic carbon content in the microbial consortium was less than those other treatments, indicating that the rate of composting in microbial consortium is higher than that other treatment. The higher organic carbon losses of this experiment directly indicate the higher biooxidative activity of the microbial inoculums (Kalemelawa *et al*., 2012).

The C: N ratio of different treatment reflects the organic waste mineralization and stabilization during the process of composting. The C: N ratio is considered to be one of the simple indices to evaluate any organics for its suitability for soil application and it is the index traditionally used to establish compost maturity (Charest and Beauchamp, 2002). The changes in C:N ratio of compost during the process of bio-composting are given in Fig. 2c. At the early stages of bio-composting the C:N ratio was wider and narrowed down at the end of composting process. Throughout the bio-composting process (30, 60, 90 and 110th day), waterhyacinth alone (control experiment) had high C:N ratio (24, 23, 20 and 19, respectively) and it was closely followed by MLSS treatment. Whereas, the microbial consortium exhibited narrow C:N ratio of 21, 19, 16 and 14 at 30, 60, 90 and 110th day of bio-composting, respectively. The C: N ratio of various treatments at the time of harvesting ranged from 14 to 19. This indicated that compost was mature enough for harvest. Generally, a C: N ratio 20 is indicative of an acceptable maturity degree, but the ratio less than 17 is preferable (Kim *et al*., 2008). As the mineralization progressed, the carbon content of the waterhyacinth biomass decreased (due to losses of carbon mainly as carbon dioxide) with nitrogen content per unit material increased, which resulted in the decrease of C: N ratio (Goyal *et al*., 2005). At maturity stage significantly lower C: N ratio of microbial consortium treatment might be due to more efficient humification of composts as a result of enhanced microbial activity.

Total nitrogen content in all the treatments increased with time from 30th day of composting to 110th day of composting (Fig. 2d). At 30th day of bio-composting, the highest total nitrogen content (1.81%) was recorded in microbial consortium, which was statistically on par with EM (1.79%). During 90 and 110th day of biocomposting, significantly higher total nitrogen content was recorded in microbial consortium (1.88 and 1.90%). The lowest total nitrogen content was exhibited in waterhyacinth alone (control experiment) at all the stages of composting. The rapid increases at initial stage might be due to the thermophilic decomposition waterhyacinth biomass (part of organic forms of nitrogen) into ammonia gas (Paredes *et al*., 2000). The higher total N content in the treatment receiving microbial consortium might be due to concentration effect caused by degradation of organic matter, which could have reduced the weight of composting mass and there by increased the concentration of N (Sanchez-Monedero *et al*., 2001). This may be also due to immobilization of N by microorganism and reduced loss of NH_3. These results are consistent with the findings of Tiquia and Tam (2002).

Similar to the total nitrogen, the total phosphorus and potassium content of the compost in all the treatments showed gradual and progressive increase from the beginning to maturity stage of the composting (Fig. 2 e & f). The reason for the increase in concentration of total phosphorus and potassium might be due to faster degradation of organic matter or mineralization in to methane or carbon dioxide, which reduced the total mass of composting material and increased the concentration of the phosphorus and potassium in the compost (Chitsan, 2008). Significantly higher total P and K content in treatment with microbial consortium for composting might be due to more effective humification in these treatments. In addition the elevated phosphorous and potassium in the microbial consortium treatment might be the immobilization of solubilized phosphorous on the microbial cells (Rashad *et al*., 2010).

Changes of microbial population during composting of waterhyacinth

Microbial succession plays a key role in composting process and appearance of some microorganisms reflects the quality of maturing compost. The population of bacteria increased from the beginning of the composting till thermophillic phase (60 day) and decreased subsequently during the composting process (Fig. 3a). The bacterial population varied from 28.6 to 98.0, 36.2 to 128.4, 32.4 to 119.6 and 19.4 to 72.8 $\times 10^6$ CFU g^{-1} at 30, 60, 90 and 110th day of bio-composting, respectively. Invariably, waterhyacinth alone exhibited lower bacterial population at all the four stages of bio-composting. Among the treatment, the maximum bacterial population was observed in microbial consortium with 128 x 10^6 CFU g^{-1} followed by the treatment EM with 121 x 10^6 CFU g^{-1}. Bacteria seem to be the dominant microorganisms during all the stages of composting. Yu and Huang (2009) showed the importance of bacteria in the composting process, particularly in the initial stages and concluded that bacterial metabolism is responsible for the drastic increase in temperature during composting.

As in the case of bacterial population, the fungal population also increased up to 60 day and decreased subsequently. The fungi are responsible for the composting of many complex polymers like lignin, cellulose and hemicellulose and enabling bacteria to continue the decomposition process through the readily available carbon sources (Golueke, 1992). The fungal population was high during early stage of composting and the low population was recorded at the end of composting (Fig. 3b). The fungal population varied from 22.8 to 72.4, 27.4 to 86.8, 20.6 to 69.2 and 19.2 to 58.4 $\times 10^4$ CFU g^{-1} at 30, 60, 90 and 110th day of bio-composting, respectively. During 60th day of composting, microbial consortium recorded the highest fungal population of 87 x 10^4 CFU g^{-1} followed by EM with 78 x 10^4 CFU g^{-1} and CS with 54 x 10^4 CFU g^{-1}, whereas the least fungal population was observed in the plain waterhyacinth with 27 x 10^4 CFU g^{-1}.

As in the case of other microbial populations, the actinomycetes population also increased up to 60th day and decreased subsequently as the composting progressed. In composting, actinomycetes also play an important role in degrading complex organic chemicals (Fig. 3c). The actinomycetes population varied from 10.2 to 38.8, 12.6 to 43.6, 9.8 to 28.6 and 7.0 to 20.8 $\times 10^3$ CFU g^{-1} at 30, 60, 90 and 110th day of bio-composting, respectively. The treatment microbial consortium recorded the highest actinomycetes population at 60th day of composting with 43 x 10^3 CFU g^{-1} followed by the treatment EM with 40 x 10^3 CFU g^{-1}, whereas the least population was recorded in plain waterhyacinth with 7 x 10^3 CFU g^{-1}. De Bertoldi *et al*. (1983) reported that the most temperature responsive microorganisms are the actinomycetes, which help in degrading the complex organics polymers.

In all the treatment, the degradable waterhyacinth biomasses were relatively high at the initial stages of composting, which encourage a higher microbial activity. Thus, the amount of organic matter (waterhyacinth biomass) decreased more quickly with the increases of corresponding by-products of organic acids or other minerals. As a result, the microbial biomass disappeared due to lack of substrate for their metabolic activity (Ma *et al*., 2003). The number of mesophilic microorganisms underwent a marked decrease during the early thermophilic period and no recolonization took place during the subsequent low temperature period of composting process. As can be seen from the figure, the number of bacterial population was higher than fungi and actinomucetes in all the stages of composting. The more bacterial population might be due to the fact that during acidogenic phases of composting prevails the growth of other microorganisms (Goyal *et al*., 2005).

Total micronutrients, calcium and magnesium content

Total micronutrients, Ca and Mg content

of the compost for different treatments are depicted in Fig. 4a & b. Treatment receiving microbial consortium recorded maximum micronutrient content of 18.4 mg kg^{-1} Cu, 428 mg kg^{-1} Mn and 196 mg kg^{-1} Zn and the maximum Ca and Mg content of 2.56 and 1.16 mg kg^{-1}, respectively. This might be due to mineralization of organic matter as a result of enhanced microbial activity and thus decreases the total biomass and concentrated the nutrients. Similar higher micronutrients, Ca and Mg content were observed by Tian *et al*. (2012) and Kalemelawa *et al*. (2012) during aerobic decomposition of organic wastes treated with different microbial inoculums.

Compost maturity tests

The compost sample collected at the end of the 110th day provided better results for the qualitative tests for compost maturity (Fig. 4c). Among the treatments, microbial consortium had recorded the maximum humic acid content of 25.61 per cent, which was statistically on par with EM treatment. The treatment waterhyacinth alone recorded minimum humic acid content of 19.15 per cent, which can be considered as the indication of compost maturity according to Aparna *et al*. (2008). Significantly higher fulvic acid content (17.34) was recorded in microbial consortium and it was statistically on par with EM, whereas the lower content of 14.18 was recorded in waterhyacinth alone.

The high number of microbial colonies detected in the microbial consortium treatment directly correlate with a decrease in waterhyacinth biomass content. The final nutrient value of the compost was possibly also due to additive effect of nutrient sources from the waterhyacinth biomass. Because the waterhyacinth biomass itself have considerable nutrient sources as they obtained from the paper mill effluent treatment plant. Finally, the produced waterhyacinth biocompost exhibited a higher nutritive value, which is suitable as soil amendments.

CONCLUSION

In the present investigation, waterhyacinth from the pulp and paper mill effluent treatment plant were biocomposted using elite microbes. The pH of the compost increased slightly upto 90th day, whereas the EC decreased gradually towards the end of compost. The treatment with microbial consortium recorded the lowest C: N ratio and the highest total N, P, K, Ca and Mg at maturity stage. The microbial populations were increased upto the 60th day and decreased subsequently irrespective of the microbial inoculants used. At the end of biocomposting, the humification parameters for all the treatments were positive indicating the compost maturity.

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