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Research Article

Accelerated Biodegradation of Solid Organic Waste through Biostimulation

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Abstract: A huge amount of solid organic waste is generated daily in cities, causing disposal and environmental problems. It is critical to manage these wastes in cost effective and environment friendly manners. Biostimulation, i.e., addition of nutrients to enhance efficacy of indigenous microorganisms, is an effective approach to enhance degradation rate of organic wastes. In our study, this approach was used to accelerate the biodegradation of household solid organic waste. Rate of degradation was monitored by observing a decrease in carbon (C)/nitrogen (N) ratio. A decrease in C/N ratio was observed ($P<0.05$) when the waste material was amended with N and phosphorus (P), in a ratio of 50:2:2 during 40-day degradation process. Other physico-chemical parameters, like pH, electrical conductivity, total organic C, total N and microbial counts increased compared to control ($P<0.05$) during the incubation process. Thus, this study revealed that biostimulation strategy could effectively enhance degradation rate of solid organic waste.

Keywords: Biostimulation, nutrients, organic waste, biodegradation

1. INTRODUCTION

Solid waste generation is a natural and global phenomenon and is positively correlated with population growth, urbanization, industrialization and changing consumption patterns [1]. Proper management of solid waste is a costly venture. For example, during the year 1990, Asian countries alone spent about 25 billion US dollars on solid waste management which was expected to rise up to 50 billion US dollars per annum by 2025 [2]. A study by Ministry of Environment and Urban Affairs, Government of Pakistan revealed an increasing waste generation trend with increase in population in selected cities of Pakistan. The study also indicated that 1.90 to 4.29 kg waste was generated per household per day in cities of Pakistan. An improper waste management, including collection, transportation and disposal or dumping of waste, has been a major problem in Pakistan which causes environmental pollution and sanitary problems [3]. This solid waste constitutes 30–55% of food by weight in different countries [4] while in Pakistan it constitutes 8.4-21% [5]. The management of food waste including landfill dumping in past has been employed for several years but now waste reduction and recycling has been enforced in different forms [4]. Landfill causes ground water contamination while in case of incineration, there is a problem of green house gas emissions, leading to the environmental degradation [6-7].

Aerobic composting is one of the best environmentally sound option for the treatment of huge amount of household organic waste [4], in which microorganisms reduce, eliminate, or transform the waste into benign products without production of any harmful byproduct. During the process, complex organic wastes are converted into stable chemical compounds with the release of heat, water vapors, and carbon dioxide (CO_2) [8]. Weed seeds and pathogens become inactivated due to the released heat. The process also converts

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gaseous N (N_2) from unstable ammonia to stable organic forms, and reduces the waste volume and improves the nature of the waste [9]. The process occurs more efficiently at carbon-to-nitrogen (C/N) ratio between 30 and 40. As aerobic composting is based on microbial respiration, so microorganisms need food, energy and habitat. They need C as their energy source in order to manufacture enzymes for complex carbohydrates degradation into simpler forms which are then being used by these microorganisms [10]. These nutrients are the basic building blocks of life and allow microbes to create the necessary enzymes which help them in the breakdown of contaminants. Carbon is the most basic element of living forms which is needed in greater quantities to microbes than other elements. Microbial cells constitute about 95% of hydrogen, oxygen, and N of the weight of cells. Phosphorous and sulfur contribute with 70%. The nutritional requirement of C/N ratio is 10:1, and carbon to phosphorous is 30:1 [11].

In present study, an attempt is made to enhance the aerobic composting through biostimulation by the addition of nutrients in order to enhance the efficacy of microorganisms [12]. Urea and trisuper phosphate (TSP) are used as nutrient source. Indigenous microorganisms are stimulated by injecting these trace nutrients to waste system to increase the activity of microorganisms [13]. The main objective of this study was to enhance the degradation process of house hold organic waste by the use of biostimulation technique. The compost obtained after the process could efficiently be used as soil amendment.

2. MATERIALS AND METHODS

2.1 Household Fruit Waste as Composting Material

Household organic waste containing food and vegetable waste was used as experimental material and were collected in polythene bags from the residential colony of PMAS Arid Agriculture University, Rawalpindi. The organic waste was then transferred to the University's research farm of Department of Environmental Sciences. It was air-dried for a couple of days to remove the excessive moisture. The unwanted substances, i.e., pieces of metals, glass and plastic, were removed manually from the wastes. The sorted organic material was crushed to fine particles and then transferred to a cylindrical composter. A moisture level of 40% (v/w) of the compost was maintained during the composting process.

2.2 Experimental Setup and Procedure

Composting was carried out in partially covered lid cylindrical composters (50 L in volume) made of high density plastic material with height of 22 inches, and a diameter of 11 inches (Fig. 1), supplied with leachate outlet and biomass outlet system. The bioreactor was filled up to 15 inches (*dc*) with organic waste. The purpose of empty space was to turning the organic waste. Composting material was mixed daily for providing proper aeration. A gap was also made between the lid and mouth of the container for aeration purpose. Urea and triple super phosphate (TSP) were used as a source of N and P respectively which were mixed with household organic waste in proportions described in Table 1.

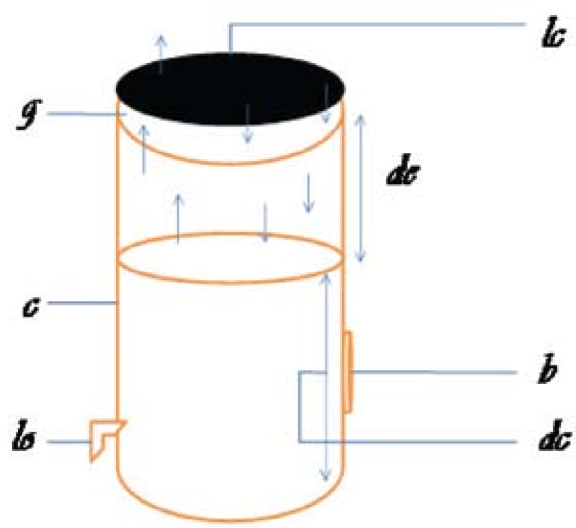

Fig. 1 Design of the compost bioreactor used in the study: *lc* (container lid), *g* (gap between lid and container mouth), *c* (bioreactor container), *lo* (leachate outlet), *dc* (area containing waste), *b* (biomass outlet for sampling), *de* (empty area for proper aeration and turning), (airflow direction).

Table 1 Experimental setup of treatments with different ratios of waste, nitrogen and phosphorus.

Treatment*	Ratio of waste, N and P_2O_5
Control (waste only)	50:0:0
B1 (waste + urea)	50:1:0
B2 (waste + urea)	50:2:0
B3 (waste + urea)	50:3:0
B4 (waste + triple super phosphate)	50:0:2
B5 (waste + urea + triple super phosphate)	50:1:2
B6 (waste + urea + triple super phosphate)	50:2:2
B7 (waste + urea + triple super phosphate)	50:3:2

*50 kg food waste (dry weight basis) in the bioreactor was amended either with urea, triple super phosphate or both.

2.3 Physico-chemical Monitoring and Analysis of Compost

A sample of 100 g was taken after every ten days of composting period from top middle and bottom of the composter for analysis of electrical conductivity, pH, total organic C, total N, P and microbial counts. Electrical conductivity and pH was determined in aqueous extract. For this purpose, 10 gram of solid moist compost sample was diluted in 90 mL of water. The electrical conductivity and pH was measured by using EC meter (DIST HI 98303) and pH meter (BMS pH-200L) respectively. The moisture content of the compost material was determined by oven drying method at 105 °C for 24 h [14].

The ash method was used for the determination of % C content in the compost samples. One gram of pre weighed oven dried compost sample was taken into silica porcelain crucible and was burned in a muffle furnace at 500 °C for 2-4 hours. The residue obtained in the form of ash is mineral content of the sample. This ash was weighed and percentage ash content was calculated by using simple percentage formula. Then C content of the sample was calculated using the following equation [15].

$$\text{Organic C (\%)} = \frac{100 - (\text{Ash \%})}{1.8} \qquad \text{(Equation 1)}$$

Organic matter content in the material was measured by burning oven at 550 °C for 6 h [14]. The loss of organic matter (k) was calculated according to the Equation 2 [16] by using the initial and final values of organic matter contents.

$$k = \frac{[\text{OM}m\ (\%) - \text{OM}p\ (\%)] \times 100}{\text{OM}m\ (\%)\ [100 - \text{OM}p\ (\%)]} \qquad \text{(Equation 2)}$$

where OM*m* is the organic matter content at the beginning of composting process while OM*p* is the organic matter content at the end of the composting process.

Total phosphorus (TP) was analyzed by spectrophotometric method by using molybdenum in sulphuric acid while total nitrogen (TN) was also analyzed by spectrophotometric method used by Anderson and Ingram [17].

For microbial analysis, dilution plate technique was used. Colony forming unit (CFU)/g was calculated according to the following formula:

$$\text{CFU/g sample} = \frac{\text{Number of colonies} \times \text{Dilution factor}}{\text{Volume of culture plate}}$$

2.4 Statistical Analysis

ANOVA was performed on data obtained during the 40-day composting process of HFW [18].

3. RESULTS AND DISCUSSION

3.1 Physico-chemical Quality of Compost

Total organic carbon (TOC) content was less in all composts compared to initial TOC. Data in Fig. 2 reveal a significant decrease in TOC at 40 days in all the treatments during control and biostimulation applications. The best results were obtained when organic waste was treated with N and P at a ratio of 50:2:2 in B 6 bioreactor and TOC content decreased from 54.4 % to 49.2 %. Our observations are supported by the results of Alkoaik and Ghaly [19] and Kumar et al [20], who reported similar type of loss of TOC during composting process. The gradual decrease in TOC content was due to loss of CO_2 during microbial respiration [4]. The high porosity of the waste material was also the reason for decrease in TOC as it allows diffusion of gases, especially entrance of oxygen and release of CO_2, which can accelerate the degradation of organics by microbes [21].

Total N was significantly higher in the end

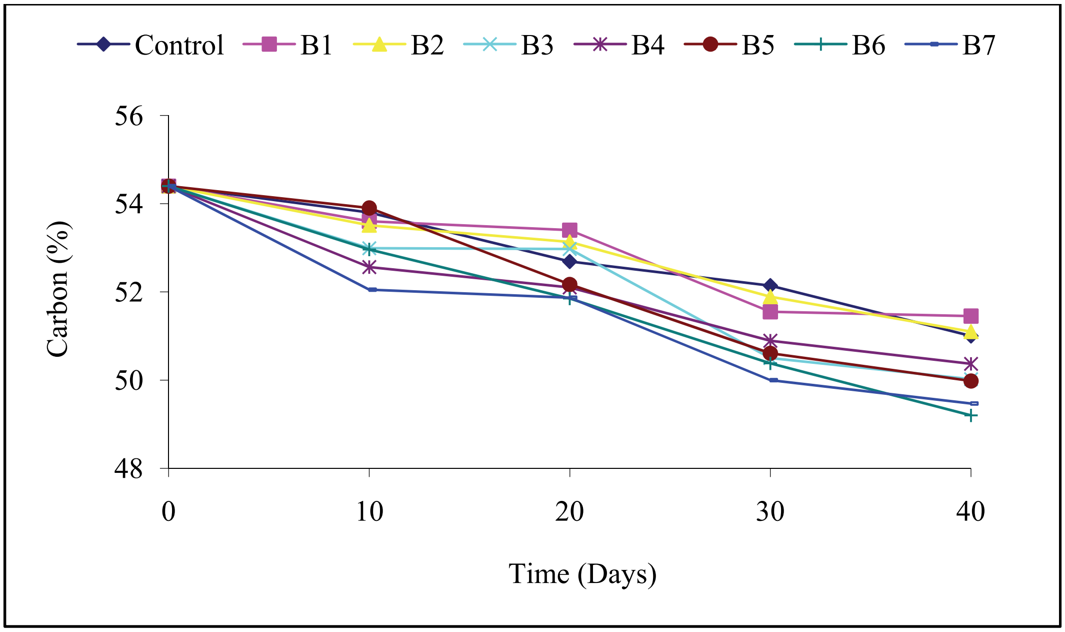

Fig. 2 TOC content of HFW in bioreactors.

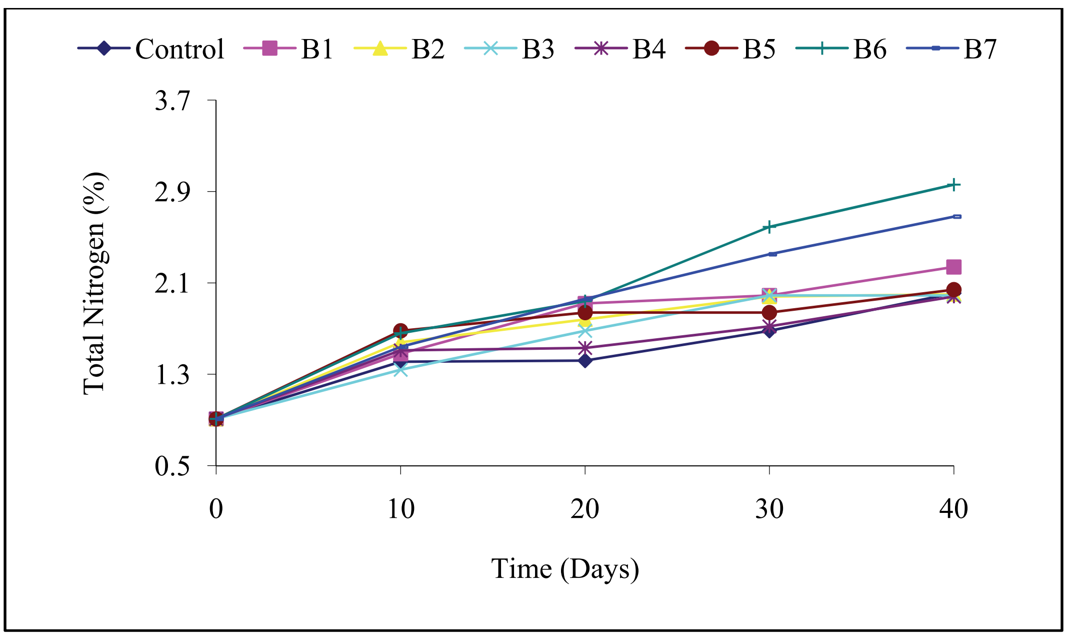

Fig. 3 TN content of HFW in bioreactors.

product than initial values (Fig. 3). Nitrogen enhancement was 2-3%. During initial composting at 30 days, N was slightly increased in all treatments. However a significant increase was observed after 40 days of incubation. The increase in percentage of total N was maximal when waste was amended with N and P in a ratio of 50:2:2 in B 6 bioreactor with a value of 3%. The increase of total N was due to net loss of dry mass, and also attributed to the concentration effect as a consequence of strong degradation of organic compounds, which reduced the weight of the composting mass. It might also be due to presence of N fixing bacteria in the compost which contribute to increase in total N [4]. However, it was also reported by Ogunwande et al [22], that the C/N ratio affected the total N loss and it was

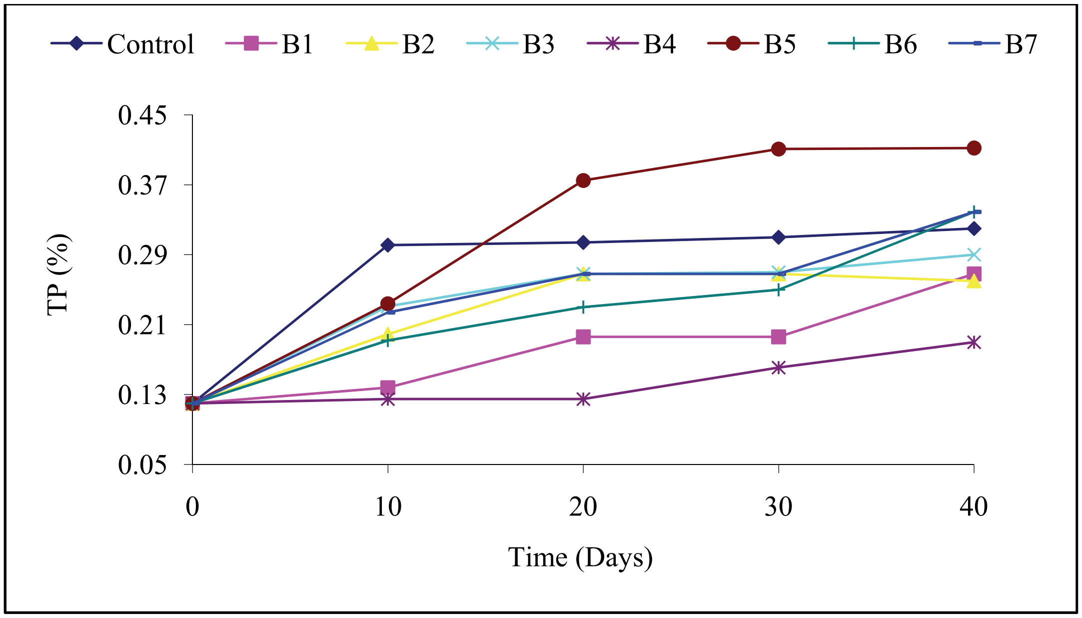

Fig. 4 TP of HFW in bioreactors.

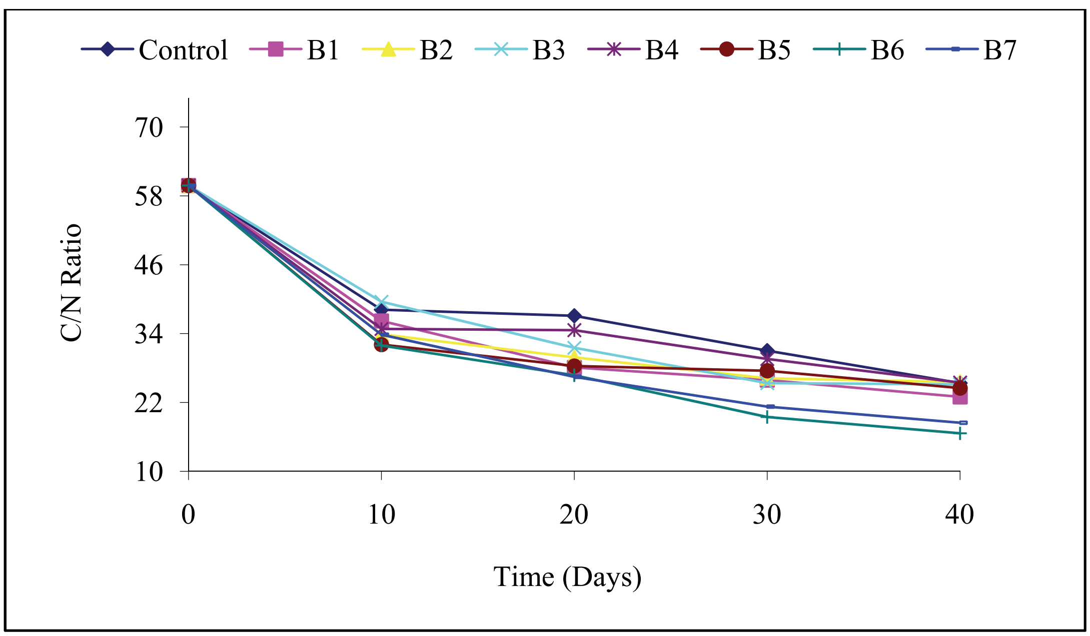

Fig. 5 C/N ratio of HFW in bioreactors.

largely attributed to the volatilization of ammonia (NH_3).

There was an increase in TP in the final composts in all bioreactors as compared to TP content in initial waste (Fig. 4). The overall increase in the TP content was maximum in the bioreactor B 5 (50:1:2) with 0.41 % and minimum increase was in the bioreactor B 4 (50:0:2) with 0.19 %. The increased TP content was in accord with the findings of Rodriguez et al [23] who observed the increasing trend of P content in compost. The increase in TP was due to addition of TSP. Furthermore; the increased bioactivity could be attributed to the elevated TP content. The decrease in P at any stage was largely attributed due to leaching of P as it is possible that a portion of the soluble/bioavailable P leached to the bottom of the

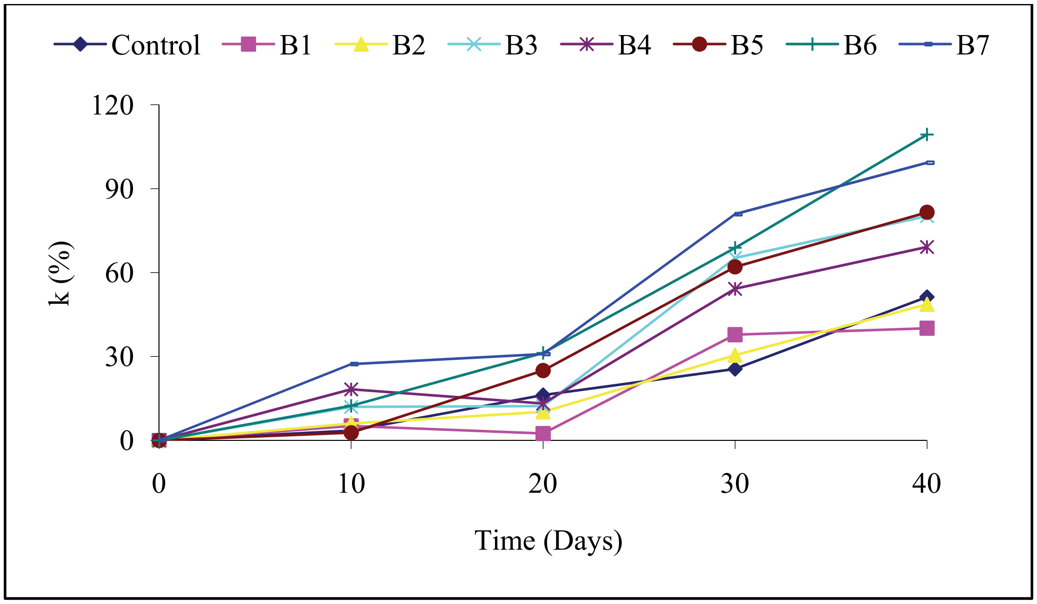

Fig. 6 Changes of loss of organic matter in bioreactors containing HFW.

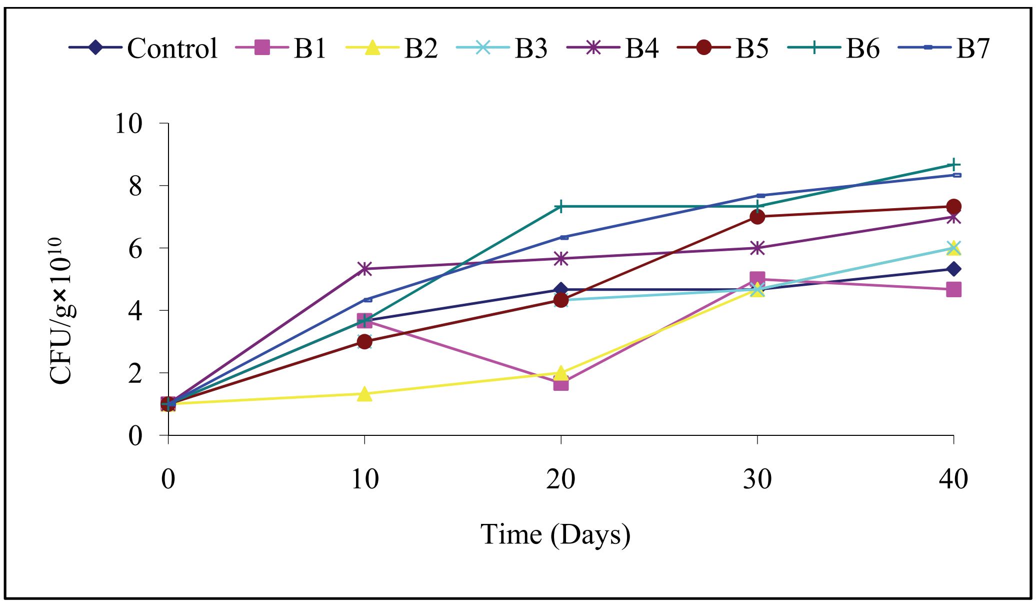

Fig. 7 Changes in microbial population in bioreactors.

bioreactor and was not sampled during analysis of compost [24].

3.2 C/N Ratio Index of Compost Maturity

The C/N ratio of substrate reflects mineralization of the organic waste and stabilization during the process of composting. It is widely used as an index of maturity for organic wastes [25]. The loss of C as CO_2 through microbial respiration and simultaneously addition of N as urea lower the C/N ratio of the substrate. The decrease in C/N ratio indicates the better degradation and maturity of the compost. The decrease in C/N ratio was due to mineralization of the organic matter by microorganisms [26] which also enhances the microbial activity as C and N are the building blocks of bacterial cell material so these are being utilized by microorganisms. Although the microorganisms are present in organic waste, they cannot necessarily be there in the numbers required

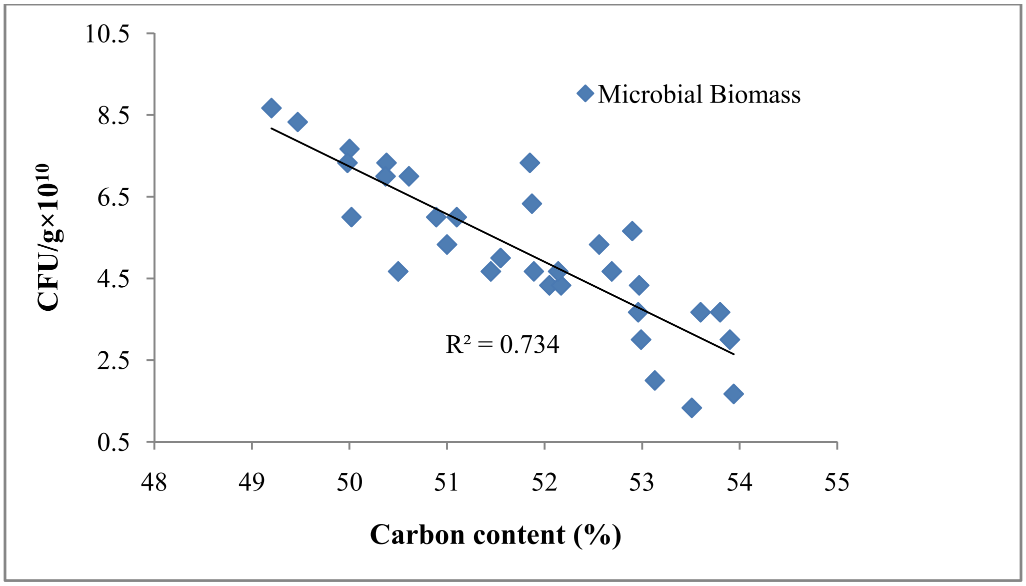

Fig. 8 Regression analysis of carbon content and microbial population.

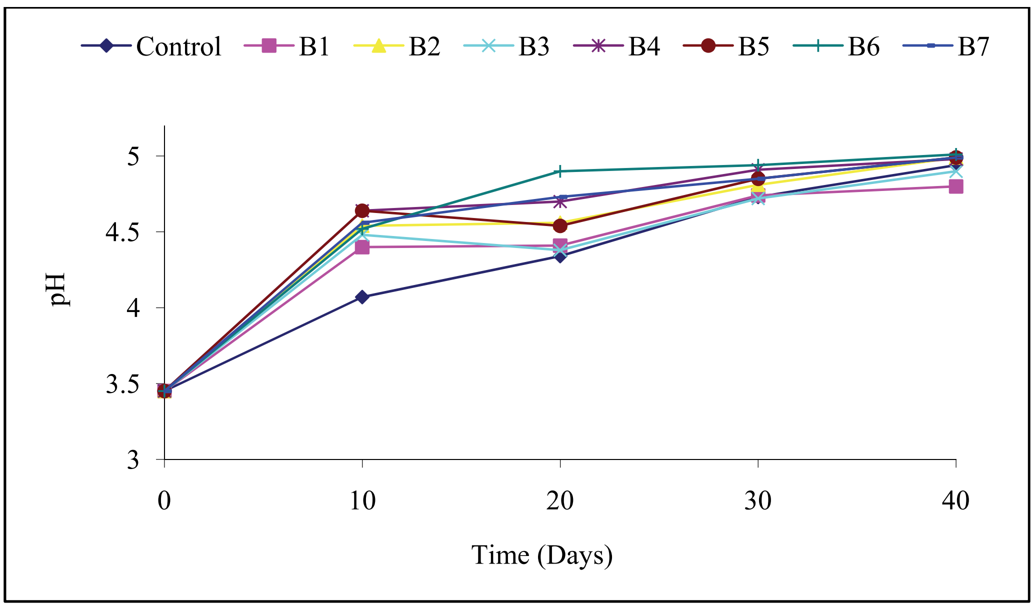

Fig. 9 Changes of pH in bioreactors.

for better degradation. Their growth and activity must be stimulated [11]. As is evident from Fig. 5, C/N ratio decreased with time in all bioreactors. Initial C/N ratio was 59.8 before the addition of N and P. Final C/N ratios were in the range of 16.6-25.6. As compared to the initial values, the order of decrease in C/N ratio was: B 6 (16.6) < B 7 (18.5) < B 1 (23.0) < B 5 (24.5) < B 3 (25.1) < B 4 (25.4) < control (25.4) < B 2 (25.6) (Fig. 5). Decline of C/N ratio to less than 20 indicates an advanced degree of organic matter stabilization and indicates a satisfactory degree of maturity of organic wastes [27]. The C/N ratios of less than 20 in bioreactors B 6 (50:2:2) and B 7 (50:3:2) revealed the extreme biodegradation of waste. Several authors took the above mentioned values as an optimum range of C/N ratio [6, 7]. The increase in C/N ratio at any stage during incubation process was probably due to concentration caused by decrease of the C substrate resulting from CO_2 loss [28] as a consequence of degradation of non-nitrogenous organic matter (carbohydrates, etc.).

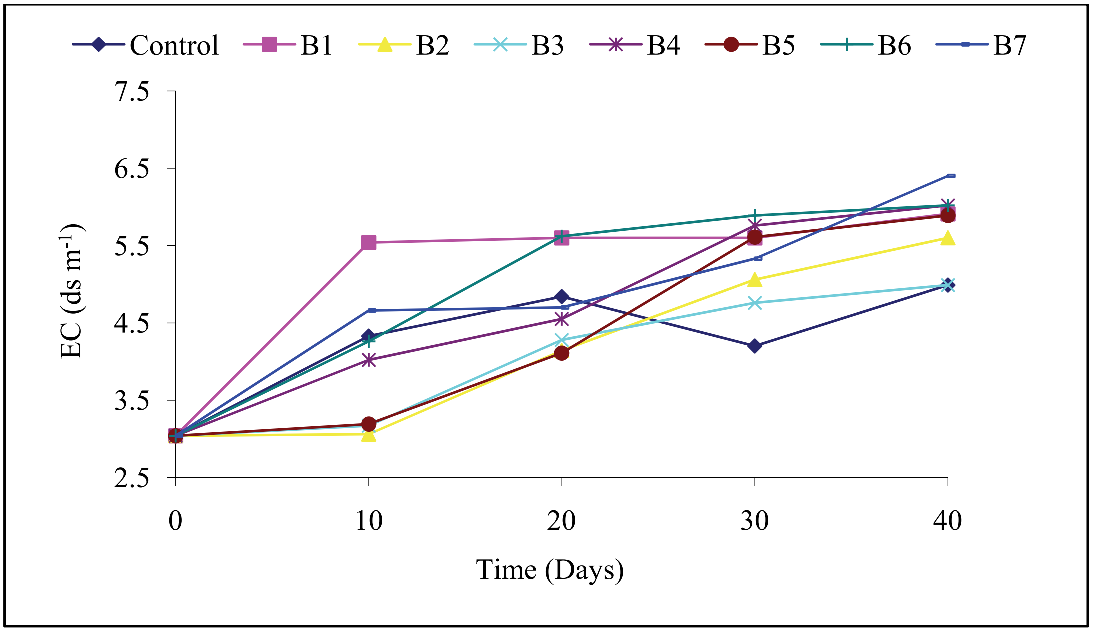

Fig. 10 Changes of EC in bioreactors.

3.3 Organic Matter Degradation

Fig. 6 shows the trend of organic matter degradation. The decrease in organic matter content indicated the overall composting rate. The volume and mass of waste under study significantly decreased during the composting period due to organic matter oxidation and conversion into CO_2, water and new microbial biomass [16]. Each bioreactor was filled with approximately 50 kg of waste which decreased significantly in terms of volume and mass due to loss of moisture and organic matter content in the bioreactors. Highest content of organic matter was degraded in bioreactor B 6 (k=109.4) in which waste was amended with N and P at a ratio of 50:2:2.

3.4 Microbial Population

The microbial growth is also important parameter of compost maturity, as composting process mainly depends upon the microorganisms [29]. Microbial growth was slow at initial stages of incubation in all bioreactors but increase gradually later on (Fig. 7). The maximum growth was observed in bioreactor B 6 (8.67×10^{10}) during 40 days of incubation and it took long time to become stable in the system due to slow acclimatization of the indigenous bacteria [4]. Regression analysis (Fig. 8) showed negative correlation between microbial counts and C content. Microbial population increases with the decrease in C content which strongly indicated that C is used by microorganisms and it lost from the system in the form of CO_2.

3.5 Trends of pH and Electrical Conductivity

The pH of the substrate material was significantly different from initial values (Fig. 9). The pH of the material in bioreactors increased significantly from acidic to alkaline during 40 days of incubation process. Highest pH value was observed in bioreactor B6 (5.01) and the lowest in B1 (4.8). The increase in pH was related to the increase in ammonia. It was observed by Sundberg and Jonsson [30] that increased aeration rates at the start of the process resulted in large heat losses, higher microbial activity, faster decomposition and a faster rise in pH. The pH observed in our research was in accordance with results of Tsai et al [6]. The decrease in pH at any stage might be due to presence of fatty acids [31]. Chroni et al [32] reported increased pH values of 4.1 to 7.8 which are contradictory to our results, which are likely attributed to the breakdown of the volatile fatty acids that are formed in first stage of the decomposition process.

Electrical conductivity indicates the salinity of compost and it is a good indicator of the applicability of compost for agricultural purposes [33]. The EC was increased in the final composts than initial values (Fig. 10). Highest EC was observed in bioreactor B7 (6.4 dS m^{-1}). Our results are supported by the work of McMahon et al [34] who also observed the similar EC trends. This increase in EC might be due to loss of organic matter [35] and release of mineral salts such as phosphate, potassium and ammonium ions through the decomposition of organic substances [36]. Increase in concentration of soluble salts reflected the progressive mineralization of the organic matter [37]. Electrical conductivity values reflected the degree of salinity in the compost, indicating its possible phytotoxic or phyto-inhibitory effects on the growth of plant if applied to soil [38].

4. CONCLUSIONS

Composting of household waste through biostimulation was characterized by estimating total organic C, total N, C/N ratio, total P, pH, electrical conductivity, organic matter degradation and microbial counts. Addition of N and P greatly enhanced composting and biodegradation of the household food waste. Decrease in C/N ratio was highest in bioreactor B 6 with a waste to N and P ratio of 50:2:2. The compost can be used beneficially for improving soil health.

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