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ORIGINAL ARTICLE

Open degradation kinetics of organic fraction of municipal solid waste

Shwetmala Kashyap[1] · **H. N. Chanakya**[1,2] · **T. V. Ramachandra**[1,3]

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Abstract

The objective of this study was to determine the time required to achieve stabilization of organic fraction of municipal solid waste and to develop a decay model to describe volatile solid (VS) loss from open degradation of organic fraction of municipal solid waste in open dump sites. The role of soil contact and access to degradation by micro and meso + microorganisms were considered in this study as the driving factors of degradation. The weight loss in the organic fraction of municipal solid waste was monitored during the 30 days of degradation. The moisture content and volatile solids were rapidly lost within 6–8 days of exposure under dry conditions followed by slowing down and stabilization to low levels. The role of micro-fauna in the early stage of degradation was important. The function of micro-organisms was restricted due to the rapid fall in the moisture content of degrading municipal solid waste and this led the rest of the process to be carried out by meso and macro fauna. The degradation followed an exponential decay pattern with two potentially acceptable rate kinetics in two phases. Phase I followed zero-order kinetics, occurred till the 6th day of degradation and after a short transition, it was followed by phase II first-order kinetics. The rate constant of phase I and phase II are 16.6 g/kg/day and 0.024/day, respectively. As most of the waste was dried in the initial phase of degradation, it lowered the decomposition rates drastically.

Keywords Decomposition rate · Disposal · Factors · Organisms · Soil contact Municipal solid waste

Introduction

India generates > 0.2 Teragram (Tg) of municipal solid wastes (MSW) everyday and in many cities facilitiess exist to treat Organic Fraction of Municipal Solid Waste (OFMSW) through either aerobic or anaerobic methods (Asnani and Zurbrugg 2008; Census of India 2011; CPHEEO 2016). About 10–20% of the collected waste is often disposed of unscientifically in the vacant land around these cities and subjected to open degradation in uncontrolled conditions without any recovery of resources. Open decomposition is evident in many emerging towns and cities and these sites are generally difficult to locate (Chanakya et al. 2015). Such open dump sites can pose a threat to the immediate environment and result in air, soil, and water contamination.

Most Indian cities have solid wastes where > 80% is OFMSW, especially when MSW is collected and sampled from households (Chanakya and Sharatchandra 2005; Chanakya and Swamy 2011). This is largely comprised of biodegradable organic fractions such as leftover food, vegetables, and fruit peels. Many of these open dumps within cities also act as ephemeral storage sites lasting 2–7 days (Chanakya et al. 2009). In these temporary open dumps, the major fraction of MSW is organic and easily fermentable and therefore has the propensity to undergo rapid microbial degradation (Biddlestone and Gray 1988; Bot and Benites 2005; Ferronato and Torretta 2019). OFMSW components such as fruits, vegetables, and food wastes tend to degrade rapidly, whereas the mature leafy components (e.g. leaf litter, garden wastes, etc.) of organic waste decompose slowly (Biddlestone and Gray 1988; Chanakya et al. 2009). This degradation process involves the biochemical transformation of complex organic materials into simple organic and inorganic compounds.

The degradation of organic waste residues cycles the nutrients contributing to biological growth and the nutrient

✉ Shwetmala Kashyap
shwetmala@gmail.com

1 Centre for Sustainable Technologies, Indian Institute of Science, Bangalore, India

2 Centre for Infrastructure, Sustainable Transportation and Urban Planning, Indian Institute of Science, Bangalore, India

3 Energy and Wetlands Research Group, Centre for Ecological Sciences, Indian Institute of Science, Bangalore, India

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recycling processes (Chanakya and Sharatchandra 2005). The degradation rate of organic matter also depends on the physical and chemical nature of organic matter, the ambient environment, and also the activity of soil organisms. In dispersed piles of MSW, the soil ecosystem functions both as a source of microbial and faunal inoculum as well as a sink for the decomposition intermediates and end-products. Under such conditions, these systems resemble decay of the fallen fruits and leaf litter of typical semi-deciduous ecosystems where contributions to the degradative process come from various modes of faunal and soil micro-flora assisted degradation. The soil microorganisms assist in the breakdown of carbon and its mineralization, fauna help in the mechanical breakdown of organic wastes, a part of which is subsequently ingested and broken down through their metabolism to be finally excreted back to soil (Brussaard 1997; Paris et al. 2008; Gougoulias et al. 2014). The degradation of organic matter added on to soil surface as similar to aerobic windrow composting has generally been represented as Y_0e^{-kt}; an exponential decay model where k modifies the degradation rates to suit temperate and tropical environments (Jenkinson and Ayanaba 1977; Jenkinson 1981; Middleton 2020). Anaerobic decomposition of various components of MSW held in pile can also be described as a two-component model wherein the first-rate describes the loss of easy to decompose constituents and the second slope describes the degradation of the slow to decompose recalcitrant components of the feedstock (Chanakya et al. 1999, 2009; Ravikumar 2014).

Earlier studies were collated to model and represent OFMSW in large and deep dumpsites and arrive at normative indices (IPCC 2000). However, there is inadequate information about the degradation pattern of OFMSW in open dump sites, especially when there is a mix of biomass with a large fraction of easy to degrade waste components and the degradative conditions fluctuate between partially aerobic to partially anaerobic. This necessitates identification and understanding of the relative contribution of different actors to the overall process, degradation pattern, and the role of agents of degradation.

The objective of this study was to identify different actors involved in the open degradation pattern of dumped OFMSW and to understand the degradation pattern of MSW with the kinetics. This study is important to various developing countries where MSW with a large OFMSW content gets disposed in several forms of open dump sites. The importance and extent of various routes thus need to be elucidated to forecast possible environmental, ecological, sustainability, and human health issues.

Materials and methods

Composition of mixed MSW

The composition of waste from domestic sources in and around Bangalore, capital city of Karnataka, India, is predominantly of easily degradable components such as fruit waste, vegetable waste, and food waste (Chanakya and Swamy 2011). For the degradation pattern analysis, the mixed MSW was considered to consist of food waste (10%), vegetable waste (38%), and fruit waste (52%) comparable to the segregated composition of OFMSW based on the previous experimental trials. The quantity of each of the components of the OFMSW sample is presented in Table 1. These biomass feedstocks were collected within and around the Indian Institute of Science (IISc) campus in Bangalore, India. Campus boundary is enclosed within 13.01°–13.02° latitude and 77.55°–77.57° longitude. Individual components OFMSW were collected fresh (within 6–8 h of generation) to synthesize the primary waste sample.

Open degradation of OFMSW with soil contact

OFMSW was shredded to 10 mm fragments and mixed in the above proportion from which replicates of 500 g each (fresh weight basis) were made. The waste quantity was selected based on the trial run. These samples were spread on a base layer of nylon mesh occupying a ground area of 35 × 35 cm of different pore sizes namely 0.1 and 2 mm (to maintain contact with soil and the organisms) as well as on

Table 1 Waste composition of the sample (500 g)

Waste categories	Waste components	Quantity (g)
Vegetables	Spinach (spinach, cabbage, spring onion)	49
	Potato	31
	Tomato	23
	Onion	47
	Others (cucumber, cauliflower, beet root, radish, carrot, green chili)	40
Total vegetables		190
Fruits	Sweet lime	44
	Mango	42
	Watermelon	34
	Pineapple	42
	Grapes	5
	Musk melon	93
Total fruits		260
Mixed food waste		50
Total waste		500

an impervious low-density polyethylene (LDPE) sheet. This facilitated recovery and analysis of decomposing samples at different periods of decomposition. These experiments were carried out in the field to take advantage of the prevailing environmental conditions resembling open dumps. This experimental area was secured to prevent the mixing of samples due to the interference of stray animals. A total of 74 samples (3 treatments, 12 time intervals, 2 replicates with 2 samples representing day 0) were used to record extent of dry weight loss (e.g. 0, 1, 2, 3, 4, 6, 8, 10, 12, 15, 18, 22 and 30 days; time intervals chosen based on a trial run). The three treatments were, (a) open to the sky but with no contact to the soil below by laying out the OFMSW on impervious LDPE sheets, (b) open to the sky with OFMSW placed on a 0.1 mm mesh allowing access to soil micro-organisms but not meso-fauna emerging from soil and (c) laid out on soil separated by a 2 mm mesh permitting both soil contact for micro-organisms as well as meso-fauna. This layout aided in understanding the role of soil as a source of microbial, micro, and meso faunal inoculum that is necessary for the degradation process (Swift et al. 1979; Bradford et al. 2002; Paris et al. 2008). Residual waste samples in the three treatments were recovered at the end of each chosen period of decomposition, their wet and dry weights were estimated. From this, loss in weight over the intervening period was determined. It indicated the role of soil contact with/without access to fauna in hastening and improving degradation of OFMSW placed in open dumps.

Role of agents in waste degradation under only 'soil contact' conditions

An attempt is made to identify the agents involved in OFMSW degradation emerging only from the ground or soil contact in this experiment. The waste composition, number of samples, and monitoring intervals were based on the previous experimental trials. A total of 50 waste samples (2 treatments, 12 time intervals, 2 replicates with 2 samples representing day 0) were deployed to represent various decomposition periods. The two treatments provided insights on the sizes of organisms involved in the degradation. These were classified as micro (< 0.1 mm) and meso + micro (2 mm). The micro involves the organisms < 0.1 mm of body size and meso + micro involve all the organisms of the body size < 2 mm. Sealed mesh bags of the two chosen mesh sizes aided in allowing the organisms to interact with waste and assimilate it (Bradford et al. 2002; Paris et al. 2008). This grouping of micro and meso + micro is based on the body sizes of organisms that are typically involved in the decomposition of organic matter in the food web (Swift et al. 1979). A sample of 500 g OFMSW was placed in nylon mesh pouches (mesh size 0.1 and 2 mm) and tied with a nylon thread. These nylon pouches were covered from the top with a strong steel mesh of pore size 5 mm to prevent interference by rodents and birds. This method helped in identifying the role of various soil-borne organisms in the degradation process while excluding larger organisms.

Monitoring of waste degradation and analysis

Residual organic waste samples collected on the respective sampling days, were weighed and blended to the homogeneous sample. Homogenized samples were then oven-dried at 105 °C to determine the total solids (TS) and later oven-dried samples were powdered fine using a laboratory grinder. APHA (American Public Health Association) (2005) methods were used for analysis. Duplicate samples of 2 g each were kept at 550 °C for 2 h to determine volatile solids (VS) and ash content. VS loss was expressed both in mass terms as g VS and as the percentage of initial VS lost at each time interval. A 1 g dry sample of degraded waste was used to analyze the carbon, hydrogen, and nitrogen using CHN analyzer (LECO elemental analyzer).

Analysis of degradation pattern and rate kinetics

VS (g) of residual material remaining in open dumps was plotted against time to obtain insights of the underlying degradation process. The best fits (R^2) were determined. All statistical analyses were done using PAST statistical software. The VS data were analyzed to explain the rate of degradation of organic waste. The overall decomposition cannot normally be described by simple equations, as different fractions of organic wastes do not necessarily degrade at the same rate. Two broad classes have been generally accepted to represent the degradation process of individual components based on the decomposition rates namely, the 'rapidly degradable' with a higher rate constant and the 'slowly degradable' with a low decay constant (Chanakya et al. 1999). Thus, in this study, rate kinetics was determined considering the pattern of organic waste decomposition in two phases depending on the relative content of rapid and slow to degrade components in the waste (Reddy et al. 1980; Ajwa and Tabatabai 1994).

Results and discussion

Waste degradation in open dump

A weight loss in OFMSW of 88 and 61% of wet weight and TS, respectively was observed during the degradation process of 30 days. Figure 1 shows the wet weight lost (WWL), total solids (TS), and moisture content (MC) with time in open dumps. During the first week, the WWL reduced to 27% of the original weight, whereas TS reduced to 56% of

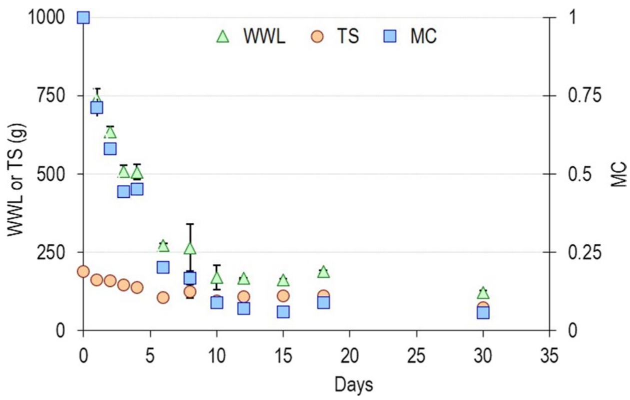

Fig. 1 Fraction of moisture and TS remaining in open degradation

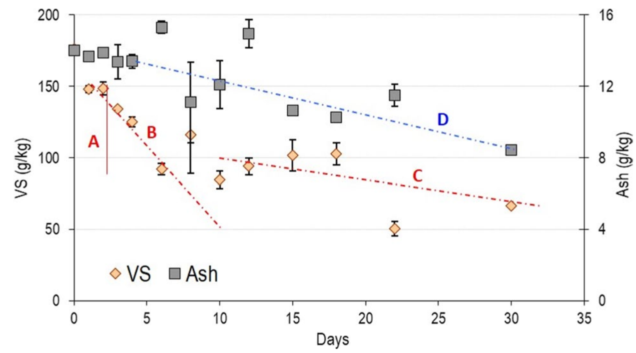

Fig. 2 Pattern change in VS (**a**–**c**) and ash (**d**) content in open degradation

the original level. The OFMSW lost moisture content rapidly during the early stages of degradation, thereafter the rate of weight loss slowed down and soon reached < 10%. The moisture content was considered to identify the potential degradative agents functioning at various stages of waste decomposition. The OFMSW left in the open dumps dried rapidly to levels < 60% moisture or wetness within 6–8 days of exposure under dry ambient conditions (summer, April–June). At this stage of dryness in OFMSW, bacterial decomposition is expected to slow down and rapidly cease or reach very low levels. The presence of surface moisture could allow a small degree of fungal decay. Yet, the moisture content is quite adequate for micro and meso-fauna to ingest and enable degradation, and field data suggest that they are the most likely actors that remove the degradable organic material after this initial stage of drying. The important role of micro and meso-fauna in such a decomposition process is common in savanna regions (e.g. Australian Bush) where for the degradation of leaf and plant litter, termites constitute 10–30% of the dry matter transformations (Collins 1981; Braithwaite et al. 1988; Ngatia et al. 2014). In this case, where the food material is far more digestible, one may expect a wider range of faunal activity. This study shows that the moisture content of degrading MSW falls rapidly to levels below which micro-organisms are unlikely to function, leaving the rest of the degradative process to be carried out by meso and macro-fauna of this area.

OFMSW was covered and protected by a steel mesh (to avoid other fauna). It continued to undergo rapid initial decomposition. As clear from Fig. 2, 48% of VS in OFMSW was lost during the initial 6 days and a further 14% of VS was lost during 6–30 days of degradation. This suggests an important role for residual micro-fauna. The loss of ash content is indicative of OFMSW's solute and mineral content emerging out of the dumped waste; most likely as (a) leachate or (b) random feeding by meso and micro-fauna. The lowering of ash levels appeared to be linear as indicated by a visual fit (D) achieving 40% over 30 days period. This level of loss is quite high and indicative of ash or minerals in the OFMSW being solubilized and migrating away from the location of the dump. This suggests greater involvement of other agents that carry away the wastes from the point of dumping (Brussaard 1997). Under normal circumstances, if the loss of TS, VS, and moisture occurred through biodegradation, only ash would be left behind, wherein the mass of the remaining ash fraction observed would continue to be reasonably constant in weight throughout the degradation period. However, depleting ash fractions suggests a small level of ash is lost through processes of consumption and transport by micro and meso faunal organisms over a longer time frame as compared to the other constituents. The large scatter in the replicates is suggestive that these occur at random.

The extent of leachate produced and that lost through infiltration could not be determined or computed in this design of experiment which would in turn help in partitioning the ash lost as minerals in the leachate produced and that flowing out, as well as that picked up by micro and meso organisms and carried away from the dump location. In the case of open dumps, of the total VS lost, about 48% occurs in the first 6 days (at 8%/day) which slows down to < 1%/day over the next 24 days. The reduction of VS mass is an indicator of the overall OFMSW degradation process. VS decline by 48% in first 6 days (B) with simultaneous loss of ash content indicates the occurrence of the acidogenesis (volatile fatty acid, VFA production) at a rapid rate and concomitant disintegration of particulate matter in OFMSW to produce leachate, and the leachate, in turn, migrates away from the dump. However, this explains only the first stage of TS/VS/ash losses.

Moisture loss reaches to 60% during the first 6 days after open dumping. The rapid initial weight reduction is therefore primarily due to the rapid loss of moisture content in the early stages of degradation and the organic matter decomposition. Similarly, in the initial phase of aerobic degradation microbial growth depends on moisture content (Makan et al. 2013). Increasing moisture content to an optimum level improved organic matter degradation. Yet, from earlier studies with wet biomass and dumped garbage containing high moisture content, it is evident that the packing density achieved, and the high rate of decomposition is conducive to anaerobic conditions (Chanakya et al. 1999). These observations suggest that in the case of open dumped OFMSW, most of it is converted to VFA rapidly at the early stages of decomposition with a tendency to produce some extent of free water that turns to leachate (Chanakya et al. 2009).

The OFMSW dries rapidly during this initial phase. Upon reaching a minimum moisture threshold (60%) for microbial survival, most microbial degradative activity (especially anaerobic bacterial degradation or fungal growth) ceases within such thinly spread 'open dumps' in and around Bangalore. This is expected to occur as the level of wetness for bacterial degradation (about 60–70%) and fungal degradation (40–70% along with high humidity) is likely to be lost within 6 days after dumping and conditions are not conducive for microbiologically mediated degradation (Ryckeboer et al. 2003).

Effect of soil contact

Figure 3 indicates that treatments with no soil contact (NSC), partial soil contact (PSC), and soil contact (SC) decompose OFMSW (initial TS = 190 g/kg) by 68, 87, and 61% of initial TS in 30 days respectively. This indicated that the category with partial soil contact had more reduction than the other two categories. This trend suggests the retention of moisture for a longer time allows the microorganisms to carry out the degradation process (Fig. 4). An analysis of variance (ANOVA) for the mass of TS in the degraded waste samples across these three categories indicated that the observed differences were not significant ($F = 0.182$, $p > 0.05$). Estimated VS content also showed a non-significant difference between the three categories ($F = 0.077$, $p > 0.05$). While the relationship of the rate of drying as a function of contact with soil suggests that the bacterial inoculum carried by the wastes was adequate for the initial level of decomposition.

OFMSW (809.6 g/kg), under complete soil contact, showed a total moisture loss of 762.6 g/kg while NSC and PSC showed a moisture loss of 740.4 and 789.8 g/kg, respectively. These three treatments were placed in the open, and there was no significant difference in the pattern of moisture lost ($F = 0.195$, $p > 0.05$). Across the three treatments, wet weight loss is quite rapid up to the point when the moisture content reaches ~ 60%. In all treatments, the highest reduction of VS content is achieved until this point is reached. MC and VS show R^2 values of 0.796, 0.653, and 0.874 for treatments with no soil contact, partial soil contact, and complete soil contact, respectively (Fig. 5). This highlights that the duration of rapid decomposition time depends upon the rate of loss in moisture content. Upon achieving a wet weight loss, leads

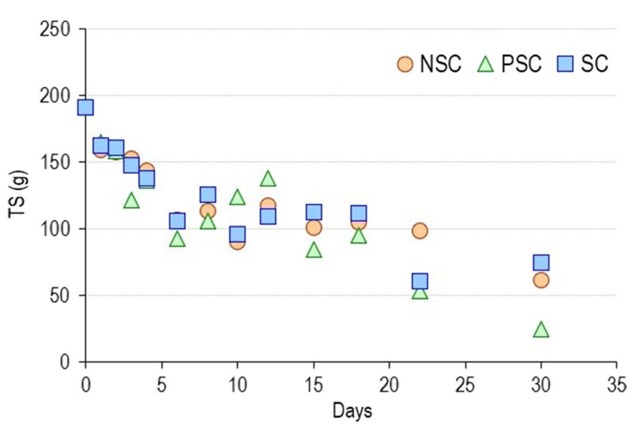

Fig. 3 Change in TS with categories of soil contact in open dumps

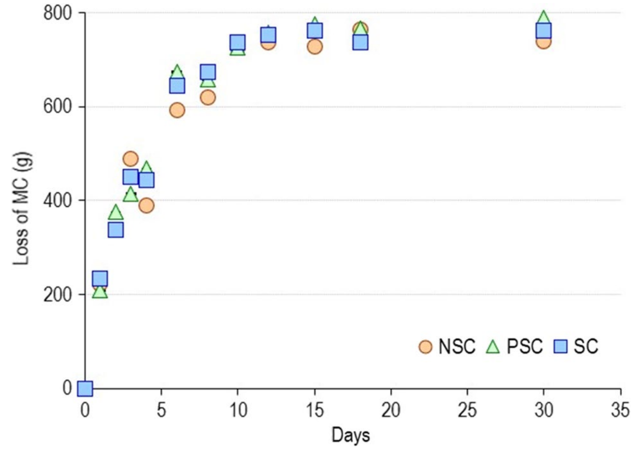

Fig. 4 Loss of MC with categories of soil contact in open dumps

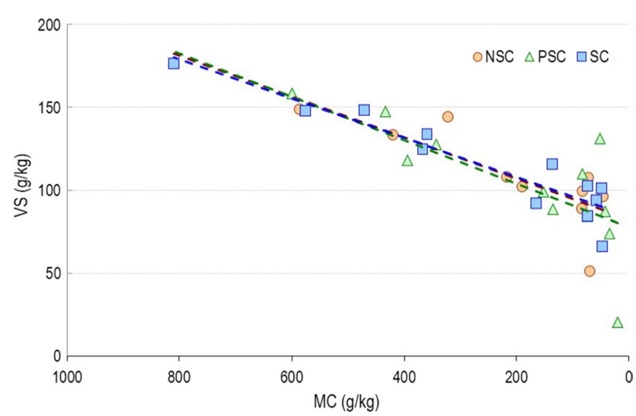

Fig. 5 Relation between MC and VS with categories of soil contact in open dumps

to a slowdown in the rate of organic waste degradation or weight loss in open OFMSW dumps. The slowing of the decomposition rates when OFMSW reaches < 60% moisture is indicative of the predominance of bacterially mediated decomposition and to be the largest contributor to TS reduction in open dumps. Figure 6 presents the changes in C, H, and N with NSC, PSC, and SC. Carbon mass had reduced from 81.2 to 22.2 g/kg (NSC), 8 (PSC), and 30.96 (SC). Some degree of soil contact (partial, without too much moisture losses) enables a more complete OFMSW degradation. Nitrogen mass had reduced from 2.71 g/kg to 1.13 (NSC), 0.62 (PSC), and 1.17 (SC). This confirms the reduction of waste quantity and also its uptake by the soil micro-flora through soil contact and partial soil contact.

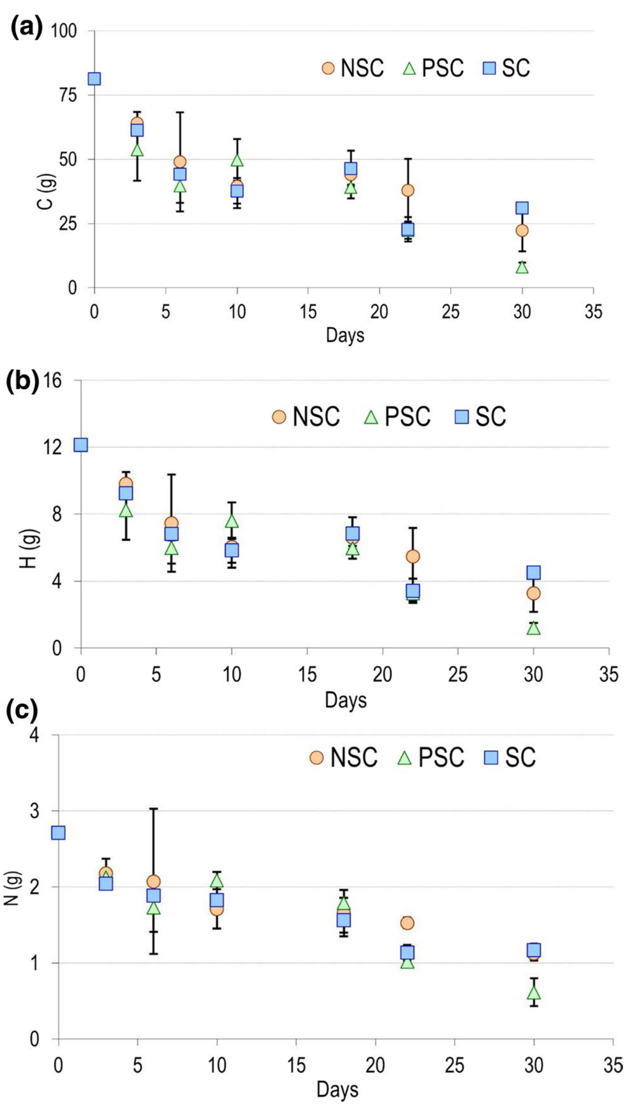

Fig. 6 C, H and N mass changes in the presence of soil contact in open dumps (**a**–**c**)

Role of agents (organisms) in waste degradation

Decomposition and its pattern with the involvement of organisms (micro and meso categories) were assessed by placing differently sized barriers between the soil and OFMSW samples. The rapidly drying waste is not conducive to microbial decomposition for a long period (> 6 days in the open) as seen earlier. Soil microorganisms help in the mineralization of carbon, whereas other fauna often helps in the mechanical breakdown of OFMSW components (Brussaard 1997; Gougoulias et al. 2014). Soil organisms include microorganisms (< 0.1 mm diameter) and meso + micro faunal (passing through 2 mm pore size of nylon mesh), both of which seem to have roles in OFMSW degradation. The microorganisms with meso-fauna communities (meso + micro) and microorganisms singly decompose 74 and 83% of initial TS in 30 days (Fig. 7). Statistical analysis of TS reduction also indicated that the observed difference was non-significant ($F = 2.157$, $p > 0.05$). Estimated VS shows a loss of 87 and 84% with the involvement of micro and meso + micro categories, respectively. Therefore, the quantity of reduction in both categories is almost the same. Figure 8 compares these two categories for VS reduction and also shows a non-significant difference ($F = 2.088$, $p > 0.05$). Similarly, degradation with the inclusion of organisms of all sizes did not have any negative

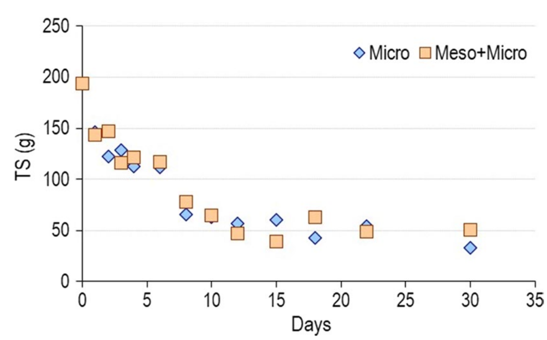

Fig. 7 Loss in TS of OFMSW restrained by different sized meshes

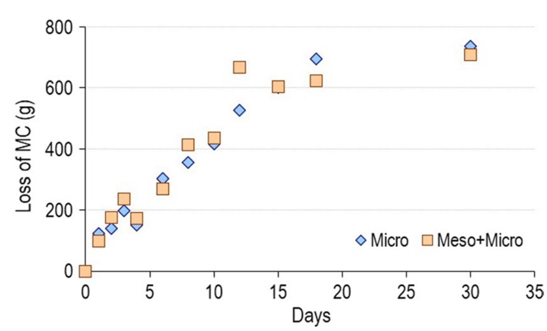

Fig. 8 Loss of MC for categories with the involvement of organisms

effect on the reduction in the quantity of organic waste lost. The reason could be that all the categories have microbial activity, which is important for the first part of degradation. The complexity of organisms brought about by using larger mesh sizes has a significant effect on moisture content lost ($F = 16.27$, $p < 0.05$) and shows a strong relationship between residual VS and available MC for different types of organisms.

Waste degradation with the involvement of micro and meso + micro categories has been found to lose 91 and 88% of initial MC respectively (of 806 g/kg found in fresh MSW), over 30 days. MC and VS show R^2 values of 0.8911 and 0.9325 for micro, and meso + microorganisms, respectively (Fig. 9) clearly showing moisture availability to be the single most governing factor in TS/VS lost during open dumps. From these studies, it is obvious that the degradation of VS is related to the moisture content in a favourable range. Larger pore size loses moisture quicker than covered systems, which in turn provide longer workable moisture regimes and a congenial environment for micro-organisms to become the predominant agents of degradation. Figure 10 represents changes in C, N, and H mass with the involvement of different size groups of organisms. Contact with soil micro and meso + microorganism categories reduced carbon mass from 80.1 to 10.3 g and 11.3 g of TS in residual waste, respectively. Nitrogen mass reduced from 2.95 to 0.99 g (by microorganisms) and 0.92 g (by meso + microorganisms) amounting to about two-third N losses. This level of N loss is a little higher than N volatilization found in open composted systems. The hydrogen mass reduction pattern was similar to that of carbon.

Comparison of pattern, rate kinetics, and carbon content

The decomposition of mixed OFMSW followed a general pattern of exponential decay with $R^2 = 0.72$, a pattern

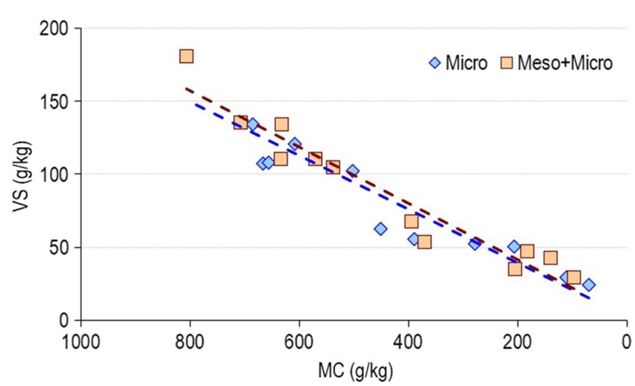

Fig. 9 Residual VS and MC relation for categories with the involvement of organisms

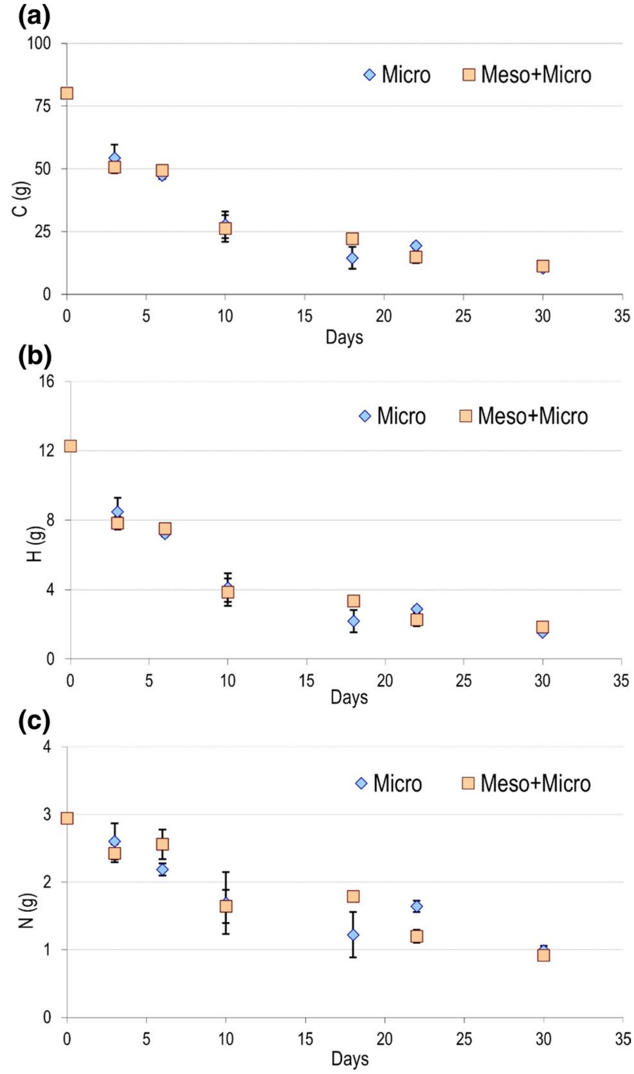

Fig. 10 C, H and N mass changes in the relation to various sizes of organisms (**a**–**c**)

typically found for organic matter decomposition in soil and anaerobic digesters (Jenkinson and Ayanaba 1977; Jenkinson 1981; Lopes et al. 2004; Chanakya et al. 2007). However, most deviations from typical exponential fit occurred at the initial point and the intermediate switch over points (Fig. 2, plot b) due to the initial rapid decomposition. It thus needs some modifications to this approach. The first six days VS data (rapid degradation phase) shows a straight line fit with an $R^2 = 0.955$ (plot a, b). The daily degradation levels were VS reduced from 14 to 8 g/kg/day after 6 days of degradation and it further reduced to approximately 4 g/kg/day. A rapid initial decomposition is due to the availability of moisture and also due to the presence of a fraction of easily decomposable substances in waste. Whereas after this period decomposition slows down both due to the absence of adequate moisture and the remaining material in OFMSW is slowly decomposable and recalcitrant.

The decomposition of waste thus occurs in two phases involving a change in the pattern of kinetics (Reddy et al. 1980; Ajwa and Tabatabai 1994; Harmon et al. 2009). Phase I occurs till the 6th day of degradation and after a short transition, it is followed by phase II. Phase I is linear and follows zero-order kinetics, as in this phase the rate of degradation appears independent of waste composition. Around the end of Phase I, the reduction in the moisture content of the waste altered the rate as falling moisture leads to lower involvement of micro and meso categories of organisms. Thus, Phase II is exponential and follows first-order kinetics since the rate of degradation appears to depend on concentration. The rate constant of phase I and phase II are 16.6 g/kg/day and 0.024/day, respectively. The process of decomposition found in composting, biomethanation and landfill is also reported to follow first-order kinetics from the initial stage till the degradation of organic matter (Hamoda et al. 1998; Chanakya et al. 1999; Abu Qdais and Asheraideh 2008; Ravikumar 2014; Abu Qdais and Al-Widyan 2016). The rate constant of phase I is highest (24.886 g/kg/day) in degradation by micro category, whereas the rate constant of phase II is highest (0.075/day) in the degradation of meso + micro category. Micro and meso categories involve microorganisms in degradation, but MC content varies. At the end of phase I, MC content in micro and meso categories were 56 and 49% of initial MC (806.29 g/kg), whereas, at the end of phase II, MC content in micro and meso categories were 9 and 12% of initial MC (Table 2). The decomposition of carbon varies across phase I and phase II for different categories. A rapid reduction of C occurred in phase I as compared to phase II due to available MC leading to favorable microbial decomposition. This confirms and supports the rapid decomposition discussed earlier as well as provides the potential cause for change in the order of kinetics (residual VS). Phase I rate constants are marginally higher in micro (24.886 g/kg/day) compared to micro + meso (22.757 g/kg/day) organisms. In the case of micro, mainly bacteria and fungi are involved in degradation. The availability of moisture at the end of phase I was 56% and the longer period of availability of moisture stretched the duration of phase I degradation. However, in meso + micro category moisture availability reduced earlier to 49%. Phase II follows first-order kinetics for both the categories. The estimated rate constants for micro and meso + micro categories are all within the same range. The rate and extent of waste degradation are related to the loss of moisture or the rate of drying.

Conclusion

The study brings out the role of actors involved in open degradation of mixed OFMSW, degradation pattern and the rate kinetics of waste degradation in open dumpsites. The mixed organic matter lost moisture content rapidly during the early stages of degradation and the degradation rate slowed down subsequently and stabilized. In such a degradation process 48% of VS was degraded till the moisture content reached levels > 60% in the first 6 days of degradation. After this, only 14% of VS was lost during 6–30 days of degradation period. The result confirms the involvement of micro and meso + micro categories. Soil contact has no significant effect (source of inoculum) on the rate of waste degradation. Across the different categories, when the moisture content reaches 50–60%, there is a maximum level of reduction of waste VS content. This reduction was greater in micro and meso + microorganism categories. This suggested that longer such 'appropriate' moisture content is maintained, greater is the involvement of microorganisms leading to enhanced biodegradation of the organic fraction. There is a reduction in C, N, and H mass with the involvement of different sizes

Table 2 Degradation pattern and rate kinetics of different conditions

Details	Organism		Soil contact		
	Micro	Meso + micro	NSC	PSC	SC
VS_0 (g/kg)	180.727	180.727	176.331	176.331	176.331
Pattern	$y = 132.97e^{-0.0643x}$	$y = 132.58e^{-0.0629x}$	$y = 154.18e^{-0.0353x}$	$y = 170.43e^{-0.0582x}$	$y = 145.75e^{-0.0325x}$
R^2	0.8945	0.8468	0.8823	0.8396	0.724
Phase I					
Period (days)	0–8	0–8	0–6	0–6	0–6
Kinetics	Zero order	Zero order	Zero order	Zero order	Zero order
K (g/kg/day)	24.88584	22.75678	14.88066	15.7474013	16.60726
Phase II					
Period (days)	8–30	8–30	6–30	6–30	6–30
Kinetics	First order	First order	First order	First order	First order
K (/day)	0.049	0.075	0.036	0.03	0.024

of organisms and with different types of soil contact. Degradation of VS is an exponential decay function during the first 'moist' period of decomposition and latter with first-order rate kinetics when MSW dries in open dumpsites.

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Declarations

Conflict of interest The authors declare no potential conflict of interest regarding the publication of this work. In addition, the ethical issues including plagiarism, informed consent, misconduct, data fabrication and, or falsification, double publication and, or submission, and redundancy have been completely witnessed by the authors.

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