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ENVIRONMENTAL FACTORS AFFECTING VERMICOMPOSTING OF MUNICIPAL SOLID WASTE

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ABSTRACT
The optimum environmental conditions such as temperature, moisture, pH, EC etc required for vermi-composting of municipal solid waste with different earth worm species and with different substrates are studied. The moisture content of final vermicompost ranged from 50.3 to 57.8% in all the samples kept for vermicomposting with E.foetida and P.excavetus. The initial temperature of compost was 34.5^{0}C and the temperature of vermicompost obtained after 60 days of vermicomposting was 27^{0}C. There is not much variation in the temperature of samples kept for vermicomposting with P.excavatus as well as E.foetida. The pH of the municipal solid waste is 6.3 and it is lower than the neutral pH. However, the pH of the municipal solid waste increased to 6.6-6.7 with the addition of soil or cow dung or both. The loss in the weight of vermicompost of municipal solid waste with E. fotedia is 62.8% after 60 days of vermicomposting where as the loss in the weight of vrmicompost in the case of P.excavatus is only 51% for municipal solid waste. Therefore, it can be inferred that the yield of vermicompost would be higher if we use P. excavatus compared to E. foetida.

KEY WORDS
Municipal solid waste, vermicompost, P. excavatus, E. foetida.

INTRODUCTION

Municipal solid waste and many other organic byproducts of agricultural production and processing industries are currently seen as waste and thus become potential environmental hazards. A portion of this waste is currently reused, recycled or reprocessed. However, a majority of it is disposed off in landfill (anaerobic composting) which is a national concern due to many factors including cost and environmental issue. Earthworms eat many types of organic waste materials and convert them into "Castings". The end product is highly valued as a soil amendment because it contains plant-available yet stable nutrients. Castings can be marketed to farmers. Another product is worms which can be directly marketed for use as fish baits, livestock feed supplement[1]. Thus vermin-composting, being eco-friendly is a technological option for organic solid waste management, avoiding foul smell and other environmental problems associated with dumping or landfill of waste and generating equal or more amount of revenue from sale of its products. The concept of commercial vermin-composting is of recent one and being practiced for a decade or more.

Many scientific investigations have established the viability of using earthworms as a treatment technique for numerous waste streams.[2] The action of earthworms in this process is both physical/mechanical and biochemical. The physical/mechanical processes include: substrate aeration, mixing, as well as actual grinding. The biochemical process is carried out by microbial decomposition of the substrate in the intestines of the earthworms. These physical or mechanical processes usually represent the largest cost associated with a traditional microbial composting process. Therefore, vermi-composting saves all these unit operations. Thus defined vermi-composting is considerd as a low cost technology system for the processing or treatment of organic wastes.

Vermi-composting of municipal solid wastes can be seen as a form of livestock (earthworms) production. Many different materials in municipal organic solid waste can be used as a feedstock for worms. Animal manures from livestock enterprises are quite useable as feedstock (cattle manure, poultry manure, etc). Plant residues have been tested as feed-stocks for commercial systems. e.g. potato and brewery waste, sugarcane pulp, coffee pulp, slaughter house solid wastes, food packing waste, waste from commercial establishments food waste, vegetable scrapes, wood pulp, shredded wood rejects, untreated wood, bio-solids and other municipal solid waste. These different waste materials may require different earthworm species and different environmental conditions.[3]

Further, vermi-cornposting is a system for turning organic 'Waste' into nutrient rich soil as it is processed by worms. It cannot really be described as a type of composting which is a heat producing process that would actually kill worms; whereas vermin-composting should establish an environment in which worms can thrive better and reproduce. The worms process organic waste excreting them as organic material rich, stable, plant-available nutrients that looks like fine textured soil. Nutrients in vermin-compost are often much higher than the traditional garden compost[4]. Though the system is extremely robust, it is essential to maintain process control for the consistent productivity through matching feed rates to population and adjusting environmental parameters to optimal level.

The application of vermi-composting processes to waste management has sought generally to obtain products which are commercially valuable like in agriculture farming and industries. For this reason many of the other possibilities they offered are disregarded and left unstudied. Vermi-composting can be applied to stabilize organic wastes like urban solid waste at the same time managing to solve, or at least minimize the environmental problems arising from their disposal without needing in many cases to complete the process. The process may be taken to completion if end products are of better structure and utility.

Therefore, in vermi-cornposting enterprises it is critical to maintain optimal conditions because of variety of substances in the waste. Environmental factors such as moisture, temperature and aerobic conditions in growing medium must be maintained to ensure healthy growing worm populations. Profitable production depends on both growth and production rates of worms as well as on the choice of suitable species for feed stuff available. Thus, an attempt is made in this paper to study the optimum environmental conditions required for vermi-composting of municipal solid waste with different earthworm species.

MATERIALS AND METHODS

The research on vermicomposting of solid waste with different earthworm species does not indicate the efficient type of earthworm for municipal solid waste. Most of the studies use organic garbage and cow dung for the experiments. Thus, an attempt is made in this study to use the substrate which has almost similar composition of original municipal solid waste. Further, two types of earth worms, one exotic type and one indigenous type, are used to explore the efficiency of native earth worms compared to that of exotic species. *Perionyx excavatus* as indigenous variety and one from exotic species, *Eisenia foetida,* are selected for the study. The main objectives of the study are to find out the proportion of municipal solid waste and manure or feed for successful vermi-composting; to identify the suitable earthworm species for successful reclamation of municipal solid waste; and to explore the optimum environmental factors required for successful reclamation of municipal solid waste.

Vegetable waste materials collected from the municipal vegetable market are used as the main substrate. Normal soil (garden soil), cow dung or farm yard manure are added in different proportions to municipal solid waste as supplements to the green waste. The problem in treating the waste with earthworms is its lower pH value. When the organic waste is piled at a place the acidity of waste will increase due to microbial action. The higher acidity or lower pH values affects the growth of earthworms used for vermin-composting. Therefore, it is necessary to mix some substances such as soil, cow dung etc in order to increase the pH of the waste for proper vermicomposting process.

EXPERIMENTAL DESIGN

Five sets of plastic pots for each earthworm species are taken for this comparative study and the methodology suggested by Patnaik and Reddy (2010)[5], and Amaravathi and Reddy (2014)[6] is followed. Each set of pots is filled with five kg of the substrate - municipal solid waste, cow dung and with soil in separate pots in the ratio given below.

Set 1 Organic waste (MSW)
Set 2 MSW and soil (3:1 ratio)
Set 3 MSW and Cow dung (3:1 ratio)
Set 4 MSW: Soil: Cow dung (2:1:1)

Out of the five sets taken, four sets are used for vermi- composting with each set using one species of earthworm and one set is used as control (without earth worms). Two species of earthworms, twenty-four-week old individuals of each species, *Eisenia foetida* and *Perionyx excavatus* were collected from the stock culture. These cultures are collected from the vermicomposting yard of SEEDS (an NGO) organization working in Duttalur village, Nellore district. These earthworms, each of fifty adult individuals, are introduced on the top of the pre-composted substrate in each of the four sets of pots keeping aside another set for composting without earthworms. All the pots were covered on the top by jute cloth cover and wire mesh to protect the earth worms from the predators- centipedes, moles, and shrews. The process of vermi-composting is carried out for a period of 60 days and the samples are collected from each set of the substrate /substrate mixture used at 0 day, 15, 30, 45 and 60th day and analyzed for various parameters such as temperature, moisture, weight, pH, EC etc using standard protocols and the results are presented in the respective tables. The temperature and moisture contents were maintained by sprinkling adequate quantity of water at frequent intervals.

To measure the pH and EC (Electrical Conductivity) of the substrates 10 gram sample was taken from each substrate in to a bottle and then mixed it with distilled water. After that the pH was determined using a digital hand pH meter (ISO 9001, Control Dynamics Ph Meter, and India) and EC was measured by

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digital EC meter at room temperature. The dry weight and moisture contents of the samples are calculated after heating the sample at 100^0c for 10-15 minutes or till the constant reading is obtained.

Statistical analysis:

All the reported data are the mean values of three replicates. Two way analysis of variance (ANOVA) was done to determine any significant difference among the parameters analyzed in vermicompost.

RESULTS AND DISCUSSION

The study is aimed at determining the optimal environmental factors required for successful vermicomposting of the waste. The environmental factors studied include weight reduction, temperature, moisture, pH and EC. The samples are analyzed for this purpose and results are presented in the following tables.

(1) Weight reduction during vermicomposting:

Earthworms use a wide variety of organic materials for food, and even in adverse conditions, extract sufficient nourishment from the soil to survive. The growth of earthworm population causes reduction in the weight of the substrate used for vermi-composting through bio-oxidation and stabilization of organic material through the interactions between earthworms and microorganisms. Although microorganisms are mainly responsible for the biochemical degradation of organic matter, earthworms play an important role in the process by fragmenting and conditioning the substrate, increasing the surface area for growth of microorganisms, and altering its biological activity [4]. High population densities of earthworms in vermin-composting systems result in a rapid turnover of fresh organic matter into earthworm casts and higher reduction in weight of the vermin-compost. As a result of the growth of earthworms and biodegradation by microorganisms there will be loss in the dry matter or weight of the compost used for vermin-composting. In the present study also the loss of weight of vermin-compost is observed and the results are presented in Table-1.

Table: 1 – Physical parameters of compost and vermicompost of different earthworm species - weight.

Eisenia foetida					
Period of vermin-composting	Control	S1	S2	S3	S4
0 Day	500 g	500 g	500 g	500 g	500 g
15 days	405	415	495	470	480
30 days	346	364	377	385	421
45 days	262	295	294	311	345
60 days	164	186	215	190	195
% weight loss after 60 days	67.2	62.8	57.0	62.0	61.0
Perionyx excavatus					
Period	Control	S1	S2	S3	S4
0 Day	500g	500 g	500 g	500 g	500 g
15 days	405	425	450	430	485
30 days	346	370	365	372	434
45 days	262	304	303	314	350
60 days	164	245	272	252	264
% weight loss after 60 days	67.2	51.0	45.6	49.6	47.2

The loss in the weight of vermicompost of municipal solid waste (S1) with *Eisenia foetida* is 62.8% after 60 days of vermicomposting where as the loss in the weight of vermicompost in the case of *Perionyx excavatus* is only 51% (Table-1). In the case of only compost or control the loss in the weight is only 31% as against 45-61% in all types of vermicomposts. It indicates that the process of vermicomposting causes greater loss in the dry matter of the waste due to the growth of earthworms. It was found that the bulk (dry) mass reduction and stabilization of both the wastes during present study through vermicomposting process were significant.

The loss in the weight of compost is higher in the case of *Eisenia foetida* compared to *Perionyx excavatus.* The loss in the weight is 62.8% after 60 days of vermicomposting in the case of *Eisenia fotedia* where as the loss in the weight of vrmicompost in the case of *Perionyx excavatus* is only 51% (Table-1) for municipal solid waste. In the case of municipal solid waste and soil mixture (S2) the loss in weight of vermicompost after 60 days of composting is 59% in the case of *E. foetida* while it is only 45.6% in the case of *P. excavatus.* For the other two samples i.e., S3 and S4 also the loss in the weight of the compost is higher for *E. foetida* compared to *P. excavatus.* Therefore, it can be inferred that the yield of vermicompost would be higher if we use *P. excavatus* compared to *E. foetida.* However, it is necessary to study the composition of vermicompost in terms of soil nutrients (N,P,K etc) before one can say that *P. excavatus* is efficient organism compared to *E. foetida.*

It is observed that the loss in the weight of the substrate or compost used varies with the composition of substrate mixture. The loss in the weight is higher (for sample S1) when municipal solid waste alone is taken for both the species of earthworms used compared to other samples. It is 51% for P. excavatus and 62.8% for *E foetida*. When the soil is added to the municipal solid waste the loss in the weight of vermicompost after 60 days is reduced compared to vermicompost prepared from municipal solid waste alone. The loss of weight of vermicompost for S2 (sample having soil) is 45.6% for P. excavatus and 57.0% for E.fetida. It indicates that there is no need to clean or wash the organic matter of municipal solid waste before vermicomposting and it can be used for vermicomposting in its available state. The loss in the dry mater of vermicompost is almost similar for organic waste and MSW with cow dung.

The results of the present study are in agreement with the studies of other researchers. It was reported that higher mass reduction of MSW was observed in the vermicompost processed by *E. eugeniae* (75%), followed by that of *E. foetida* (63%), *and P. excavatus* (50%) compared to that of compost (26%), whereas the mass reduction was higher 83%, in vermicompost produced by *E. eugeniae,* 67% by that of *E. foetida*, 56% in that of *P. excavatus,* and 30% in sole compost than that of farm waste (FW) [5]. The marked stabilization of both the substrates due to vermicomposting process was higher in the vermicompost processed by *E. eugeniae* compared to that of other two earhtworms and the compost. The farm waste and its vermicomposts and composts were found to be more stabilized than that of MSW.

(2) Moisture Requirements: Moisture is critical to the survival of all earthworm species. Moisture within the worms body gives it shape, enables it to move, and aids in the worm's ability to absorb oxygen. The moisture range for most worm species is from 60 - 85 percent which ensures that the worm can absorb as much moisture as may be lost through evaporation[6]

In the present study all the samples are kept in plastic pots having small holes at the bottom and adequate quantity of water is sprinkled at frequent intervals in order to maintain the temperature and moisture contents at optimal level. The moisture content of the samples at the initial stage was 78% and it declined gradually to 55.4% after 60 days of vermicomposting in the case of municipal solid waste using *E. foetida* and 53.2% in the case of *P. excavatus* (Table-2). Similar trend in the decline of moisture percentage in the compost during vermicompost for 60 days could be observed for all the samples. The moisture content in the compost without earthworms is higher compared to vermicomposts of both the species of earthworms used. The lower level of moisture content in the vermicompost, compared to the moisture at the initial stage, could be attributed to proper drainage of water sprinkled daily on the samples and proper air circulation. As the vermicomposting progresses earthworms excrete vermin casts of cylindrical or oval shape. When the quantity of these castings increase the drainage of sprinkled water will be increased resulting in lower moisture content in the vermicompost obtained.

In the present study the moisture content of final vermicompost ranged from 50.3 to 57.8% in all the samples kept for vermicomposting with *E.foetida*.(Table-2). However, the moisture content of the vermicompost obtained after 60 days of vermicomposting with *P.excavtus* ranged from 52.5 to 53.6%. It indicates that the vermicompost obtained using *P.excavatus* has lower level of moisture content compared to that of *E.foetida*. Lower level of moisture in the final product is desirable for longer storage and for its quality. Therefore it can be inferred that *P.excavatus* is more desirable for vermicomposting of municipal solid waste compared to *E.foetida*. However, the difference in moisture content in vermicomposts obtained from both these earthworm species is narrow, and not significant.

Table: 2 – Moisture percentage of compost and vermicompost of different earthworm

Eisenia foetida					
Period	Control	S1	S2	S3	S4
0 Day	78.0	78.0	78.0	78.0	78.0
15 days	76.3	74.2	71.4	72.5	75.9
30 days	65.4	65.5	62.2	64.7	63.5
45 days	64.8	60.1	59.4	57.6	58.8
60 days	63.6	55.4	57.8	50.3	54.5
% change after 60 days	22.64	41.54	34.95	55.07	43.11
Perionyx excavatus					
Period	Control	S1	S2	S3	S4
0 Day	78.0	78.0	78.0	78.0	78.0
15 days	75.8	76.5	71.7	73.4	75.5
30 days	65.0	67.4	63.5	59.3	64.9
45 days	62.8	61.2	55.9	54.3	53.5
60 days	59.4	53.2	53.6	52.5	52.6
% change after 60 days	31.31	46.61	45.52	48.57	48.28

As reported in other studies it was observed that moisture content of the vermicompost ranged from 50–70% [8]. It was reported that optimum moisture content for growth of earthworms—*E. foetida, E. eugeniae and P. excavatus*—was 85% in organic waste management. The rate of mineralization and decomposition becomes faster with the optimum moisture content[9]. According to Liang et al , the moisture content of 60–70% was proved having maximal microbial activity, while 50% moisture content was the minimal requirement for rapid rise in microbial activity. It was reported that vermicompost samples showed higher moisture content than the compost and substrate, which may be due to their high absorption capacity, and may also be because of assimilation rate by microbial population indicating the higher rate of degradation of waste by earthworms[5]. Relatively highest moisture content of vermicompost produced by *E.eugeniae* followed by that of *E. foetida* and *P. excavatus* implied greater palatability of the substrate by the species.

(3) Temperature: Specific temperature requirements and tolerances vary from species to species, though the ideal range for most worm species is between 15° to 27° C. The worm's ability to tolerate temperature outside of ideal temperature is highly dependent on the level of moisture in the system. Heat causes more problems for vermin-composting than cold. In general, worms like cool weather. They are at their highest activity and reproductive levels as the weather cools and warms in the spring. The temperature of various vermicompsts prepared by different earthworm species and composts are presented in Table-3.

Table- 3: Temperature (°C) of vermicompost of different earthworm species.

Eisenia foetida					
Period	**Control without earth worms**	**S1**	**S2**	**S3**	**S4**
0 Day	34.5°c	34.5°c	34.5°c	34.5°c	34.5°c
15 days	36.2°c	32.4°c	32.2°c	32.9°c	32.5°c
30 days	34.5°c	28.2°c	28.4°c	28.3°c	28.6°c
45 days	32.4°c	28.3°c	28.5°c	28.6°c	28.4°c
60 days	29.6°c	27.4°c	27.6°c	27.2°c	27.5°c
Perionyx excavatus					
Period	Control	S1	S2	S3	S4
0 Day	34.5°c	34.5°c	34.5°c	34.5°c	34.5°c
15 days	36.2°c	32.3°c	32.6°c	32.4°c	32.2°c
30 days	35.5°c	28.4°c	28.2°c	28.6°c	28.5°c
45 days	32.4°c	28.5°c	28.4°c	28.3°c	28.6°c
60 days	29.6°c	27.2°c	27.3°c	27.4°c	27.5°c

The initial temperature of compost was 34.5^{0}c and the temperature of vermicompost obtained after 60 days of vermicomposting was 27^{0}c (Table-3). The warm temperature of the compost at the initial level is due to the period or season of the study. The experiment was initiated in the month of august and the normal atmospheric temperature in this region is about 33-36^{0}c. All the pots having composting samples are kept in a thatched shed and water is sprinkled periodically (daily in the evening) to control the ambient temperature.

In the case of vermicmposting of municipal solid waste and other combinations of waste with *Eisenia foetida*, the temperature of the substrate was high and then decreased gradually to about 27^0c as the composting process progressed (Table-3). The heat released by the oxidative action of intensive microbial activity on the organic matter might have resulted in the rise in temperature during the first mesophilic phase of composting process. The decline in the temperature may due to the aeration through the furrows caused by earthworms. There is not much variation in the temperature of samples kept for vermicomposting with *Perionyx excavatus*, and *Eisenia foetida.*

In the case of compost (without earthworms) there is rise in the temperature of the substrate from 34.5^oc to 36.2^oc during the first 30 days of composting. There after there is decline in the temperature of the substrate gradually till the end of the composting process. The heat released by the oxidative action of intensive microbial activity on the organic matter might have resulted in the rise in temperature during the first mesophilic phase of composting process [11]. The temperature of the following thermophilic phase rose above 34°C when most of the organic matter was degraded with the help of thermophilic bacteria and fungi, consequently depleting most of the oxygen. The thermophilic phase was followed by cooling phase, when compost maturation stage occurred and compost temperature dropped to that of the ambient [12].Then, the decreasing trend of temperature with the progress of composting process occurred, which was probably due to the decreased bacterial activity. It may also be attributable to regular sprinkling of water.

(4) pH Requirements:

The pH of the substrate is an important factor which determines the growth of earthworms and microorganisms present in the gut of earthworms. For the better activity of microbes and earthworms the pH of the substrate preferred shall be neutral or around 7.0. The pH of the municipal solid waste is 6.3 and it is lower than the neutral pH. However, the pH of the municipal solid waste increased to 6.6-6.7 with the addition of soil or cow dung or both (Table-4). Therefore, the addition of soil or cow dung appears to be essential in order to provide favorable medium for the growth of earth worms and microorganisms present in them. As microorganisms breakdown organic matter it goes through series of naturally occurring changes in pH and earthworms are adopted to tolerate these pH fluctuations with little or no change in their activity levels.

After 15 days of composting the pH of all the substrates declined slightly. The decomposition of organic matter produces organic acids that lower the pH of the bedding soil. After that the pH of the substrate increased and the final pH of vermin-compost obtained for all the samples is neutral or near neutral. In the case of *Eisenia foetida* the pH of municipal solid waste (S1) is 6.3 at the beginning and it rose to 6.9 after 60 days of vermin-composting. Similarly the mixture of municipal solid waste (MSW) and soil substrate (S2) showed the same trend in the pH by increasing from 6.7 at 0 day of composting to 7.0 at the end of 60 days. Similar results could be observed in the case of municipal solid waste (msw) and cow dung mixture (S3) and msw, cow dung and soil mixture (S4). In the case of other earthworm, *Perionyx excavatus,* also the same trend in the change of pH of the substrate with period of vermin-composting is observed. This analysis shows that the vermin-compost prepared out of MSW with the addition of soil or cow dung is of neutral pH and this would help the growth of earthworms used for vermin-composting.

Table-4: Changes in pH during vermi-composting of MSW using different earthworms

Eisenia foetida					
Period	**Control**	**S1**	**S2**	**S3**	**S4**
0 Day	6.3±0.1	6.3±0.1	6.7±0.2	6.8±0.2	6.7±0.4
15 days	6.2±0.3	6.5±0.2	6.8±0.4	6.9±0.4	6.8±0.5
30 days	6.2±0.1	6.7±0.3	6.9±0.2	7.0±0.2	6.9±0.4
45 days	6.4±0.2	6.8±0.1	7.0±0.1	7.1±0.4	7.0±0.2
60 days	6.5±0.2	6.9+0.2	7.1+0.2	7.2±0.4	7.1+0.2
Perionyx excavatus					
Period	**Control**	**S1**	**S2**	**S3**	**S4**
0 Day	6.3±0.1	6.3±0.1	6.7±0.2	6.8±0.2	6.7±0.4
15 days	6.2±0.3	6.7±0.2	6.8±0.2	6.9±0.3	6.8±0.2
30 days	6.2±0.1	6.8±0.4	7.0±0.1	6.9±0.2	6.9±0.3
45 days	6.4±0.2	6.9±0.1	7.1±0.3	7.1±0.4	7.0±0.2
60 days	6.5±0.2	7.0+0.2	7.2±0.2	7.2±0.3	7.2±0.4

The near –neutral pH of vermi-compost may be attributed by the secretion of NH^{+4} ions that reduce the pool of H^+ ions[13] and the activity of calciferous glands in earthworms containing carbonic anhydrase that catalyzes the fixation of CO_2 as $CaCO_3$, thereby preventing the fall in Ph[5,14]. The results are in consistence with the findings of [15 , 5] and [16], who reported increased pH values during composting which was attributed to higher mineralization. On the other hand the increasing trend of pH in the vermi-compost and compost samples is not in consistence with the findings of [17], [13] and [1] who reported lower PH. The increased pH during the process was probably due to the degradation of short-chained fatty acids and ammonification of organic nitrogen[19, 20],[21] .The increased pH at the end of the composting process, was attributed to progressive utilization of organic acids and increase in mineral constituents of waste.

Earthworms are very sensitive to pH, thus pH of soil or waste is sometimes a factor that limits the distribution, numbers and species of earthworms. Little information is available on the effect of substrate pH during vermicomposting. In a vermicomposting experiment with different soil proportions (1:2, 1:3, 1:4, 1:6) of waste the earthworms reduced the pH: *Eisenia foetida*, 6.7 to 6.1; *Eudrilus eugeniae*, 6.7to 6.0; and *Megascolex megascolex*, 6.7to 6.4 [7] Several researchers have stated that most species of earthworms prefer a pH of about 7.0 [22, 23, 24,] reported a wide range of pH 5.4 to 7.5 in Ohio, USA [18, 25] suggested a neutral substrate pH for vermicomposting using deep burrower species *Pheretima elongata*.

5. Electrical Conductivity (EC): The measure of electrical conductivity will indicate the concentration of soluble salts in the soil or compost at any particular temperature. The presence of minerals in the form of soluble salts facilitates the plants to absorb required salts from the soil easily. Therefore, the higher electrical conductivity of substrate or vermin-compost is a favorable character for the improvement of soil fertility. The vermi-compost having higher electrical conductivity is considered as good quality vermi-compost.

Out of the five substrates taken for vermin-composting, MSW has lower electrical conductivity value compared to msw + soil, msw +cow dung, and msw+soil+cow dung samples. The substrate having soil sample has shown higher electrical conductivity value and this could be attributed to the availability of more salts in soil when the samples are subjected to vermi-composting. There is increase in the electrical conductivity for all the samples during vermi-composting (Table-5). The increase in the electrical conductivity has shown an increasing trend with the time of vermi-composting.

Table-5: Changes in EC during vermi-composting of MSW using different earthworm (ohms/cm).

Eisenia foetida					
Period	Control	S1	S2	S3	S4
0 Day	2.87±0.2	2.87±0.2	4.85±0.7	2.40±0.2	3.86±0.6
15 days	2.90±0.1	3.01±0.3	4.90±0.5	2.60±0.3	3.94±0.1
30 days	2.94±0.2	3.11±0.1	5.14±0.4	2.73±0.1	4.20±0.2
45 days	2.96±0.3	3.09±0.1	6.15±0.5	2.80±0.2	4.46±0.4
60 days	2.98±0.4	3.15±0.1	7.17±0.6	2.90±0.3	4.80±0.6
Perionyx excavatus					
Period	Control	S1	S2	S3	S4
0 Day	2.87±0.2	2.87±0.2	4.85±0.7	2.40±0.2	3.86±0.6
15 days	2.90±0.1	0.36±0.3	5.65±0.5	3.40±0.3	4.56±0.1
30 days	2.94±0.2	4.11±0.1	6.42±0.4	3.97±0.1	5.20±0.2
45 days	2.96±0.3	4.44±0.1	7.21±0.5	4.26±0.2	5.80±0.4
60 days	2.98±0.4	4.90±0.1	7.90±0.8	4.54±0.3	5.98±0.6

The raise in the electrical conductivity of the substrate is due to the breakdown of organic waste into soluble salts by earthworms. The more electrical conductivity in vermin-compost indicates the efficiency of earthworm species used for the vermin-composting process. A gradual increase in EC was observed with increase in decomposition time.[26]. The increase in EC might have been due to the loss of weight of organic matter and release of different mineral salts in available forms (such as phosphate, ammonium, and potassium). The increased EC during the period of the composting and vermi-composting processes is in consistence with that of earlier workers [27, 28], which was probably due to the degradation of organic matter releasing minerals such as exchangeable Ca, Mg, K, and P in the available forms, i. e, in the form of cations in the vermin-compost and compost[19, 21].

Summary:

Vermi-composting of municipal solid waste is becoming a commercial enterprise and it is critical to maintain optimal conditions because of variety of substances in the waste. An attempt is made in this study to use the substrate which has almost similar composition of original municipal solid waste. Further, two types of earthworms, one exotic type and one indigenous type, are used to explore the efficiency of native earthworms compared to that of exotic species. The optimum environmental conditions such as temperature, moisture, pH, EC etc required for vermi-composting of municipal solid waste with different earthworm species and with different substrates are studied. The moisture content of final vermicompost ranged from 50.3 to 57.8% in all the samples kept for vermicomposting with *E.foetida* and for *P.excavatus* the moisture content ranged from 52.5 to 53.6%. The

temperature of the substrate was high and then decreased gradually to about 27^{0}c as the composting process progressed. The pH of the municipal solid waste is 6.3 and it is lower than the neutral pH. However, the pH of the municipal solid waste increased to 6.6-6.7 with the addition of soil or cow dung or both. Therefore, the addition of soil or cow dung appears to be essential in order to provide favorable medium for the growth of earthworms and microorganisms present in them. The loss in the weight of vermicompost of municipal solid waste with *Eisenia foetida* is 62.8% after 60 days of vermi-composting where as the loss in the weight of vermicompost in the case of *Perionyx excavatus* is only 51% for municipal solid waste. However, it is necessary to study the composition of vermicompost in terms of soil nutrients (N,P,K etc) before one can say that *P. excavatus* is efficient organism compared to *E. foetida.*

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