Effect of Substrate Depth on Vermicomposting

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In view of the growing awareness about vermicomposting technology in recycling different types of organic wastes, the effect of substrate depth on vermicomposting was studied. The initial substrate depth of 5 cm, 7.5 cm and 10 cm remained aerobic while 12.5 cm and 15 cm thicknesses turned anaerobic during vermicomposting. The temperature in 12.5 cm and 15 cm sets rose up to 35°C in few hours which subsequently became lethal to earthworms. The initial substrate depth of 10 cm was found to be optimum organic loading for vermicomposting. The time for substrate stabilization during vermicomposting was also found to be lesser as compared to composting without earthworms. The substrate depth variation with respect to time followed an exponential curve.

Keywords : Vermicomposting; Waste recycling; Substrate depth

INTRODUCTION

The concept of vermicomposting started from the knowledge that certain species of earthworms grow and consume a wide range of organic residues very rapidly, converting them into vermicompost, a humus like, soil building substance in short time. Different varieties of earthworms have been recommended to be used in vermicomposting by various workers, such as, deep burrowing[4] and surface dwellers[1,3,6,7,10,11,13,15,18,20,23] and it has been established that the epigeic forms (surface dwellers) of earthworms are the most suitable form for vermicomposting. However, in spite of various studies on vermicomposting technology, very little scientific information has so for been available on the effect of the depth of the substrate heap on vermicomposting.

In view of this gap in knowledge, this study was particularly carried out to evaluate the variation effect of depth of the solid waste material as this will enable the optimization of the depth up to which the solid wastes can be heaped up, to avoid adverse and anaerobic conditions for obvious aesthetic reasons. The results will be useful for development of a better understanding about the effect of substrate column depth on vermicomposting process.

LITERATURE REVIEW

There has been reported[16] reduced growth rates at 30°C and death at 35°C when *Dendrobaena veneta*, *E fetida*, *Eudrilus eugeniae*, *Perionyx excavatus* and *Pheretima hawayana* were grown in biosolids. Data indicated that *D Veneta*, *E fetida* and *P excavatus* have a broad temperature optimum from 15°C - 25°C while other species had narrower tolerance rages. The optimum temperature for cocoon production was 25°C for all species. It has also been reported[5] that by optimizing the key variable of temperature and nutrition, *Lumbricus terrestris L* can be grown from cocoon to sexual maturity in less than half the time taken in the field.

It has been recommended[9] that about 1 kg of earthworms are needed to start vermicomposting of a 0.5 m^3 fresh or one week old pre-composted materials. Vermiculture can be fed daily with about 5 cm layer of pre-compost spread on top of the windrow. A regular observation and monitoring of substrate bed (windrow) has been recommended to check the inner temperature of the windrow. The feeding rate can be adjusted according the inner temperature to ensure ambient temperature inside the windrow. It has been recommended that application of thin layer of un-composted material at frequent intervals is possible on vermicomposting beds (windrows or stacked bins) and also continuous monitoring of substrate temperature can be done. The normal recommended thickness of layer is 7.5 cm, which can be increased in the winter up to 15 cm. It has been further reported that worm beds can be fed daily across their entire surface, and that controlling the depth of feeding was critical to the process. If too much of the substrate was fed, or if it is fed in greater thickness there could be potential for the material to compost, or turn anaerobic. Thus accordingly, both the conditions (namely composting or anaerobic conditions) would prevent earthworm's activity. It was concluded that the quantity of substrate fed should match the daily quantity consumed by the earthworms, which was approximately equal to their body weight.

It has been reported[12] that the basic governing principle of all the successful processing systems is to add the waste frequently in thin layers of about 2 cm to 5 cm and allow the earthworms to process the aerobic layers of wastes successively. The earthworms would get concentrated in the upper 15 cm layer of the material and move upwards as each successive waste layer is added. The adding of wastes in thin layers would avoid overheating during thermophilic composting, but would be appropriate to maintain suitable temperature for the worm growth during cold seasons. It has also been reported that no

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pre-composting practice existed in Oregon and Australia. It has been reported[17] that daily application of 7 cm-8 cm thick layer of pre-consumer produce material collected from super markets mixed with shredded wax paper and cardboards into 2.5 cm × 0.75 cm (approximate size) raised trough having mesh flooring using *E fetida*, while it has been recommended[2,14] that 5 cm-8 cm thick manure layer application on vermicomposting beds which could be increased up to 15 cm in colder weather. It has been recommended[22] that regular addition of thin layers of organic matter at 1 day-3 day intervals to maintain aerobicity and to avoid the increase of temperature above 35°C (which can be lethal to the earthworms).

There still remains knowledge about the effect of substrate depth on the vermicomposting if aerobicity is to be ensured.

METHODOLOGY

All the experiments were performed out in truncated porous earthen pots of approximately 8-litre capacity. The pots were initially filled to a 2.5 cm height with 12.5 cm nominal size chips of stone (aggregates), which was then covered with 2.5 cm thick layer of 1 mm-5 mm size gravel to ensure proper drainage of excess water. A layer of local soil mixed with cow dung humus in 1:1 ratio of 2.5 cm thickness was used above the gravel bed to provide natural habitat to the earthworms. The experimental pots were kept in the laboratory.

Mixed vegetable residues (organic waste) collected from institute's hostels were inoculated with 20 local adult (clitellate) epigeic earthworms (*perionyx excavatus*) for the purpose of vermicomposting. The earthworms were introduced to prepared pots one day prior to feeding of waste into the pots. This was done with a view that earthworms could acclimatize into the new environment and settle themselves in the new habitat. The vegetable waste was then top feeded into the five different experimental pots with varying thickness of 5 cm, 7.5 cm, 10 cm, 12.5 cm and 15 cm to ensure the effect of the substrate depth variation.

A control (of 10 cm initial waste thickness) was maintained without earthworms. All the experiments were performed in replicates. Regular water sprinkling was done in all the experimental pots including in the control pot in such a way as to ensuring the maintenance of approximately 70% moisture level, to account for the loss of water due to evaporation and drainage. The depth of substrate was measured using a graduated steel ruler on alternate days at 4 spots-5 spots in the exposed substrate area and arithmetic mean value was recorded. Similarly, on the same day and same time, the temperature of substrate was also similarly measured with an L-shaped mercury thermometer and the arithmetic mean was recorded. The ambient temperature was continuously recorded with the help of a room thermometer.

RESULTS

Based on the observation carried out for a period of 35 days, the results of the variations in the substrate column depth with respect to the time ambient temperature, substrate temperature during the course of vermicomposting are presented in Table 1.

DISCUSSION

The variation in the substrate column depth with respect to time plotted in the Figure 1 depicts that the maximum depth reduction takes place in the first seven days in all the test runs taken at the various initial depths of the substrate which may be the results of initial decomposition of substrate by the microorganisms in the presence of easily available nutrients. Initial depth reduction in the substrate may also be attributed to the natural compaction due to self-weight, fragmentation of waste material due to decomposition and water sprinkling. The depth reduction rate subsequently slowed down during the 20 days-25 days of vermicomposting. Afterwards, (*ie,* after about 25 days), almost no depth reduction was observed in 5 cm and 7.5 cm initial depth test runs while very slower rate of depth reduction was observed in other three test runs. Control showed similar rate of the depth reduction up to 4 days-5 days and afterwards slower rate of depth reduction was observed as compared to the vermicomposting. The faster rate of depth reduction in vermicomposting sets can be the result of enhanced organic matter decomposition in the presence of earthworms[8,21]. Almost constant depth at about 23 days, 28 days and 30 days was observed in 5 cm, 7.5 cm, 10 cm, 12.5 cm and 15 cm runs respectively which showed the final stabilization of the waste material, while the depth of control set was decreasing till last day of observation (35 days) which can be correlated to slower rate of decomposition in the absence of earthworms. It can be concluded that the organic wastes can be stabilized by vermicomposting in shorter period as compared to composting. It can also be hypothesized that the depth reduction is a function of time and the initial depth. Foul odour was observed in 12.5 cm and 15 cm depth sets around 5-7 days indicating the development of anaerobic conditions in the process. Possibility of developing anaerobic condition in thicker depth of substrate had also been reported. The above observation confirms that maintenance of aerobic condition during vermicomposting depends upon the initial substrate depth.

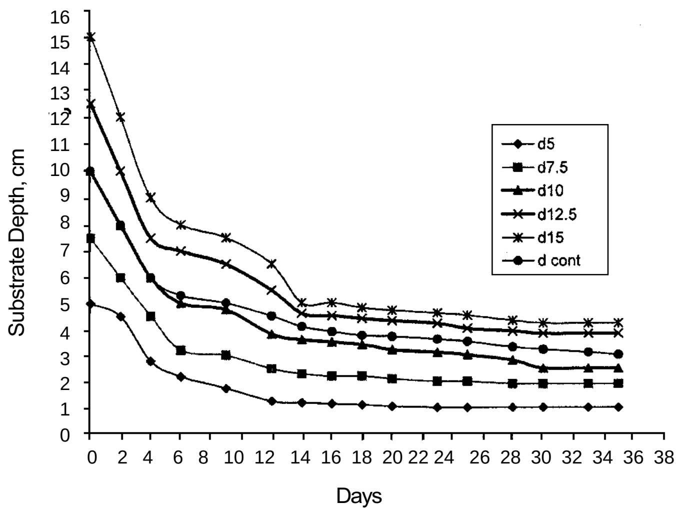

Figure 1 Variation in the substrate column depth with respect to time

Table 1 Data of vermicomposting for depth variation and temperature of the substrate

Day	Ta	Initial Depth of Substrate															Control Run of 10 cm		
		5 cm			7.5 cm			10 cm			12.5 cm			15 cm					
		d	T	T–Ta	d	T	T–Ta	d	T	T–Ta	d	T	T–Ta	d	T	T–Ta	d	T	T–a
0	32.0	5.00	32.5	0.5	7.5	34.0	2.0	10.0	34.5	2.5	12.5	35.0	3.0	15.0	35.0	3.0	10.00	34.5	2.5
2	31.2	4.50	31.5	0.3	6.0	32.0	0.8	8.0	33.0	1.8	10.0	33.5	2.3	12.0	34.0	2.8	8.00	33.0	1.8
4	28.7	2.80	28.5	−0.2	4.5	28.5	−0.2	6.0	28.5	−0.2	7.5	28.5	−0.2	9.0	29.0	0.3	6.00	28.5	−0.2
6	31.5	2.20	28.5	−3.0	3.2	28.5	−3.0	5.0	28.5	−3.0	7.0	28.5	−3.0	8.0	28.5	−3.0	5.30	28.5	−3.0
9	32.5	1.75	30.0	−2.5	3.0	30.0	−2.5	4.8	30.5	−2.0	6.5	30.5	−2.0	7.5	30.5	−2.0	5.00	30.2	−2.3
12	32.7	1.25	30.5	−2.2	2.5	31.5	−2.2	3.8	32.0	−0.7	5.5	33.0	0.3	6.5	33.0	0.3	4.50	31.6	−1.1
14	33.0	1.20	30.0	−3.0	2.3	30.0	−3.0	3.6	30.5	−2.5	4.6	32.5	−0.5	5.0	31.5	−1.5	4.10	30.2	−2.8
16	32.5	1.15	30.0	−2.5	2.2	30.0	−2.5	3.5	30.0	−2.5	4.5	33.5	1.0	5.0	32.5	0.0	3.90	29.8	−2.7
18	31.2	1.10	30.0	−1.2	2.2	28.5	−2.7	3.4	30.0	−1.2	4.4	32.0	0.8	4.8	32.0	0.8	3.75	29.7	−1.5
20	29.0	1.05	28.5	−0.5	2.1	28.0	−1.0	3.2	28.5	−0.5	4.3	30.0	1.0	4.7	30.0	1.0	3.70	28.6	−0.4
23	28.5	1.00	27.0	−1.5	2.0	28.0	−0.5	3.1	28.0	−0.5	4.2	27.5	−1.0	4.6	27.5	−1.0	3.60	28.2	−0.3
25	28.0	1.00	27.0	−1.0	2.0	27.0	−1.0	3.0	27.0	−1.0	4.0	27.0	−1.0	4.5	27.0	−1.0	3.50	27.2	−0.8
28	28.5	1.00	27.5	−1.0	1.9	27.5	−1.0	2.8	27.5	−1.0	3.9	27.0	−1.5	4.3	27.5	−1.0	3.30	27.5	−1.0
30	28.5	1.00	27.5	−1.0	1.9	27.5	−1.0	2.5	27.5	−1.0	3.8	27.5	−1.0	4.2	27.5	−1.0	3.20	27.5	−1.0
33	28.0	1.00	27.0	−1.0	1.9	27.0	−1.0	2.5	27.0	−1.0	3.8	27.0	−1.0	4.2	27.0	−1.0	3.10	27.0	−1.0
35	28.5	1.00	27.5	−1.0	1.9	27.5	−1.0	2.5	27.5	−1.0	3.8	27.5	−1.0	4.2	27.5	−1.0	3.00	27.5	−1.0

Note : d : Depth of the substrate remaining at the stated time, cm; T : Temperature of the substrate at the stated time, °C; Ta : Ambient (room) temperature, °C; and The control run having no earthworms monitored the simple aerobic degradation of the waste

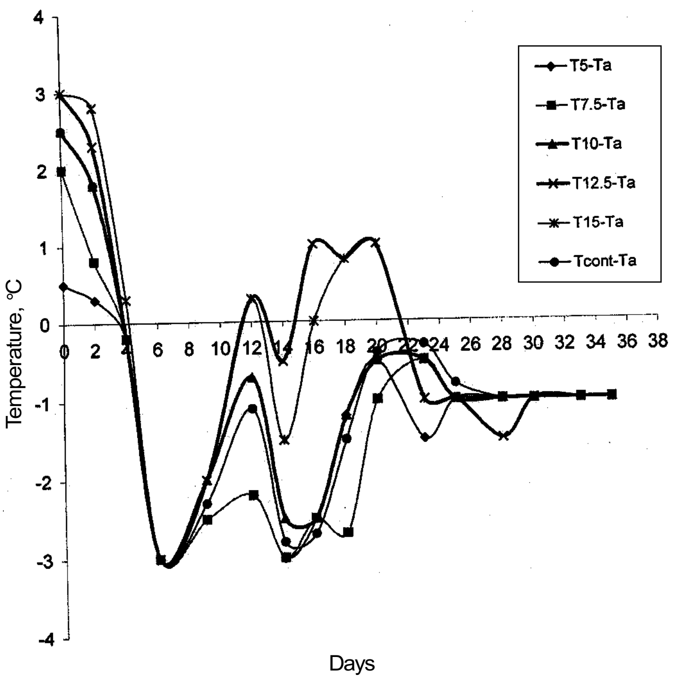

Figure 2 Heat evolution during the process with respect to time

The substrate temperature was observed to be 32.5°C, 34°C, 34.5°C, 35°C, 35°C and 34.5°C in 5 cm, 7.5 cm, 10 cm, 12.5 cm, 15 cm initial depth of vermicomposting and 10 cm control runs respectively as compared to ambient temperature of 32°C. Out of 20 earthworms each, initially left in the 12.5 cm and 15 cm sets of vemicomposting, 4 numbers and 7 numbers of earthworms respectively, were found dead on the top surface of the substrate on the second day. This can be the result of initial high temperature in the substrate. the temperature above 35°C has been reported to be lethal for many varieties of earthworms[7,16]. The difference of substrate temperature and ambient temperature with respect to time presented in Figure 2 depicts that the temperature of substrate in all the sets was initially higher than the ambient temperature. The substrate temperature followed a reducing pattern up to 6 days. However, from the 4th day, the substrate temperature was observed to be below the ambient temperature. The maximum increase in temperature over the ambient temperature was as much as 3°C. The control also followed similar pattern of temperature variation. The fall in temperature can be ascribed to sprinkling of water for maintenance of 70% moisture level and decrease in microbial action due to non-availability of simple form of substrate as well as aeration by the movement of earthworms in the substrate. Subsequently after 6 days, temperature of the substrate started rising that can be the result of enhanced microbial action after lag phase (of some 6 days) due to easily available simple forms of nutrients after initial decomposition for their growth and reproduction. The increased microbial action in the presence of earthworms has, also been reported[8]. The temperature in 12.5 cm and 15 cm initial depth runs which turned anaerobic after 7 days, increased above ambient temperature, while temperature of the 5 cm, 7.5 cm and 10 cm depth substrate sets was well below ambient temperature that is also an indication of maintenance of aerobic conditions in them. Further, at about 25 days, no temperature fluctuation in the substrate was observed which could be correlated to the stabilization of the substrate at this stage. Similar pattern of temperature variation has, also been reported[19] while studying population dynamics of Eisenia andrei in different organic wastes. keeping in view the stabilization of substrate, fresh waste material could be applied after about 15 days.

ANALYSIS OF RESULTS

Utilizing the observation presented in Table 1 for the different initial depths (in cm) of the substrate, the depth variation with respect to the time of vermicomposting during the course of the experimentation in the laboratory of the institute are presented in Figure 1. Heat evolution manifested during the process, *ie,* substrate temperature (T °C) minus ambient temperature (Ta °C), *ie,* (T – Ta) with respect to time is plotted in Figure 2. The variation graphs for varying depth (d) minus constant (the stabilized) depth (d_c) of substrate, *ie,* ($d - d_c$) verses time of vermicomposting are presented in Figure 3. Further, for modelling purposes, the lines of best fits in respect of each of the initial depth, depicting the variations of depth (d) at the different times of vermicomposting, are shown in Figure 4, 5, 6, 7, 8 and 9 (control). These variations are subjected to curve fitting using the least square regression technique and all the stated curves are seen to follow exponential law as per the following details:

$d = ae^{-kt} + d_c$ (where d = substrate depth at time t; a = constant ; k = rate of decay; t = time at which depth is predicted; d_c = stabilized depth of the substrate at the end of the experimental run, cm). The regressed equations for all the five different initial depths and control are as follows:

(i) $Y = 4.5495\, e^{-0.22x} + 1.0\, (R^2 = 0.9908)$

(ii) $Y = 4.7395\, e^{-0.1629x} + 1.9\, (R^2 = 0.9838)$

(iii) $Y = 5.7405\, e^{-0.1047x} + 2.5\, (R^2 = 0.9735)$

(iv) $Y = 8.2646\, e^{-0.1474x} + 3.8\, (R^2 = 0.9793)$

(v) $Y = 10.394\, e^{-0.1534x} + 4.2\, (R^2 = 0.9718)$

(vi) $Y = 7.0556\, e^{-0.0283x}\, (R^2 = 0.839)$ (control run)

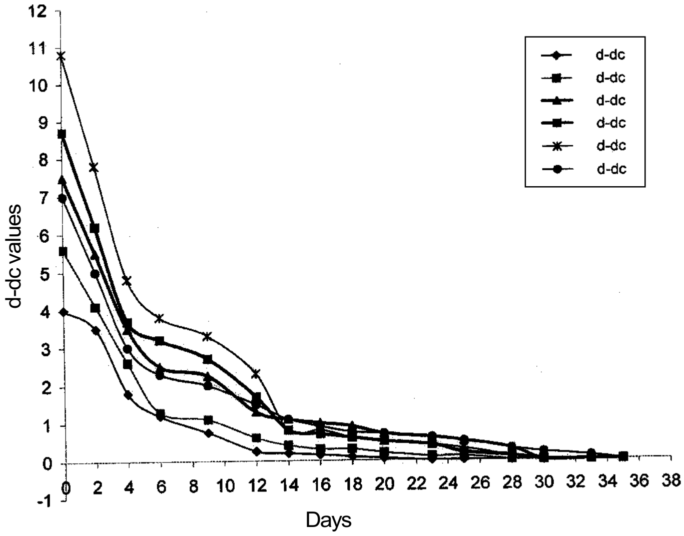

Figure 3 Initial depth minus constant depth (d-dc) variation with respect to time

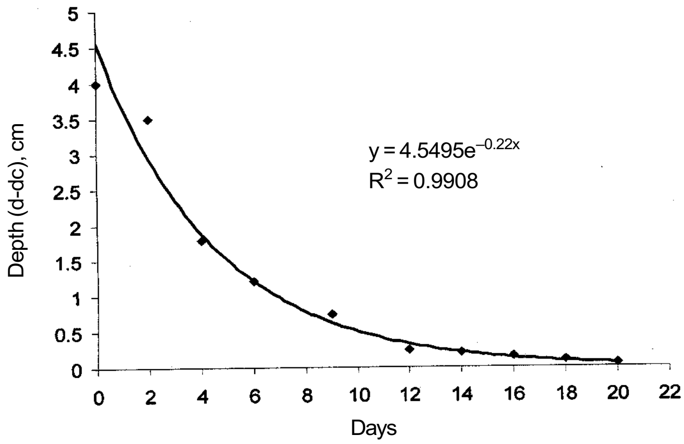

Figure 4 Depth (d-dc) variation for 5 cm initial depth

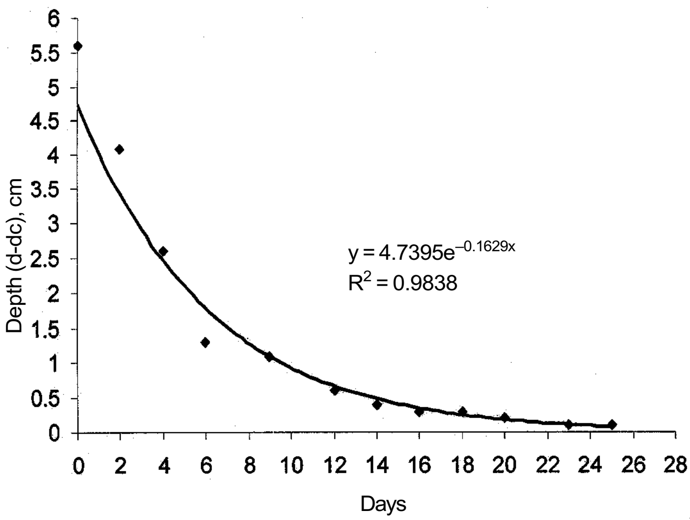

Figure 5 Depth (d-dc) variation for 7.5 cm initial depth

where Y = depth of substrate with respect to time; and x = time in days. least square regression and curve fitting for depth variation with respect to time follows exponential pattern, which is true for all biological mass balance systems.

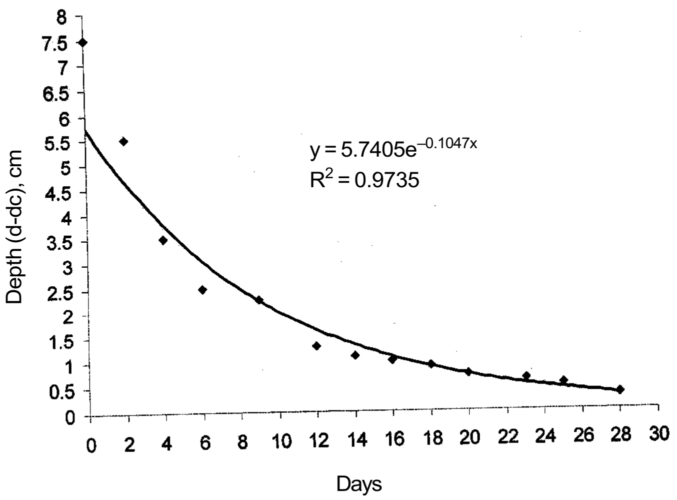

Figure 6 Depth (d-dc) variation for 10 cm initial depth

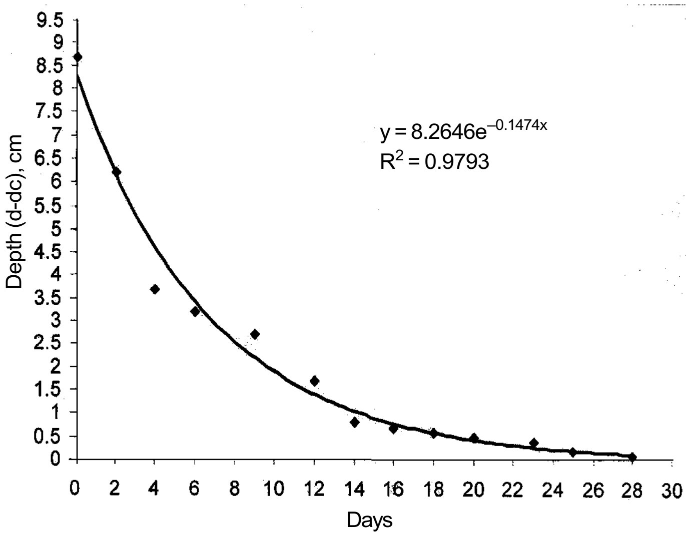

Figure 7 Depth (d-dc) variation for 12.5 cm initial depth

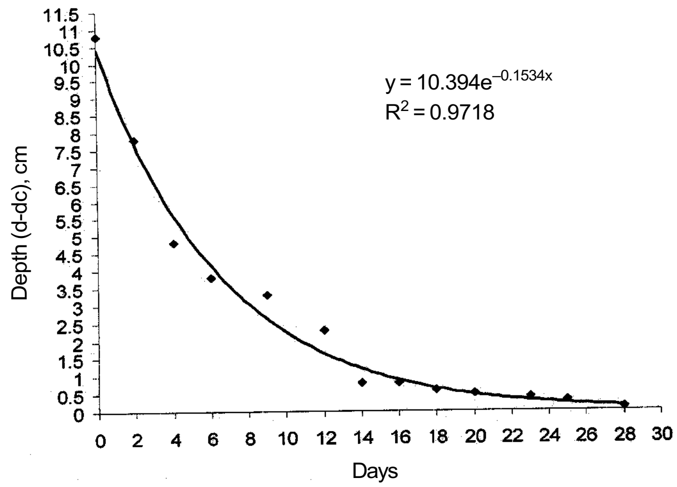

Figure 8 Depth (d-dc) variation for 15 cm initial depth

Furthermore, constant *a, k* and d_c (for vermicomposting only) variation with respect to the initial substrate depth are presented in Figure 10, 11 and 12 with an aim to establish correlation between the model constants and initial depth to define

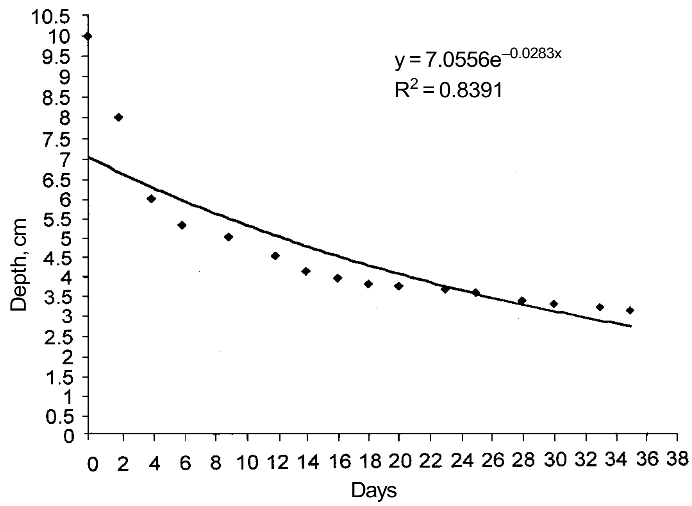

Figure 9 Depth (d-dc) variation for 10 cm initial depth control set

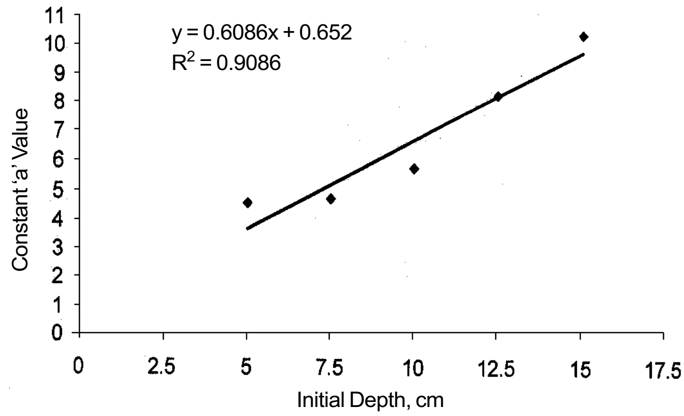

Figure 10 Constant 'a' variation with respect to initial depth

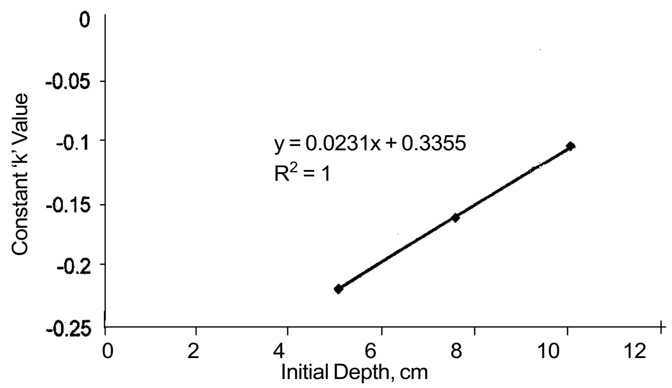

Figure 11 Constant 'k' variation with respect to time

theme as a function of the initial depth. Constant '*a*' variation follows a linear trend and corresponds to an equation (least square regression) $Y = 0.6086\ X + 0.652$ ($R^2 = 0.9086$) where Y represents '*a*' value and X represents initial depth. Similarly, the stabilized (tending to be constant) depth of substrate (below which it virtually does not decrease), also follows a linear trend and using the least square regression, it corresponds to $Y = 0.332\ X - 0.64$ ($R^2 = 0.9802$) where Y and X represents d_c value and initial depth. But, the constant *k* does not show any standard set trend. This can be attributed to the

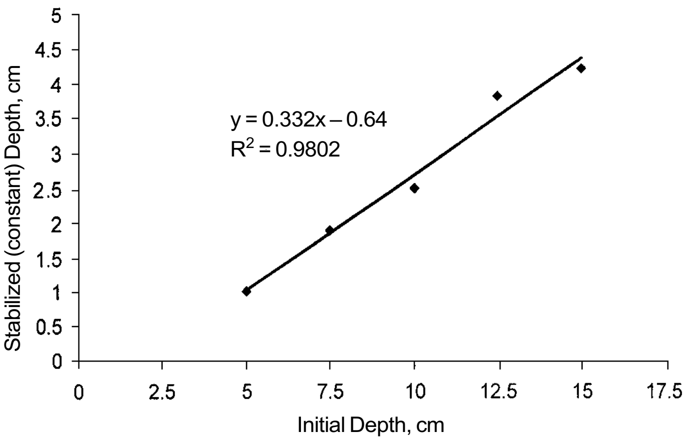

Figure 12 Variation of stabilized depth with respect to initial depth of substrate

development of anaerobic conditions that were set in the 12.5 cm and 15 cm depths. Therefore, 12.5 cm and 15 cm depth values are discarded and first three values are considered for a possible relationship. A linear trend (using the least square regression) is seen to follow corresponding to the equation $Y = 0.0231\,X - 0.3355$ ($R^2 = 1$) where *Y* and *X* represents *k* value and initial depth. the substitution of the constants would yield a generalized equation (for depth variation as follows:

$$d = (0.6086\,d_o + 0.652)\,e^{-(0.0231 d_o - 0.3355)t} + (0.332\,d_o - 0.64)$$

where d = depth of the substrate with respect to time t in cm, d_o = initial depth of the substrate in cm, and t = time in days.

CONCLUSION

The information presented in this paper indicates that the depth reduction is a function of time and initial depth. the present study reveals that 7.5 cm to 10 cm depth is optimum loading of the substrate to be fed/spread over vermicomposting bins or windrows. The substrate depth above 10 cm turned anaerobic during vermicomposting indicating that the depth should be restricted to 10 cm thickness as well as the heat evolution during initial period of vermicomposting in thicker depths may become lethal to the earthworms. The depth variation with respect to time follows exponential curve and least square regression results in to a higher degree of correlation (R^2 = 0.97 to 0.98).

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