Part II

Vermicomposting of water hyacinth
Part II

VERMICOMPOSTING OF WATER HYACINTH

Water hyacinth has successfully resisted all attempts of eradicating it by chemical, biological, mechanical, or hybrid means (Abbasi and Ramasamy, 1999). A large number of reports are available on the possible ways of utilizing water hyacinth. These include use as paper pulp, poultry/veterinary feed, material for furniture and carry bags, source of medicinals etc etc. But the only utilization option that has proved economically viable is deployment of the weed in purifying wastewaters (Tchobanoglous et al., 1989, Tchobanoglous and Burton, 1999). But the quantity of weed that can be thus utilized is very very small; indeed beyond the 'seed' plants needed to start the wastewater purification systems, one does not need water hyacinth growing in nature for this purpose. Furthermore, the water hyacinth that grows in wastewater treatment systems has to be periodically harvested and disposed, just as the weed growing in the nature has to (Gajalakshmi et al., 2002).

Attempts to find other economically viable means of utilizing water hyacinth have been made. These include the extraction of volatile fatty acids (VFAs) from water hyacinth for use as feed-supplement in biogas digesters (Ramasamy and Abbasi, 1999; 2000), solid-feed anaerobic digestion of the weed to generate fuel as methane (Ramasamy, 1997; Abbasi and Ramasamy, 1999). Even as these options are gainful, the problem of disposal of 'spent' weed ensuing from VFA extractors, anaerobic digestion, or wastewater treatment systems still remains.

We have studied vermicomposting of water hyacinth – directly or after composting – due to the following likely benefits:

Water hyacinth, even in its decayed or dried form, has the ability to vegetatively propagate itself. But studies conducted by us (Gajalakshmi et al., 2002) have revealed that the weed loses this ability once it passes through
the earthworm's gut. Vermicast is very popular as soil conditioner among the farmers, especially in the third world.

Vermicomposting thus appeared to be a highly promising option for not only large-scale utilization of water hyacinth, but also its ultimate disposal. In the following chapters studies on various aspects of utilization of water hyacinth by composting-vermicomposting is presented.

At the start, four of the earthworm species – two anecics and two epigeics were screened for their potential as vermiconverters of water hyacinth. The study has since been published in Bioresource Technology, 76, 177-181 (2001) and is reproduced as chapter 4.

As the vermicast output may depend on the size and texture of the feed, water hyacinth in various forms – fresh, chopped, dried, precomposted, and with/without cowdung supplement – was tried as substrate for vermicomposting. The study has been published in Bioresource Technology, 82, 165-169 (2002) and is reproduced as chapter 5.

Chapter 6 focuses on the viability of reactors fed with different proportions of water hyacinth and cowdung. Attempts were also made to improve the efficiency of the vermireactors in terms of vermicast output per unit time and per unit reactor volume. The study has been published in Bioresource Technology, 80, 131-135 (2001) and is reproduced as chapter 6.

In an attempt to develop a system with which water hyacinth can be economically processed to generate vermicompost in large quantities, the feed was first composted and then subjected to vermicomposting in reactors with large earthworm densities. The study has been published in Bioresource Technology, 83, 235-239 (2002) and is reproduced as chapter 7.
Studies to see whether water hyacinth vermicompost can trigger infestation of the weed

One of the reasons behind the exceptional intransigence and colonizing ability of water hyacinth is that the weed can propagate sexually as well as vegetatively. Even a tiny piece of a water hyacinth petiole can grow into a plant and become the source of propagation of water hyacinth in water bodies hitherto free from the weed.

When we set out to use water hyacinth as a possible substrate for generating vermicompost it was felt expedient to check whether water hyacinth vermicompost contains any remnant of the weed in a form that can lead to vegetative reproduction of the weed if the remnant had to accidentally reach an otherwise hyacinth-free water body.

Therefore the following experiments were conducted:

Two sets of circular plastic containers were filled with garden soil upto half of their volume. Of these in one set, water was filled upto the brim and in the other set, the soil was moistened, maintaining approximately 60-70% moisture content. A third set of containers was filled with only water. In all the containers, a known quantity of castings obtained from water hyacinth fed reactor was applied and the containers were kept under continuous monitoring.

The experiment was continued for six months retaining the same conditions. There was no sign of germination of water hyacinth in any of the containers. Hence it may be concluded that water hyacinth loses its ability to reproduce after it has passed through the earthworm gut.
References


Ramasamy, E.V., 1997. *Biowaste treatment with anaerobic reactors*, Ph D thesis submitted to Pondicherry University, Pondicherry, India, pp


Chapter 4

Bioresource Technology 76 (2001) 177-181

Potential of two epigeic and two anecic earthworm species in vermicomposting of water hyacinth

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Abstract

The potential of two epigeic species (Eudrilus eugeniae Kinberg, and Perionyx excavatus Perrier) and two anecic species (Lampito mauritii Kinberg and Drawida willsi Michaelson) of earthworms was assessed in terms of efficiency and sustainability of vermicomposting water hyacinth (Eichhornia crassipes, Mart. Solm.). In different vermireactors, each run in duplicate with one of the four species of earthworms, and 75 g of 6.1 water hyacinth; cowdung as feed, vermicasts were produced with steadily increasing output in all the reactors. E. eugeniae was by far the most efficient producer of vermicasts, followed by the other epigeic P. excavatus. The two anecics came next, with D. willsi being the least effective which could generate only about half the quantity of vermicasts achieved in a corresponding time by E. eugeniae. In all the reactors, the earthworms grew well, increasing their weights by more than 250%. The maximum net gain of weight (average 30.7 g) was by E. eugeniae, followed by P. excavatus, L. mauritii and D. willsi. This trend, which followed the efficiency of vermicast production, was also shown in terms of reproductive ability as measured by the number of offspring produced by the four species. © 2000 Elsevier Science Ltd. All rights reserved.

Keywords: Vermicomposting, Eudrilus eugeniae; Lampito mauritii; Perionyx excavatus; Drawida willsi; Vermicast; Water hyacinth

1. Introduction

Water hyacinth (Eichhornia crassipes Mart. Solm.) is one of the most intransigent weeds of the world (Abbasi, 1998). It has successfully resisted all attempts of eradicating it by chemical, biological, mechanical, or hybrid means (Abbasi and Ramasamy, 1999a). At present these methods succeed only in keeping the weed infestation in check at enormous costs. Wherever water hyacinth is not controlled, due to limited resources or other reasons, it rapidly covers all the water-bodies and surrounding marshy areas in those regions. At an average annual productivity of 50 dry (ash-free) tonnes per hectare per year, water hyacinth is one of the most productive - perhaps the most productive - plants in the world (Abbasi and Nipaney, 1986; Abbasi and Ramasamy, 1999a). This attribute helps the weed to cover water surfaces faster than most other plants. Such colonization of wetlands leads to rapid decline of the quantity and the quality of water contained in the wetlands - eventually causing the loss of the wetlands.

The authors have been trying to find ways and means of utilizing water hyacinth by low-cost and labour-intensive technology so that farmers and householders living near the wetlands are encouraged to harvest the weed, thus keeping it under control when other means of controlling it are not available. These attempts have led to the extraction of volatile fatty acids (VFAs) from water hyacinth to be used as feed-supplement in slurry biogas digesters (Abbasi and Ramasamy, 1996; Ramasamy and Abbasi, 2000), and solid-feed digesters to generate fuel (Ramasamy, 1997; Abbasi and Ramasamy, 1999b). Another economically viable means of utilizing water hyacinth, from among numerous options (Lakshman, 1987; Abbasi and Nipaney, 1993), has been the use of the weed in treating wastewaters with biodegradable pollutants (Tchobanoglous et al., 1989; Tchobanoglous and Burton, 1999). Even if these options are gainful, the problem of disposal of 'spent' weed still remains.

In this paper, we present studies on the efficacy and sustainability of using four species of epigeic (phytophagous) and anecic (geophytophagous) earthworms in generating vermicasts from water hyacinth. In India - as also many other parts of the world - vermicasts are believed to have several components which improve the
soil to which they are applied (Ashok Kumar, 1994; Ismail, 1997). The perceived, sometimes demonstrated, benefits include improvement in the water retention capability of the soil, and better plant availability of the nutrients in the vermicasts compared to the 'parent' (pre-vermicomposted) material (Ismail, 1998). Vermicast are also believed to contain enzymes and hormones that stimulate plant growth and discourage pathogens (Ismail, 1998). Vermicast are also believed to contain enzymes and hormones that stimulate plant growth and discourage pathogens (Ismail, 1997; Abbasi and Ramasamy, 1999a; Slocck, 1999). For these reasons vermicasts are popular soil applicants among the farmers, and find a ready market.

In earlier studies (Abbasi and Ramasamy, 1996; Abbasi et al., 1996), we had found that water hyacinth loses its ability to reproduce vegetatively or sexually after it has passed through the earthworm gut. Otherwise even tiny pieces of the weed petioles, if introduced in a water-logged area, can lead to reproduction and vigorous colonization. These observations have encouraged us to explore possibilities of vermicomposting water hyacinth as a means of final disposal of the weed.

2. Methods

2.1. Choice of the earthworm species

The epigeic Eudrilus eugeniae Kinberg is a manure worm which has been extensively used in north America and Europe for vermicomposting because of its voracious appetite, high rate of growth, and reproductive ability. A few years back it was brought to India and has been favoured with progressively increasing application in the vermicomposting of animal manure and other forms of biomass (Ashok Kumar, 1994; Ismail, 1998).

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### Table 1

<table>
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<th>Runs (each of 15 days)</th>
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<th>P. exoantus</th>
<th>L. mauritii</th>
<th>D. willii</th>
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### Table 2

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</table>

Net increase: 30.7 25.8 23.3 22.8
The other epigeic species of worm studied by us — *Perionyx excavatus* Perrier — is indigenous and occurs in most parts of India (Gaur and Singh, 1995; Ismail, 1997). It is also common in several other regions across the world (Manna et al., 1997).

Both the anecic (geophytophagous) species of worms utilized in this study occur in India, as also elsewhere, but *Dendrobaena willsi* Michaelson is particularly common in the southern part of the Indian peninsula.

### 2.2 Vermireactors

Circular, 4 l plastic containers (dia. 24 cm, depth 9 cm) were filled from bottom up with successive layers of sawdust, river sand and soil of depths 1, 2, and 4 cm, respectively. In each reactor, 20 healthy and adult animals of the chosen species were introduced. These animals were picked from the cultures maintained by the authors with cowdung as the feed. Each culture had more than 200 animals from which 20 individuals were randomly picked for these experiments. The average moisture content of the vermireactors was maintained at 45 ± 1% by monitoring the moisture content at different heights of the reactors every week and sprinkling the required quantities of water. Usually the top one-third of the reactors had 29 ± 1% moisture, the middle one-third 45 ± 1%, and the bottom one-third 61 ± 1%. All quantities were adjusted so that the feed and the casting mass reported in this paper represent dry weights (taken after oven-drying at 105°C to constant weight). The earthworm biomass is reported as live weight, taken after rinsing adhering material off the worms and blotting them dry. The castings were carefully sieved to separate other particles. A portion of the castings was then weighed and thoroughly washed with water to separate the small soil particles contained in the castings from the organic matter. The separated soil was oven

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### Table 3

<table>
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<tr>
<th>Runs (each of 15 days)</th>
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<th>L. mauritii</th>
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<td>Net increase</td>
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<td>21</td>
<td>23</td>
<td>22</td>
<td>20</td>
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Fig. 1. Recovery of vermicasts (%) each fortnight by (a) *E. eugenia* (b) *P. excavatus* (c) *L. mauritii* (d) *D. willsi.*
dried (105°C) to constant weight. This enabled determination of the mass fraction of soil particles contained in the castings. This fraction was subtracted from the total mass of castings recovered. Thus, the vermicomposting data presented here pertain to conversion of only the feed to the castings, and exclude the entrained soil.

The reactors, all run in duplicate, were started with 75 g of feed comprising of water hyacinth:cowdung at 6:1 (w/w, dry weight). After 15 days, the castings and the earthworms were removed and placed in separate containers for quantification while the rest of the reactor contents were discarded. Within a few minutes fresh reactors were started. The juveniles, if any were generated in the previous run, were separated and the 20 worms, with which the reactors had been started, were weighed and reintroduced. It was very easy to distinguish ‘parent’ worms as they were much larger in size than the juveniles produced during the run. All subsequent measurements were taken once in 15 days in the manner described above, resetting the vermicomposting each time so that the same sets of worms with which the reactors were started continued to be the principal producers of vermicasts.

3. Results and discussion

The average vermicast recovery as the fraction of feed mass (Table 1) was low during the first fortnight of reactor operation, indicating that the earthworms, which had been cultured with cowdung as the principal feed, took some time to acclimatize with the changeover to water hyacinth feed. As the reactor outputs had been fluctuating, albeit within a narrow range, trend lines were drawn using an appropriate software (Microsoft, 1997) in order to assess whether the fluctuations were leading to a net rising, falling, or steady vermicast output. The results indicated rising trends of small slopes (Fig. 1). Further, successive runs yielded a fairly consistent recovery, agreeing to within 3% of each other. The vermicast output from reactors run in duplicate was also reproducible; the duplicates agreeing to within 4% in most runs. As the reactors were comprised of poorly mixed, heterogenous solids, this level of agreement within duplicates may be deemed quite good.

The average mass of the earthworms of all the four species increased (Table 2) by close to three orders of magnitude, and was still increasing as reflected in the last three runs. We would, therefore, expect that the vermicast output would continue to rise till the earthworms reached the height of feeding activity. Thereafter it might decline as the earthworms lived beyond their most active age.

All species of earthworms reproduced successfully in these reactors (Table 3). Had the offspring not been continuously removed, the earthworm population in reactors with P. excavatus, L. mauritii and D. willsi would have almost doubled and in reactors with E. eu-

![Fig. 2. Number of juveniles produced by 20 animals of E. eugeni (a), P. excavatus (b), L. mauritii (c), D. willsi (d) over six months.](image-url)
It would have increased two-and-a-half times (Figs. 1 and 2). On the basis of this observation, one can assume that all the reactors might continue to run indefinitely on the water hyacinth feed, with new generations of earthworms gradually taking over the vermiconversion as the previous generation gradually declined in activity and died.

In terms of the efficiency of vermiconversion of water hyacinth (as reflected in the mass of vermicasts produced per unit time for the given rate of feed input), the animal species followed the trend *E. eugeniae* > *P. excavatus* > *L. mauriti* > *D. willsi*. Similar trends were observed for increase in animal biomass (Table 2), and number of offspring produced, with the exception that in the latter aspect *L. mauriti* was indistinguishable from *D. willsi*.

In our earlier experiments with the performance of vermireactors run on these four species and with waste paper as the principal feed, we had found that the phytophagous *L. mauriti* was not only the most efficient producer of vermicasts but also generated more offspring during the six-month long trials (Gajalakshmi et al., 2000). In the present instance, the phytophagous *E. eugeniae* and *P. excavatus* were seen to score over the two phytophagous, or anecic, species. Besides the fact that water hyacinth is phytomass and ought to be naturally preferred by phytophagous species, the relative ‘hardness’ of waste paper feed may be a reason why phytophagous worms were able to feed upon it more voraciously than did the phytophagous species.

Acknowledgements

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References


Chapter 5
Bioresource Technology 82 (2002) 165-169

Vermicomposting of different forms of water hyacinth by the earthworm *Eudrilus eugeniae*, Kinberg

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Abstract

Six-month long trials were conducted on different vermicomposts fed with one of the following forms of water hyacinth: (a) fresh whole plants, (b) dried whole plants, (c) chopped pieces of fresh plants, (d) 'spent' weed taken from reactors after extracting volatile fatty acids (VFAs), (e) precomposted fresh weed and (f) precomposted spent weed. The first four forms were studied with and without cowdung. The experiments revealed three clear trends (i) of the various forms of the weed assessed, the precomposted forms were the most favoured as feed by *Eudrilus eugeniae*, Kinberg, while the fresh whole form was the least favoured, (ii) the different forms of spent weed were favoured over the corresponding forms of fresh weed, and (iii) blending of cowdung (~ 14% of the feed mass) with different forms of water hyacinth had a significant positive impact on vermicast output, growth in worm biomass, and production of offspring relative to the corresponding unblended feed. In all reactors, the 'parent' earthworms steadily grew in size over the six-month span, and produced offspring. There was no mortality. The experiments thus confirm that water hyacinth can be sustainably vermicomposted in any of the forms with *E. eugeniae*. © 2002 Elsevier Science Ltd. All rights reserved.

Keywords: Vermicomposting, *Eudrilus eugeniae*; Vermicast; Water hyacinth; Vermicompost

1. Introduction

Water hyacinth grows profusely in freshwater bodies, especially the ones grossly polluted with biodegradable wastes. It is one of the most intransigent weeds of the world (Abbasi, 1998; Tchobanogios and Burton, 1999). It multiplies to form large tracts of dense stands in a water-body, often pushing the water out of sight.

Water hyacinth has successfully resisted all attempts of eradicating it by chemical, biological, mechanical, or hybrid means (Abbasi and Ramasamy, 1999). A large number of reports are available on the possible ways of utilizing water hyacinth. These include use as paper pulp, poultry/veterinary feed, material for furniture and carry bags, source of medicinals, etc. But the only utilization option that has proved economically viable is deployment of the weed in purifying wastewaters (Tchobanogios et al., 1989; Tchobanoglos and Burton, 1999). But the quantity of weed that can be thus utilized is very small; indeed beyond the 'seed' plants needed to start the wastewater purification systems, one does not need water hyacinth growing in nature for this purpose. Furthermore, the water hyacinth that grows in wastewater treatment systems has to be periodically harvested and disposed of, just as the weed growing in nature has to.

The authors have been making attempts to find other economically viable means of utilizing water hyacinth; these include the extraction of volatile fatty acids (VFAs) from water hyacinth to supplement cowdung as feed in biogas digesters (Abbasi and Ramasamy, 1996, 1999; Ramasamy and Abbasi, 2000), and solid-feed anaerobic digestion of the weed to generate fuel as methane (Ramasamy, 1997; Abbasi and Ramasamy, 1999). Even as these options are gainful, the problem of disposal of spent weed ensuing from VFA extractors, anaerobic digestion, or wastewater treatment systems still remains.

In this paper, we present studies on the performance of the earthworm, *Eudrilus eugeniae* Kinberg in generating vermicasts from different vermicomposts fed with various forms of water hyacinth as feed. We had earlier observed (Abbasi et al., 2000) that water hyacinth, even in its decayed or dried form, has the ability to vegetatively propagate itself; the weed loses this ability once it passes through the earthworm's gut. Further, vermicast...
is very popular as soil conditioner among the farmers, especially in the third world. Vermicomposting thus appears to be a highly promising option for not only a large-scale utilization of water hyacinth, but also for its ultimate disposal.

In an earlier sequence of six-month long trials (Gajalakshmi et al., 2001), four species of earthworms – comprising two epigeics E. eugeniae, Kinberg and Perionyx excavatus, Perrier, and two anecics Dravida willisi, Michaelsen and Lampros mauritii Kinberg – were screened for their efficiency and sustainability in producing castings from feed consisting of blends of water hyacinth (fresh and chopped) and cowdung in 6:1 ratio (by weight). The trials revealed that E. eugeniae produced significantly more castings per unit feed and per unit reactor volume than the other epigeic P. excavatus, and the two anecies L. mauritii and D. willisi. Similar trend was observed with regard to the increase in efficiency and mass of castings recovered each time. Thus, the vermicompostation data presented herein pertain to conversion of only the feed to the castings, and exclude the entrained soil.

2.3. Vermireactor operation

All reactors were operated under identical environmental settings (average day and night ambient temperatures and humidity: 32, 24 °C; 80%, 77%, respectively). Duplicates were run for all forms of the feed and were all started with 75 g of feed. Six forms of water hyacinth were studied in this manner: fresh whole plants, dried whole plants, fresh chopped plants, spent weed (weed residue after the extraction of VFAs in acidogenic fermenters), partially composted (please see below) forms of the weed and the fresh chopped/spent weed. In the first four of the above cases, the weed was subjected to vermicomposting in two ways: (i) directly, without cowdung supplement and (ii) with 6:1 weed:cowdung blends. In the last two forms cowdung had been added during partial composting, hence these forms were vermicomposted without further addition of cowdung.

The partial composting was done as follows. The substrate (fresh chopped or spent weed) was mixed with soil and cowdung in 6:3:1 weight ratio and left undisturbed in cloth-covered earthen pots for a week. This process partially composted the substrate and made it softer.

All quantities were adjusted so that the reported data represent dry weights (taken after oven-drying the concerned substrate at 105 °C to constant weight), except earthworms which are quantified after rinsing them off the adhering material and blotting them dry.

In each run, the castings and the earthworms were removed from the reactors on the 15th day from the start. They were placed in separate containers for quantification while the rest of the reactor contents was discarded. Within a few minutes fresh reactors were started. The juveniles, if any, generated in the previous run, were separated and the 20 worms, with which the reactors had been started, were weighed and reintroduced. It was very easy to distinguish parent worms as they were much larger in size than the juveniles produced during the run. All subsequent measurements were taken once in 15 days in the manner described above.

As the castings contained soil particles besides semi-midigested organic matter, a portion of the castings were oven dried (105 °C) to constant weight and thoroughly washed with water to separate the thin soil particles contained in the castings from the organic matter. The separated soils were also oven dried (105 °C) to constant weight. This enabled us to determine the mass fraction of soil particles contained in the castings each time. This fraction was subtracted from the total mass of castings recovered each time. Thus, the vermicomposting data presented herein pertain to conversion of only the feed to the castings, and exclude the entrained soil.

2. Methods

2.1. Vermireactors

Circular plastic containers (volume 3 l, diameter 24 cm, depth 7 cm) were filled from bottom up with successive layers of sawdust, river sand, and soil of depths 1.2 and 3.8 cm, respectively. In each reactor, 20 healthy, adult individuals of E. eugeniae were introduced. These animals were randomly picked from the cultures maintained by the authors with cowdung as the feed. Each culture had more than 2000 animals from where 20 individuals were randomly picked for these experiments. Moisture was maintained by periodic sprinkling of adequate quantities of water. The moisture content was monitored at different heights of the reactors every week. Usually the top one-third of the reactors had 25 ± 1% moisture, the middle one-third had 43 ± 1% and the bottom one-third 60 ± 1%.

2.2. Assessment of vermicast output

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The present study has been focused on the following aspect: recovery of vermicast from different digesters fed with one of the following forms of water hyacinth: fresh whole plant, dried whole plant, chopped pieces of fresh weed, and spent weed taken from fermenters after extracting VFAs. The above forms of water hyacinth were subjected to the earthworms with or without cowdung supplement. In addition, precomposted forms of fresh and spent weed were also explored as feed.
ensure that the rate of vermicomposting was neither influenced in the long run by the unutilized feed accumulating and biodegrading in the reactors nor by the vermicasts produced by the offspring of the parent earthworms.

3. Results and discussion

3.1. Reproducibility of the reactor performance

Epigeic (phytophagous) species like *E. eugeniae* have very shallow burrows in which they lie during the day. Being nocturnal animals, their feeding activity is brisk only during the night when they pull the feed from the reactor surface and ingest it in their burrows. They come to the reactor surface again to deposit the casting. This mechanism indicates that vermicreactors used in the present study can be classified as ‘poorly mixed heterogeneous solid reaction systems’. An illustrative set of reactor output data is presented in Table 1. The duplicates agree to within ±2.3 mg of vermicast output, the maximum relative error—in run number 3—is 7%. In all other runs (of which the results have been summarized in Fig. 1), too, the scatter in the vermicast output in any given run was always less than ±2.5 mg. Considering the heterogeneity of these bioreactors, this level of reproducibility may be considered as very good.

3.2. Gestation and vermicast output trends

Illustrative curves of vermicast output in two reactors, as a function of time, along with statistical trend lines which were drawn by using the software Microsoft Excel (1997) are presented in Fig. 2. In the first two runs the vermicast output was low, indicating a gestation period. The earthworms used in the present experiments had been cultured on cowdung-fed reactors. The gesta-

<table>
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<th>Reactor I</th>
<th>Reactor II</th>
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<th>Relative error (%)</th>
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<td>30.6</td>
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</tr>
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<td>37.7</td>
<td>36.15 ± 1.6</td>
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<td>46.8 ± 1.4</td>
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<tr>
<td>12</td>
<td>44.9</td>
<td>47.5</td>
<td>46.2 ± 1.3</td>
<td>2.8</td>
</tr>
</tbody>
</table>

Table 1: Reproducibility of the reactor performance: illustrative example of vermicast output (g) per fortnight in duplicate reactors fed with 75 g of precomposted water hyacinth per fortnight.

![Graph](https://example.com/graph1.png)

Fig. 1. Production of vermicasts (% of feed mass) by *E. eugeniae* in reactors fed with different forms of water hyacinth: (1) precomposted spent weed; (2) precomposted WH; (3) spent weed and cowdung (6:1); (4) WH and cowdung (6:1); (5) spent weed; (6) dried whole plant and cowdung (6:1); (7) dried whole plant; (8) WH; (9) fresh whole plant and cowdung (6:1); (10) fresh whole plant.
tion period implies that they took some time to get used to water hyacinth feed. The trend lines indicate that the reactor output was still rising. We presume that it would peak only after the earthworms crossed their most active age which, as per reports, averages 12 months post-adulthood for manure-worms such as *E. eugeniae*.

### 3.3. Suitability of different forms of water hyacinth as feed

The maximum mass of castings per unit feed mass and time (six-month average: 56.2%) was produced from precomposted spent water hyacinth (Fig. 1). This was closely followed by precomposted water hyacinth. Progressively less palatable to *E. eugeniae* were fresh chopped plants, dried whole plants, and fresh whole plants (Fig. 1). In all cases, water hyacinth fortified with cowdung was vermicomposted at a higher rate than the unfortified weed.

The results (Fig. 1) indicate that *E. eugeniae* prefers the feed in this order: precomposted spent weed > precomposted chopped weed > spent weed fortified with cowdung > chopped weed fortified with cowdung > spent weed > dried whole plants fortified with cowdung > dried whole plants ~ chopped weed > fresh whole plants with cowdung > fresh whole plants.

The spent water hyacinth is the softest of these feeds, softer than ‘fresh’ chopped weed because the former typically spends four or more days under dilute aqueous solution in the VFA generation reactors. This makes the plant more blotched and pulpy than fresh water hyacinth which is mostly above water in its natural state.

Further, VFA reactors only extract some C, H and O from the weed; N, P, K, and other nutrients are not removed. This, apparently, leaves the spent weed softer but no less nutritious than fresh water hyacinth. Precomposted forms of water hyacinth are preferred over uncomposted forms due to the same reason; composting renders the feed softer than it was.

An interesting and useful finding is that dried whole water hyacinth plants are vermicomposted faster than fresh chopped and fresh whole plants (Fig. 1). The practical utility of this observation stems from the fact that large quantities of water hyacinth may be harvested in situations where it may not be possible to vermiconvert it on-site, thus necessitating transportation. And since water hyacinth contains 94–96% water, drying it to less than half its fresh weight before transportation can substantially reduce the transportation costs.

The reason why worms are able to feed upon the dried weed more easily than fresh form is that the dried plants become brittle and become more easily utilizable by the worms than the harder and more tensile whole plants.

The number of offspring produced and the net increase in worm mass (Fig. 3) in the various reactors followed the trend of net vermicast output with the three exceptions: the worm mass gained with cowdung-fortified spent weed was slightly higher than with precomposted water hyacinth, the zoomass gained with fresh chopped water hyacinth was greater than dried water hyacinth, and the number of offspring produced...
with fresh chopped water hyacinth was greater than with dried water hyacinth.

There was no mortality in any of the 20 reactors. In all reactors the animals grew in size and produced offspring, albeit to different degrees. These observations confirm that *E. eugeniac* can be utilized to sustainably vermicompost different forms of water hyacinth in semi-continuously fed reactors.

Acknowledgements

The authors thank the Department of Science and Technology, Government of India, New Delhi, for the financial support.

References


Assessment of sustainable vermiconversion of water hyacinth at different reactor efficiencies employing *Eudrilus eugeniae* Kinberg

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**Abstract**

The viability of vermireactors fed with different proportions of water hyacinth (WH) and cowdung (CD) was assessed over six-month trials. All reactors performed sustanably with a steadily rising vermicast output, worm zoonoom, and number of offsprings. There was no mortality in any of the reactors. A change in the WH:CD ratios from 4:1 to 6:1 had no discernible impact on the reactor performances. Attempts were also made to improve the efficiency of the reactors in terms of vermicast production per unit time and per unit digester volume. These attempts led to the 'high-rate' vermireactor in which 5.6 times greater vermicast was produced per litre of digester volume per day than in the 'low-rate' reactors. The high-rate vermireactors also performed sustainably, with steady vermicast output, animal growth, and reproduction. © 2001 Elsevier Science Ltd. All rights reserved.

**Keywords:** Vermicomposting; Water hyacinth; *Eudrilus eugeniae*; Vermicast; Vermireactors

1. Introduction

Water hyacinth (WH; *Eichhornia crassipes* Mart. Solms) continues to justify the sobriquet of 'the world’s worst weed' by defying all the attempts that have been made across the world of eradicating it or finding commercially viable methods of its large-scale utilization (Gajalakshmi et al., 2001; Abbasi and Krishnakumari, 1996; Abbasi and Ramasamy, 1999). The only use of WH that has found world-wide acceptance is in treating biodegradable wastewaters (Tchobanoglous and Burton, 1999; Tchobanoglous et al., 1989). But the quantities of the weed that can be utilized in this manner are very low. Further this utilization option leaves the basic problem of disposal of the weed unsolved.

Vermicomposting is a labour-intensive, simple, and inexpensive process by which non-toxic organic solid wastes can be bioconverted to generate soil conditioners popular with farmers (Ismail, 1997). We found out earlier (Abbasi et al., 2000) that the remains of WH, which came out as vermicast from earthworm guts, had lost their ability to vegetatively reproduce, or grow. Encouraged by this we have been exploring the possibilities of vermicomposting WH so that large masses of the weed can be processed close to the lakes, ponds, canals, and swamps where the weed grows profusely. Screening of four species of earthworms for vermicomposting WH (Gajalakshmi et al., 2001) revealed that *Eudrilus eugeniae* produced more vermicast as well as offsprings per unit time in WH-fed vermireactors than *Perionyx excavatus* Perrier, *Lampito mauritii* Kinberg, and *Drewida willsi* Michaelson. For this reason we have conducted the present study with *E. eugeniae* as the main bioagent.

Six-month long experiments were first conducted on vermireactors which had 20 animals per 3 l reactor volume, and which were given 75 g feed (dry weight) every fortnight consisting of WH (fresh, chopped to pieces of ~6 cm length) and cowdung (CD) in dry weight ratios of 4:1, 5:1, and 6:1. The animal density and feed quantity in the reactors were so kept, as these have been described as ‘ideal’ by past workers (Ashok Kumar, 1994; Dash and Senapati, 1986). In the second phase of the experimentation we increased the earthworm density in the reactors 12.5 times. The feed loading rate was also increased by the same magnitude. The reactors were operated for six months to assess the sustainability and efficiency of the new mode of operation.

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E-mail address: prof_abbasi@vnl.com (S.A. Abbasi).
2. Methods

2.1. First phase

Vermibeds of effective volume 3 l were prepared by filling 4 plastic containers with sawdust, river sand, and soil in layers 1, 2, and 3.8 cm deep, respectively (from bottom upwards). In each reactor, 20 healthy adult animals of the species *E. eugeniae* were introduced. This level of animal density has been earlier recommended as ideal for vermicompostors by other workers (Ashok Kumar, 1994; Dash and Senapati, 1986). The animals were randomly picked from the culture of over 200 animals, with CD as the feed, maintained by the authors. The average moisture content of the vermireactors was maintained at 45 ± 1% by monitoring the content at different heights of the reactors every week and sprinkling the required quantities of water. Usually the top one-third of the reactors had 29 ± 1% moisture, the middle one-third 45 ± 1%, and the bottom one-third 61 ± 1%. All quantities were adjusted so that the feed and the casting mass reported in this paper represent dry weights (taken after oven-drying at 105°C to constant weight). The earthworm biomass is reported as live weight, taken after rinsing adhering material off the worms and blotting them dry. The castings were carefully sieved to separate other particles. A portion of the castings was then weighed and thoroughly washed with water to separate the small soil particles contained in the castings from the organic matter. The separated soil was oven-dried (105°C) to constant weight. This enabled determination of the mass fraction of soil particles contained in the castings. This fraction was subtracted from the total mass of the recovered castings. Thus, the vermicompostation data presented in the paper pertain to conversion of only the feed to the castings, and exclude the entrained soil.

Three sets of reactors, all run in duplicate, were started with 75 g of feed composed of WH:CD in 4:1, 5:1 and 6:1 ratios (W/W, dry weight in different ratios). Once in every 10 days the castings and the earthworms were removed and placed in separate containers for quantification, while the rest of the reactor contents were discarded. Within a few minutes, fresh reactors were restarted with everything else being the same except that from the earthworms removed from the previous run, the juveniles, if any, generated were separated, and the 20 worms with which the reactors were started were weighed and reintroduced.

2.2. Second phase

For this phase vermicompostors were set up, operated, and monitored in exactly the same fashion as the reactors in the first phase, with the exception that the populations of *E. eugeniae* in these reactors were maintained at 250 animals per reactor and the feed loading rate was 950 g in each 10-day run. Thus, the animal densities and feed loading rates were ~12.5 times higher in these reactors than in their 'low-rate' counterparts.

### Table 1

<table>
<thead>
<tr>
<th>Days</th>
<th>Vermicompost output (mg 1&quot;d&quot;⁻¹)</th>
<th>Increase in worm biomass (g)</th>
<th>Number of offspring</th>
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<tr>
<td></td>
<td>I</td>
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<td>Avg.</td>
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</table>

| Avg. | 1169.7* | 1183.3* | 1176.5* | 18.5* | 18.7* | 18.6* | 32* | 30* | 31* |

*Average vermicompost output, mg 1"d"⁻¹.

*Net increase in earthworm biomass, g, in six months.

*Number of offspring produced in six months.
3. Results and discussion

3.1. First phase

The performance of vermireactors fed with different proportions of WH–CD blends is summarized in Tables 2 and 3. During the first 10 days of operation the vermicast output as well as growth in the worm biomass was low. As the worms had been cultured to adulthood on CD feed before they were introduced to the predominantly WH-fed reactors, they had apparently taken some time to adapt to the new feed. From the second run onwards

Table 2
Recovery of vermicast as a function of time in low-rate reactors (I, II) with the feed WH:CD in 5:1 ratio

<table>
<thead>
<tr>
<th>Days</th>
<th>Vermicast output (mg l⁻¹ d⁻¹)</th>
<th>Increase in worm biomass (g)</th>
<th>Number of offspring</th>
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* Average vermicast output, mg l⁻¹ d⁻¹.

Table 3
Recovery of vermicast as a function of time in low-rate reactors with the feed WH:CD in 6:1 ratio

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<th>Days</th>
<th>Vermicast output (mg l⁻¹ d⁻¹)</th>
<th>Increase in worm biomass (g)</th>
<th>Number of offspring</th>
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* Average vermicast output, mg l⁻¹ d⁻¹.

- Net increase in earthworm biomass, g, in six months.
- Number of offspring produced in six months.

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the worm activity became manifestly more brisk and the first crop of offspring appeared in two of the four reactors by the 40th day. Trend lines were drawn with the software Microsoft Excel (Excel 97, Microsoft, 1997) to assess whether the vermireactor performance was tending towards further increase, decrease, or no change in output; a typical set of curves is presented in Fig. 1. It indicates that the vermicast output, worm zoomass, and production of offspring have all registered net increasing trends over time even though the variables have fluctuated in different runs.

The output in duplicates agreed with each other within relative errors of ±10% in a few cases, and within ±5% in most cases. This level of reproducibility can be deemed very good considering that the reactants are made up of poorly mixed solids. The six-month average vermicast output in the three 'low-rate' reactors was within the narrow range 1170 ± 20 mg l⁻¹ d⁻¹. The net increase in worm zoomass ranged from 16.3 g (5:1 reactors) to 18.6 g (4:1 reactors). The number of offspring produced was 28 in 5:1 and 6:1 reactors and 31 in the 4:1 reactor. Further, the net vermicast output was marginally higher in 4:1 ratio WH:CD reactors than in 5:1 WH:CD reactors but the latter was less than the vermicast output from 6:1 WH:CD reactors. All these results point towards the absence of a consistent trend which might have linked proportion of CD in the WH:CD blends to vermicast output, growth in the worm zoomass or extent of reproduction. We, therefore, conclude that a decrease in the proportion of CD from 4:1 to 6:1 in the WH:CD blends does not adversely affect the vermireactor performance. This finding is significant because CD is a valued bioproduct in the third world, with numerous uses in the households and on farms. If the vermireactors can be successfully operated at WH:CD mass ratios of 6:1 or higher, it would mean larger masses of the weed could be processed with smaller inputs of CD.

3.2. Second phase

The 'high-rate' vermireactors fed with 6:1 WH-CD blend were 5.6 times more efficient, generating an average 6481.9 mg vermicast per litre of digester volume per day (Table 4) against the output of 1157.4 mg l⁻¹ d⁻¹ achieved in the lower-rate digesters operated on 6:1 WH-CD blend (Table 3). Even though the earthworm density was 12.5 times more in the high-rate reactor than in the low-rate ones, there was no mortality over six months. The worm zoomass regis-

![Graphs showing vermicast recovery for different feeding ratios.](image-url)
tered a net gain of 101.6 g over the initial 173.5 g. There was consistent reproduction, too; an average of 87 offspring were produced per reactor. There was no discernible difference in the colour or morphology between the adults or offspring from the high-rate reactor, the low-rate reactor, or the ones taken from CD-fed cultures. All these observations confirm the viability of the high-rate vermireactor concept and the suitability of WH as a vermivert. Further, as vermireactors require little energy or other expensive inputs for their operation, the major source of cost is the vermireactor. By increasing vermicast output per unit digester volume 5-6 times in the ‘high-rate’ reactors, the entire benefit-cost ratio of WH vermicomposting is being improved by a similar magnitude.

Acknowledgements

The authors thank the Department of Science and Technology, Government of India, New Delhi, for financial support.

References


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Table 4
Recovery of vermicast as a function of time in high-rate reactors with the feed WH:CD in 4:1 ratio

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<th>Vermicast output (mg l⁻¹ d⁻¹)</th>
<th>Increase in worm zoosmass (g)</th>
<th>Number of offspring</th>
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*Average vermicast output. mg l⁻¹ d⁻¹.

*Net increase in earthworm zoosmass, g, in six months.

*Number of offspring produced in six months.
High-rate composting–vermicomposting of water hyacinth
(*Eichhornia crassipes*, Mart. Solms)

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Abstract

In an attempt to develop a system with which the aquatic weed water hyacinth (*Eichhornia crassipes*, Mart. Solms) can be economically processed to generate vermicompost in large quantities, the weed was first composted by a 'high-rate' method and then subjected to vermicomposting in reactors operating at much larger densities of earthworm than recommended hitherto: 50, 62.5, 75, 87.5, 100, 112.5, 125, 137.5, and 150 adults of *Eudrilus eugeniae* Kinberg per litre of digester volume.

The composting step was accomplished in 20 days and the composted weed was found to be vermicomposted three times as rapidly as uncomposted water hyacinth [Bioresource Technology 76 (2001) 177]. The studies substantiated the feasibility of high-rate composting–vermicomposting systems, as all reactors yielded consistent vermicast output during seven months of operation. There was no earthworm mortality during the first four months in spite of the high animal densities in the reactors. In the subsequent three months a total of 79 worms died out of 1650, representing less than 1.6% mortality per month. The results also indicated that an increase in the surface-to-volume ratio of the reactors might further improve their efficiency. © 2002 Published by Elsevier Science Ltd.

Keywords: Composting; Vermicomposting; Water hyacinth; *Eichhornia crassipes*; *Eudrilus eugeniae*

1. Introduction

We have described (Gajalakshmi et al., 2001a) water hyacinth (*Eichhornia crassipes* Mart. Solms) as one of the most productive and hardy of all weeds and no attempt to control or destroy it by chemical, biological, mechanical, or hybrid means has ever achieved total success (Reddy and Smith, 1987; Ramasamy, 1997; Abbasi et al., 1997). We have also recapitulated (Gajalakshmi et al., 2001a) that the only means of utilization of water hyacinth which has proved economically viable across the world (treatment of biodegradable wastewaters, Tchobanoglous and Burton, 1999) still leaves the problem of final disposal of the weed unsolved. In this background we had taken up studies on vermicomposting of water hyacinth (Gajalakshmi et al., 2001a). After screening four of the faster growing (hence voracious feed-consuming) species of earthworms – *Eudrilus eugeniae* Kinberg, *Lampito mauritii* Kinberg, *Perionyx excavatus* Perrier, and *Drawida willsi* Michelsson – we had found that *E. eugeniae* and *P. excavatus* produced more vermicast output per unit time, more zoomass, and more offspring during six months of digester operation than the two anecics *L. mauritii* and *D. willsi*. Between the two epigeics, *E. eugeniae* was clearly the better performer. Hence it was identified for further studies on water hyacinth.

We have also conducted a series of long-term experiments (Gajalakshmi et al., 2001b) on the vermicomposting of water hyacinth fed to vermicreators in several different forms – fresh whole plants, chopped plants, 'spent' plants taken from reactors in which volatile fatty acids were extracted from the weed, dried plants etc. Vermiconversion of these forms was studied with or without cowdung supplement. Effect of short-term partial precomposting on the palatability of the weed was also assessed. These experiments have indicated that precomposting makes the weed more easily utilizable by the worms than all other forms of water hyacinth charged with or without cowdung in the vermicreators. Lastly we have also determined, by experimentation...
Table 1
Average vermiest from duplicate reactors operated at a feed loading rate of 1 kg per 10 days; the recovery has been expressed as % of feed mass

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<td>74.5 ± 2.2</td>
<td>78.9 ± 1.6</td>
<td>83.8 ± 1.9</td>
<td>86.9 ± 2.6</td>
<td>91.4 ± 2.7</td>
<td>95.4 ± 1.6</td>
</tr>
<tr>
<td>210</td>
<td>49.6 ± 1.9</td>
<td>58.8 ± 1.0</td>
<td>61.3 ± 1.4</td>
<td>72.9 ± 2.0</td>
<td>80.8 ± 2.1</td>
<td>81.2 ± 1.7</td>
<td>88.6 ± 2.0</td>
<td>93.2 ± 1.6</td>
<td>96.8 ± 2.2</td>
</tr>
<tr>
<td>Average</td>
<td>46.6</td>
<td>56.2</td>
<td>60.4</td>
<td>68.8</td>
<td>74.5</td>
<td>78.1</td>
<td>83.5</td>
<td>87.0</td>
<td>93.4</td>
</tr>
</tbody>
</table>
(Gajalakshmi et al., 2001c), that earthworm densities higher than ~7 animals 1^{-1} of reactor volume reported as ideal by previous workers (Ashok Kumar, 1994; Dash and Senapathi, 1986) are sustainable.

We now report a seven-month long series of experiments in which water hyacinth was first fully composted and then subjected to vermicomposting in 'high-rate' reactors operating at up to 21 times higher earthworm densities than recommended earlier.

2. Methods

2.1. E. eugeniae

Healthy, adult animals were randomly picked from several cultures of over 2000 animals each maintained by us with cowdung as feed. Batches of animals thus picked were thoroughly washed with distilled water to free them from adhering soil and other particles, blotted dry, and weighed, before releasing them in vermireactors.

2.2. Water hyacinth

The weed was harvested from natural ponds and rinsed very thoroughly with saline (2 M NaCl) water, aqueous EDTA (2 g l^{-1}), tap water, and distilled water in this order to free it from adhering microflora and muck. It was drained of most of the adhering water by softly thrashing it against multiple folds of cotton cloth.

2.3. Cowdung slurry

Slurry from a cowdung-fed biogas digester was air dried. The 2 m^3 digester was a semi-continuous, low-rate, plug-flow reactor of ferrocement construction operating at a hydraulic retention time (HRT) of ca. 40 days.

2.4. Stoichiometry

Except the weight of earthworms, which was taken as described earlier, all other quantities were dry weight which was obtained by oven drying known quantities of material at 105 °C to constant weight.

2.5. C:N ratio

Carbon was determined by a modified Walkely-Black method and nitrogen by wet digestion as detailed elsewhere (Rao, 1993). All chemicals used were analytical reagent grade, and alkali-resistant borosilicate glass was employed throughout. Water was deionized and doubly distilled in an all-glass still for analytical work.

2.6. Composting of water hyacinth

The feed was prepared by composting water hyacinth as a process earlier standardized in this laboratory. It consisted of setting up successive layers, 10 and 5 cm thick, respectively, of washed water hyacinth and digested cowdung slurry in 50 l wooden boxes. The slurry was drawn from the effluent sump of the cowdung-fed biogas digester described above. The organic solids were topped with a 1 cm layer of garden soil. The entire contents were sprinkled with adequate water to generate average moisture content of ~50% and were covered with cardboard and thick black plastic sheets. The temperature of the reactor contents was monitored with a probe. After the initial setting, the compost boxes were left undisturbed as the aerobic process of composting started and gradually lifted the temperature of the reactor contents from the initial ca. 31 to 55–60 °C within 5–8 days of the start. After another 3–4 days, the temperature usually began to fall; at that stage the plastic covers were removed and the contents thoroughly mixed. The covers were then replaced and the boxes left once again to continue the composting. In subsequent cycles the temperature rose to ca. 60 °C within 3–4 days of mixing and remained at that level for another 3–4 days, before beginning to fall, signifying the need for again mixing - which naturally caused aeration as well - of the substrate. In this manner the water hyacinth was turned into sludge-like compost in ca. 5 weeks.

<table>
<thead>
<tr>
<th>Months</th>
<th>Reactor with 200 worms</th>
<th>Reactor with 250 worms</th>
<th>Reactor with 300 worms</th>
<th>Reactor with 350 worms</th>
<th>Reactor with 400 worms</th>
<th>Reactor with 450 worms</th>
<th>Reactor with 500 worms</th>
<th>Reactor with 550 worms</th>
<th>Reactor with 600 worms</th>
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</thead>
<tbody>
<tr>
<td>Initial</td>
<td>134.8</td>
<td>165.5</td>
<td>198.9</td>
<td>229.5</td>
<td>265.0</td>
<td>296.8</td>
<td>330.1</td>
<td>363.8</td>
<td>396.6</td>
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<td>1</td>
<td>152.6</td>
<td>179.2</td>
<td>211.6</td>
<td>238.7</td>
<td>276.2</td>
<td>307.1</td>
<td>341.8</td>
<td>376.2</td>
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<td>2</td>
<td>160.8</td>
<td>194.6</td>
<td>228.7</td>
<td>250.6</td>
<td>285.4</td>
<td>316.9</td>
<td>354.3</td>
<td>391.0</td>
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<tr>
<td>3</td>
<td>172.7</td>
<td>202.8</td>
<td>236.4</td>
<td>261.8</td>
<td>298.1</td>
<td>329.4</td>
<td>368.1</td>
<td>402.8</td>
<td>434.2</td>
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<td>4</td>
<td>180.9</td>
<td>219.4</td>
<td>251.6</td>
<td>273.4</td>
<td>311.6</td>
<td>341.6</td>
<td>376.9</td>
<td>414.4</td>
<td>446.1</td>
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<td>5</td>
<td>196.8</td>
<td>230.1</td>
<td>264.8</td>
<td>282.6</td>
<td>320.1</td>
<td>350.8</td>
<td>389.2</td>
<td>426.1</td>
<td>459.2</td>
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<tr>
<td>6</td>
<td>205.1</td>
<td>248.9</td>
<td>278.2</td>
<td>291.8</td>
<td>332.6</td>
<td>368.4</td>
<td>401.4</td>
<td>435.8</td>
<td>469.9</td>
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<tr>
<td>7</td>
<td>216.2</td>
<td>261.7</td>
<td>291.9</td>
<td>300.9</td>
<td>341.6</td>
<td>380.2</td>
<td>415.6</td>
<td>448.2</td>
<td>481.5</td>
</tr>
</tbody>
</table>

Net increase: 81.4 96.2 93.0 71.4 76.6 83.4 85.5 84.4 84.9
The completion of composting was indicated when mixing the contents and keeping them undisturbed after covering did not lead to a rise in temperature. The C:N ratio of the compost, determined by standard methods (Rao, 1993) was 20.8.

2.7. Vermicomposting

Vermireactors were set up as detailed earlier (Gajjalakshmi et al., 2001a) by filling 4 l circular plastic containers with successive layers of sawdust, river sand, soil, and hyacinth feed of depths 1, 2, 3.8, and 2 cm, respectively. The average moisture content of the reactors was maintained at ~45% by periodic monitoring and appropriate replenishment as detailed earlier.

Nine sets of duplicates were provided with earthworm populations of 200, 250, 300, 350, 400, 450, 500, 550, and 600 animals. Each of the reactors was supplied with 1 kg of composted water hyacinth. The overall volume of the contents of each reactor was ~4 l. All the reactors were kept under identical ambient conditions (temperature ±2 °C, relative humidity 60–70%) and were provided with protection from insects, rodents and other pests.

After 10 days from start the vermicast from each reactor was harvested, treated for separation of soil, and quantified as described earlier (Gajialakshmi et al., 2001a,b,c). The animals were removed, separated from offspring, if any, generated, and reintroduced into fresh reactors which were identical to the reactors at the start. In this manner it was possible to assess the vermicast output of 'parent' worms as a function of 1 kg of feed without competition from offspring. It also ensured that the unutilized feed did not accumulate, and possibly biodegrade, in the reactors.

3. Results and discussion

The vermicast output from the 18 reactors, studied for seven months, is summarized in Table 1. In all but two cases, the output of the duplicates agreed to within ±5%; in the remaining two cases it was within ±7.5%.

The vermicast outputs in successive runs also agreed to within ±8%. These figures reflect good reproducibility in the reactor performance, more so because the reactors are essentially solid-feed heterogeneous systems.

The vermicast yield consistently increased with worm density – from the average 46.6% in 50 worm \(1^1\) reactors to 93.4% in 150 worm \(1^1\) reactors – but it did not do so by the same magnitude as the latter; a threefold

Table 3

<table>
<thead>
<tr>
<th>Months</th>
<th>Reactors with 200 worms</th>
<th>Reactors with 250 worms</th>
<th>Reactors with 300 worms</th>
<th>Reactors with 350 worms</th>
<th>Reactors with 400 worms</th>
<th>Reactors with 450 worms</th>
<th>Reactors with 500 worms</th>
<th>Reactors with 550 worms</th>
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</thead>
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<td>11</td>
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<td>109</td>
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<td>101</td>
<td>92</td>
<td>88</td>
<td>90</td>
<td>83</td>
<td>74</td>
<td>70</td>
</tr>
</tbody>
</table>
increase in the former caused only a twofold increase in the latter. The vermicast recovery–worm density curve was extrapolated (figure not shown here), using the forecasting package SMART (Abbas and Arya, 2001). It indicated that increase in worm density beyond 125 animals $l^{-1}$ would cause little further increase in the vermicast output.

The worm zoomass in each reactor increased with time (Table 2). There was also production of offspring in all reactors during each and every run (Table 3) but the increase in zoomass per worm as well as number of off-spring produced per worm sharply declined with increase in worm density (Fig. 1). Even as crowding is expected to adversely affect the access of the animals to the feed, hence their growth, and reproduction, it is also possible that the reactor geometry may be contributing to the loss of efficiency per worm. *E. eugieniae* are surface dwelling epigeics with very shallow burrows. Their feeding, mating and resting activities are largely confined to the reactor surface. It is, therefore, likely that an increase in surface-to-volume ratio of the reactors might enhance the access of the animals to the feed, thereby contributing better vermicast production, growth, and reproduction per worm even in the more crowded of vermicreactors.

Acknowledgements

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References


