A novel vermicomposting machine for rapid processing of phytomass and other organic solid waste

Tauseef S. M.[1], Tasneem Abbasi[2], Tabassum- Abbasi[1], Pratiksha Patnaik [2], and Abbasi S. A.[2]

[1]University of Petroleum and Energy Studies
[2]Pondicherry University

May 5, 2020

Abstract

A novel machine, acronymed HEVSTOW (High Efficiency Vertically Stacked vermicomposting system for Treating Organic Waste), of which a patent has recently been granted, is described. The machine is based on the paradigm of high-rate vermicomposting earlier developed by the authors. It makes it possible to rapidly vermicompost not only animal manure but also substrates like phytomass and paper waste which the conventional vermireactors are not able to process without elaborate pre-treatment and/or augmentation of animal manure. The machine also makes it possible to simultaneously vermicompost different substrates as also use different species of earthworms without one batch influencing the other. The applicability of the machine is demonstrated by its application in simultaneous yet independent processing of paper waste and a weed, each with two species of earthworms.

1. Introduction

We have recently developed the concept of 'high-rate vermicomposting' (Abbasi *et al.,* 2015) which enables substrates such as weeds, agricultural waste, and paper waste to be directly and rapidly vermicomposted. Pre-existing vermireacors have been unable to handle such wastes for reasons detailed earlier (Abbasi *et al.,* 2015). We have also shown that vermicomposts derived from even toxic and allelopathic weeds like parthenium and ipomoea are benign organic fertilizers, as effective as manure-based vemricomposts are known to be (Hussain and Abbasi, 2018). The machine acronymed HEVSTOW (High Efficiency Vertically Stacked vermicomposting system for Treating Organic Waste), being presented here, has been designed to derive maximum advantage from the positive attributes of the high-rate vermicomposting paradigm. No similar machine has been designed or developed earlier, and after ascertaining its novelty in the context of global prior art, a patent has been granted to it (Tauseef *et al.,* 2018). In the present paper the efficacy of the machine has been demonstrated by its utilization in simultaneous vermicomposting of two different substrates with two different species of earthworms.

2. The HEVSTOW design

HEVSTOW consists of a set of modular reactors arranged in series as well as parallel. The unit is provided with loading, unloading, and harvesting arrangements (Figure 1).

HEVSTOW comprises of a fixed frame **B** to hold modules **A**loaded in series as well as in parallel. The modules **A** move over the fixed frame **B** with the help of wheels **C**provided on either side. The wheels move within the brackets to prevent the module **A** from moving in vertical direction at the time of harvesting. The unit consists of a sprinkler system **D** used to maintain the moisture content in modules **A** ; the sprinkler system has nozzles **E** positioned above the modules to serve the purpose. A rod **F** is placed below the modules

A, which can be rotated 180° using gear mechanism **G.** It helps in emptying the contents of the modules on to the conveyor belt **H**placed below each track. The guiding mechanism at one end of the conveyor belt **H** serves in collecting the content of the modules without spillage in to the collection tray**.** The loading**J** and unloading **K** systems help in loading and unloading of the modules **A** on to the fixed frame **B**using rack and pinion arrangement **R** and **T** .

Module **A** is placed over the fixed frame **B** with the help of wheels **C** fixed on either side of the module **A** ; the base of the module **A** opens to empty its content on to the conveyor belt **H** placed below.

The harvesting system of HEVSTOW consists of a conveyor belt **H**and a guiding mechanism at one end of the conveyor belt **H.** The guiding mechanism aids in collecting the content of the conveyor belt**H** without spillage into the collection tray**.** A roller attached to a motor helps in rotating the conveyor belt **H** at the time of harvesting.

Module **A** is filled with substrate and placed on the loading end**J.** The motor aids in the lifting of the module with the help of a rope **Z.** The rack and pinion **R** and **T**arrangement driven by motor **U** helps in placing the module**A** on to the fixed frames **B** . Motor **U** for the rack and pinion arrangement is supported on a frame and the rod**W** is attached to a hinge **X** . The whole 60 set-up is placed on a frame **Y** .

2.1 Working of the HEVSTOW unit

A typical series of steps needed to operate a HEVSTOW unit comprise of the following:-

1. The substrate along with the specified earthworm species is loaded on to the modules **A** (0.4 m * 0.4 m * 0.12 m), which is filled up to 8 cm height and placed in the loading end **J** where the module is carried over to the fixed frame **B** by the rope**Z** with the help of a motor **U** and the rack and pinion**R** &**T** arrangement.
2. The modules **A** with wheels **C** on either side move within the bracket, this restricts the vertical movement of the modules.
3. Each module **A** is split into two equal halves at its bottom to aid in easy emptying of the modules during harvesting.
4. Each reactor is left for vermicomposting for 20-25 days. The substrate is almost fully utilized in this time by the worms making it easy to harvest the product.
5. When the module is ready for harvesting the rod **F** below the modules **A** (dissected at the base) is rotated to 180° downwards using the gear mechanism **G** . The supporting rod moves and the base of module **A** opens to empty the contents on to a conveyor belt **H** .
6. The conveyor **H** is then rotated with the help of a motor. The vermicast along with worms and the remaining undigested matter gets collected in the collection vessel.

2.2 The automated paper soaking unit (APSU) accessory

This accessory has been especially designed to make waste paper ready for charging into HEVSTOW. As paper is made almost entirely of cellulose, with very low content of nitrogen, phosphorous, and other nutrients, APSU enables stacks of waste paper sheets to be automatically soaked in cow-dung slurry. This not only provides the needed nutrients but also softens the paper matrix, making it amenable to rapid feeding by the earthworm. It (Figure 1) consists of a hopper that spreads the paper waste evenly in thin layers over a conveyor belt, which transports it to a surface inclined at an angle of 15o. The inclined surface is fitted with a set of overhead sprinklers and an array of taps to spread a thin layer of cowdung slurry over the inclined surface. This not only ensures proper soaking, reinforced with the help of a set of overhead sprinklers, but also facilitates transportation and deposition of the paper waste into the collection module placed at the bottom of the 2 m long inclined surface. The paper soaked in cow-dung slurry is collected and transferred to the vermicomposting unit. The excess slurry is collected and recycled to the overhead tank, used to store and supply cow-dung slurry to the sprinkler system.

Among the distinguishing features of the design is the feed arrangement which consists of a hopper fitted with a vibrator and a mechanism to move it to-and-fro. This to-and-fro movement along with the vibration helps in evenly spreading the paper waste over the conveyor belt. The overhead sprinklers along with the array of taps fitted on the inclined surface ensure proper soaking and transport of paper waste into the collection vessel. The excess cow-dung slurry is collected underneath and is recycled to the overheard storage tank. The flow chart of the system is depicted in Figure 1.

Each APSU, shown in figure 2, typically included a hopper **A**mounted over a conveyor belt **B** of 0.6 m in length, a 2 m long metal sheet **C** placed at the end of the conveyor belt. The metal sheet **C** is placed such that it has an inclination of 15o. An array of taps **D** is positioned on the top of the inclined surface **C** . These taps apply a thin layer of cow-dung slurry over the inclined surface. As the cow-dung slurry flows down the inclined surface **C** , under the force of gravity, it carries the paper waste, transported from the conveyor belt **B** , to the collection module **E** . The proper soaking of the paper waste is ensured by a set of overhead sprinklers **F** . The collection module is fitted with a mesh **G** under which a collection tank is placed to collect the excess slurry. The collected slurry is then recycled to the overhead tank which is 56 used to store and supply the cow-dung slurry to APSU. The height of a typical paper soaking unit is 1.1 m.

The hopper (**A** ; 0.4 m* 0.4 m* 0.4 m) is mounted on a set of rods; it can slide freely over these rods. A set of levers is used to couple the movement of the conveyor belt and the hopper. Thus, only a single motor is required to drive both the hopper and the conveyor belt. In order to regulate the flow of paper waste, the hopper is provided a set of shutters which are adjusted to provide a clearance of 5mm between the conveyor belt and the hopper. The thin layer of Paper waste is then conveyed onto the inclined metal sheet fitted with the sprinkler system.

The sprinkler system is designed to minimize the energy required to run the unit. The gravity driven flow of cow-dung slurry over the inclined sheet provides a thin film of fluid over which the paper waste is easily transported down the slope. The over head sprinklers ensure that the paper waste is properly soaked before it floats out of the unit and into the collection module. A collection module is provided at the end of the inclined surface to facilitate collection and recycle of excess cow-dung slurry to the overhead tank.

A collection module is provided at the end of the inclined surface to facilitate collection and recycle of excess cow-dung slurry to the overhead tank.

The functions of the main components are defined as follows:

1. *Side-wise moveable hopper*The hopper is designed to spread thin layers of paper waste onto the inclined surface. It moves sideways to aid equal distribution of paper waste on the conveyor belt placed below. Hopper can hold up to 5 to 7 kg of paper waste at a time.
2. *Conveyor belt*Below the hopper is the conveyor belt, which is attached to the mechanical handle to rotate the belt. When conveyor belt is rotated the paper waste falls on the inclined surface.
3. *Inclined surface*This is specially designed to hold thin sheets of paper waste. The paper waste slides downwards due to gravity as it is getting soaked in the cow dung slurry.
4. *Sprinkler system and the cow dung slurry pump*Cow dung slurry is loaded into a slurry tank and as the pump runs the slurry is sprayed on the inclined surface which has paper waste, through the sprinklers attached on the inclined surface.
5. *Mesh and collection vessel*As the soaked paper slides down the slurry drains into the collection vessel placed below. The collection vessel has a drain which is attached to the slurry tank through which the excess slurry is sent to the slurry tank and reused. The mesh filters out the soaked paper waste which can be sent to the vermicomposting unit for further processing.*2.2.1 Distinguishing features of the APSU design*

- The unit ensures proper soaking of paper waste in cow dung slurry, thus accelerating the vermicomposting process.
- The design can be easily scaled up or down to suit the desired plant capacity.
- The paper can be easy fed into the hopper either manually or with the help of an automated loading system.

- A system of levers is used to couple the movement of the conveyor and the hopper to cut down the energy requirement.
- The unit exploits the gravity driven slurry flow over an inclined surface to reduce energy requirement.
- The excess slurry is collected and recycled to the overhead tank, leaving no waste.
- Being only 1.1 m in height, the unit enables easy loading and operation.
- The automated process saves the labor required to separate waste paper sheets prior to soaking, thus making the overall process more efficient and economical.

3. Materials and method

Prototypes of HEVSTOW and APSU were fabricated (Figures 4 and 5) as per the designs given in Figures 1 and 3, respectively. Close ups of the typical modules of HEVSTOW, its conveyer belt, and sprinkler system are shown in Figures 6-8.

To test the functioning of these machines simultaneous but separate vermicomposting of paper waste and the aquatic weed water hyacinth was explored with two earthworm species *Esienia andrei* and*Lumbricus rubillus* . Eight of the 10 modules (M_1-M_B) of HEVSTOW were charged with 4 substrate-earthworm combinations, each in duplicate: a) water hyacinth-*E.andrei* (M_1, M_2) b) water hyacinth- *L.rubillus* (M_3, M_4), c) paper waste- *E.andrei* , (M_5, M_6) and d) paper waste *L.rubillus* (M_7, M_8). The remaining two modules were used to maintain cultures of *E.andrei* and *L.rubillus* respectively. All the modules had 3 mm thick water-soaked bedding of jute cloth at their bottom and the feed was laid uniformly over it.

Whole plants of water hyacinth, collected from ponds situated near the author's work-place, and chopped to pieces of 8±2 cm length were fed directly to M_1-M_4. Paper waste was pre-soaked in water containing 10% (w/v) fresh cow-dung with APSU, and fed to M_5-M_8. In all cases fresh weights of the substrates equivalent to the corresponding 200 g of dry weight were taken. For this purpose dry weights were determined by oven-drying pooled samples of fresh substrates to their constant weights at 105$^{\mathrm{o}}$C. In the like manner dry weights were determined of the vermicast generated and the extents of vermicompost granted per earthworm have been computed on the basis of dry weights.

In each module 50 adult and healthy individuals of the corresponding species of earthworms, randomly picked from their culture, were released. The sprinkler system was set to maintain a moisture level of 60±10% in each module.

After 20 days of start of the experiment the modules were emptied one by one and the vermicast, the earthworm, and the unconsumed substrate were separated using the substrate-earthworm-vermicompost-separation (SEVS) machine designed earlier by us (Tauseef *et al.,* 2014; Abbasi*et al.,* 2019). Simultaneously all the modules were charged with fresh substrate of the same quantity as was used at the start and the 50 adult earthworm, separated from the contents of that module in the previous batch by the SEVS machine, were reintroduced into that module.

The juveniles and cocoons found in the unused substrate, nor the unused substrate, were reintroduced. All subsequent 20-day runs were carried out in the same fashion. This manner of vermireactor operation has been named pseudo-discretized continuous operation protocol (PDCOP) by us, as detailed elsewhere (Nayeem-Shah *et al.,* 2015). It has the advantage of enabling us to measure the rate of vermicast generated per adult earthworm as a function of duration of the experiment while not allowing factors such as a) natural biodegradation of the unused substrate in the vermireactor with time, and b) feeding by offspring born in the reactors, to exert any significant influence on that assessment. Thus, eventhough each reactor was operated in discreet 20-day pulses, its measure of vemricast production was as if the reactor was operated continuously, with the worms predominantly feeding on the fresh (or nearly fresh) substrate all through.

4. Results and discussion

The results are summarized in Table 1. The extent of vermicomposting has been reported in terms of vemricast generated per animal, per day, as it gives a more realistic picture than the statistic of 'percent convertion' which is a function of earthworm density employed. The statistic of vermicast generated per worm per day can be used to estimate the extent of convertion of the substrate to vermicast had the number of animals been larger or smaller.

The rate of vermicomposting was at its slowest during the first 20 days possibly because of the lack of familiarity with the new feed of the earthworms who had, till then, been fed cow-dung. During the next 80 days the extent of vermicast production increased by about 35%. In subsequent 100 days there was further increase, though at much slower rate. The overall trend lines (Figure 9) reveal that the vermicompost generated per animal would have risen further had the experiment been continued. It would have perhaps peaked before the earthworms entered their old age and began to die.

All through the 6-month long uninterrupted experiment the HEVSTOW system, including the APSU and the SEVS machines flawlessly functioned to their designed potential. It is thus shown that the system can be, as designed, used in the simultaneous and efficient vermicomposting of different substrates with different species of earthworms.

Vermicomposting is essentially an aerobic decomposition process during which the microorganisms present in the earthworm gut decompose the organic carbon contained in the feed. An estimated 50±10% of the total solids present in a feed are converted to carbon dioxide in the course of the feed's vermicomposting. The CO_2 is then emitted and is thus lost to the vermireactor. Hence each unit mass of vermicast generated represents the bioconvertion of about twice as much feed mass.

The approximately 40 mg of vermicompost being generated per earthworm per day in the vermireactors by the 180th day represent the bioconvertion of about 80 mg of the substrate per worm per day. In other words about 80 * 20 * 50 mg, or 80 g, of the substrate was getting vermicomposted in 20-day pulses by the 50 earthworms in each reactor. As the feed mas was 200 g per module, this represents 40% of it getting vermicomposted in 20 days. By employing a larger number of earthworms this could be easily enhanced to about 60% of vermicomposting occurring over 20 days, or the entire feed getting vermicomposted in about 35 days. This leads to a rate of vermicomposting that is several times higher than the 90-120 days required by conventional systems (Edwards *et al.,* 2011; Banupriya, 2018).

Moreover, in the controlled experiment, the earthworm offshoot born in the vermireactor were removed once every 20 days so that only the vermicast generated by the 50 'parant' worms could be quantified. But in subsequent HEVSTOW operation, this removal was not done. It soon built up an increasingly dense earthworm population in each module, causing 100% vermicomposting within 20 days. By engaging larger number of vertically stacked modules in HEVSTOW, a very high space efficiency can also be achieved. Hence with its defining virtues, HEVSTOW enables high vermicomposting ability in terms of space as well as time.

5. Summary and conclusion

The design and functioning of a novel vermicomposting machine, acronymed HEVSTOW (High Efficiency Vertically Stacked vermicomposting system for Treating Organic Waste), on which a patent has recently been granted, is described. Over 6-month long uninterrupted operation HEVSTOW was able to simultaneously vermicompost different substrates with different species of earthworms. It functioned to its designed capability and efficiency throughout. By following the paradigm of high-rate vermicomposting, developed earlier by the authors, it was possible to directly vermicompost in HEVSTOW the weed water hyacinth *(Eichhornia crassipes)* without pre-composting it or doing any other form of pre-treatment. The machine was also able to vermicompost paper waste - which had been pre-soaked in water containing 10% (w/v) of fresh cow-dung - as swiftly as it processed water hyacinth. It was possible to achieve convertion of all the substrate to vermicompost within a solid retention time of just 20 days. The vertically stacked multi-module design of HEVSTOW was thus seen to enable unprecedentedly high efficiency of vermicomposting in terms of space as well as time.

Acknowledgement

SAA thanks the Council of Scientific and Industrial Research (CSIR), New Delhi, for the Emeritus Scientist grant (21(1034)/16/EMR-II).

References

Abbasi, T., Anuradha, J., Ganaie, S. U., Abbasi, S. A., (2015). Gainful utilization of the highly intransigent weed ipomoea in the synthesis of gold nanoparticles. J. King. Saud. Univ. Sci. 27 (1), 15-22.

Abbasi, T., Tauseef, S. M., Aravindan, T., and Abbasi S. A., (2019). Assessment of the ability of a novel machine to separate different types of substrate-earthworm-vermicompost mixtures, in Siddiqui, N. A., S. M. Tauseef, & B. Kansal, (eds.), *Advances in Health and Environment Safety, Springer Transactions in Civil and Environmental Engineering* , Chapter 18.

Banupriya, D., (2018). Towards development of mechanizable high-rate vermicomposting systems for converting biodegradable solid waste into organic fertilizers, Pondicherry University, Pages 239.

Edwards, C. A., Norman, Q. A., Sherman, R., (2011). Vermiculture Technology, Earthworms Organic Waste and Environmental Management. CRC Press, Boca Raton, USA. 220-231.

Hussain, N., Abbasi, S. A., (2018). Efficacy of the vermicomposts of different organic wastes as "clean" fertilizers: state-of-the-art,*Sustainability, 10,* 1-63; doi: 10.3390/su10041205.

Nayeem-Shah, M., Gajalakshmi, S., and Abbasi, S. A., (2015). Direct, rapid and sustainable vermicomposting of the leaf litter of neem*(Azadirachta indica). Applied Biochemistry and Biotechnology,*2(175), 792-801.

Tauseef, S. M., Abbasi, T., Banupriya, D., Vaishnavi, G., and Abbasi, S. A., (2013). HEVSPAR: A novel vermireactor system for treating paper waste, *Official Journal of the Patent Office, 24* 12726, Patent granted, number 312587, w.e.f 15.04.2013.

Tauseef, S. M., Abbasi, T., Banupriya, G., Banupriya, D., and Abbasi S. A., (2014). A new machine for clean and rapid separation of vermicast, earthworms and undigested substrate in vermicomposting systems,*Journal of Environmental Science and Engineering* , *56* (4), 495-498.

Tauseef, S. M., Abbasi, T., Banupriya, G., Banupriya, D., and Abbasi S. A., (2014). A new machine for clean and rapid separation of vermicast, earthworms and undigested substrate in vermicomposting systems,*Journal of Environmental Science and Engineering* , *56* (4), 495-498.

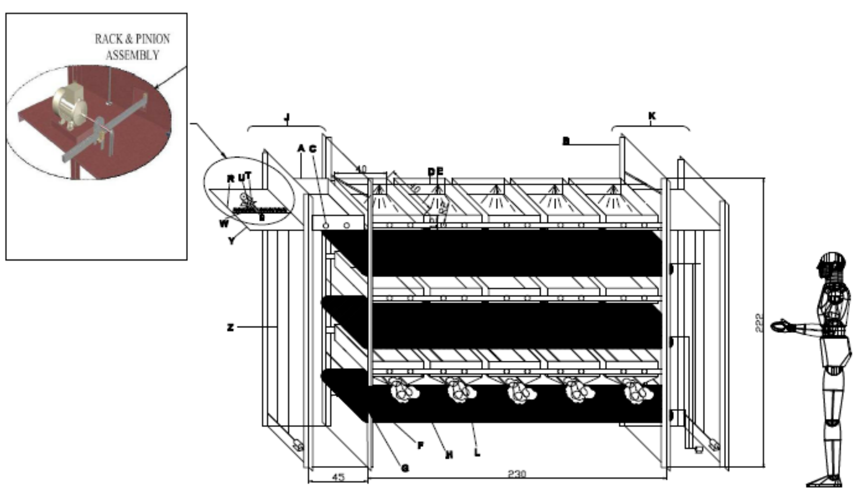

Fig 3; High efficiency vertically stacked vermireactor (VSV)

Figure 1: Schematic of the High Efficiency Vertically Stacked vermicomposting system for Treating Organic Waste (HEVSTOW); the human figure has been put to give an indication of the size.

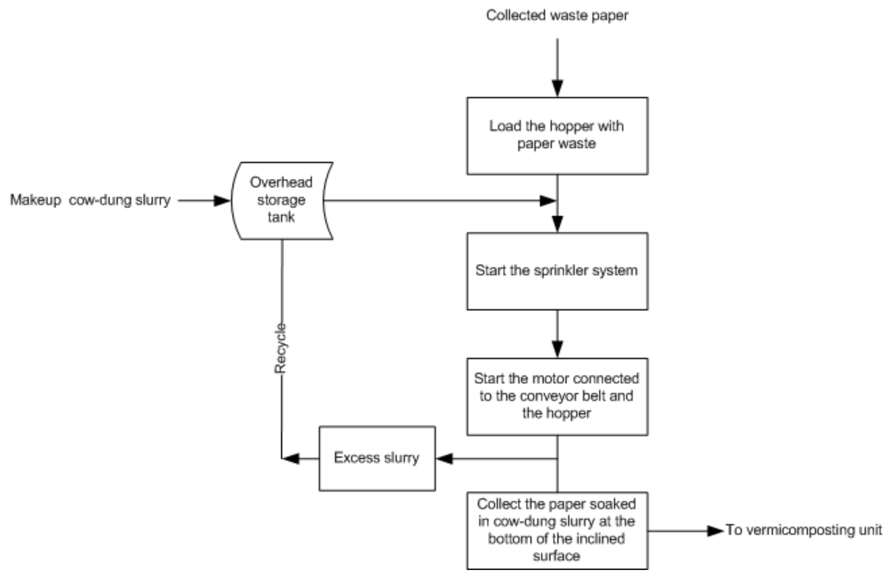

Figure 2: Flow chart of the automated paper soaking unit (APSU)

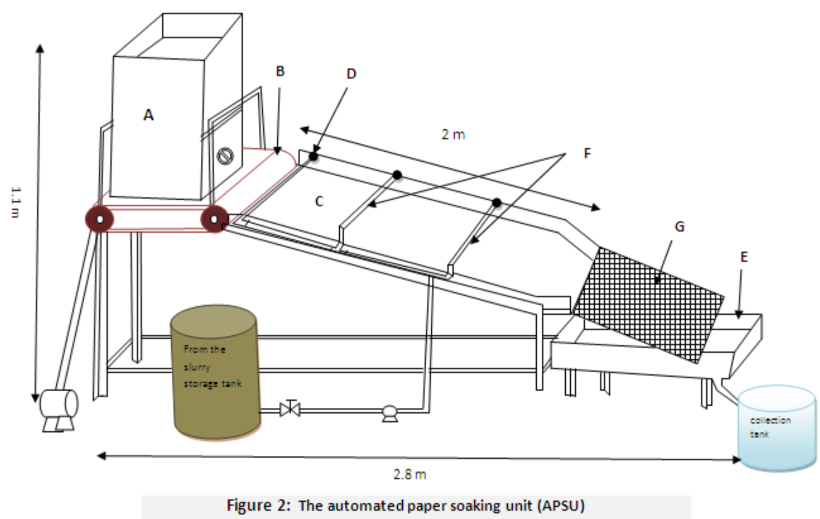

Figure 3: Schematic of the automated paper soaking machine (APSU)

Figure 4: Prototype of the VSV unit

Figure 5: The HESTOW unit system in operation

Figure 6: A typical module showing the arrangement at the base with which the content can be emptied. The guiding wheel is seen at the side.

Figure 7: The conveyor belt with a slant at its unloading end

Figure 8: A view of the sprinkler system placed above each module

[CHART]

[CHART]

[CHART]

[CHART]

Figure 9: Vermicast production as a function of time from water hyacinth and from paper waste by *E.andrei* (A and C), and*L.rubillus* (B and D) respectively. Trend lines are also shown.

Days	*Vermicast generated per worm (mg) per day from water hyacinth by*	*Vermicast generated per worm (mg) per da*
	E.andrei	*L.rubillus*
0-20	24.1 ± 2.6	22.9 ± 1.9
21-40	28.8 ± 2.3	27.2 ± 2.2
41-60	30.9 ± 1.8	31.1 ± 2.4
61-80	35.5 ± 1.9	36.3 ± 2.1
81-100	36.4 ± 1.6	35.5 ± 1.6
101-120	35.8 ± 2.9	36.4 ± 1.8
121-140	37.1 ± 1.8	36.9 ± 1.5
141-160	38.0 ± 2.2	37.4 ± 2.4
161-180	39.6 ± 2.1	38.2 ± 1.9

Table 1: Vermicast generated per worm, per day in the HEVSTOW module