Vermiculture and waste management: study of action of earthworms Elsinia foetida, Eudrilus euginae and Perionyx excavatus on biodegradation of some community wastes in India and Australia

RAJIV K. SINHA*, SUNIL HERAT, SUNITA AGARWAL, RAVI ASADI and EMILIO CARRETERO

School of Environmental Engineering, Griffith University, Nathan Campus, Brisbane, Queensland – 4111, Australia.

Keywords: Organic wastes; biodegradation; vermicomposting; secondary decomposers; **Summary**

The practice of vermiculture is at least a century old but it is now being revived worldwide with diverse ecological objectives such as waste management, soil detoxification and regeneration and sustainable agriculture. Earthworms act in the soil as aerators, grinders, crushers, chemical degraders and biological stimulators. They secrete enzymes, proteases, lipases, amylases, cellulases and chitinases which bring about rapid biochemical conversion of the cellulosic and the proteinaceous materials in the variety of organic wastes which originate from homes, gardens, dairies and farms. The process is odour free because earthworms release coelomic fluids in the decaying waste biomass which has anti-bacterial properties which kills pathogens. The species used in India were Indian blue (*Perionyx excavatus*), African night crawler (*Eudrilus euginiae*) and the Tiger worm (*Elsinia foetida*). *E.foetida* was used in Australia. *E. euginiae* was found to have higher feeding, growth and biodegradation capacity compared to other two species.

Earthworm action enhances natural biodegradation and decomposition of wastes (between 60 to 80 percent under optimum conditions), thus significantly reducing the composting time by several weeks. Within 5 to 6 weeks, 95-100 % degradation of all cellulosic materials is achieved and even hard fruit and egg shells and bones are degraded although these may take longer.

Introduction

Vermiculture (derived from the Latin *vermis* meaning worm) involves the mass production of earthworms for waste degradation, and composting with 'vermicast' production. Earthworms are a major soil fauna on Earth, constituting 80 percent of the soil invertebrate population in many ecosystems, especially in the tropical ecosystems.

^{*} Formerly Assistant Professor at the University of Rajasthan, Jaipur, India; presently Visiting Research Fellow at the School of Environmental Engineering, Griffith University (email: rajivksinha@hotmail.com). Sunil Herat is a Senior Lecturer at the same School. Sunita Agarwal is Assistant Professor at Department of Home Science, University of Rajasthan, Jaipur, India. Ravi Asadi and Emilio Carretero are postgraduates in the School of Environmental Engineering at Griffith University.

The Greek philospher, Aristotle named them the 'Intestine of Earth'. There are about 3920 named species of earthworm so far reported worldwide. In India, so far, 509 species, referable to 67 genera and 10 families, have been reported (Kale, 1991).

Ecology of earthworms

Earthworms are burrowing animals and form tunnels by literally eating their way through the soil. The distribution of earthworms in soil depends on factors like soil moisture, availability of organic matter and pH of the soil. They occur in diverse habitats specially those which are dark and moist. Organic materials like humus, cattle dung and kitchen wastes are highly attractive sites for some species. Earthworms are generally absent or rare in soil with a very coarse texture in soil and high clay content or soil with pH < 4 (Gunathilagraj, 1996). Earthworms are very sensitive to touch, light and dryness. Water logging in the soil can cause them to come to the surface. Worms can tolerate a temperature range between 5° C to 29° C. A temperature of 20° C to 25° C and a moisture of 50-60 percent is optimum for earthworm function (Hand, 1988).

Biology of earthworms

Earthworms are long, narrow, cylindrical, bilaterally symmetrical, segmented animals without bones. The body is dark brown, glistening and covered with delicate cuticle. They weigh about 700-1400 mg after 10 weeks. They have a muscular gizzard which finely grinds the food (fresh and decaying plant debris, living or dead larvae and small animals, and bacteria and protozoa mixed with earth) to a size of 2-4 microns. The gut of the earthworm is inhabited by millions of decomposer micro-organisms. They are bisexual animals and cross-fertilization occurs as a rule. Copulation may last for about an hour, the worms then separate. Later the clitellum of each worm eject cocoon where sperms enter to fertilize the eggs. Up to 3 cocoons per worm per week are produced. From each cocoon about 10-12 tiny worms emerge. Earthworm continue to grow throughout their life and the number of segments continuously proliferate from a 'growing zone' just in front of the anus. Earthworms contain 70-80 percent high quality lysine rich protein on a dry weight basis. They can be useful as animal feed. Usually the life span of an earthworm is about 3 to 7 years depending upon the type of species and the ecological situation.

Vermiculture and environmental management

Vermiculture is practiced for the mass production of earthworms with the multiple objectives of waste management, soil fertility and detoxification and vermicompost production for sustainable agriculture. The practice was started in the middle of 20^{th} century and the first serious experiments were established in Holland in 1970, and subsequently in England, and Canada. Later vermiculture practices were followed in USA, Italy, Philippines, Thailand, China, Korea, Japan, Brazil, France, Australia and Israel (Edward,1988). In UK large, 1000 M vermicomposting plants have been erected in Wales (Frederickson, 2000). The American Earthworm Technology Company started a

'vermicomposting farm' in 1978-79 with 500 t /month of vermicompost production (Edward,1988). Collier (1978) and Hartenstein and Bisesi (1989) have reported on the management of sewage sludge and effluents from intensively housed livestock by vermiculture in USA. Japan imported 3000 mt of earthworms from the USA during the period 1985-87 for cellulose waste degradation (Kale,1991). The Aoka Sangyo Co. Ltd., has three 1000 t /month plants processing waste from paper pulp and the food industry (Kale,1991). This produces 400 t of vermicompost and 10 t of live earthworms per month. The Toyhira Seiden Kogyo Co. of Japan is using rice straw, municipal sludge, sawdust and paper waste for vermicomposting involving 20 plants which in total produce 2-3 thousands t per month (Edward, 1988). In Italy vermiculture is used to biodegrade municipal and paper mill sludges. Aerobic and anaerobic sludges are mixed and aerated for more than 15 days and in 5000 M³ of sludge 5 kg of earthworms are added. In about 8 months the sludge is converted into vermicompost (Ceccanti and Masciandaro, 1999).

Vermiculture is being practised and propagated on large scale in Australia as a part of the 'Urban Agriculture Development Program' which utilizes the urban wastes. Australia's 'Worm Grower Association' is the largest in world with more than 1200 members. The Sydney Waters in New South Wales has set up a vermiculture plant of 40 million worms to degrade up to 200 t of urban wastes a week. Sydney's St. George Hospital is setting up plant to biodegrade its kitchen waste and fertilise its hospital gardens. The Redland Shire Council in Queensland, Australia has been operating a 20000 t pa⁻¹ capacity vermicompost plant since 1998 to treat sewage sludge and piggery waste (Lotzof, 2000).

India has yet to appreciate the full importance of vermiculture despite the potential for the production of 400 million t of vermicompost annually from waste degradation (Sinha,1996). Senapati (1992) has stressed the importance of vermiculture for the management of all cellulosic wastes in India. Gunathilagraj and Ramesh (1996) and Gunathilagaraj and Ravignanam (1996) reported respectively about management of coir and sericultural wastes by earthworms in India. Kale et al., (1993), Seenappa and Kale (1993), and Seenappa et al., (1995) have each advocated vermicomposting and management on aspects of sugar factory waste, solid wastes from the aromatic oil industries, and distillery wastes in India. In 1998, the Government of India announced exemption from tax liability to all those institutions, organizations, and individuals in India practicing vermiculture on commercial scale. Vermicomposting plants are operating in Pune and Bangalore with 100 t⁻¹ day capacity (Sinha, 1996). Chennai, Mumbai, Indore, Jaipur and several other Indian cities are also setting up vermiculture farms. The Bhawalkar Earthworm Research Institute (BERI) is one of the largest non-governmental organisations involved in vermiculture practice at Pune in India and is operating a vermiculture plant on a commercial scale for the management of municipal wastes (Bhawalkar and Bhawalkar, 1994).

Earthworms in general are highly resistant to many pesticides and have been reported to concentrate the pesticides and heavy metals in their tissues. They also inhibit the soil borne pathogens and work as a detoxifying agent for polluted soil (Davis, 1971; Ireland, 1983). These properties of earthworms can be utilized for effluent treatment and heavy metal and pesticides removal from industrial and agricultural wastes.

Earthworms are important 'secondary decomposers' and vermicomposting in nature is an ongoing process if the natural population of earthworms are undisturbed. Vermiculture engineers the growth of beneficial nitrogen fixing and decomposer bacteria and actinomycetes fungus in the degraded waste (vermicompost). In nature, biodegradation of organic wastes (debris of leaves and grasses) is reported to be from 50 to 80 t ha⁻¹ yr⁻¹ in India as against 18 to 40 t ha⁻¹ yr⁻¹ in the UK (Dash, 1978). This is because India has voracious waste eater tropical species of earthworms. The warm and moist climatic conditions of India are also favourable for earthworm rapid biodegradation action.

An earthworm promotes the growth of 'beneficial decomposer bacteria' in waste biomass and acts as an aerator, grinder, crusher, chemical degrader and a biological stimulator. Given the optimum conditions of temperature and moisture, the earthworms eat the organic component of the waste biomass, which is finely ground into small particles in their gizzard and passed on to the intestine for enzymatic actions. The worms secrete enzymes; proteases, lipases, amylases, cellulases and chitinases in their gizzard and intestine which bring about rapid biochemical conversion of the cellulosic and the proteinaceous materials in the organic wastes (Hand, 1988). The gizzard and the intestine work as a 'bioreactor'. Only 5-10 percent of the chemically digested and ingested material is absorbed into the body and the rest is excreted out in the form of fine mucus coated granular aggregates called 'vermicastings' which are rich in nitrates, phosphates and potash. Earthworm participation enhances natural biodegradation and decomposition of wastes from 60 to 80 percent (given optimum temperature and moisture) thus significantly reducing the composting time by several weeks. Within 6 to 8 weeks 80-100 percent degradation of all cellulosic materials is achieved (Agarwal, 1999). This process is odour free because earthworms release coelomic fluids in the decaying waste biomass which have anti-bacterial properties and kill pathogens (Pierre et al., 1982). Earthworms also create aerobic conditions in the waste materials, inhibiting the action of anaerobic micro-organisms which release foul-smelling hydrogen sulfide and mercaptans. Elsinia foetida, E. andrei, Eudrilus euginae, Lumbricus rubellus and Perionyx excavatus are major waste eater and biodegrader earthworm species. They are used worldwide for waste degradation and are found to be very successful functionaries for the ecological management of organic municipal wastes (Edwards, 1988). E. euginae and P. excavatus are believed to be the more versatile waste managers (Graff, 1981; Kale et al., 1982).

Organic wastes degraded by earthworms

Earthworms feed on nitrogen rich organic wastes. They feed easily on partially degraded materials like cattle dung, primarily acted upon by microbes. The following categories of wastes are very effectively degraded and managed by earthworms.

Kitchen wastes: Vegetable and fruit, both raw and cooked; cooked rice and pulse, remains of bread and chapatis, raw and cooked meat, crushed bones, egg shells; tea and coffee rejects.

Garden wastes: Fresh and dead leaves, weeds and grasses; flower petals, etc.

Farm wastes: Crop residues, rice and wheat straw, bran and husks; rejected fruits, seeds, sugar-cane trash, banana stems, coir wastes, weeds etc.

Dairy farm wastes: Cattle dung. (Fresh dung should be avoided as it releases methane and may be injurious to earthworms. About a week old dung is very suitable feed).

Sugar mill residues: Pressed mud-cake, spoiled bagasse and trash.

Slaughterhouse wastes: Residues such as the flesh, feathers, bones and blood.

Distillery and hatchery wastes;

Municipal waste: All organic residues in municipal wastes including garbage and sewage sludge. Earthworms are particularly effective for sewage sludge management. In sludge they increase oxygen consumption, decrease anaerobic decomposition and increase mineralisation.

Preparation of culture beds for earthworm rearing and experimental study

Culture beds were prepared in wooden boxes, cement tanks, plastic trays or earthen pots with small holes at the bottom for discharge of excessive water to prevent water-logging and with a capacity to accommodate from 100 to 500 worms over a period of 6 to 8 weeks. At the bottom of the bed about 3-4 cm of moist coconut coir waste or saw dust was placed. Above that about 5-6 cm of cattle dung or poultry droppings were placed as a 'bait' (feed material). The worms feed on partially degraded cattle dung and this allowed a smooth transition to other organic waste subsequently placed on top. Water was regularly sprinkled on the container to maintain the moisture content at 40 to 60 percent. The container was kept covered, preferably with a moist jute bag. This provided darkness for the worms and protects them from predators, it retains moisture, maintains stability of temperature of the immediate environment, and also allows sufficient aeration. After the waste had been degraded and converted into a loose, black, granular mass, the worms start aggregating at the base of the container. The upper layer of odourless compost was then removed and dried in the shade.

Experimental study I: (Jaipur, India: Rao, 1997)

(E. foetida, E. euginae, and

This experiment was carried out in plastic tubs. 150 tiny earthworms consisting of all the three species, *viz. Elsinia foetida, Eudrilus euginae*, and *Perionyx excavatus* were added to 1 kg each of buffalo dung, garden and kitchen wastes in different tubs. In another three tubs of each of these wastes the three species of worms were used separately to assess their individual feeding and biogradation abilities.

P. excavatus)

(From Rao, 1997)

Table 1: Biodegradation and composting of community wastes by Earthworms

Waste	Time taken in biodegradation and vermicomposting (in days)						
(1 kg of each)	E. foetida,	E. euginae,	P. excavatus	Mixed Species			
Cattle dung	59	44	62	45			
(Week old and sem	ui-dry)						
Kitchen wastes	78	61	83	70			
(Raw spinach stem	ıs, cauliflower & b	rinjal)					
Garden wastes	89	69	91	80			
(Grasses and dry l	'eaves)						

Finding:

- The general rate of waste degradation was slower when the experiment was carried out during winter months (Jan.- March). Cattle dung degraded much faster than the kitchen and garden wastes (Table 1).
- *Eudrilus euginae* was found to have the highest feeding, growth and biodegradation capacity followed by *Elsinia fetida* and *Perionyx excavatus*.
- Several fold increase in the population and size of individual earthworm species were observed at the end of the study.
- About 1 kg of vermicompost was recovered at the end of the experiment from the tub with cattle dung, about 900 gm from the tub with kitchen waste and about 850 gm from the garden waste.
- While the cattle dung was completely degraded, there was some residual material left in the tubs with kitchen wastes and somewhat more from the garden wastes.

Experimental study II: (Jaipur, India: Agrawal, 1999)

This experiment was carried out in earthen pots on different cooked and raw kitchen wastes. A control (pot without worms but with all other conditions identical) was kept for the purpose of comparison. In each pot 100 worms (*Elsinia foetida*, *Eudrilus euginiae and Perionyx excavatus*) were released. Experiments were continued throughout the year in both summer, rainy and winter seasons to assess the effect of temperature variation, humidity and climate change on worm activity.

Table. 2 Biodegradation of raw and cooked kitchen wastes by mixed earthworm species (*E. foetida, E. euginiae & P. excavatus*) (After Agrawal, 1999)

Waste (500 gm each)			Degradation Rate in Days					
Worms (100 no	os.)	25%	50	?⁄o	759	/ ₀	100	0%
	EP	EA	EP	EA	EP	EA	EP	EA
Raw Potato	7 (11)	25 (31)	11 (19)	60 (68)	16 (24)	84 (91)	22 (33)	NA
Cooked Potato	6 (10)	22 (29)	10 (16)	56 (61)	15 (21)	79 (85)	20 (28)	NA
Raw Cabbage	7 (9)	28 (34)	13 (17)	65 (71)	18 (23)	92 (99)	23 (31)	NA
Cooked Cabbag	e 5 (8)	24 (30)	11 (15)	58 (64)	16 (22)	82 (91)	21 (29)	NA
Cooked Rice	7 (13)	31 (39)	13 (19)	68 (73)	19 (25)	100 (107)	24 (30)	NA
Chapati	9 (17)	38 (47)	15 (22)	78 (87)	21 (29)	110 (119)	28 (37)	NA

Data is for warmer climate (May-July 1998: Temperature Min. 20°C ; Max. 42°C), while those in brackets are for cold periods (Dec.1998 – Feb. 99: Temperature Min. 8° C; Max.

18°C) (EP= Earthworms present; EA= Earthworms absent (Control); NA= Never achieved)

Finding:

- The overall worm activity and biodegradation rates were higher in the warmer and humid climate of the summer and rainy season (May July) and slower when the weather was cold and dry (Dec.- Feb. in India) (Table 2).
- Those kitchen wastes which were degraded by the earthworms in just 20-28 days (in the summer season) could not be degraded in its absence (EA) either in winter or summer months, even in 3 months.
- Cooked kitchen wastes were degraded quicker than the raw ones.
- Waste pots with earthworms were odorless while those without worms smelt foul .
- There was an appreciable increase in the size and number of earthworms in all pots containing waste where worms had been introduced.

Experimental study III: (Brisbane, Australia; Asadi and Carretero, 2000)

Experiments were carried out in coolite (thermocol) boxes and the worm *Elsinia foetida*, readily available in Australia was used. Raw potato, lettuce, egg shells and chicken bones were used as waste materials. In one set of experiments 50 worms, while in another set 100 worms were released into each box containing the same amount of waste. A control was maintained for comparison. June to August is relatively cold periods in Australia and hence the worm activity was rather slow.

Table. 3 Biodegradation of kitchen wastes by *Elsinia foetida* (After Asadi and Carretero, 2000)

Waste Component	Degrada	tion Rate in Days (Percentage Degradation)				
(Amount 500 gm ea	nch)					
	Earthwor	ms present (EP)	Earthworms absent (EA)			
Raw Potato	* 50 (95 %)	** 35 (100 %)	50 (60%)			
Raw Lettuce	* 28 (100 %)	** 20 (100%)	54 days (100 %)			
Egg shells	* 70 (40 %)	** 70 (60 %)	70 days (10 %)			
Chicken Bones	* 70 (50 %)	** 70 (70 %)	70 (10 %)			

^{*} Using 50 worms to degrade 500 gm of waste

Percentage degradation within the given period of time (days) is indicated in brackets.

^{**} Using 100 worms to degrade 500 gm of waste

Finding:

- Lettuce was completely degraded the most speedly followed by potato. Egg shells and bones were more difficult for earthworms to degrade, yet bones were a preferred food. Due to time constraints the experiment could not be prolonged till complete degradation of egg shells and bones were achieved. (Table 3).
- Doubling the number of earthworms to degrade the same amount and nature of waste enhanced the degradation rate significantly but not necessarily by 100 per cent.
- There was an appreciable increase in the size and number of earthworms in the lettuce and potato wastes. This increase was more where 50 worms were used. They increased by about 25 percent while those with 100 worms increased only by 15 percent.
- In the absence of earthworms (EA) the waste degradation process was significantly reduced and it took longer time in unaided degradation.
- A significant decline in the number of worms in the completely degraded (vermicomposted) waste occurred if they were left for sometime and not supplied further with waste (food) material. (Earthworms cannot survive for long time in their own waste and also starvation occurs).
- When the boxes were not covered (by mistake), degradation was very slow. Once covered with a moist jute bag, degradation accelerated. This experiment was repeated to confirm the observation. (Earthworms function better in darkness).

Conclusions

On the basis of the observations and findings in all three experimental studies on vermiculture made in India and continued in Australia, the following conclusions were drawn, some readily verify the accepted concepts known about vermiculture.

- At low temperatures and in the light the activity of the earthworms is impaired. Warm, humid and dark conditions are favorable for worm function.
- Although the worm *Eudrilus euginae* is a better waste degrader when used alone (Table 1), mixed species of worms together appear to degrade the waste faster. Individual worm species may prefer a particular food components in the waste.

- The larger the population of the earthworms, the faster the biodegradation activity. But worm activity and multiplication also depends upon the carrying capacity of the immediate environment (i.e. available food in the waste materials). 50 worms (Table

- 3) were provided with sufficient food for action and reproduction, whereas for 100 worms it was insufficient. The larger number accelerated the waste degradation initially and multiplied. When food became less available the worm activity slowed.

In those organic wastes in which the primary cellulosic materials are intact (leaves and grasses, raw vegetables and fruits) or where there are brittle calcium compounds (bones and egg shells), these were degraded rather more slowly by the earthworms. Cooking (heating) breaks the primary material into simpler compounds and softens them, and

.

therefore cooked food wastes are more easily degraded. Cattle dung was already a partially degraded cellulosic material and easily vermicomposted.

- Earthworms refuse to stay in their own excreta (vermicast) for long periods and they die if no food is available.
- Earthworms will slowly accept kitchen wastes directly if no bait material like cattle dung is available.
- Vermiculture is a very convenient and odour free process and the operating costs are negligible as compared to the conventional methods of waste treatment. Residents can be educated to vermicompost their entire kitchen and garden wastes and reduce the burden on the municipal councils. There are, therefore, both economic as well as ecological implications.

Acknowledgement

The authors are grateful to Mrs N.S. Sunitha, of the Department of Zoology, GKVK Agricultural University, Bangalore, India, and the farmers in Brisbane, Australia for supplying worms.

References

Agarwal, S.(1999) Vermiculture biotechnology for ecological degradation of kitchen wastes and growth of vegetable crops on the biodegraded waste products (Vermicompost); PhD Thesis University of Rajasthan, Jaipur, India.

Asadi, R and Carretero, E (2000) Biodegradation of kitchen wastes by earthworms *Elsinia foetida*; Project report, School of Environmental Engineering, Griffith University, Brisbane, Australia.

Bhawalkar, V. and Bhawalkar, U. (1994) *Vermiculture Biotechnology*; Pub. of Bhawalkar Earthworm Research Institute (BERI), Pune, India.

Ceccanti, B. and Masciandaro G. (1999) Researchers study vermicomposting of municipal and paper mill sludges; *Biocycle Magazine*, (June) ,Italy.

Collier, J (1978) Use of earthworms in sludge lagoons; In: R. Hartenstein (ed.) *Utilization of Soil Organisms in Sludge Management*; Virginia. USA; pp.133-137.

Dash, M.C (1978) Role of earthworms in the decomposer system; In: J.S. Singh and B. Gopal (eds.) *Glimpses of Ecology*; India International Scientific Publication, New Delhi, pp.399-406.

Davis, B. (1971) Laboratory studies on the uptake of dieldrin and DDT by earthworms; *Soil Biology and Biochemistry*, .3, pp. 221-223.

Edwards, C.A. (1988) Breakdown of animal, vegetable and industrial organic wastes by earthworms; In: Edwards C.A. and Neuhauser E.P. (eds.) *Earthworms in Waste and Environmental Management*, SPB Academic Publication; The Hague, Netherlands.

Frederickson, J. (2000) The worm's turn; Waste Management Magazine; August, UK.

Graff, O. (1981) Preliminary experiment of vermicomposting of different waste materials using *Eudrilus euginae* Kingberg; In: M. Appelhof (ed.) Proc. of the workshop on '*Role of Earthworms in the stabilization of organic residues*'; Malanazoo Pub. Michigan, USA.; pp.179-191.

Gunathilagraj, K. (1996) *Earthworm: An Introduction;* Indian Council of Agricultural Research Training Program; Tamil Nadu Agriculture University, Coimbatore.

Gunathilagraj, K. and Ramesh, P.T. (1996) Degradation of coir wastes and tapoica peels by earthworms; Training Program in Vermiculture; Indian Council of Agricultural Research (ICAR), New Delhi.

Gunathilagraj, K and T, Ravignanam (1996) Vermicomposting of sericultural wastes; *Madras Agricultural Journal*; Coimbatore, India; pp. 455-457.

Hand, P (1988) *Earthworm Biotechnology;* In : Greenshields, R. (ed.) *Resources and Application of Biotechnology : The New Wave;* MacMillan Press Ltd. US.

Hartenstein, R. and Bisesi, M.S. (1989) Use of earthworm biotechnology for the management of effluents from intensively housed livestock; *Outlook Agriculture*; USA, 18; pp. 72-76.

Ireland, M.P. (1983) Heavy metals uptake in earthworms; *Earthworm Ecology*; Chapman & Hall, London.

Kale, R. (1991) Vermiculture: Scope for New Biotechnology Zoological Survey of India, Pub., Calcutta.

Kale, R., Bano, K., and Krishnamoorthy, R.V.(1982) Potential of *Perionyx excavatus* in utilization of organic wastes; *Pedo-Biologia*, 23, pp. 419-425.

Kale, R., Seenappa S.N. and Rao J. (1993) Sugar factory refuse for the production of vermicompost and worm biomass; V International Symposium on Earthworms; Ohio University, USA.

Lotzof, M. (2000) Vermiculture: An Australian technology success story; *Waste Management Magazine*; February, Australia.

Pierre, V, Phillip, R. Margnerite, L. and Pierrette, C. (1982) Anti-bacterial activity of the haemolytic system from the earthworms *Eisinia foetida andrei*; *Invertebrate Pathology*, 40, pp. 21-27.

Rao, J. (1997) Management of municipal urban wastes: some innovative strategies; PhD Thesis, University of Rajasthan, Jaipur, India.

Seenappa, S.N. and Kale, R. (1993) Efficiency of earthworm *Eudrillus euginae* in converting the solid wastes from the aromatic oil extraction units into vermicompost; *Journal of IAEM*; Vol. 22; pp.267-269.

Seenappa, S.N., . Rao, J. and Kale, R. (1995) Conversion of distillery wastes into organic manure by earthworm *Eudrillus euginae*; *Journal of IAEM*; Vol. 22; No.3; pp.244-246.

Senapati, B.K. (1992) Vermitechnology as an option for recycling of cellulose waste in India; In: Subba Rao, N.S., Balgopalan, C. and Raman Krishna, S.V. (eds.) *New Trends in Biotechnology*; Oxford and IBH Pub. Co. Pvt. Ltd., pp.347-358.

Sinha, R.K. (1996) Vermiculture biotechnology for waste management and sustainable agriculture; In: R.K.Sinha (ed.) Environmental Crisis and Human's at Risk INA Shree Publication, India; pp.233-240