PU 252

Use of earthworms for reintroducing of organic matter from towns: A restoration of natural cycle by a new ecotechnology Features and efficiency of the first industrial unit

M.B. BOUCHE[1] AND M. NOUGARET[2]

[1] Laboratoire de Zooécologie du sol, INRA/CNRS, CEFE, BP 5051, F 34033 Montpellier cedex, France.

[2] Sovadec Technologies, Chemin du Petit Pelican, F-26200 Montelimar, France.

ABSTRACT

By exploiting ecosystems, the human activity globaly results in garbage, i. e. waste organic matter mixed with inert components and various pollutants.This causes.environmental problems and dictates the restoration of the natural cycles of organic matter. Earthworms have the capacity to ingest organic components and to defecate calibrated matter. In synergy with micro-organisms acting before ingestion, during digestion and after defecation, earthworms allow an advanced maturation of the organic matter (C/N < 15) within a rather short time (< 3 months).Therefore, a new technology, using *Eisenia andrei*, has been developed for industrial application. It consists 1) in an opening of garbage bags, 2) a grading of the matter, 3) various mechanical and manual sortings, 4) a sanitization process by an aerobic thermophilic fermentation at *circa* 75° C, killing weed seeds, most pathogenics and grubs, 5) the vermicomposting phase and 6) the final refining phase. It allows efficient sortings and refinings. The various vermicomposts produced by this way for agricultural, horticultural or domestic uses provide a real improvement to soil fertility. On these principles, the first treatment unit making use of soil animals was built in 1991 and is in operation. Operational results are presented here.

Keywords: Vermicomposting, earthworms, *Eisenia andrei*, solid state fermentation, house hold waste, sanitization, microorganism, recycled material, compost, pollution, waste disposal.

RESUME

Utilisation des lombriciens, pour valoriser la matière organique issue des villes. Un rétablissement ces cycles naturels par une nouvelle ecotechnologie. Caractéristiques et rendements de la première réalisation industrielle.

BOUCHE M.B. ET NOUGARET M.

Les activités humaines, utilisants des matières premières issues d'écosystèmes, produisant *in fine* des déchets sous forme de mélanges variables de matière organiques et inertes additionnées de divers contaminants. Ces déchets causent différents problèmes environnementaux et obligent à rétalbir les cycles naturels des matières. En co-action avec les microorganismes agissant avant ingestion, en cours de digestion et arpès défécation, les lombriciens permettent une rapide (< 3 mois) bonne maturation (C/N < 15) de la matière organique. L'application industrielle utilise *Eisenia andrei* et porte sur six étapes: 1- ouverture des sacs d'ordures, 2- tamisage puis 3- triage physiques complétés namuellement des déchets, 4- hygiénisation par fermentation thermophile (= 75°C) réduisant les maivaises graines, insectes et germes pathogènes, 5-lombriculture formant le lombricompostage et 6- affinage des produits. La production de diverses qualités de lombricomposts à usages horticoles et agricoles contribue à la fertilité des sols. L'article présente les résultats opérationnels de la première unité industrielle construite en 1991 et utilisant les lombriciens en biotechnologie.

Mots clés : Lombricompostage, lombriciens, *Eisenia andrei,* vers de terre, fermentation en milieu solide, ordure ménagère, hygiénisation, microorganismes thermophiles, matériaux recyclés, compost, lombricompost, pollution, traitement des déchets.

INTRODUCTION

Generally speaking, humans, in the exploitation of forest, meadow or cultivated ecosystems, remove organic matter (wood, meat, plants) in huge quantities. As it is insufficiently recycled back into soils, this organic matter soon becomes deficient in the ecosystem and this leads to leaching, slatching, a decrease in water-holding capacity as well as erosion.

In order to restore the natural cycle of organic matter, it is necessary to improve the transfer back into ecosystems. This cycle restoration allows the reintroduction of biogenic elements (N, P, K, Mg, etc.), the biological properties of organic matter (carbon compounds), which are essential for microbial and animal life in soils, and the resulting soil physical qualities.

The raw materials removed from fields by humans are transformed into food, packaging or technical products, such as paper. Most of these products and the leftovers are thrown away after use as urban waste, which, contains large quantities of inert components (glass, scrap iron, plastics, rubble) and various pollutants (inks, batteries, pesticides, medecines, etc.) (Table 1).

Table 1. Composition of household waste in France (Anred, 1991)

Category	Gross Weight (%)
Decomposable material	25
Paper and cardboard	30
Rags	2
Plastics	10
Metals	6
Glass	12
Miscellaneous (incl. medecines, batteries)	15

The great diversity in this rather complex mixture makes it difficult to recycle the organic part of domestic waste back into ecosystems. The traditional methods of treatment (landfilling, incineration and composting) do not allow for a complete recycling. These also do not take into account, or do so only partially, the environmental requirements of all types, such as a) physical : volumes of landfill tips, b)chemical : carcinogenetic chemicals, heavy metals, emissions of methane gas and carbon dioxide which contribute to the greenhouse effect, offensive-smelling gases, c) biological : pathogenic bacteria, insects, weed seeds, and d) social : implantation, costs.

In such a substrates, which are extremely diverse in nature, earthworms have the capacity to sort out and consume the organic part (peelings, leftovers, paper and cardboard). Amongst epigeous species of earthworms living in almost pure organic milieus, forest litter or decaying bark of dead trees are the best candidates. For practical and empirical reason, *Eisenia andrei* Bouché 1972 was the most efficient species and finally selected. In synergy with microorganisms, they ingest, digest and produce an advanced maturation of organic matter (C/N < 15) in a relatively short time (< three months). Inert elements, which are not destroyed, are easily separated from the graded earthworm faeces and can then be mostly recycled.

Taking this observation as a starting point, and in order to make the best possible use of these properties, it was necessary to design a completely new technology, which 1) avoids any sort of crushing (this makes the inert matter unreclaimable and contaminates the organic matter) and 2) allows for a continuous control of contaminants. The end result was the NATURBA process, which is in operation at present. A description of the process, including its environmental assessment as well as material balance are presented in this paper.

EARTHWORMS, ORGANIC MATTER AND WASTE

The important role played by earthworms in ecosystems, as the main protagonist in the health of soils, through their physical activity in breaking up soils and their biophysicochemical activity in recycling organic matter, was highlighted at a very early date (White, 1777, as quoted by Russel, 1910; and Darwin, 1837). The use of earthworms for the processing of organic matter was advocated (Barret, 1949) for manure heaps and various types of plant waste, while the high-quality of matter obtained was demonstrated by Anstett (1952). This technique was, however, not suggested for use on domestic waste before 1976 (Bouché, 1979). The enhancing of organic matter is what is sought after for this type of substrate (Bouché, 1982, 1987; Fayolle, 1982) containing contaminants (Table 1), as opposed to the production of earthworms (Chaudonneret, 1977) which comes up against the problem of contamination (Bouché, 1979).

The fundamental technical aspects were rapidly determined (Bouché, 1979, 1982, 1987; Fayolle, 1982; Chaudonneret, 1977), but their application to small units (Straumann, 1988) could not be adapted on an industrial scale, which must be simultaneously of scientific, technical, social and environmental types (Bouché, 1987).

All these aspects led to the perfecting of the NATURBA process, developed by the SOVADEC Company. It was tested and experimented during 1988-1991, commercially launched in 1990 and took shape with the building of the first unit in La Voulte-sur-Rhône (France) in 1991.

The NATURBA process uses both physical and biological methods. The requirements of -microorganisms and earthworms, the biological actors- determine the general plan of operation and the biological methods used.

THE BIOLOGICAL METHODS

The direct treatment of fresh waste, using earthworms, turned out to be negative as these creatures do not stand up to the heat given off by the aerobic fermentation. Earthworms require living conditions, which are incompatible with the destruction of undesirable organisms (insects, pathogenic bacteria or weed seeds). Therefore, these two stages had to be separated both in terms of in time and space into bisanitization and vermicomposting.

BISANITIZATION

The conditioned waste, resulting from the initial stages of sorting, undergoes a process using thermophilic aerobic microorganisms. By breaking down the most heat-labile organic parts, these microorganisms ensure a significant rise in temperature to 70-75°C, if good ventilation is ensured in heaps. This destroys most pathogenic microorganisms, weed seeds and grubs.

Simustaneously, microorganisms produce different antibiotics, which act on plant and animal pathogens, during the succession of psychrophilic, mesophilic and thermophilic microflorae. Hence, the term bisanitization has been derived for this association of two mechanisms of sanitization, through temperature and antibiotics. The bisanitization consumes oxygen and water to produce carbon dioxide and steam. A constant control of the water and oxygen supplies is absolutely essential.

As the heat-labile organic part in the matter decreases, both microbial activity and the temperature are reduced. Simultaneously, the quality of the organic matter is modified and it becomes, after 4 to 6 weeks, soft and partially composted. It, however, remains insufficiently mature for agronomic use and hence, earthworms must be brought into action.

BIOLOGICAL SORTING AND ORGANIC MATURATION THROUGH THE USE OF EARTHWORMS

After bisanitization, the matter can be ingested, digested and rejected as graded faeces by *Eisenia andrei*. These creatures require good aeration and plenty of moisture (pF = 2.7), temperatures which are compatible with their requirements (25--30°C) and a constant food supply.

The earthworm's primary function is, by selection of organic food only, to allow a complete separation of organic matter from inert matter, thereby making there fractions cleaner and more acceptable. Their second function is their digestive actions. Breaking up, together with the complex action of the enzymes of the digestive tract and microorganisms, leads to the production of a mature, stable, homogeneous organic matter.

The separation of inert matter from the organic part involves, both before and after the biological treatment, physical sorting without any crushing, which otherwise would pollute the organic part and would make the inert matter unreclaimable.

GENERAL PLAN OF OPERATION AND METHODS USED

The NATURBA process is structured around four successive blocks (Fig. 1), as described below:

After reception from collecting trucks, the urban waste from selective or non-selective collection goes through a specific patented machine, the Autoselecteur, which ensures 1) the opening of plastic bags by thermofusion without any sort of crushing or breaking up and 2) sifting of the articles smaller than 160 mm, thereby separating the rubbish in two fractions.

Large articles (over 160 mm), approximately 17% of the arriving tonnage, are sorted manually, so as to take out rags, clean papers and cardboards, plastics and metals for enhancing their value. This sorting aims to eliminate certain cumbersome articles such as tyres or car batteries. Other elements (branches, large cardboard boxes) are broken up mechanically (= the brocken fraction).

The graded part (< 160 mm) is subjected to a magnetic field to eliminate scrap iron. Then rolling objects, as bottles, are eliminated by automatic sorting using a stick-bounce machine. These rolling objects are sorted manually in order to recover glass, PVC and PET bottles and aluminium. The main part constitutes, with brocken fraction, the conditioned waste (about 72% of the initial tonnage). It is transferred into the bisanitization block.

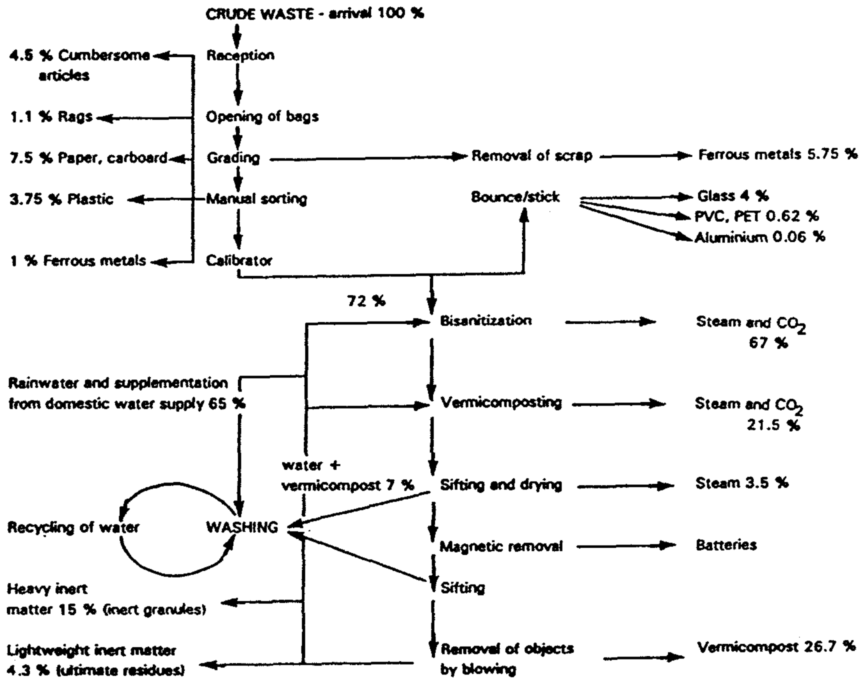

Fig.1 : General plan of operations and weight balance of the process. Notice they are two entries (crude waste 100 % and water supply 66 %). All values are expressed as % of the crude waste processed.

BISANITIZATION

The conditions required by aerobic microorganisms led to the conception of mechanical methods which allow oxidation of the substrate above the threshold at which anaerobiosis occurs. An automatic grab carries out a daily ventilation of the matter by turning over the heaps as they are moved along for 40 days. A sprinkler system compensates for the loss of water as steam due to the temperature rise.

Enforced ventilation of the building brings in the oxygen necessary for the respiration.

The daily turning over and ventilation are carried out according to a sequence which has been decided upon empirically. Each heap is moved along in small successive quantities and turned over in such a way as to bring what is at the bottom to the top. Each dose is allowed a pause so that it can be in air contact for at least five minutes. This daily turning over also prevents excessive compaction of the matter, which would reduce air circulation.

Each tonne of conditioned waste uses between 650 and 800 litres of water (depending on the season and the composition of the domestic waste) according to the Table 2. The water is added by sprinkling so that it has time sufficient enough to get absorbed.

Table 2. Water consumption *versus* time, during the bisanitization (for a total of 750 litres)

Age (days)	Water Supply (L/ton)
0	90
4	100
9	120
14	120
17	85
21	75
26	60
31	50
36	50

Measurements have enabled to establish that 25% of the mass is lost in the form of CO_2 ; two thirds of this during the bisanitization phase. This necessitates, in theory, to bring in 3 cubic meters of air per hour per tonne of dry matter to keep the building's CO_2 content in the air to below 5% (the equivalent of human respiration). In practice, a safety margin has been adopted and the ventilation carries 15 cubic metres of air per hour per tonne of dry matter.

Under these conditions, thermic evolution (Fig. 2) ensures sanitization of the matter by a rise in temperature to 70-75°C (155-170°F). After several days, a drop temperature is needed for efficient functioning of the next stage of vermicomposting.

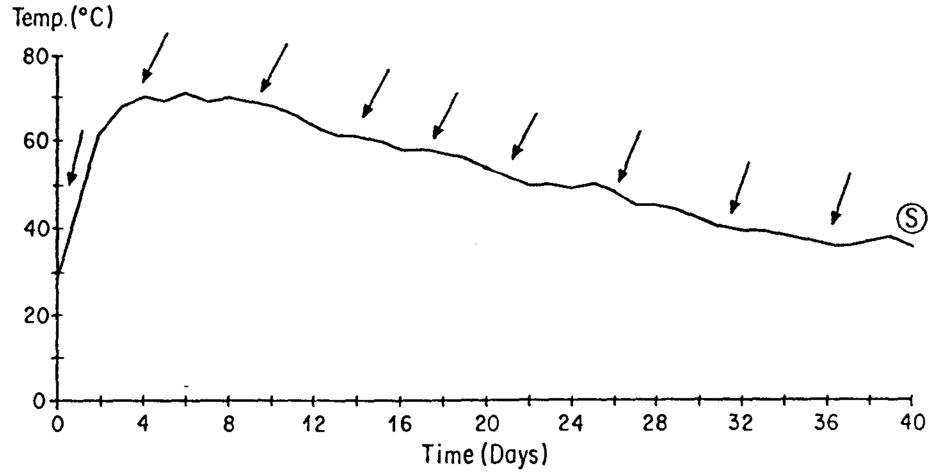

Fig. 2 : Evolution of the mass temperature during the bisanitization phase. Arrows indicate water supply to compensate evaporation. S : steeping.

BIOLOGICAL SORTING BY VERMICOMPOSTING

Different species of earthworms belonging to the ecological category of epigeics (Bouché, 1971) were tested. They were already known to be particularly well-adapted to this type of substratum. *Eisenia fetida* (Savigny, 1826), *Eisenia andrei*, (Bouché, 1972) and *Eudrilus eugeniae* (Kinberg, 1867) were found to be the most efficient. Although their biological requirements were closely related, *Eisenia andrei*, the most prolific, was chosen as it allowed a greater flexibility in use. Its vital requirements concerning moisture and heat were defined as per the methodologies used by (Fayolle, 1982) and (Reinecke and Venter, 1987).The means of acquiring them were studied and these studies led to the perfecting of the lombricontrôleur.

The vermicomposting is conducted in a building in which temperature, relative humidity and ventilation are controlled so as to obtain the best earthworm activity. Ventilation is 7 cubic metres of air per hour per tonne of dry matter and relative humidity is maintained between 65 and 100%. The temperature of the air has, in fact, only an indirect influence, as the temperature of the matter is very important and must not exceed 29°C, the upper temperature tolerance limit of *Eisenia andrei.*

The waste is managed in quantities of equal volume, moistened and cooled by soaking, when it comes out of the bisanitization block and then spread in successive layers in separate lombricubateurs, where vermicomposting takes place. The lombricubateurs are metallic containers operating continuously, the matter is poured in at the top and emptied from the bottom as per the patented mechanical extractor. The matter remains in the lombricubateurs for two months, moving slowly from top to bottom.

The earthworms reproduce, colonize and ingest this matter in lombricubateurs (Reinecke and Viljoen, 1990). They move against the current of the matter, moving endlessly up towards the freshly-added layers at top. The earthworms tend to over-reproduce but population growth is limited by food supply and remains well-balanced. After two years of the operation, it has not become necessary to introduce an extra supply of earthworms. The living requirements of earthworms have determined the size of the lombricubateurs, a width of 85 cm should not be exceeded if problems of asphyxia and increase in temperature in the centre of the lombricubateurs are to be avoided. On the other hand, their excellent capacity to move upwards allows the use of units which are 4.50 m high and 4 m long. Each lombricubateur is made up of four compartments of a total volume of 31 cubic metres.

This method of operation in separate units enables to cope up with possible problems of accidental contamination, which would only affect one unit without upsetting the others. Removal, after the two biological phases (bisanitization and vermicomposting) totalling to about 100 days, allows to obtain an unrefined vermicompost (vermicompost plus a quantity of small inert elements) which is then dried and refined.

SORTING AND REFINING

After drying at a moderate temperature (< 60°C), the unrefined vermicompost undergoes refining by different physical process, thereby permitting the separation of vermicomposts from batteries (and in particular all button batteries) and final waste.

A double sifting operation (50 mm and 7 mm) produces three different parts, i. e., a) inert matter contaminated by organic traces (> 50 mm), b) inert matter containing heavy metals (in the form of batteries) of between 50 mm and 7 mm, and c) organic matter vermicompost with inert matter (< 7 mm).

Part b) is subjected to a high magnetic field, which is highly efficient in its action on the graded substrates, all batteries, including button batteries are removed intact as they have not undergone crushing or breaking.

The rest of part b) rejoins part a) and then undergoes washing and decanting. This draws off the residual organic matter (in the form of sludge), thereby leaving behind the heavy inert matter which is recycled in granule form and lightweight inert matter. The latter, together with the lightweight inert matter, which has been blown out of part c), make up the final residue.

The quality of vermicomposts obtained is constantly monitored, especially concerning maturity (C/N), physico-chemical and agronomic characteristics and content of macro-elements and oligo-elements (Mg, Mn, Ca, etc) as well as heavy metal, in order to comply with the strictest acceptable levels pescribed by of North European countries (Table 3).

Table 3. Characteristics of vermicompost and compost regulations.

	Physical Characteristics	Standard (France)		
pH	7.5	none		
Organic matter *	31.8	>10		
Water content *	80.8	none		
Water capacity *	150.0	none		
Macroelements *				
C	15.9	none		
N	1.2	<2		
C/N	13.2	<20		
$P(P_2O_5)$	0.9	none		
$K(K_2O)$	1.5	none		
Ca(CaO)	11.9	none		
Oligoelements Heavy metals (ppm DM)		Limits in compost		
		F	B	CH
Na	2781	none	none	none
Mg	5392	none	none	none
Mn	314	none	none	none
Zn	391	none	1000	500
Cu	102	none	100	150
Pb	150	800	600	150
Hg	1.9	8	5	3
Cd	3.0	8	5	3
Ni	32.5	200	50	50

* % of dry matter ,F : France ; B : Belgium ; CH: Switzerland, DM: dry matter

ASSESSMENT

MATERIAL ASSESSMENT

The factory in La Voulte-sur-Rhône has been in operation for more than two years. The values reported are the results of the first eleven months of operation (Table 4) during which the unit treated a total of 8200 tonnes.

Table 4. Material assessment (percentages of the initial gross tonnage).

RECYCLED RAW MATERIALS	
Ferrous metal (scrap iron)	6.7
Non ferrous metals	0.1
PVC, PET	0.6
Paper and cardboard	7.5
Rags	1.1
Glass	4.0
Plastics	3.7
Total	23.7
VERMICOMPOSTS	26.7
GRANULES FROM RECYCLING	15.0
BATTERIES	0.03
ULTIMATE WASTE	
Cumbersome articles	4,5
Residues	4,3
LOSS IN WEIGHT (through respiration)	25.5

ENVIRONMENTAL ASSESSMENT

The unit as a whole uses up water and so there is no liquid effluent (Fig.3) The gaseous exchanges are those of a biological respiration, i.e., using oxygen and producing steam and carbon dioxide. This CO_2 is given off in quantities and at a rhythm similar to that of natural humification in meadows or forests. There is, therefore, no excessive contribution to the greenhouse effect.

The contaminants are monitored by dosing the earthworm concentrations. Batteries of all types, the main source of heavy metals, are removed from contact with all other products.

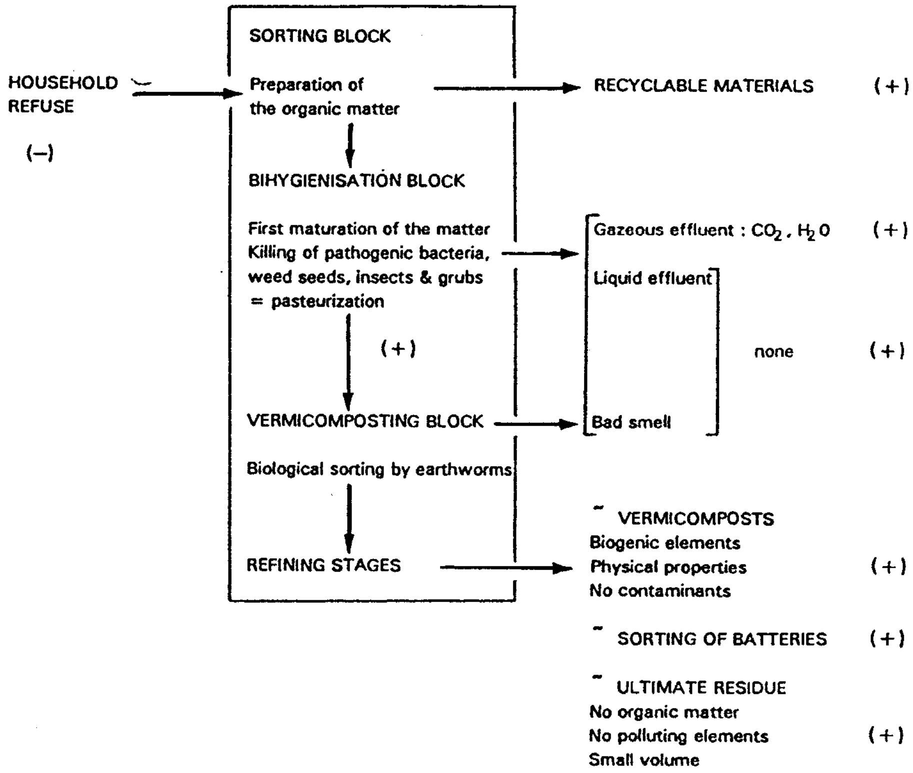

Fig. 3 : Environmental balance of the process : (-) negative aspects and (+) positive aspects

The ultimate remaining waste has to be treated in the traditional way (*e.g.* land filling), and only represents 20 % of initial tonnage and 3).% of volume. An additional fraction of granulated inert materials (15%) could be re-used by public works. The total balance is presented Table 4.

CONCLUSION

Social, commercial and industrial organisation of developed society has led to a break in the natural recycling of organic matter and biogenic elements. Consequently, it has been necessary to make up for)the lack of biogenic elements by using chemical fertilisers which very often turn out to be pollutant in use, and organic matter obtained by the exploiting of peat bogs, which often have to be closed down to preserve these fragile milieus. This has not prevented a deficiency of organic matter in soils, and leading to leaching, slatching, decrease in water-holding capacity and soil erosion.

The fact that earthworms have been replaced in their ecosystemic place within an industrial process conceived to that end, allows us to take advantage of the properties of these creatures, i. e., their capacity to sort and digest organic matter. These properties have made it much easier to find a solution to environmental management of problems associated with urban and ordinary industrial waste.

This very first industrial implementation in the world, using a soil-based creature, paves the way for other uses, especially for the recycling of agro-industrial waste.

AKNOWLEDGMENT

The authors are undelited to Prof. B.K. LONSANE for its valuable criticism of the manuscript.

REFERENCES

Bouché, M.B. 1971. Relations entre les structures spatiales et fonctionnelles des ecosystèmes illustrées par le rôle pédobiologique des vers de terre. In: Pesson, *La vie dans les sols,* Gauthier-Villars, Paris, 187-209.

ANRED, 1991. *Les déchets en France: Les chiffres clés.* ANRED, Angers, 27 pp.

Anstett, A. 1952. Sur l'activation macrobiologique des phénomènes d'humidification. *C.R. Acad. agric.* 37:262-264.

Barret, T.J. 1949. *Harnessing the earthworm.* Faber & Faber Publ., London. 166 pp.

Bouché, M.B. 1979. Valorisation des déchets organiques par les lombriciens. La Doc. *Franç., Orléans, Coll. Rech. environ.* (15-17/03/77), 11: 401.

Bouché, M.B. 1982. Des vers de terre pour le traitement des déchets. *Biofutur,* 7: 43-46.

Bouché, M.B. 1987. Emergence and development of vermiculture and vermicomposting : from a hobby to an industry, from marketing to a biotechnology, from irrational to credible practices. In: Bonvicini, A.M., Pagliari, A.M. and Omodeo, P. (eds) *On earthworms,* Select symp. and Monog. U.Z.I., Mucchi, Modena, 2: 519-531.

Chaudonneret, M.B. 1977. Quelques données sur la composition biochimique des vers de terre, aliment éventuel du bétail et de l'homme. *Rapport de fin d'études INSA*, Lyon, 37 pp.

Darwin, Ch. 1837 The formation of vegetable mould through the action of worms. *Trans. Geol. Soc.* (London), 5: 505-509.

Fayolle, L. 1982. Etude de l'évolution du système déchets-lombriciens-microorganismes : perspectives appliquées. *Thése doct.-ing., Université C. Bernard* ,Lyon I, 130 pp.

Straumann, G. 1988. *Filière de traitement des déchets urbains par lombricompostage. Rapport final : étude de faisabilité technique et économique du lombricompostage des ordures ménagères.* Ed. Capene, Montpellier, 89 pp.

Reinecke, A.J. and Venter, J.M. 1987. Moisture preferrences, growth and reproduction of the compost worm *Eisenia fetida* (Oligochaeta). *Biol. Fert. Soils*, 3: 135-141.

Reinecke, A.J. and Viljoen 1990. The influence of feeding patterns on growth and reproduction of the vermicomposting earthworm *Eisenia fetida* (Oligochaeta). *Biol. Fertil. Soils* 10: 184-187.

Russel, E.J. 1910. The effects of earthworms on soil productiveness. *J. Agr. Sci.* 3: 246-257.