*Wat. Sci. Tech.* Vol. 22, No. 9, pp. 33–41, 1990.
Printed in Great Britain. All rights reserved.

0273–1223/90 $0·00 + ·50

# ANAEROBIC DIGESTION AND COMPOSTING IN AN INTEGRATED STRATEGY FOR MANAGING VEGETABLE RESIDUES FROM AGRO-INDUSTRIES OR SORTED ORGANIC FRACTION OF MUNICIPAL SOLID WASTE

F. Cecchi*, G. Vallini** and J. Mata-Alvarez***

**Dipartimento di Scienze Ambientali Universita' di Venezia, Calle Larga S. Marta 2137, 30123 Venezia, Italy*
***Centro di Studio per la Microbiologia del Suolo, C.N.R., Via del Borghetto, 80 56100 Pisa, Italy*
****Dep. Enginyeria Quimica, Universitat de Barcelona, C/ Marti i Franques 1, Pta. 6. 08028 Barcelona, Spain*

## ABSTRACT

The co-digestion concept to improve the anaerobic digestion of several biological wastes is examined together with the integration of anaerobic digestion and composting biotechnologies. A series of experiments were carried out using the mechanically selected organic fraction of municipal solid waste. The anaerobically digested waste was composted with fresh substrate. The results show that the waste is perfectly stabilized and the pathogen indicators are greatly reduced.

## KEYWORDS

Anaerobic digestion; composting; municipal solid waste; agricultural wastes; agro-industry; integrated disposal; mesophilic; phytotoxicity.

## INTRODUCTION

The final disposal of the organic residues produced in the agro-industries, contained in municipal solid waste (MSW), and deriving from wastewater treatment plants is often carried out using similar biological technologies (anaerobic digestion, activated sludges, composting, land application etc...) (Cecchi et al. 1986, Debosere et al. 1986). This is justified by the similar characteristics of the wastes. Because of this likeness, their final disposal could also be considered according to an unique logic approach centered on an integrated plant.

As an example, the integrated management of biological wastes could consider the following substrates: 1) residues of transformation of vegetable crops (e.g. wine, sugar, cannery, distillery factories); 2) residues of transformation of animal products (e.g. slaughtering, dairy, tannery); 3) urban wastes (sewage sludge (SS), source-sorted organic fraction of MSW (SS-OFMSW), separately-collected organic fraction of municipal solid waste (SC-OFMSW), organic fraction of municipal solid waste sorted by plant (mechanically sorted, MS-OFMSW). The main physical, chemical characteristics of these biological wastes are reported in Table 1 and can justify the integrated approach here described. In fact the wastes with high content of putrescible fraction (e.g. tomato residues, source sorted organic fraction of municipal solid waste, etc.) can be mixed with the others (e.g. mechanically selected organic fraction of municipal solid waste, sewage sludge etc.) that are poor in these substances in order to obtain a more balanced substrate, even as far as the moisture content is concerned. This aspect is particularly important in the composting process.

The aim of this paper is firstly to present the experiments carried out by the authors regarding the combined treatment of different substrates either by means of the anaerobic digestion process or by composting process and, secondly to report original data concerning the integration of both technologies for exhaustive organic waste processing.

TABLE 1 Chemical characteristics of several biological wastes

| Parameters | TS % | TVS %TS | TCOD $gO_2/Kg$ | TC %TS | STVS %TVS | N %TS | P %TS | Ref. |
|---|---|---|---|---|---|---|---|---|
| Waste: | | | | | | | | |
| Tannery (a) | 5.6 | 48.8 | 3.8 | - | - | 3.1 | 0.15 | Vallini et al. 1984b |
| Olive (b) | 62.5 | - | 498.9 | - | - | 1.3 | 0.08 | " |
| Tomato (c) | 38.4 | 94.8 | - | - | - | 1.7 | 0.07 | " |
| SS (d) | 1.8 | 64.8 | - | 27.1 | - | 4.8 | 0.58 | " |
| PSS (e) | 4.1 | 73.3 | 39.0 | 39.9 | 4.0 | 2.3 | 0.4 | Cecchi et al. 1988 |
| SS (f) | 5.3 | 46.0 | 40.0 | 25.0 | 1.5 | 2.6 | 0.2 | " |
| SS-OFMSW (g) | 20.0 | 88.0 | 218.0 | 48.0 | 28.6 | 3.2 | 0.4 | " |
| SC-OFMSW (h) | 16.3 | 87.7 | 192.0 | 45.0 | 64.0 | 2.2 | 0.3 | " |
| MS-OFMSW (i) | 53.3 | 70.7 | 437.0 | - | - | 1.6 | 0.16 | Vallini et al. 1984b |
| MS-OFMSW (l) | 76.3 | 43.9 | 448.6 | 20.6 | 9.6 | 2.2 | 0.1 | Cecchi et al. 1989 |

TS = total solids; TVS = total volatile solids; TCOD total chemical oxygen demand; TC = total carbon; STVS = solute fraction of TVS; SCOD = solute fraction of TCOD; STC = solute fraction of TC; N = total nitrogen; P=total phosphorus (as P); SS = Sewage Sludge; SS-OFMSW = Source sorted organic fraction of municipal solid waste; SC-OFMSW = separately collected organic fraction of municipal solid waste; MS-OFMSW = mechanically selected organic fraction of municipal solid waste.

(a) vegetable tannery sludge; (b) exhausted olive husks; (c) tomato processing wastewater; (d) from Pistoia wastewater facilities; (e) from Treviso wastewater facilities; (f) from Terni wastewater facilities; (g) source sorted by the families of the town of Treviso; (h) separately collected in garden-produce markets and in canteens of the town of Terni; (i) sorted in the Pistoia sorting plant; (l) sorted in the S. Giorgio di Nogaro sorting plant and pre-composted.

## INTEGRATION OF ORGANIC WASTES AS SUBSTRATES IN THE ANAEROBIC DIGESTION OR COMPOSTING PROCESSES

### The anaerobic digestion process.

Two examples of integration in anaerobic technology will be presented in this section of the paper. The first deals with the codigestion of primary sewage sludge and source sorted organic fraction of municipal solid waste and the second concerns sewage sludge and separately collected organic fraction of municipal solid waste. Before the illustration of the advantages which can be obtained from the application of the co-digestion concept to these refuses, it would seem useful to outline the biological bases which allow us to carry out the co-digestion of the substrates mentioned above.

As discussed elsewhere (Cecchi and Mata, 1989) the biological degradation to biogas for a given substrate depends on the ultimate methane yield (B0) (Chen and Hashimoto, 1978) and on the kinetics of the process. A relation has been written in which the specific gas production rate (SGPR, $m^3$/KgTVS) depends only on the G0 (ultimate gas production rate), and the firt order kinetic constant, k for a given operative hydraulic, solids retention time (HRT, SRT days) (Cecchi and Mata, 1989):

$$SGPR = G0 / (1 + 1 / HRT\ k) \qquad (1)$$

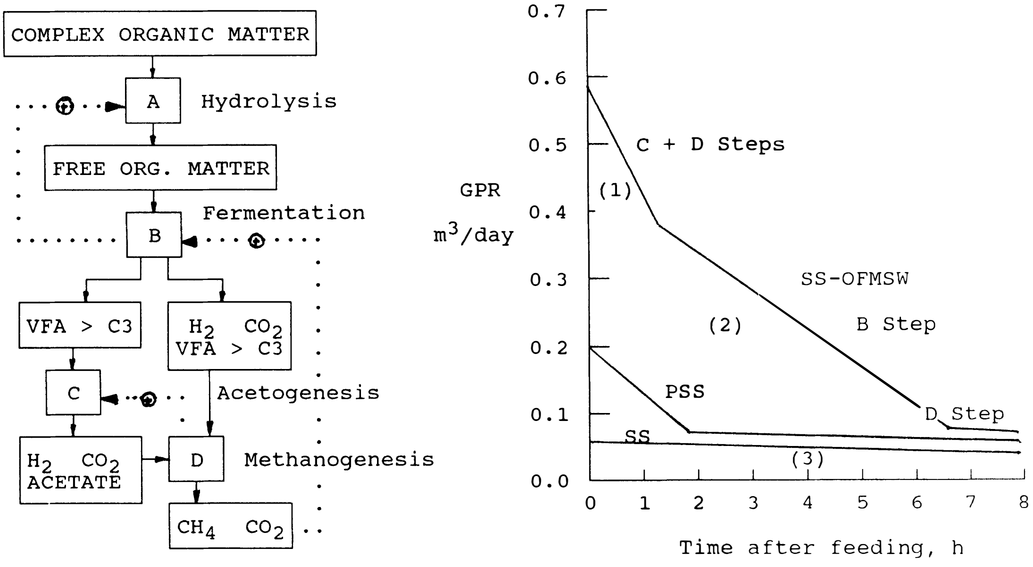
Since the operative HRT,SRT is in general very high (> 15 days) and the biodegradation (fB = SGPR / G0) over 80%, the process performance can be substantially varied simply by changing the kinetic value and thus enriching the digester feed in rapidly biodegradable compounds.

Considering a first order kinetic model, widely used in modelling the utilization of complex substrate (Mata and Cecchi, 1989), in going from mechanically selected organic fraction of municipal solid waste pre-composted to source sorted or separately collected organic fraction of municipal solid waste the kinetic constant in mesophilic conditions changes from 0.3 to 3.0 $\text{day}^{-1}$. The kinetic constant related to primary sewage sludge and sewage sludge are 1.11 and 0.28 $\text{day}^{-1}$ respectively. The kinetic constant for sewage sludge and primary sewage sludge is closely comparable with that of mechanically selected organic fraction of municipal solid waste (0.6 $d^{-1}$, Cecchi et al., 1989) but much lower than those of source sorted or separately collected organic fraction of municipal solid waste. Due to these different kinetic characteristics, the integration of the residues can be applied leading to an increase in performance of the digester.

From the practical point of view the different behaviour in substrate utilization can be experimentally observed by plotting the gas production rate ($m^3$/d) versus the time after feeding. Bearing in mind that this plot can be fitted using simple straight lines and that each line can be associated with the utilization of a group of compounds making part of the substrate (Cecchi et al. 1989a), the connection between the anaerobic trophic chain and the experimental substrate utilization can be illustrated through Fig. 1. As can be deduced from Fig.1B, the kinetic differences between sewage sludge and source sorted organic fraction of municipal solid waste can be justified by the presence of compounds rapidly utilizable by the microorganisms of the last two or three steps (C+D or B+C+D). These compounds can be easily quantified by reference to the amount of the volatile fatty acids (VFA) and to the substrate soluble fraction. A quantitative example of the distribution of these fractions

TABLE 2 Concentration of the main group of compounds in the source sorted organic fraction of municipal solid waste. Values are in $gC/m^3$ and are related to each step.

| Compounds utilizable in: | step 1 | step 2 | step 3 |
|---|---|---|---|
| Chemical analysis | 28 | 145 | 255 |
| Mathematical Model | 18 | 137 | 265 |



(A) (B)

Fig. 1. Steps in the anaerobic trophic chain (A) and corresponding gas production pathway between two digester feed for primary sewage sludge (PSS), sewage sludge (SS) and source sorted organic fraction of municipal solid waste (SS-OFMSW)

of substrate is reported in Table 2 for source sorted organic fraction of municipal solid waste. In the same table, experimental results are compared with the theoretical ones. Comparison is carried out considering the compounds evaluated in a chemical analysis and computed using the fitted straight line representing the biogas production profiles during each step of degradation, in accordance with the "step diffusional" proposed by the authors (Cecchi et al. 1989a). For each compound there is a corresponding area in the plot (see Fig. 1.B area 1, 2, 3).

## Experimental examples of co-digestion.

Data reported in Table 3 is the basis for the comparison of the co-digestion performances of two pilot plants treating separately collected organic fraction of municipal solid waste and sewage sludge mixed at various ratios between 0 to 80% (TS basis) and source sorted organic fraction of municipal solid waste and primary sewage sludge between 0 to 100% . The comparison is made in terms of experimental values for OLR applied to the digesters, HRT, SRT, $CH_4$ content in the biogas, SGPR, SMPR and TVS removal and in terms of calculated values for G0, B0, biodegradation achieved and kinetic constants. Analysis of Table 3 allows the conclusion that addition of source sorted/separately collected organic fraction of municipal solid waste to a digester treating sewage sludge or primary sewage sludge, substantially increases the reactor performance. The increase depends on the balance of the carbon quality of the organic matter fed to the digester. Of particular importance is the promptly utilizable substrate which is metabolized in steps C and D of the trophic chain and of the free organic compounds which start to be utilized from step B. The change of the substrate quality greatly influences the kinetics of the process, which can increase by about one order of magnitude. The specific methane production rate increases in going from 0 to 100% source sorted/separately collected organic fraction of municipal solid waste by about 60%. This improvement of the energy balance allows the possibility of achieving energy autonomy in wastewater treatment plants if the co-digestion concept is applied (Mata-Alvarez and Cecchi 1989).

Comparing the characteristics of agro-industrial residues with those of the source sorted/separately collected organic fraction of municipal solid waste (Table 1) it can be reasonably assumed that their similarity allows the extension of the results illustrated to these type of wastes.

TABLE 3 Performances of two digesters treating mixtures of sewage sludge, separately collected organic fraction of municipal solid waste, primary sewage sludge and source sorted organic fraction of municipal solid waste

| | SS + SC-OFMSW | | | | | PSS + SS-OFMSW | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| % OFMSW,TS basis | 0% | 25% | 50% | 80% | 100% | 0% | 16% | 35% | 60% | 100% |
| OLR,$KgTVS/m^3d$ | 1.7 | 1.9 | 2.8 | 3.9 | 4.5 | 1.6 | 1.3 | 1.4 | 1.9 | 2.1 |
| HRT,days | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 18.0 | 16.0 | 25.0 | 25.0 |
| SRT,days | 14.5 | 14.5 | 14.5 | 14.5 | 14.5 | 33.0 | 32.0 | 21.0 | 25.0 | 25.0 |
| $CH_4$ content,% | 77.5 | 73.0 | 67.5 | 61.0 | 57.0 | 71.9 | 73.5 | 70.1 | 65.5 | 63.2 |
| 1st order k,$d^{-1}$ | 0.28 | 0.9* | 1.5 | 2.2 | 2.9 | 1.11 | 1.4* | 1.8* | 2.2* | 3.0 |
| SGPR,$m^3$/KgTVS | 0.32 | 0.41 | 0.54 | 0.66 | 0.75 | 0.36 | 0.43 | 0.56 | 0.58 | 0.63 |
| SMPR,$m^3$/KgTVS | 0.25 | 0.30 | 0.37 | 0.40 | 0.43 | 0.26 | 0.32 | 0.39 | 0.38 | 0.40 |
| G0,$m^3$/KgTVS | 0.40 | 0.44* | 0.57 | 0.68 | 0.77 | 0.38 | 0.45 | 0.58 | 0.59 | 0.64 |
| B0,$m^3$/KgTVS | 0.31 | 0.32* | 0.38 | 0.42 | 0.44 | 0.27 | 0.33 | 0.41 | 0.39 | 0.40 |
| TVS removal,% | 25 | 43 | 56 | 70 | 75 | 40 | 43 | 49 | 56 | 69 |
| Biodegradat. fB,% | 80 | 93 | 96 | 97 | 98 | 95 | 96 | 97 | 98 | 98 |

* estimated from interpolation

TS = total solids; TVS = total volatile solids; TCOD total chemical oxygen demand; OLR = organic loading rate; HRT = hydraulic retention time; SRT = sludge retention time; k = first order kinetic constant; SGPR = specific gas production rate; SMPR = specific methane production rate; $G_0$ = ultimate biogas production; $B_0$ = ultimate methane production; $f_B$ = biodegradation achieved; SS = sewage sludge; SS-OFMSW = source sorted organic fraction of municipal solid waste; SC-OFMSW = separately collected organic fraction of municipal solid waste.

## Composting application to biological waste treatment

There is a large body of scientific literature which deals with the possibility of composting an array of putrescible organic wastes (Loeher, 1974; Bewick, 1980; Vallini et al., 1984a). In fact, a possible generalization is that any type of putrescible organic matter, after a proper physico-mechanical and in some cases chemical-conditioning, lends itself to aerobic biostabilization through composting.

Besides the important role in agriculture that organic fertilizer obtained from the correct composting of organic wastes has, it must be remembered that these organic wastes with agricultural, agro-industrial and municipal origins cannot, in any case, be directly introduced into the environment. Therefore composting can simply be considered a sure and economical method for cutting down organic waste putrescibility even if the compost produced has to be ultimately disposed off by landfilling.

Past experience has moreover confirmed the application of composting in the combined treatment of wastewaters and organic residues (Vallini et al., 1984b) Thus, composting is a reliable alternative for the treatment of the entire wastewater derived from the production of tomato purée when mixed with a ligno-cellulosic bulking agent such as wheat straw.

Olive husks constitute other agro-industrial residues tested as biomass in co-composting trials with sewage sludge. Data on experiments on the aerobic biostabilization of these mixtures is available concerning systems where composting piles are aerated by periodically turning them over (Vallini et al., 1984b). Stabilization of the initial substrate is reached within 8 weeks in these conditions. Also the tanning industry, closely linked to animal husbandry can, in some cases, make use of co-composting methods to dispose of process wastewaters. Only tanneries using vegetable tannins were taken into consideration for the aerobic biostabilization of wastewater sludge, as it does not contain chrome. However, the presence of tanning substances and relative phenolic derivatives in the vegetable tannery sludge, together with reduced sulphur compounds, precludes the direct use of this sludge in agriculture due to the toxic effect of its pollutants on the biochemistry of soil and plants (Vallini et al., 1989).

A compost compatible with agronomical uses was obtained by co-composting vegetable tannery sludge with the organic fraction of municipal solid waste as a bulking agent (Vallini et al., 1984b). Co-composting was carried out in static windrows aerated by blowing air from the bottom. The system adopted allowed for the complete oxidative stabilization of the initial substrate within 4 weeks, with a decrease of about 61% of tannins and about 97% of the sulphides present in the starting mixture. In the context of the treatment of putrescible organic wastes derived from the municipal circuit, a unique experience is represented by the composting of only the vegetable residues separately collected at garden-produce markets (Vallini and Pera, 1989). The aerobic biostabilization of these wastes produces the so-called "green compost", a high quality organic soil conditioner which is almost uncontaminated by heavy metals and free of microorganisms potentially pathogenic for man.

TABLE 4 Performance of the co-composting processes of several agroindustrial organic wastes.

| Mixture: | "A" | | "B" | | "C" | |
|---|---|---|---|---|---|---|
| | fresh | compost | fresh | compost | fresh | compost |
| TS, % | 31.3 | 60.0 | 37.1 | 62.5 | 32.8 | 61.5 |
| TVS, %TS | 84.6 | 48.3 | 87.5 | 86.0 | 71.3 | 42.7 |
| Humidified Matter, %TVS | - | - | 13.9 | 21.1 | 0.8 | 34.7 |
| Composting Method | (a) | | (a) | | (b) | |
| Composting Time, weeks | 8 | | 8 | | 4 | |

"A" = 40% tomato processing wastewater, 60% wheat straw (w/w); "B" = 35% exhausted olive husks, 65% sewage sludge from Pistoia wastewater facilities (w/w); "C" = 40% vegetable tannery sludge, 60% mechanically selected organic fraction of municipal solid waste from Pistoia sorting plant. (a) aeration by turning piles; (b) aeration by air blowing via temperature feedback control. TS = Total Solids; TVS = Total volatile solids.

According to this discussion Table 4 summarizes the experimental results obtained. Two main aspects can be pointed out: One is related to the efficiency of the aeration method (see the shorter stabilization time when the controlled air blowing aeration is adopted), the other concerns the low TVS reduction when exhausted olive husks mixed with sewage sludge are composted. This behaviour can be explained by considering the typical high content of slowly degradable compounds in the olive residues.

## INTEGRATION OF ANAEROBIC DIGESTION AND COMPOSTING BIOTECHNOLOGIES.

Figure 2 shows a possible scheme where anaerobic digestion and aerobic biostabilization could be effectively integrated in the treatment of fermentable biomasses and, particularly, in the management of the mechanically selected organic fraction of municipal solid waste and sludges coming from civil wastewater treatment.

As can be seen, the final treatment of the effluent from digesters remains a problem. It may still have putrescibility and can not be directly destined for land application because of its phytotoxicity. Thus a composting step appears as a reliable solution to make the anaerobic effluent compatible with agronomical uses. Furthermore, co-composting mixtures of effluent from anaerobic digesters fed with organic fraction of municipal solid waste in semi-dry fermentation conditions allows the closing of the MSW derived wastewater cycle and energy recovery.

The experiments described in this part of the paper deal with the efficiency of controlled co-composting stabilization process from the viewpoint of the abatement of putrescibility, malodorous emissions, phytotoxicity and pathogen content when applied to a digested mechanically selected organic fraction of municipal solid waste derived effluent mixed with fresh mechanically selected organic fraction of municipal solid waste.

Experimental trials. The mechanically selected organic fraction of municipal solid waste came from the downstream separation of refuse from the industrial sorting plant operating in S. Giorgio di Nogaro (UD - Italy). Its characteristics are reported in Table 1. Anaerobic digestion of this biomass was carried out in the pilot plant of the University of Venice (Cecchi et al., 1988) running under the following conditions: reactor temperature, 36 °C; TS

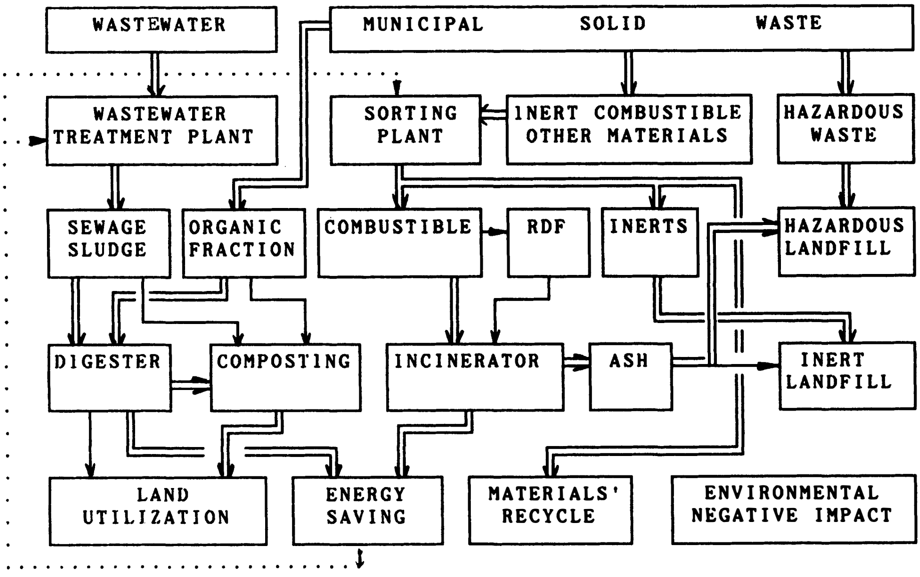


Fig. 2 Scheme of integration of the anaerobic digestion and aerobic biostabilization processes (RDF = Refuse Derived Fuel).

in the feed, 223 $Kg/m^3$; TVS in the feed, 49.5 % TS; HRT=SRT, 14.7 days; OLR, 7.5 $KgTVS/(m^3d)$; GPR, 1.4 $m^3/(m^3d)$; SGPR, 0.20 $m^3/KgTVS$; $CH_4$ in the biogas, 52%; TVS removal, 23% (the balance is carried out on the basis of the feed flow rate and the gas production). The main characteristics of the reactor effluent were: TS, 154 $Kg/m^3$; TVS, 72 $Kg/m^3$; pH 7.1; TCOD, 94.4 $KgO_2/m^3$ (see tables 2 and 3 for notation).

For composting experiments the digester effluent was mixed with the fresh mechanically selected organic fraction of municipal solid waste in the ratio of 35/65 (w/w). The mixture obtained was then formed into a 1.50 m high windrow of about 3 metric tons in a composting yard prepared for pile ventilation by forced air blowing from the bottom via temperature feedback control at the Soil Microbiology Center of the National Research Council (CNR) in Pisa (De Bertoldi et al., 1982; Vallini et al., 1984.b, Vallini and Pera, 1989).

Characteristics of the composting mixture throughout the biostabilization process are reported in Table 5. The system adopted allowed the complete stabilization of the initial substrate within a month (see temperature evolution in Fig. 3) even if the real thermophilic phase (T> 55°C) was within 21 days. These results were made possible by controlling temperature through the use of the forced-pressure ventilation technique. Temperature exceeded 70°C only for a few days, thus inhibitory conditions for the microorganisms involved in substrate transformation were limited and a substantial shortening in stabilization and humidification time of the starting mixture was obtained. The irregular trend of moisture during composting (see Table 5) was because of the extra addition of water to the mixture in order to correct excessive drying of the material. Actually starting the composting process with 54% moisture of the substrate is a limit condition. In spite of these corrective measures the progressive loss of moisture by evaporation, as a consequence of the microbial heat generation, was observed. This represented an important indicator of organic matter decomposition and process performance (Finstein et al., 1983). that is also confirmed by the observed C/N ratio evolution (see Table 5).

TABLE 5 Dynamics of some physical chemical parameters of the substrate during composting.

| Time , days | 0 | 3 | 7 | 14 | 21 | 28 | 35 | 50 |
|---|---|---|---|---|---|---|---|---|
| Moisture, %TS | 54.2 | 46.3 | 39.3 | 38.1 | 33.2 | 35.8 | 30.7 | 26.8 |
| pH | 7.7 | 7.8 | 7.9 | 8.0 | 8.1 | 8.5 | 8.5 | 8.4 |
| Ash, %TS | 55.0 | 54.8 | 56.8 | 57.5 | 57.6 | 64.8 | 64.1 | 67.2 |
| Carbon, %TS (a) | 30.8 | 31.5 | 30.4 | 30.0 | 27.1 | 23.1 | 23.1 | 22.1 |
| TKN, %TS | 1.1 | 1.3 | 1.2 | 1.4 | 1.2 | 1.1 | 1.1 | 1.1 |
| C/N | 28.8 | 25.0 | 25.8 | 21.7 | 22.7 | 21.0 | 21.2 | 19.7 |

TS = total solids; N = total nitrogen; TKN = Total Kjeldhal Nitrogen.

With reference to table 5, the windrow was humidified at days 20, 27, 33, and the carbon, as %TS, was analyzed according to Jackson (1958).

With regard to the hygienization aspect, the microorganisms indicating fecal contamination in the initial substrate were drastically reduced or completely deactivated at the end of the compost biostabilization process (see Table 6). Although the composting process was effective in past experiments for the complete inactivation of Salmonella sp., in this case the microorganisms were not present in the initial substrate. This could be due to the fermentative, heat producing activity the mechanically selected organic fraction of municipal solid waste underwent during the transportation of the substrate from S. Giorgio di Nogaro to Pisa.

TABLE 6 Number of pathogenic microorganisms in the mixture during the composting process.

| Days: | 0 | 7 | 21 | 35 | 50 |
|---|---|---|---|---|---|
| Total Coliforms: | 1.2 $10^8$ | 1.0 $10^5$ | 8.1 $10^3$ | 1.9 $10^3$ | 5.7 $10^2$ |
| Fecal Coliforms: | 1.3 $10^6$ | absent | absent | absent | absent |
| Fecal Streptococci: | 1.9 $10^7$ | 6.1 $10^4$ | 1.9 $10^3$ | 5.5 $10^2$ | 2.6 $10^2$ |
| Salmonella sp.: | absent | absent | absent | absent | absent |

According to the procedures of the cress (Lepidium sativum) bioassay (Zucconi et al., 1981), disappearance of phytotoxicity was proved. The response of cress germinating seeds to the 10% and 30% dilutions of the aqueous extract from the mixture allowed us to obtain a germination index not lower than 60% (threshold of phytotoxicity) within 7 and 28 days respectively (Fig. 4). The result of the test with the higher concentration of the extract from the composting material stresses the almost complete lack of plant toxicity in the end product (compost). In fact the response to the 10% dilution is usually considered probative.

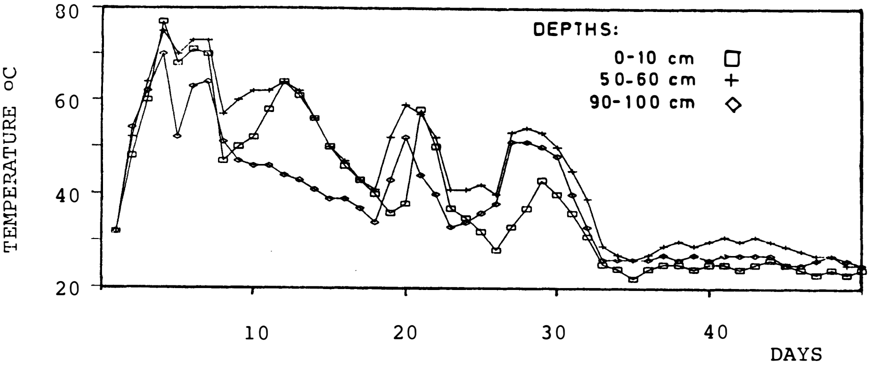


Fig. 3 Evolution of temperature during composting at different depths in the windrow.

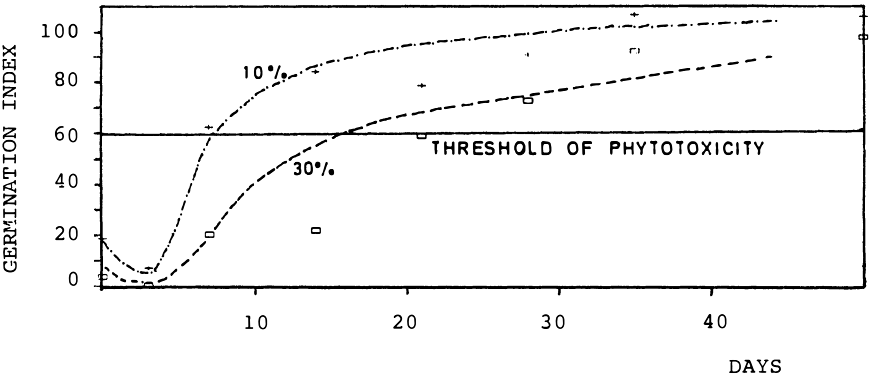


Fig. 4 Phytotoxicity pattern during composting according to the cress Lepidium sativum bioassay.

## CONCLUSIONS

From the analysis carried out it appears clearly that an integrated strategy such as that illustrated in Fig. 2 seems to be reliable for managing biological wastes of different origins. The following possible advantages may be obtained: a) the phytotoxicity of the digested matter is removed and land application allowed; b) the digester water balance can be closed without having recourse to a wastewater treatment plant; c) in digesting a part of the organic fraction of municipal solid waste, energy is recovered and its balance improved; d) all the biowastes are hygienized.

## ACKNOWLEDGEMENT

Authors acknowledge support of the "Instituto Trevigiano di Ricerca Scientifica del Comune di Treviso" and of NATO grant No. 0178/87.

## REFERENCES

Bewick, M.W.M. (1980). Handbook of organic waste conversion. Van Nostrand Reinhold Co., New York.

Cecchi, F., Traverso, P.G., Clancy, J., Mata-A., J., Zaror, C. (1986). MSW and vegetable by-products, guidelines for research: from the harvesting procedure to the anaerobic process. in Biomass energy: from harvesting to storage, G.L. Ferrero, G. Grassi. H.E. Williams (Eds). Elsevier Science, Amsterdam, pp 225-235.

Cecchi, F., Traverso, P.G., Perin, G. and Vallini G. (1988). Comparison of co-digestion performance of two differently collected organic fractions of municipal solid waste with sewage sludge. Env. Technol. Letters, 9, 391-400.

Cecchi, F., Mata-Alvarez,J., Marcomini, A., Pavan, P. and Fazzini G. (1989). Mesophilic digestion of the refuse organic fraction sorted by plant. Performance & kinetic study. Waste Manag. & Res., submitted.

Cecchi, F. and Mata-Alvarez, J. (1989). International Research Workshop on "Biotechnology and Biodegradation". Lisbon, June 19-23.

Cecchi, F., Mata-Alvarez, J., Traverso, P.G., Medici, F., Fazzini, G.,(1989a). Comparison between the literature and a new approach to the kinetic study of anaerobic degradation of the organic fraction of municipal solid waste. Biomass, submitted.

Chen, Y. and Hashimoto, A. (1978). Kinetics of methane fermentation. Biotech. Bioeng. Symp., 8, 269-282.

de Bertoldi, M., Vallini, G., Pera, A. and Zucconi, F. (1982). Comparison of three windrow compost systems. BioCycle, 23 (2), 45-50.

Debosere, S., De Baere, L., Smis, J., Six, J. and Vestraete, W. (1986). Dry anaerobic fermentation of concentrated substrates. In: Proc. Anaerobic Treat. a Grown-up Technol. Amsterdam (The Netherlands), 15-19 September, pp 477-488.

Finstein, M.S., Miller, F.C., Strom, P.F., MacGregor,S.T., and Psarianos, K.M. (1983). Composting ecosystem management for waste treatment. BioTechnology, 1, 374-353.

Jackson, M.L. (1958). Soil chemical analysis. Prentice Hall Ed., pp 219.

Loehr, R.C. (1974). Agricultural waste management. Academic Press, New York.

Mata, J. and Cecchi, F. (1989). Joint anaerobic digestion of sewage and sorted organic fraction of municipal solid waste to attain energetic autonomy in wastewater treatment plants. In: Proc. of First Workshop of CNRE on Biogas Prod. Technol. Zaragoza (Spain) 10-11 April, in press.

Mata, J. and Cecchi, F. (1989). "A review of kinetic models applied to the anaerobic digestion of complex organic matter. Kinetics of the biomethanization of the organic fraction of municipal solid waste". Proc.of the Intern. Workshop on Biotech. and Biodegr. Vale de Lobos, Portugal.

Vallini, G., Bianchin, M.L., Pera, A. and de Bertoldi, M. (1984a). Composting of food factory, fruit and vegetable waste, tannery sludge and cork waste. In: Seminar on composting agricultural and other wastes, Oxford (U.K.), 19-22 March, pp 3-18.

Vallini, G., Bianchin, M.L., Pera, A. and de Bertoldi, M. (1984b). Composting agro-industrial byproducts. BioCycle, 25 (4), 43-51.

Vallini, G, and Pera, A. (1989). Green compost production from vegetable waste separately collected in metropolitan garden-produce markets. Biological Wastes, 29, 33-41.

Vallini, G, Pera, A., Cecchi, F., Briglia, H. and Perghem, F. (1989). Compost detoxification of vegetable-tannery sludge. Waste Manag. & Research (in press).

Zucconi, F., Forte, M., Monaco, A. and de Bertoldi, M. (1981). Biological evaluation of compost maturity. BioCycle, 22 (4), 27-29.