Proc. 8th European Biosolids and Organic Residuals Conference, Wakefield, UK, 23-26 Nov 2003. Vol. 2

ENVIRONMENT AGENCY REVIEW OF METHODS FOR DETERMINING ORGANIC WASTE BIODEGRADABILITY FOR LANDFILL AND MUNICIPAL WASTE DIVERSION

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ABSTRACT

The Environment Agency is required to regulate the landfilling of biodegradable organic wastes and their diversion from landfilling. Simple, cost effective, reliable and widely applicable methods for the measurement of organic waste and its biodegradability are needed for this activity. A review of such methods was carried out in order to select promising methods for an experimental screening exercise. The review considered both biological and non-biological methods including simple methods that may provide a surrogate measurement of waste biodegradability instead of the time-consuming biological methods. The biological methods selected for further evaluation were the aerobic specific oxygen uptake rate (SOUR) and dynamic respiration index (DRI) tests, and the anaerobic biochemical methane potential (BMP) test.

The non-biological methods selected for further evaluation were dry matter (DM), loss on ignition (LOI), total organic carbon (TOC), total nitrogen (TN), water extractable dissolved organic carbon (DOC), BOD and COD, the lignin and cellulose content and the cellulase hydrolysis method. These tests are being evaluated on a wide variety of typical organic materials that might be found in municipal solid waste (MSW) such as newspaper corrugated paper, compost, kitchen waste (vegetable and animal), garden wastes (grass and twigs), nappies, cotton and wool textiles.

KEYWORDS

Waste Biodegradable Organic Compost DRI SOUR BMP AT4 Landfill Diversion

INTRODUCTION

The Landfill Directive (1999/3 1/EC)[12] sets tough new targets on the UK that limit the landfill of biodegradable municipal solid waste (MSW). This is a significant waste stream; approximately 28 million tonnes of MSW was produced in England in 2000/1 of which about 55% is the biodegradable component (garden waste, paper & board, putrescible kitchen waste).

Approximately 80% of MSW in England is currently landfilled (Waste Strategy 2000)[9]. Additionally the amount of MSW generated is increasing annually by 3-4% each year.

The Government has decided to allocate the MSW diversion targets for England to individual Waste Disposal Authorities (WDAs) by means of a landfill allowances system and proposes to make the Environment Agency responsible for monitoring the performance of WDAs in meeting these targets. Where the treatment of MSW or of one or more biodegradable fractions would produce a waste that is then landfilled, it will be necessary to assess the amount of biodegradable material of that waste that has been removed by treatment. Additionally the criteria for acceptance of organic non-hazardous (treated) waste into landfills are to be set at the national level[11] and in the UK there is no means of assessing this at present.

In order to assess the biodegradable content of that waste removed by treatment on a fair basis, the Agency and Defra propose to supply information to WDAs on the diversion amounts which will be allowed for different processes treating different waste fractions and MSW containing these fractions in different proportion.

As a precursor to determining the diversion amounts that will be allowed for different processes treating different waste fractions, the Agency and Defra wish to establish: the suitability of various tests for measuring waste organic matter content and its biodegradability, particularly with respect to different MSW organic matter fractions and the impact of waste treatment processes on biodegradability.

The overall objective of the project is to derive a means of assessing the biodegradable content of municipal solid waste that has been removed by treatment (and that which remains) prior to that waste being landfilled in accordance with Article 5 of the Landfill Directive[12]. This paper describes the key findings of a review of methods for assessing the biodegradable content and biodegradability of MSW and some preliminary results from an experimental evaluation of the selected methods on eleven different organic materials (cellulose, newspaper, corrugated paper, vegetables, tinned meat, nappies, cotton sheets, wool, twigs, grass clippings and greenwaste compost).

REVIEW OF METHODS

There are several analytical (chemical, physical and biological) methods that might be used to assess organic waste. This review considered mainly established standard methods available either from contract analytical laboratories or that can be carried out in-house, and that apply to a wide range of raw and treated organic wastes, whether composed of a single (e.g. newspaper, kitchen waste) or mixture of organic materials (e.g. MSW). Methods vary in simplicity, cost and time to complete, and with the information they provided with regard to the organic waste characteristics. In general biological methods are the most complex, costly and time-consuming and provide a direct measure of waste biodegradability. It is appropriate to seek less exacting chemical or physical methods that might act as surrogates for biological methods by providing information on biodegradability. The methods therefore can be considered as those that provide a general waste characterization, those that measure waste biodegradability and those non-biological methods that act as surrogates for biological methods.

GENERAL WASTE CHARACTERIZATION METHODS

These methods measure the general composition, including organic matter content, of the wastes. They do not measure waste biodegradability as the methods include materials such as non-biodegradable plastics within the organic matter values.

GRAVIMETRIC

Determination of general waste composition for moisture and dry matter (DM) contents (by drying at 105^{o}C) and organic matter content (loss on ignition LOI at 550^{o}C) were considered obligatory methods of waste characterization. During the experimental evaluation eleven wastes were measured by these methods in three laboratories with close agreement in results (Table 1). The DM content of the wastes varied considerably and with the exception of compost, the organic matter content (LOI) was similar to the DM content. Most MSW is also likely to be similar to compost and have a LOI content lower than the DM content. Waste mass was therefore expressed in terms of both DM and LOI but biodegradability was expressed in terms of LOI.

ELEMENTAL COMPOSITION

Determination of the waste total organic carbon (TOC) and total nitrogen (TN) contents was also carried out. The TOC provides a cross-check of the LOI content, is used as a landfill waste acceptance criteria[11], and is required to calibrate other test methods. The TOC contents of the wastes were typical for organic materials (36 to 55%, average 43%, of the LOI, Fig. 1). Total nitrogen determination is required for some biological biodegradation tests to ensure sufficient N is present as a nutrient to support microbial growth. The TN contents of the eleven waste samples varied considerably. (Fig. 2). Wastes composed mainly of cellulose (newspaper, corrugated paper) were virtually N free whilst wool (composed mainly of protein) had the highest N content. Determination of the phosphorus content of the waste may also be required for some biological test methods (e.g. ASTM 5975-96)[2].

BIOLOGICAL METHODS

Biological methods involve incubating the organic waste in the presence of microorganisms that utilize the organic matter (decompose) as a substrate for their growth. Tests may be carried out under anaerobic (methanogenic) or aerobic conditions and are monitored by measuring either the organic carbon (OC) mineralization products CH_4 and CO_2, or O_2 consumption (in aerobic tests). Since the tests involve live micro-organisms the test conditions must be optimal for microbial activity. This includes suitable environmental conditions (e.g. pH, temperature, moisture content, ionic strength), the presence of sufficient microbial nutrients (e.g. N, P, K, S, trace elements and O_2 for aerobic tests), and a microbial culture capable of degrading the organic components. Most organic wastes contain a variety of organic compounds (e.g. sugars, amino acids, fats, proteins, nucleic acids, polysaccharides, lignin) that have varying degrees of biodegradability. Microbial species are often selective in the types of organic compounds they degrade and if the microbial seed lacks the microbes that degrade a particular organic compound false negative or low biodegradability results will be obtained. A further factor is the solid waste particle size and in general the waste decomposition rate increases as the particle size decreases because of the increase in the surface area that the microbes can access.

ANAEROBIC BIOCHEMICAL METHANE POTENTIAL (BMP)

This test measures waste biodegradability under anaerobic methanogenic conditions using digester sludge as the source of microbes. These degrade OC to a mixture of CO_2 and CH_4 (biogas), and are monitored by measuring the amount of biogas or specifically CH_4 produced. The microbial growth efficiency is low and only about 10% of the degraded OC is converted to new microbial biomass. This means that biogas production provides an accurate measure of the amount of degradation (mineralization) of the waste. A small-scale test[18, 22] developed from a standard method for measuring anaerobic biodegradability of organic chemicals[28] utilizes a waste sample of 0.5 g DM. This is probably too small a sample size when considering heterogeneous mixed organic wastes. Larger scale tests (GB21, GP21, GS90 tests)[5, 10, 20] contain more waste (50 g of waste in 200 – 350 ml) but require long time-scales to reach completion (over 90 days) although the result after 21 days may provide a good reflection of overall waste biodegradability. These tests consider a waste with a biogas production below 20 Nl/kg LOI as non-biodegradable.

Since landfills are generally anaerobic environments an anaerobic method was selected for further evaluation. A modified BMP test, using 20 g LOI of waste, based on a Blue Book method[27] for determining anaerobic degradability of sewage sludges was used in the screening exercise. The tests were carried out over 55 days in triplicate at a temperature of 3 5^{o}C. The results (Table 2) showed good reproducibility between replicates and the relative biodegradability of the different wastes was consistent with other studies[19, 24]. Biogas production was still occurring in some wastes after 55 days indicating that the degradation was incomplete.

AEROBIC WASTE BIODEGRADATION TEST METHODS

Several aerobic waste biodegradability test methods exist as well as different monitoring techniques and ways of expressing results. They can be categorized into three main method types; static respiration index (SRI), dynamic respiration index (DRI) and liquid systems (specific oxygen uptake rate SOUR).

The SRI method is a closed solid state technique and involves monitoring changes in the O_2 concentration in the air-space by reduction in air pressure after removal of evolved CO_2 by adsorption in an alkaline trap. The Sapromat™ AT4 method is a form of SRI widely used to measure organic waste biodegradability. The SRI method resembles or mimics a static pile compost heap.

The DRI method is also a solid state technique but is an open system involving passing air through the waste (mixed with compost as microbial source) and monitoring the difference in either O_2 (consumed) or CO_2 (produced) between the inflow and out-flowing air. This method is used in the ASTM standard method[2].

The SOUR test[21] is a liquid technique loosely based on the method used for measuring the biological oxygen demand (BOD) of waste-waters[29]. It involves homogenizing the waste in a water suspension and monitoring the removal of dissolved oxygen (DO) from the liquid using a DO probe. Since the O_2 demand of the waste is much higher than the amount of DO present the DO is intermittently replaced by sparging with air. The SOUR method uses a relatively small waste sample (up to 8 g wet weight) and would probably need to be scaled up to improve its reproducibility with heterogeneous mixed waste samples.

The review also considered but did not evaluate further other aerobic degradation methods including the Sulflita™ test kit and the Dewar self heating test[31]. These methods are specifically designed for assessing compost maturity and whilst they would provide simple methods of monitoring compost they would not be applicable for assessing the biodegradability of raw wastes or wastes treated by other processes (e.g. by anaerobic digestion).

MEASUREMENT OF OXYGEN OR CARBON DIOXIDE

Aerobic biological waste degradation methods may be monitored by either O_2 consumption or CO_2 production and there is some debate on the merits of each. Oxygen consumption is a direct measurement of aerobic respiration but O_2 consumption from chemical reactions is also possible, e.g. oxidation of reduced compounds such as sulphide. Carbon dioxide monitoring provides a measure of OC mineralization but CO_2 will still be produced if the system becomes anaerobic, or from decomposition of inorganic carbonates under acidic conditions. On balance we accept both measurements and convert the CO_2 data to O_2 on the basis of an equivalent mole per mole ratio.

EXPRESSION OF AEROBIC RESULTS

If microbial degradation of readily biodegradable glucose is considered it would be expected to be completely consumed during a biodegradation test. The microbes would grow exponentially on the glucose and the rate of O_2 consumption would increase until all glucose was consumed and then decline. Since aerobic microbial growth is more efficient than anaerobic growth, a significant fraction of the glucose C (approximately 50%) would have been converted to new microbial biomass. This microbial biomass would slowly decompose further over an extended time period. Therefore whilst glucose was completely biodegraded the test would show incomplete mineralization in the short term as much of the glucose C will be present as microbial C. This effect (not so significant in anaerobic tests) needs consideration when interpreting aerobic degradation results.

It is common to express degradation results as either the peak oxygen consumption rate often termed the respiration index or SOUR, or the cumulative oxygen consumption over a set period which we call the AT value. The draft Biowaste directive[13] gives limits for biodegradability in both terms, i.e. a four day AT value (AT4) of 10 g O/kg DM and a respiration index of 1000 mg O/kg LOI.h. Since the peak rate is a single point in time and depends on several factors including microbial population size present and the available remaining biodegradable waste we prefer monitoring degradation by the cumulative O_2 consumption (AT4 value).

COMPARISON OF SRI, DRI AND SOUR METHODS

Many studies have compared the results from the different methods with generally good correlations being reported between them[1,23]. The SRI method, however generally gives lower biodegradability values than the DRI method[1], which, reflects the greater aeration in the DRI tests. The air-flow rate used in the DRI method is an important variable as degradation rate increases with increasing aeration[1]. The SOUR method being liquid based, with macerated waste and nutrient addition, is believed to provide the most optimum conditions for microbial growth and therefore the greatest chance of the degradation test being completed. In SOUR tests the peak oxygen uptake rate is often achieved within 24 hours of initiating the test and the test is usually completed within 4 days.

For these main reasons the DRI and SOUR method were selected over the SRI method for further evaluation. The DRI tests were carried out at either 35^{o}C or 50^oC over seven days using the greenwaste compost as microbial seed and an alkaline trap method for monitoring CO_2 production. The results (Table 3, Fig. 3) indicated that the tests were incomplete within the seven day incubation time and that there was considerable variation between replicates. There was the hint that temperature increased the AT4 values as expected although this was not statistically valid at P<0. 1. The order of decreasing biodegradability was similar to the BMP tests and a reasonable correlation between BMP and DRI results was obtained (Fig. 4). This correlation excludes the results for nappies, which degraded much better in the BMP test.

The SOUR tests were carried out in triplicate by Leeds University and showed good reproducibility between replicates (Table 4). However it was found that materials composed principally of polymeric materials (e.g.. cellulose, newspaper, corrugated paper, nappies) gave low biodegradability results in the SOUR test compared with the BMP and DRI test (Table 5). This might reflect the microbial seed properties (activated sludge), e.g. if it lacked sufficient cellulose degrading activity within the SOUR test time-scale. We did not find a significant correlation between the SOUR and either the BMP or DRI test results.

COMMENTS ON THE ASTM METHOD

The ASTM method[2] is widely quoted as the approved test of biodegradability. There are some features of this test that need consideration. The test is carried out at 58^oC using a mature compost as microbial seed. This is a high temperature, which means that the microbial source must be compost that has been produced at the same temperature, i.e. contains thermotolerant microbes. The temperature may also influence the oxygen transfer into the waste as the solubility of oxygen in water decreases with increasing temperature[26]. Ensuring such a high temperature test is not oxygen limited may require that careful consideration is given to the air flow rate and porosity of the compost waste mixture. The test also requires that the moisture content and nutritional state (N and P contents) of the test mixture are adjusted prior to incubation. Achieving uniform mixing these components into a solid matrix may not be easy.

SURROGATE TESTS FOR BIODEGRADABILITY

In addition to the direct measurement of waste biodegradability by biological test methods it is possible that other simpler, rapid and cheaper chemical methods may provide surrogate methods for assessing waste biodegradability. Several of these potential surrogate methods have been considered.

WATER EXTRACTABLE DISSOLVED ORGANIC CARBON (DOC), BOD AND COD

Leaching tests (e.g. EN 12457-3:2002)[17] are to be used to characterize wastes for landfill acceptance[11]. These involve extracting the waste with water and then analyzing the eluate for leached components. It has been proposed that extracted DOC might correlate with overall waste biodegradability[5] since the extracted DOC will mainly comprise the soluble readily degradable components of the waste. It is questionable however whether biodegradable materials composed principally of polymeric materials (e.g. cellulose containing newspaper) would release soluble DOC, or whether the DOC released from biologically treated wastes (e.g. compost) would be readily degradable.

The biodegradability of the extracted DOC as determined by the standard biochemical oxygen demand BOD_5 test[29] and considered as the BOD/COD (chemical oxygen demand) ratio has also been postulated to correlate with the overall waste biodegradability[5,8]. That is a low BOD/COD ratio indicates that the extracted DOC (and the parent waste) is not readily biodegradable.

These tests on eluate from the one-stage batch leaching test[16] were selected for further evaluation in the screening exercise (Table 6). As might be expected the water extractable DOC was low in wastes composed principally of polymeric materials (cellulose, wool, cotton, newspaper, corrugated paper) and much greater in materials composed of direct plant or animal matter (vegetables, meat, twigs, grass). The BOD was very high in wastes with high extractable DOC. For most of the other wastes the BOD/COD ratios were within the range 0.2 – 0.8 suggesting that the extracted DOC was relatively biodegradable. For compost, however, the BOD/COD ratio was low (0.05) suggesting that the extracted DOC was much more recalcitrant. This would be expected from a waste pre-treated in a biological process. In our test we could find no good correlation between BOD, COD, BOD/COD and any of the biological tests (BMP, SOUR, DRI). There was however some correlation between the DOC and the BMP test, and between the DOC expressed as a percentage of the waste TOC and the BMP test, although the relationship was not particularly good (Fig. 5). The DOC did not correlate with the DRI and SOUR tests.

ALKALINE EXTRACTABLE DOC, HUMIC ACID AND FULVIC ACID

This method[7] extracts the alkaline (pH 12) soluble DOC from the waste and then estimates the amount of humic acid (HA) and fulvic acid (FA) fractions of the DOC. The results may be expressed as absolute amounts (e.g. mg HA/kg LOI), the HA/FA ratio and the degree of humification (DH = [HA+FA]/DOC). During composting the HA fraction usually increases and the FA fraction decreases[6]. Similar changes may occur during anaerobic decomposition of landfilled waste[4]. We have not found in our review, reports correlating the HA and FA contents with raw waste biodegradability. Therefore whilst this method might have value in monitoring specific organic waste treatment processes it is not likely to be applicable to all wastes and therefore was not considered for further evaluation.

CELLULOSE AND LIGNIN CONTENT

Most organic waste is plant derived and therefore will contain cellulose, hemicelluloses and lignin as major polymeric organic component. In general lignin is poorly biodegradable and is unaffected during biological degradation tests, hemicelluloses are hydrolysed rapidly by hemicellulases and may be considered as biodegradable. Cellulose hydrolysis by cellulase is slower relative to hemicellulose hydrolysis and the amount of cellulose degraded is affected by the amount of lignin present, i.e. the lignin protects the cellulose from attack by cellulase enzymes. During biological decomposition it is expected that that the amount of hemicellulose decreases significantly, some of the cellulose and the ratio of cellulose to lignin (C/L ratio) decreases.

The "cellulose" (sum of cellulose and hemicellulose) and lignin content of organic wastes can be determined by several methods[14,22] although care is required to understand exactly what might be included in the method as contaminating waste components. Correlations however between the cellulose, lignin, C/L ratio and the waste biodegradability[3, 15, 30] have been reported. This test was selected for further screening as possible surrogate for biodegradability. The results (Table 6) showed the cellulose and lignin contents varied and reflected the different waste materials (e.g. high cellulose and low lignin in the commercial cellulose material). For most wastes the cellulose content exceeded the lignin value except for compost. This is to be expected since composting biological treatment would have removed significant cellulose but left the lignin intact. Interestingly wool, which lacks cellulose and lignin, gave high values indicating the test is not totally specific for cellulose and lignin and needs to be applied with caution. There was no obvious correlation between the cellulose, lignin and C/L ratios and the waste biological degradability tests.

CELLULASE/HEMICELLULASE HYDROLYSIS.
Cellulose and hemicelluloses are major components of plant derived organic wastes. During decomposition of such wastes microorganisms produce enzymes (cellulase and hemicellulases) to hydrolyse these complex polysaccharides into simple soluble sugars, which are then utilized by the microorganisms. It is possible that the waste hydrolysis achieved by enzymatic treatment with purified cellulase and hemicellulases might correlate with microbial biodegradation. Such a test[25] may only take 40 hours and be more rapid than biological methods. Monitoring the test by measurement of the soluble monosaccharide sugars released would require specialist equipment. However, the release of soluble dissolved organic carbon (DOC) would be a simpler and less costly monitoring parameter. Whilst this test is not a standard or widely applied method it has the possibility of providing a rapid surrogate method for waste biodegradation for many plant derived wastes. The test was therefore selected for limited further evaluation in the screening exercise using the commercial cellulose as substrate. The results indicated that the DOC released from the cellulose by the cellulase treatment corresponded to 15% of the cellulose TOC and that this might correlate well with the DRI and BMP tests where 7% and 15.2% mineralization of the cellulose was achieved respectively. This test is being considered further on all the wastes tested.

CONCLUSIONS

This study has reviewed and carried out a screening exercise of methods for characterizing organic wastes according to their biodegradable content. The study has concluded that general waste characterization in terms of dry matter (DM) and organic matter (LOI) contents is essential and that biodegradability be reported in terms of the LOI content and that the general waste mass should be reported in terms of both DM and LOI. The TOC and TN contents of waste are also useful measurements as the TOC provides a cross-check of the organic content and both assist with the setting up of biological tests. The LOI and TOC tests do not characterize the biodegradability of the waste however and such a measure is required for accepting treated organic waste in landfills and accounting for organic waste diverted from landfills. The most promising biological tests evaluated in this study were the DRI and BMP methods although the DRI method was found to be most variable between replicates and the BMP test is very time-consuming. The BMP and DRI results showed a good correlation but neither correlated well with the SOUR method. There were few correlations of biological methods with potential surrogate non-biological methods for assessing waste biodegradability and the only tests of interest is the DOC when expressed as % of the TOC and the cellulase hydrolysis test which is to be further evaluated. The biological tests are also being evaluated further in longer-term tests to obtain complete degradation and to determine if better correlations can be found between biological and non-biological tests.

From this the most promising tests are considered to be DM, LOI, TOC, TN, DRI, BMP and possibly cellulase hydrolysis.

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ACKNOWLEDGEMENTS

The authors would like thank the Environment Agency and Prof. Ed Stentiford (Leeds University) for their help and assistance.

TABLES

TABLE 1. RESULTS FROM THREE LABORATORIES OF DRY MATTER AND LOSS ON IGNITION CONTENTS OF WASTES USED IN METHOD SCREENING EXERCISE (RTD% IS THE RELATIVE STANDARD DEVIATION)

	Dry matter content at 105°C (% wet weight)				Loss on Ignition at 550°C (% dry matter)			
Waste sample	**WRC-Lab A**	**WRc-Lab B**	**Leeds-Uni**	**RTD (%)**	**WRC-Lab A**	**WRc-Lab B**	**Leeds-Uni**	**RTD (%)**
Cellulose	95.8	96.9	96.9	0.66	99.4	99.9	99.7	0.25
Newspaper	90.8	94.4	95.4	2.59	92.8	89.7	95.8	3.29
Corr-paper	92.3	94	94.2	1.12	90	91.7	91.2	0.96
Grass	18.9	18.2	19.5	3.45	86.4	84.7	84	1.45
Twigs	63.5	63.8	64	0.39	96.6	95.4	96	0.63
Vegetables	13.5	12.9	11.9	6.33	94.5	93.2	93.8	0.69
Meat	22.7	22.9	23	0.67	93.8	91.5	90.6	1.79
Cotton	97.2	97.7	99	0.95	99.3	99.9	99.5	0.31
Wool	93.9	96.5	95.1	1.37	94.9	83.7	89.9	6.27
Nappies	96.8	97.7	97.8	0.57	85.6	90.4	89.9	2.98
Compost	62.8	64	65.2	1.88	31.8	31	29.7	3.44

TABLE 2. RESULTS OF WASTE DEGRADATION BY ANAEROBIC BMP METHOD (RSD% IS RELATIVE STANDARD DEVIATION)

Waste	**Mean Biogas (litre/kg LOI)**	**RSD %**	**Estimated waste C mineralised (%)**
Nappies	278	12.8	38.5
Grass	225	24.8	33.1
Corr-paper	210	2.8	24.7
Vegetables	164	21.1	21.3
Cellulose	142	4	18.1
Meat	107	10.5	10.4
Twigs	93	3.8	10.0
Newspaper	76	14.2	8.5
Cotton	26	7.8	2.6
Wool	21	1.7	3.4
Compost	16	4.2	2.7

TABLE 3. RESULTS FROM THE DRI AEROBIC BIODEGRADATION TEST.

Waste	Test conditions	Number of replicates	Average AT4 value (mgO/kgLOI)	RSD%
Meat	50 g DM, 50oC	2	218650	45.8
Vegetables	50oC	2	169450	61.6
Meat	50 g DM, 35oC	2	149674	57.7
Vegetables	35oC	2	137410	18.7
Corru-paper	35oC	2	124850	4.7
Grass	35oC	3	119387	42.0
Nappies	35oC	2	86125	3.4
Cellulose	35oC	2	84905	10.4
Newspaper	35oC	2	76625	28.6
Cellulose	50oC	2	73535	71.7
Twigs	35oC	3	57100	54.7
Compost	50oC	2	48785	1.4
Compost	35oC	8	26321	56.6
Wool	35oC	2	16980	17.3
Cotton	35oC	2	12880	5.7

TABLE 4. RESULTS FROM THE AEROBIC SOUR DEGRADATION TEST

Waste	Number of replicates	Time of peak SOUR from start (h)	Average SOUR (mgO/kg LOI.h)	RSD%	90 hour cumulative O consumption (mgO/kgLOI)
Vegetables	3	8.5	24700	4.2	499000
Twigs	3	6	13900	8.0	57900
Meat	3	16.5	12600	20.0	447000
Grass	3	7.8	2880	5.8	158000
Corr-paper	3	55	660	20.7	22100
Compost	3	1	580	42.5	15700
Cotton	2	8.3	530	76.0	5570
Nappies	3		240	15.8	1630
Newspaper	3		150	76.7	1650
Wool	2	7.5	90	31.4	3760
Cellulose	3	10.5	20	31.2	750

TABLE 5. COMPARISON OF THE WASTE MINERALIZATION ACHIEVED IN THE BMP, DRI AND SOUR BIOLOGICAL DEGRADATION TESTS.

Waste	DRI – method % C mineralised in 96 hours	SOUR – method %C mineralised in 90 hours	Anaerobic BMP % C mineralised in 55 days
Cellulose	7.59	0.07	18.1
Newspaper	6.05	0.13	8.5
Corr-paper	10.33	1.83	24.7
Grass	12.32	16.30	33.1
Twigs	4.29	4.34	10
Vegetables	12.46	45.46	21.3
Meat	10.28	30.53	10.4
Cotton	0.91	0.39	2.6
Wool	1.90	0.42	3.4
Nappies	8.35	0.16	38.5
Compost	3.12	1.91	2.7

TABLE 6. THE WATER EXTRACTABLE DOC, BOD AND COD AND THE CELLULOSE AND LIGNIN CONTENTS OF THE WASTES.

Waste	DOC mg C/kg DM	BOD mg O/kg DM	COD mg O/kg DM	Cellulose % DM	Lignin % DM
Cellulose	1570	1420	3690	83.4	4.2
Newspaper	1290	1730	3680	54	16.9
Corr-paper	8410	2090	22500	61.1	9.6
Grass	27700	104000	134000	21.6	12.8
Twigs	25000	55700	94900	45.9	13.1
Vegetables	13900	369000	33100	17.8	6.1
Meat	7560	150000	20400	8.4	5.5
Cotton	1540	1330	4760	92.4	2.1
Wool	686	485	2340	39.1	33.1
Nappies	17100	10000	49500	74.3	27.9
Compost	2460	259	5210	8.9	17.7

FIGURES

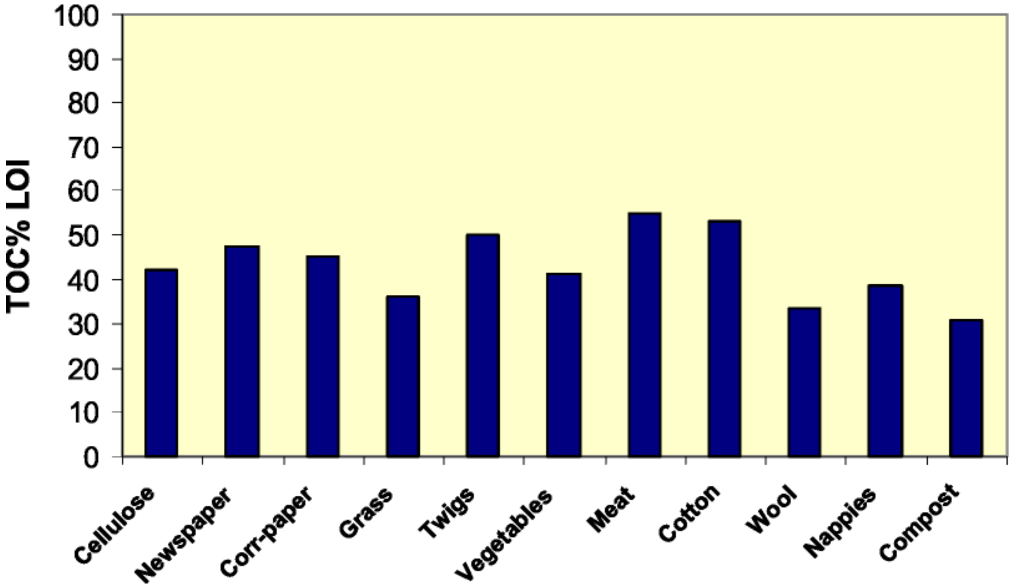

Fig. 1. The waste total organic carbon content TOC expressed as a percentage of the loss on ignition LOI.

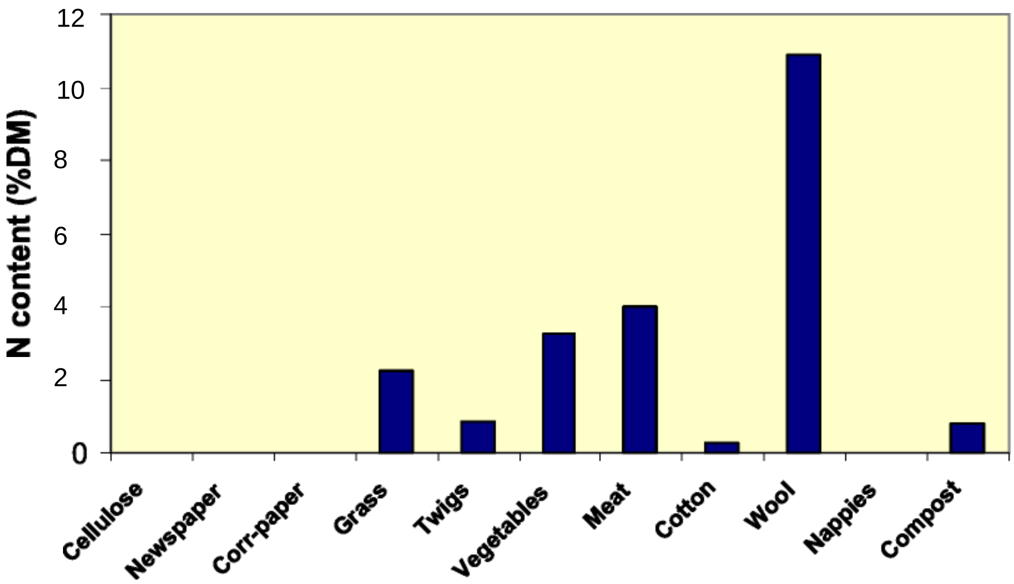

Fig. 2. The waste total nitrogen content expressed as a percentage of the dry matter content

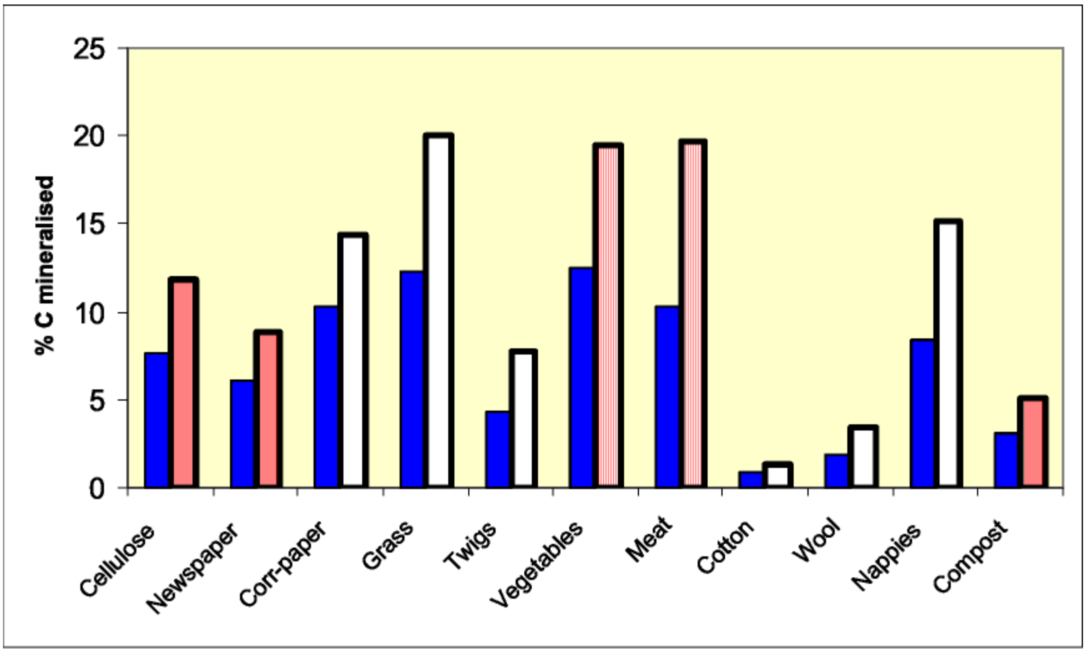

Fig. 3. Percentage waste C mineralized after 4 (dark bars) and 7 (light bars) days in the aerobic DRI test

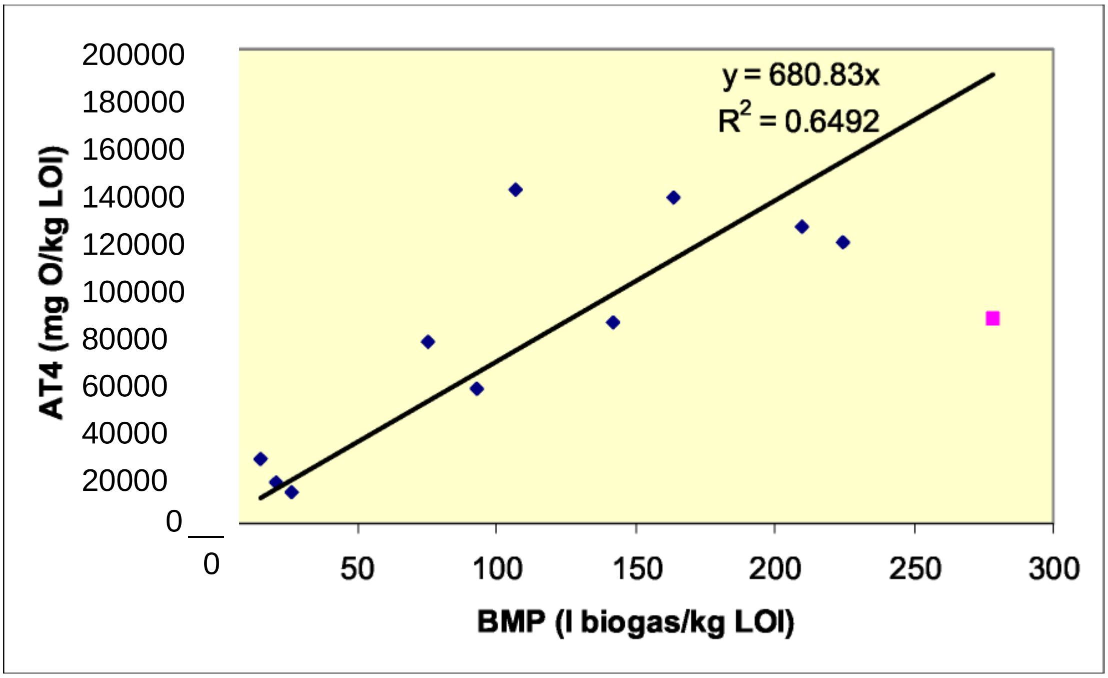

Fig. 4. Correlation between the aerobic DRI test (AT4 value) and the anaerobic BMP test (biogas production). The square point is the data for nappies and is excluded from the correlation (P<0.05).

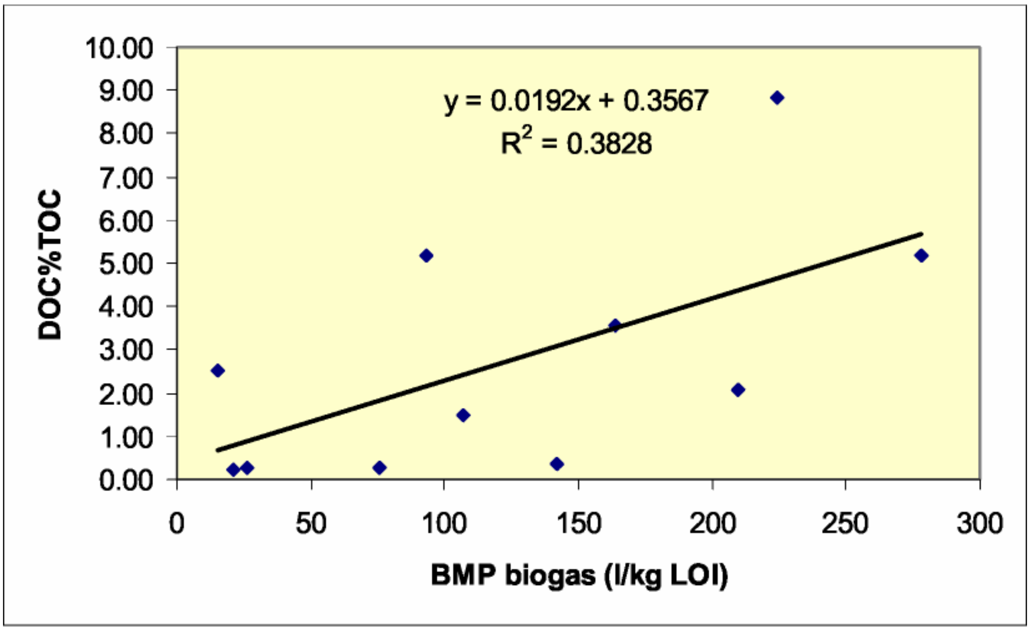

Fig. 5. Correlation between the water extractable DOC as a percentage of the TOC and the biogas production in the BMP test (P<0.05).

Environment Agency review of methods for determining organic waste biodegradability and municipal waste diversion.

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2003-11