Environmental Technology Section

Composting of Fytocell®

Biological degradation of Fytocell® under composting conditions

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Summary

Fytocell is used in horticulture as a soilless culture medium that completely replaces the use of soil in situ in greenhouses. For economical waste management it is important to know whether combined composting of both plant biowaste and Fytocell into a single and reusable product is feasible. Therefore, the main objective of this study was to demonstrate the biodegradation of Fytocell under composting conditions and subsequently to assess the options for re-use.

The biodegradation of Fytocell under composting conditions was studied in the presence of biowaste from tomato plants. The experiments were carried out in aerobic 5 and 20 litre reactors that were operated for 5 weeks at 50 – 55 ^{0}C. In the off-gasses from the reactors oxygen was measured continuously and ammonia was measured discontinuously. Mass balances were made for both organic matter and nitrogen. During the first five days of the incubations a rapid degradation was observed that probably originated from the readily degradable fraction of organic matter in tomato plants. After this, the microbial respiration rate attained to a low basic level. From mass balance calculations on organic matter it was shown that degradation of Fytocell had occurred. For Fytocell 4.4 % biodegradation was found, which according to expectation was much lower than 61.9 % found for biowaste from tomato plants.

After the composting process the mixtures of Fytocell and biowaste from tomato plants are microbiologically stabilized to an odourless product with a yellowish-brown colour in which a small amount of plant fragments is still visible. Reuse of this material as compost complies with the Dutch legal standards in the BOOM decree.

1. Introduction

At the end of a horticultural growing season the crop remains and the substrate on which it has been grown must be somehow disposed of or processed. Further processing is usually limited to the composting of only the plant remains because the widely used substrate mineral wool is not biologically degradable. In comparison, the combined composting of plant-rich horticultural waste with used Fytocell substrate offers an environmental advantage.

1.1 Composting

1.1.1 Definition of composting

In The Practical Handbook of Compost Engineering, (Haug, 1993), practical definitions of the composting process and the end product, compost, are given. In this textbook the composting process is described in terms of aerobic, thermophillic biological reduction and stabilisation of organic matter. Important physical conditions for composting, are . the presence of sufficient water and air for the development of heat so that microbial degradation at thermophilic temperatures above 45°C can occur the thermophillic microbiological degradation The target end product must be biologically stable, both concerning the biological oxygen demand of the remaining organic matter, and the presence or absence of pathogens and seeds.

From a 2001 review article by Day & Shaw comes an overview of the important parameters in the different biological, chemical and physical processes of composting:

- Temperature
- Oxygen concentration
- pH value
- Moisture content
- Carbon/nitrogen ratio (C/N ratio)

1.1.2 Temperature

In general, a higher temperature brings about a higher rate of biological activity. The temperature has a great influence on the rate of composting and determines whether or not a reaction is carried out by specific groups of micro-organisms. There are three distinct temperature intervals: 0-20°C (psychrophile), 20-45°C (mesophile), and 45-70°C (thermophile). By controlling the composting process at temperatures of around 55°C, an optimum temperature is reached at which growth and death of micro-organisms are in balance. With composting processes the optimum temperature is reached within a few days. Actinomycetes are important in the thermophilic phase r; they represent a very diverse bacterial group with a fungal-like growth mode. In general, the amount of bacteria present per gram of compost is one hundred times the amount of fungus present. Above 70°C there is a strong reduction in the biological activity of the micro-organisms involved in composting.

1.1.3 Oxygen

The concentration of oxygen is a determining factor in a biological oxidation process such as composting. The oxygen usage is an indication of the process rate and is determined by the substrate content, temperature, moisture content, and the phase the process is at. There is a direct relationship between temperature and microbial oxygen consumption during the composting process. The highest oxygen consumption is between 30 and 55°C. At the start of the composting process, the need for oxygen is at its highest due to the presence of large amounts of intact organic matter. Too high oxygen concentrations are indicative of too much aeration whereby the compost heap will cool down unnecessarily.Too low concentrations of oxygen will inhibit the activity of aerobic bacteria and fungi.

The oxygen supply can be provided by diffusion, natural ventilation, by turning and mixing of the compost heap, or by forced aeration which is common in intensive composting operations. For complete oxidation of 1 gram of organic matter, 1 to 2 grams of oxygen are required. To prevent anaerobicconditions , the oxygen concentration must be between 5 and 20 vol%, which is equivalent to $1m^3$ of air per hour per ton of organic matter, depending on type and degree of stabilisation.

1.1.4 pH value

Composting of organic material with a pH between 6 and 9 is possible without too many problems. The optimum pH for bacteria is neutral; fungi grow better in a slightly acidic environment. In practice the pH can be adjusted with the content of the ingoing material. At the beginning of the composting process the pH will fall as a result of the transformation of carbohydrates to volatile fatty acids by acid forming bacteria. The pH will rise again when the fatty acids are transformed by other bacteria. In the end the pH reaches an equilibrium, dependending on buffering capacity of organic acids, carbon dioxide (CO_2) and ammonia (NH_3) formed by the micro-organisms.

1.1.5 Moisture content

For microbial activity the presence of sufficient water containing dissolved nutrient salts is essential for the composting process. If the moisture content is too high anaerobic conditions can occur, and as a result the process temperature will be too low or will rise too slowly. If the moisture content is too low there will be insufficient microbial activity. Hence the thermophilic phase will notfunction optimally, this may resultthe formation of biologically instable end products if the compost heap dries out. Changing the moisture content of the compost heap is possible by the addition of water during the turning of the compost heap. The optimum moisture content of 60-65% is determined by the structure and the amount of organic matter of the raw material. It can be influenced by drying and by the addition of dry organic bulk material.

1.1.6 Carbon-nitrogen ratio

Micro-organisms need carbon (C) and nitrogen (N) in a certain ratio for their elementary growth and energy needs. In general, a growth medium with a C/N ratio of 8-12 (in w/w) is sufficient for micro-organisms. For a good composting process a ratio of available carbon to available nitrogen varies from 20 to 35; literature is not conclusiveon this subject. Lower C/N ratios can cause ammonia emissions, possibly increased by higher process temperatures, rising pH levels and intensive aeration. An overly low C/N ratio can be corrected by addition of organic matter with a high C-value, for example straw, corn stalks and wood chips. With C/N ratios greater than 35, the excess of carbon inhibits the composting process due to limitations of nitrogen available for microbial growth.

1.2 Soilless culture

1.2.1 Mineral wool

In the last decennia many materials have been experimented with to try to replace the primary function of soil in horticulture: plantsupport and the holding of air and water with dissolved nutrients. Mineral wool, because of its' inertness and water buffering capabilities, is widely used as a soil-replacement substrate in horticulture. A disadvantage of this development is that a nationwide waste problem has arisen because the opportunities for re-use of the inorganic mineral wool are limited.

1.2.2 Fytocell

The product name Fytocell® stands for an aminoplast foam developed and produced according to a specific recipe by Verheijen Resins bv, (Boven-Leeuwen, NL). Originally aminoplast foams are organic synthetic polymers that have been used in agriculture for physical soil improvement for over 50 years(Baumann, 1967, 1991). An important characteristic of these foams is the presence of curved surfaces and narrow channels. Nearcurved surfaces the pressure (p) is not equal on both sides: p on the concave side is greater than p on the convex side. The difference (Δp) is called capillary pressure, which allows liquid flow from high to low pressure (Koopal and De Keizer, 1999). Through the presence of narrow channels in the aminoplast foam, capillar flow continues until the hydrostatic pressure equals the capillary pressure.

A second important property of aminoplast foams is the presence of an open cell structure characterized by a spatial system of interconnected hollow spheres. Fytocell combines these two physical properties with a low specific weight and good stability. Through having a favourable water-air capacity it is possible for the entire foam mass to be homogeneously penetrable for roots(Ekto, 1995). Figure 1 is a scanning electron microscopy image showing the characteristically open cell structure of Fytocell with a root of a tomato plant growing through it.

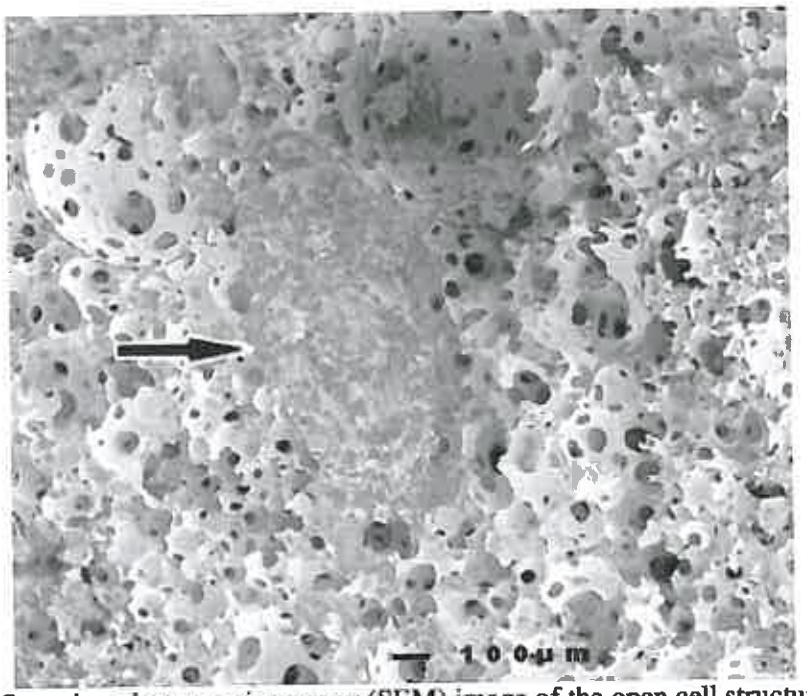

Figure 1. Scanning electron microscopy (SEM) image of the open cell structure of Fytocell. This material was used for soilless culture and shows a cross-section of a tomato plant root in the centre. The reference bar corresponds to 100 micrometers.

1.3 Project aims

With Fytocell an important step has been made from the use of aminoplast foams as physical soil improvers in agriculture to a total soil replacement in horticulture. To allow the Fytocell user to dispose of both plant waste and substrate as economically as possible, it is important to know whether composting to a single and potentially re-usable end product isfeasible. The most important aim of this investigation was to demonstrate the microbiological degradation of Fytocell in combination with tomato waste under aerobic thermophilic composting conditions on a small scale in the laboratory. The second aim was to assess the possible re-use of the processed material.

2. Materials and Methods

2.1 Reactors

2.1.1 Composting conditions

Duplicate series of experiments with Fytocell and tomato waste were conducted in two 5 litre reactors and two 20 litre reactors. The reactors were placed in a thermostatic bath which was set to 50-55°C as shown in Figure 2.

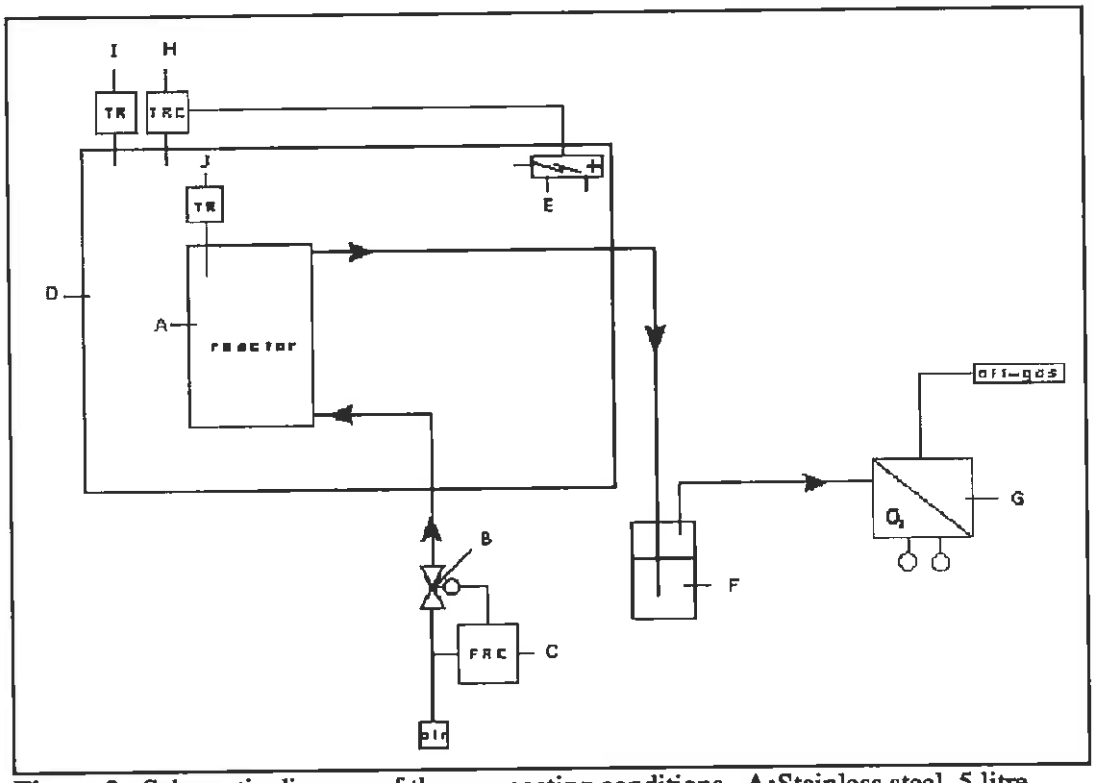

Figure 2. Schematic diagram of the composting conditions. **A:**Stainless steel 5 litre reactor (R1+R2) or 20 litre reactor (R3+R4). **B:** Mass flow controller (MFC) Brooks, 5850S flow range 0-30nL*/min (R1+R2) 0-300nL/min (R3+R4). **C:** Flow recording controller (FRC) readout unit for MFC, Brooks 0154. **D:** Stainless steel water bath. **E:** Haake hanging thermostat D1. **F:** Gas scrubber bottle for ammonia absorption. **G:** Oxygen meter. **H:** Temperature recording controller (TRC) temperature regulator for the Haake hanging thermostat. **I:** Temperature recording (TR) temperature measurer of water bath, thermocouple type T. **J:** Temperature measurer of the reactor, thermocouple type T.
(nL*): normal Litre, standardised gas volume at 0°C and 1 atm.

The oxygen meters and thermocouples shown in Figure 2 were connected via signal conditioning blocks type 5B (Analog Devices) and Data Acquisition Card RTI820 (Analog Devices) to the computer (HP-Vectra QS). The data measurements were logged using a Control EG v3.58 (Quinn-Curtis).

2.1.2 Oxygen usage

On the basis of the oxygen usage and the amount of organic matter in the reactor, the respiration rate (R) in mmol O_2 per kg organic matter per hour can be calculated according to the equation:

$$R = \frac{F_{gas} \cdot (O_{2,in} - O_{2,out}) \cdot 0.2095 \cdot 0.0446}{W \cdot DS \cdot OS}$$

In which F_{gas} is the gas flux through the reactor, $O_{2,in}$ and $O_{2,out}$ the ingoing and outgoing oxygen concentration (% of ambient air), 0.2095 the fraction of O_2 in the ambient air, 0.0446 the number of moles of O_2 per litre of air, W the weight of the substrate, DS the dry matter content, and OS the organic matter content.

2.2 Raw materials

2.2.1 Preparation of composting samples

Fytocell substrate slabs with tomato plants grown on them(Aromata, 4 plants per slab)were separated by cutting the tomato plant stems just above the substrate surface. The Fytocell slabs were broken up by hand. Tomatoes were removed from the plants and subsequently the plants were shredded to give tomato waste.

2.2.2 Contents of the composting reactor

The broken up Fytocell slabs and the tomato waste were mixed together in the two ratios shown in Table 1. The following fresh weight materials were added tothe 5 litre reactors: 0.75kg tomato waste and 1.62kg Fytocell (R1); 0.39kg tomato waste and 1.61kg Fytocell (R2). In the 20 litre reactors the added fresh weight materials were: : 2.36kg tomato waste and 5.15kg Fytocell (R3), 1.21kg tomato waste and 4.98kg Fytocell (R4).

2.3 Analyses

2.3.1 Dry matter and organic matter

The dry matter and organic matter contents were determined according to the NEN 5747 guidelines,measured after 24 hours of drying at 105°C and 550°C, respectively.

2.3.2 Ammonia

The emission of ammonia from the reactors was collected 8 times during the entire incubation period by absorption in a gas scrubber bottle filled with 1 N sulphuric acid, and determined by the LCK 303 photometric Lange cuvette test.

2.3.3 Oxygen

The continuous measurement of the oxygen percentage in the ingoing and outgoing airstream was done with a WTW Oxi219 oxygen meter equipped with an Oxi91 oxygen

sensor.

2.3.4 Nitrogen

The determination of total nitrogen, ammonium-nitrogen and nitrate-nitrogen of the broken up Fytocell slabs, the tomato waste and the content of the composting reactors was carried out by the IMAG Environmental Laboratory in Wageningen UR, NL (Appendix 1). The sampled material was stored at 4°C until further use.

2.3.5 Heavy metals

The determination of the heavy metal content was carried out by Blgg-Oosterbeek, NL for an unused Fytocell slab and a mixture from reactors 2 and 4 sampled at the end of the incubations (Appendix 2).

3. Results

3.1 Mass reactor content

Fytocell and tomato waste in two ratios were incubator in 5 litre and 20 litre reactors under thermophillic aerobic conditions for 5 weeks. Table 1 shows the amounts of the raw materials added to the reactors and the weight of the reactor content after incubation.

Table 1. Fresh weights of the amount of Fytocell and tomato waste used and the end weight after incubation.

Reactor	Volume (L)	Tomato waste (kg)	Fytocell (kg)	Total before (kg)	Total after (kg)
1	5	0.75	1.62	2.37	1.62
2	5	0.39	1.61	2.00	1.41
3	20	2.36	5.15	7.51	4.92
4	20	1.21	4.98	6.19	3.72

The different mass ratios of Fytocell and tomato waste in the reactors expressed as total weight, dry matter and organic matter are shown in Table 2.

Table 2. Ingoing mass ratios of Fytocell and tomato waste per reactor as total waste, dry matter and organic matter.

	Mass ratios of Fytocell - tomato waste on the basis of

Reactor	Volume (L)	Total weight	Dry matter	Organic matter
1	5	2.2	1.5	1.7
2	5	4.1	2.8	3.3
3	20	2.2	1.5	1.8
4	20	4.1	2.8	3.3

3.2 Continuous oxygen and temperature measurements

The temperature of the incubation for each reactor is shown in Figure 3. The temperature of all reactors was maintained at a thermophillic level of 50-55oC. The small temperature differences between the reactors do not give a different degradation rate and on the basis of temperature the results are directly comparable.

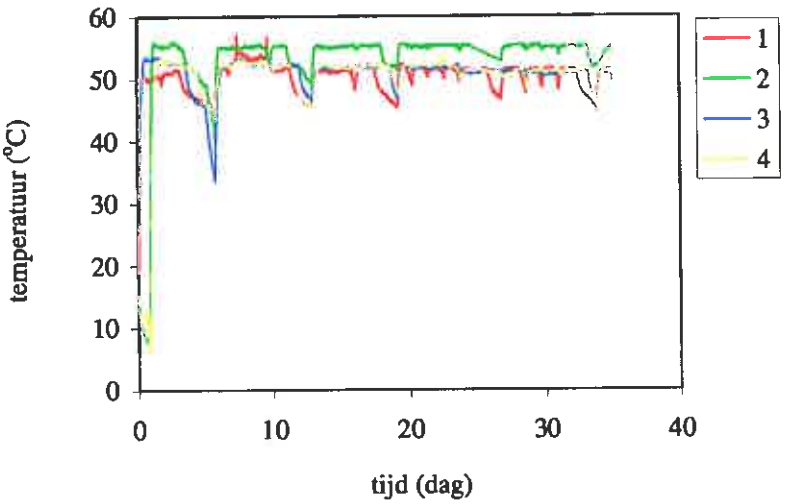

Figure 3. The incubation temperature per reactor as a function of time.

The oxygen level in the outgoing air from the reactors is shown in Figure 4 (100% is comparable with the oxygen concentration in the atmosphere, 20.95 Vol%). The oxygen content in all of the reactors is set at the same level during incubation. In the first phase of incubation the oxygen level is lower because the rate of degradation in that period is highest. The oxygen level in the outgoing air shows that aerobic conditions are present in the reactors. After three weeks the registration of oxygen usage is stopped. The percentage of oxygen in the outgoing airstream from the reactors, as shown in Figure 4, is constant after this time. Changes fall within the accuracy limit of 0.5% and can not be measured accurately.

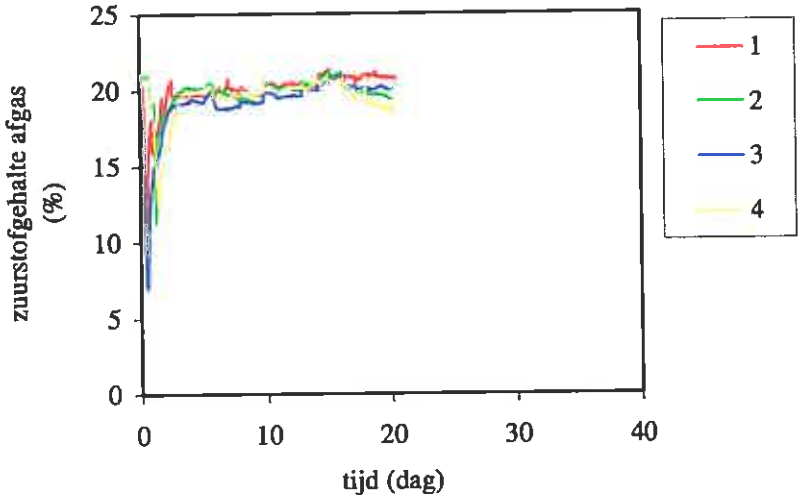

Figure 4. The oxygen concentration in the outgoing gas of the reactors as a function of time.

On the basis of the oxygen consumption and the amount of organic matter in the reactor, the respiration rate can be calculated in mmolO_2 per kg organic matter (OS) per hour.

Figure 5 shows that the respiration rates of the four reactors are of a comparable order of magnitude. During the first few days of the aerobicthermophilic incubation there is an increased oxygen demanddue to the degradation of readily degradable organic matter. This is probably caused by the readily degradable fraction of tomato waste; Fytocell does not have such a fraction. Figure 5 shows that there is no difference between the two mixing ratios of Fytocell and tomato waste. A double quantity of tomato waste in the reactors does not show a measurable influence on the respiration rate. After this relatively fast oxidation of the mixtures of Fytocell and tomato waste, the microbial respiration rate after 5 days reached a stable base level of 10-20 mmol O_2/kg OS/hour. The respiration rate after 3 weeks is not shown because the outgoing oxygen concentration lies around a constant 100%. In th case the respiration rate falls within the accuracy limit of 0.5% and can therefore no longer be calculated accurately.

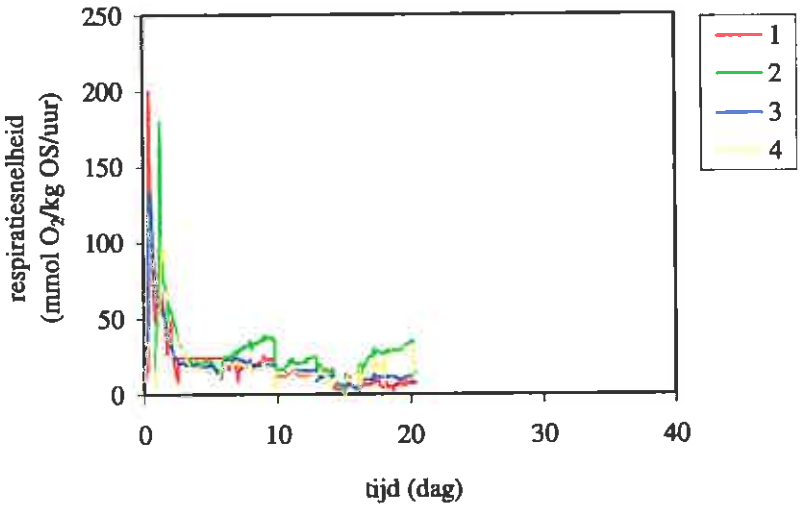

Figure 5. The respiration rate per reactor as a function of time.

The total respiration of organic matter in mol O_2 is shown in figure 6. The total respiration of the two mixtures of Fytocell and tomato waste are equal. The total respiration is no longer shown after 3 weeks because the outgoing oxygen concentration from the reactors is around a constant value of 100%. For that reason the total respiration can no longer be accurately calculated.

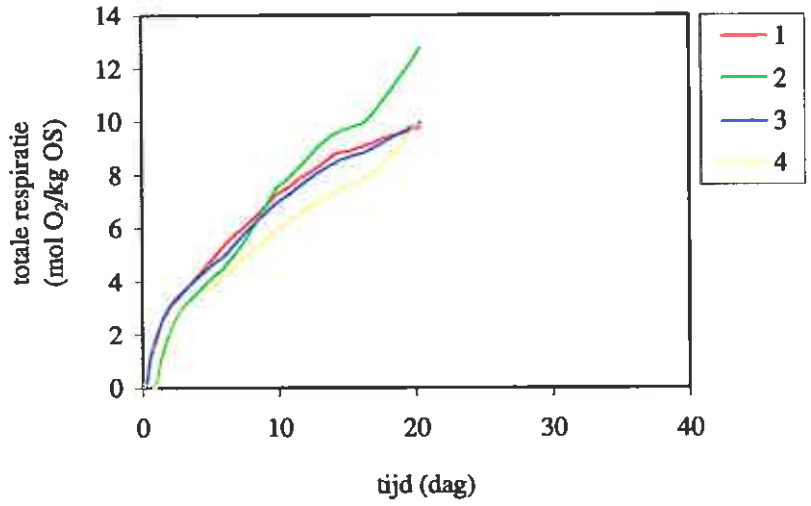

Figure 6. The total respiration per reactor as a function of time.

3.3 Analyses of organic matter and nitrogen

Table 3 shows the composition on the basis of dry matter, organic matter and nitrogen of: (1) Fytocell and tomato waste separately, and (2) the content of the four reactors at the start and end of the incubation. The composition of Fytocell and tomato waste together with the content of the reactors was analysed after the incubation. The composition of the ingoing material to the reactors was calculated according to the ratios of the two mixtures used.

Table 3. The composition on the basis of dry matter (DM), organic matter (OM) and nitrogen (N) of Fytocell and tomato waste shown separately and per reactor mixture (R) at the start and end of the incubation.

	DS (g/kg)	OS (g/kg DS)	Total-N (g/kg DS)	C/N*	NH4-N (g/kg DS)	NO3-N (g/kg DS)	pH
Tomato waste	97	757	20.1	19	<0.5	13.8	5.3
Fytocell	67	893	271.4	1.7	<0.5	11.7	6.7
Start of incubation							
R1	76	838	170.1	2.5	<0.5	12.6	-
R2	73	858	205.8	2.1	<0.5	12.6	-
R3	76	839	170.7	2.5	<0.5	12.6	-
R4	73	858	205.7	2.1	<0.5	12.6	-
End of incubation							
R1	85	823	219.6	1.9	1.15	-	-
R2	110	861	238.2	1.8	0.84	-	-
R3	89	822	203.6	2.0	0.99	-	-
R4	110	856	218.7	1.9	0.81	-	-

(-): not determined
(*): with the C/N ratio it is assumed that 50% of organic matter comprises carbon (C)

The water content of Fytocell (93%) is higher than that of the tomato waste (90%). The mixture in the reactors at the start of the incubation has an average moisture content (92%) higher than what is considered optimal for composting (60-65%). The combined pH of Fytocell and tomato waste in the ingoing material was favourable for composting, and at the end of the incubation was measured at 7.2 (Appendix 2). Nitrate was not determined at the end of the incubation because nitrification and denitrification do not occur under aerobic thermophilic conditions.
Table 3 shows that through calculation Fytocell has a higher organic matter content (89%) than tomato waste (76%). The very low C/N ratio of both Fytocell and the reactor mixtures is remarkable, as is the very low development of ammonia. The carbon/nitrogen values show that the C/N ratio of Fytocell (1.7) is much lower than that of tomato waste (19). The C/N ratios of both mixtures at the start of the incubation were

respectively 2.1 and 2.5. By the end of the experiment the C/N ratios of the two mixtures have fallen to 1.9 and 2.0.

The decrease of the C/N values is connected with the breakdown of organic matter and can be calculated in two ways:

- Oxygen usage;
- Decrease in absolute amount of organic matter.

Since the oxygen concentration intheoff gas is around 100% after 5 days, the oxygen consumption cannot be calculated accurately because the oxygen probe has an error margin of 1-3%. Therefore this method cannot be used for the calculating theorganic matter degradation.

On the basis of the decrease in the absolute amount of organic matter (OM) the following calculation is used:

$$Degradation\ OM = \frac{W_{start} \cdot DM_{start} \cdot OM_{start} - W_{end} \cdot DM_{end} \cdot OM_{end}}{W_{start} \cdot DM_{start} \cdot OM_{start}} \cdot 100 \text{ (in \%)}$$

In which W stands for fresh weight of the substrate, and DM and OM stand for the amount of dry matter and organic matter, respectively. The degradation of organic matter in the four reactors, calculated using the equation above, is shown in Table 4.

Table 4. Total breakdown of organic matter in the mixtures of Fytocell and tomato waste.

Reactor	Volume (L)	Mass ratio of organic matter	Degradationas percentage of total organic matter
1	5	1.7	26
2	5	2.8	-8
3	20	1.3	25
4	20	2.8	18

Table 4 shows good duplication for reactors 1 and 3, however for reactor 2 the value is unrealistic and is therefore not considered any further. The organic matter degradation in reactor 4 was less than that in reactors 1 and 3. With an increased Fytocell concentration there is a reduction in the degradation of organic matter which, as expected, points towards the degradation of tomato waste being faster. It is true that although Table 4 shows that relatively more tomato waste gives a higher degradationof organic matter, this does not result in a measurable increase in the respiration rate in the reactor (Figure 5).

The ammonia emission per reactor as shown in Figure 7, and the nitrogen balance in Table 5 do not show a conclusive result.

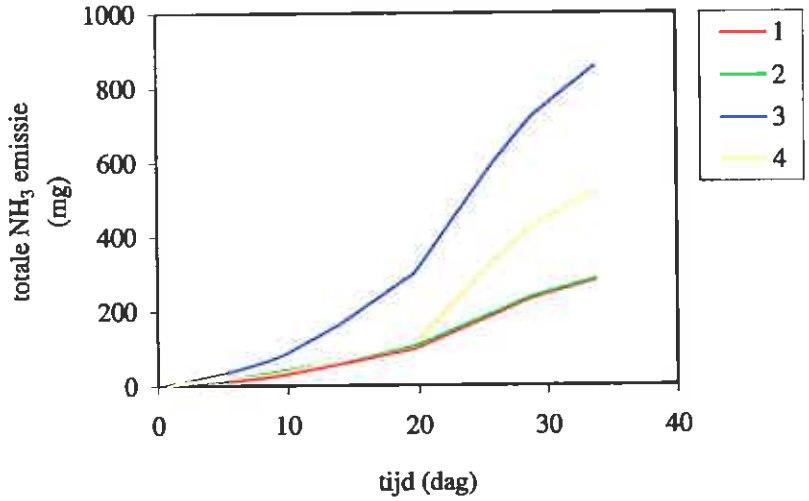

Figure 7. The ammonia emission per reactor as a function of time.

The ammonia emission as a function (Figure 7) does not show any difference between the mass ratios in the reactors. A nitrogen balance as shown in Table 5 cannot be made for the incubations . There is too much difference between reactors 1 and 3, and reactor 2 is not representative. Therefore a valid calculation of microbial degradation of Fytocell on the basis of nitrogen data is not possible.

Table 5. Nitrogen balance per reactor for the mixtures of Fytocell and tomato waste before and after incubation.

Reactor	Start (g)	End (g)	Emission (g)	Difference in N mass balance (g)	Difference in N mass balance (%)
1	30.8	30.1	0.28	0.7	1.3
2	29.9	37.1	0.29	-7.2	-24.9
3	97.8	89.5	0.86	8.4	7.7
4	92.5	81.1	0.52	11.4	11.8

When the assumption is made that (1) the total degradation is the sum of the combined degradation of Fytocell and tomato waste, and that (2) the degradation of the separate components in all the reactors is equal, then the degradationof every component can be calculated using the following equation:

$$OM - \deg radation_{TOTAL} = OM_{FYTOCELL} \cdot OM - \deg radation_{FYTOCELL} + OM_{tomatoes} \cdot OM - \deg radation_{tomatoes}$$

The total organic matter degradation was determined (Table 4) , furthermore the fraction of organic matter of every component is known. The degradation of organic matter from every component can be subsequently be calculated using the smallest-square method with the Solver in MS Excel. These calculations when carried out on the reactors 1, 3 and 4 give the percentages of degradation for Fytocell and tomato waste based on the organic matter (Table 6)

Table 6. ercentage of degradation for Fytocell and tomato waste based on organic matter.

	Percentage based on organic matter
Breakdown of Fytocell	4.4%
Breakdown of tomato waste	61.9%

Table 6 shows that based on organic matter, degradation of Fytocell does occur under aerobic thermophilic conditions.

4. Discussion

The most important aim of this research was to show that there is microbial degradation of Fytocell combined with tomato waste under aerobic thermophilic conditions. To accomplish this a continuous measurement of oxygen and mass balances of nitrogen and organic matter were used . The second aim was to assess the potential for re-use of the composted material.

4.1 Microbial degradation of Fytocell

Calculations using the mass balances shown in Table 6 show that degradation of Fytocell has occurred. The 4.4% degradation of Fytocell was, as expected, lower than the readily degraded biopolymers of tomato waste (61.9%). This percentage was found under controlled aerobic conditions after 5 weeks of incubation at 50-55°C. Given an average soil temperature in The Netherlands of 10-11°C, the following extrapolation with the Q_{10}-value for enzymatic reactions can be made. Enzymatic reactions are limited to a temperature range. Generally, their reaction rates doubles in response to a 10°C temperature increase (Haug, 1993). Consequently, when the Q_{10} is given a value of 2 the rate of enzymatic reactions increases by a factor of 8 as temperature from increases from 10 to 50°C. This means that for the biodegradation of Fytocell under Dutch field circumstances, the estimated yearly breakdown is 5.7%.

Microbiological degradation of aminoplasts(NB not as foams) was originally published in Nature (Corke and Robinson, 1966). To date it is unclear in the literature which micro-organisms or via which metabolic pathway the process of biodegradation is carried out. Aminoplasts have been used in practice for decennia as slow-release nitrogen fertilizers in soils (Alexander, 1990). An important advantage compared to urea, is that through the relatively slow aminoplast degradation the plant availability of nitrogen is better, but also the risk of evaporation of ammonia and nitrate leaching to the groundwater is less. With the application of aminoplasts no known negative effects on the natural degradation processes in the soil have been reported (Aarnio et al., 1996).

Aminoplast foams are heterogeneous three-dimensional by nature which is probably why they are not initially degraded by hydrolytic enzymes as is the case with for example cellulose. Analogous to the degradation of irregularly formed lignin (Kirk and Farrell, 1987), it is conceivable that the degradation of Fytocell also dependent on the presence of readily degradable co-substrate, and the concurrent production of hydrogen peroxide by the enzyme peroxidase. At the start of the incubation a lot of readily degradable tomato waste is present, Proportionally to this the degradation of Fytocell can proceed relatively quickly. From previous experiments carried out with a respirometer, (model Oxitop), at the Environmental Technology Section no degradation of Fytocell could be demonstrated. In these initial experiments there was no extra carbon source available.

4.2 Re-use of Fytocell

After 5 weeks of incubation the mixtures of Fytocell and tomato waste are microbiologically stablelised odourless products with a humus-like yellow-brown colour, in which a limited amount of plant-like fragments are still visible. With the re-use of this product as compost, it is important to comply with the definition of compost given in the BOOM decree: Regulations on quality and re-use of other organic fertilisers (Sdu, 1991). The definition used in the BOOM, (version valid from 01-01-2002), describes compost as a product that entirely or mainly consists of one or more organic waste compounds degraded by micro-organisms and transformed to a stable end product characterized by slow degrading humic compounds Fytocell is to be considered as an organic waste in this sense. Moreover, its content of organic matter is even greater than tomato waste (Table 3). The end product of the incubation of Fytocell and tomato waste is stable as the oxygen consumption rate as a function of time clearly shows in Figure 5. However, the exclusive role of slow degrading humic compounds is less clear. Although humic compounds are highly complex in nature they merit further description here. According to Table 6 the organic material from tomato waste is degraded for 61.9%. The biopolymers lignin, polysaccaride and protein present in tomato waste will be microbiologically transformed into carbon dioxide, water, biomass and humus. In this process lignin will be partly degraded by thermophile bacteria. Lignin has a complex, irregular chemical structure and therefore it is difficult todegrade (exclusively aerobically). Lignin is considered to be single most important precursor of humus. During this degradation process - but certainly also in the post-thermophilic stage of composting - reactive fragments of lignin can react with plant derived products and

repolymerise in an irregular way. (Schlegel, 1993). This humification process is important for both composting and degradation processes naturally occurring in soils. It results in the characteristic yellow-brownish to brownish colored humic compounds often termed humus.. Humus is a complex mixture of different organic compounds of which humic acids and polysaccharides are important constituents.. From a view point of both adsorption and ion exchange as well as nitrogen fertilising andstructural properties (e.g. water binding), humus is an indispensable soil constituent (Stevenson, 1994). Accordingly humic compounds as defined in the BOOM are of considerable importance in the further use of compost.. Moreover, slowly degrading humic compounds could even function as co-substrates and thus promote the biodegradation of Fytocell

The mixture of Fytocell and tomato waste that remains after treatment under aerobic thermophilic conditions matches with the definition of compost in the BOOM . The subsequent use as soil conditioner or fertiliser demands compliance with quality requirements on organic matter and heavy metals (BOOM Appendix II respectively III). The legal standards for heavy metals are in practice no obstacle for re-use of compost containing organic waste from domestic origin. This also holds for compost originating from Fytocell combined with tomato waste. The organic matter concentrationof this combination was 80% presented in Table 3 fairly well exceeds the legal criterium of 20% (on dry matter basis) for compost.

Heavy metal analysis (Appendix 2) shows a remarkably high zinc concentration (135mg per kg dry matter) in the treated sample of Fytocell and tomato waste.. However, the relatively high background levels in plant waste (45 ± 35 mg zinc per kg dry waste) and degradation of organic matter in tomato waste(61,9%) may result in a concentration effect of zinc(Veeken en Hamelers, 2002). In comparison, a sample of unused Fytocell only contains 6mg zinc per kg dry matter. All heavy metals concentrations found in this study however are all within the range defined for compost in BOOM.

5. Conclusions and recommendations

The most important conclusions from the results of this research are as follows:

- Microbiological degradation of Fytocell wasfound under aerobic thermophilic composting conditions in the presence of tomato waste;
- Literature research has not provided any enzymatic mechanism responsible for the microbial degradation of Fytocell and related aminoplasts;
- Re-use as compost of the treated combination of Fytocell and tomato waste complies with the prevailing legal framework of the BOOM;

From the present research the following recommendations can be made:

- In a future full scale study the energy content of Fytocell combined tomato waste must be sufficient to ensure biological stabilisation under aerobic thermophilic composting conditions;
- Pressing out water from Fytocell, addition of extra readily degradable organic matter and the presence of a good structure of the incubation mixture are important practical points for full scale composting;
- Given the good structure of the composted mixture of Fytocell and plant waste, it remains to a similar follow-up research to show whether its physical soil stability is comparable to that of related aminoplast foams;

The prediction of Fytocell degradation and other aminoplasts under field conditions requires more fundamental knowledge of the microbial processes involved.

6. LITERATURE

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Appendix 1 Nitrogen analysis

Appendix 2 Heavy metals analysis