Results and discussion

This work represents a development from scientific reductionism to studies on system-level complexities. Paper I and II describe empirical experiments on cultivation and on composting, respectively. Paper III and IV contain synthesis of plant nutrients recirculation based on analysis of experiments in Papers I and II and on literature studies, focusing on needs which appear in ecologically sound cultivation systems and in future organic waste management. The results give an advance to holistic approach, leading to sustainable development of systems for solid and liquid organic waste management as well as sustainable development in cultivation systems. The four themes show a brief presentation of 'closing the loop' from plant nutrients in composts through cultivated crops to organic waste and through controlled microbial transformation back to plant nutrients in biofertilisers.

Cultivation

In Paper I, a study of the response of five horticultural test crops to compost from cs and ss MSW is described. In the cultivation media made of peat with cs composts, both fresh and dry weight of the tested crops were lowest compared with yields of the crops grown in peat amended with ss compost, in the seven peat-based commercial horticultural cultivation media, and in peat. Some variation in crop response was observed already during germination and emergence. Seeds of garden cress, ryegrass and African marigold were less inhibited by cs compost, while seeds of lettuce and radish were severely delayed, compared with those germinated in commercial media and in media amended with ss composts. The liquid fertiliser Superba S caused more striking increase in yield when added to peat-compost media than when added to peat or commercial peat-based media.

The susceptibility of crops to cs and ss composts affected the yield. With increased amount of compost in the media the yield of garden cress increased and was highest in 40% mixture. Ryegrass showed opposite tendencies, the highest yield was obtained in 10% mixture. The yield of radish leaves and lettuce was highest in 20% mixture, while the yield of African marigold and radish roots was highest in 30% mixture.

When the amount of compost added to peat was similar the addition of ss composts gave higher yield than cs composts for all the five cultivated crops. This tendency indicates that composts from ss raw material are to prefer. The ss composts were of better quality than cs composts, in spite of mismanagement of the raw material,

which was caused (a) by the long collection time of the organic waste (food residues were already rotten before start of composting process), (b) by the lack of bulking agent (the rotten wet materials were composted without dry additives), and (c) by the composting process which was carried out on open windrows. The procedures during composting were adjusted to the centrally sorted waste and not to the source separated one. It is obvious that the separated organic waste was not processed at optimal conditions needed for product-oriented composting. In spite of that the results of cultivation experiment indicate that there is a great potential hidden in properly made composts. Therefore it was concluded that it is necessary to increase precision in organic waste management if we want to use composts in cultivation systems.

The used composting methods were expensive and the main goal was to treat cs and ss MSW primarily for volume reduction. The production costs were in this case about 60 US$ per ton compost, calculated in present value. The quality of both tested composts was poor. After addition of the liquid fertiliser Superba S, the growth of the tested crops increased in both composts, probably mostly due to addition of nitrogen, which was lost during the composting process.

It is extremely difficult, if not impossible, to sell compost of low quality for cultivation purposes. At present time in Germany there is an overproduction of composts made from MSW, mainly because high amounts of heavy metals make them unattractive (Almström, 1996). A technology for disposal of organic waste materials should be changed towards a technology for its reuse. la Rivière (1977) suggested improving the existing methods, as well as their change into more profitable waste utilisation.

Finck (1982) stated that fertility is the capacity of the soil to provide plant yields, soil productivity or yield potential and that fertilisation which can no longer be routinely undertaken according to simple rules, must be carried out according to extended and improved concepts, as overall production conditions change. He pointed out that even small errors in fertilisation such as deficiency or imbalance of nutrient supply, can considerably reduce the yield and primarily the net profit when production costs are high. Finck (1982) also observed that a high rate of fertiliser application per unit area by itself does not ensure an optimum nutrient supply. Therefore the purpose of using biofertilisers should be to obtain high yields and crops of high quality. By improving the application methods for supply of nutrient elements and energy-rich compounds, the fertility of the soil will maintain or can be improved without harmful effects on the environment.

Biofertilisers adjusted to cultivated crops will, in extension, also support beneficial microorganisms in the root environment and thus improve biological control of plant pathogens. Decreased use of synthetic agrochemicals can possibly increase food quality and improve human health.

Lynch (1983) proposed more intensive studies of the physiology of rhizosphere organisms which will bring scientific and commercial credibility to the integration of the agro-bio-chemical industry in the future. Effects of biofertilisers (i.e. composts of high quality) will hopefully play a central role in maintaining or improving the productivity of soils.

Increased crop production and conservation of natural resources can be achieved with cultivation systems which are both efficient and sustainable. The efficiency can be reached by improvements of technology and by development of novel methods. They have to be compared with old ones and evaluated in terms of utilisation of energy and plant nutrients as well as the impact on the environment and economy.

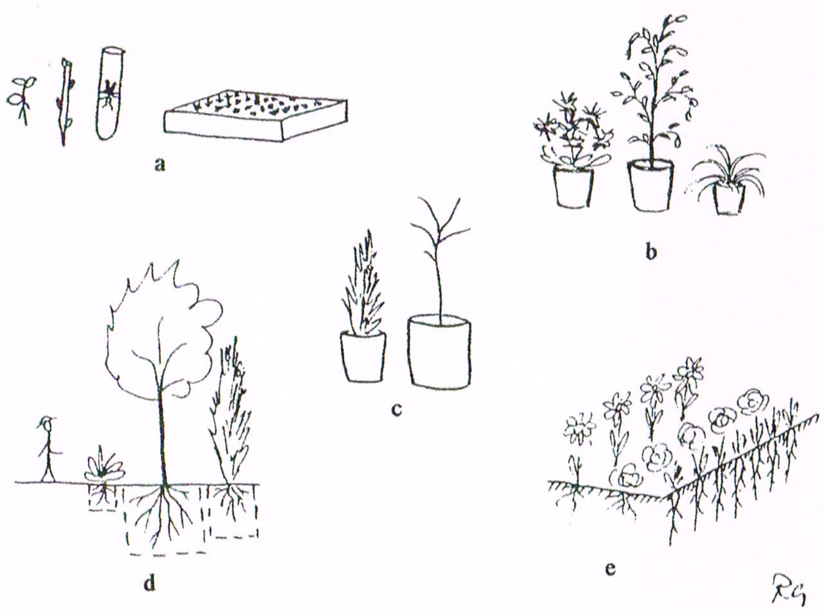

Figure 7. Quality of biofertilisers have to be adjusted to demands of various horticultural crops and the stage of development. a - propagation, b - pot plants, c - nursery plants, d - trees and bushes, e - vegetables.

Composting

In Paper II an investigation of possibilities for product-oriented composting with focus on development of methods and techniques was presented. The composting experiments, which were carried out in bioreactors in a laboratory, differ from other by use of simple equipment and methods which at the same time included following criteria: well disintegrated reproducible standard substrate made of ecologically grown fresh vegetables mixed with straw and sawdust; the standard substrate and its constituents were analysed on total content of 19 elements before the start of processing; different additives were used for studies of their effects on the process; well insulated vessels with forced aeration were used first as static, later as sequentially rotated bioreactors; temperature development was registered 10 times per hour; pH was measured daily during the first week of processing; two weeks retention time was practised; mass reduction was registered; and content of readily available plant nutrients was analysed at the termination of the runs.

Composting, i.e. aerobic bioconversion or microbial transformation, was studied in experiments dealing with investigations of the effects of (a) standard substrate with and without additives, (b) its particle size (disintegration), (c) water content, (d) thermal insulation of bioreactors, (e) aeration, and (f) agitation during the process on following factors: temperature development, changes in pH, mass flow and analyses of readily available plant nutrients, which were registered and evaluated.

There is still a need to investigate what is the optimal particle size for various raw materials. The fact that microorganisms act mostly on the surface of particles, in a thin water-bio-film, is especially important when some of the raw materials are more resistant to microbial decomposition. These are often used as various dry bulking materials (straw, sawdust, bark, paper, etc.). When well disintegrated raw material is used a higher amount of substrate can be processed. Also a better control of the process can be practised and thus retention time will decrease. At the same time uniform and safe products of refined quality (where pathogens and seeds are inactivated) can be obtained. The economics of the bioconversion will probably benefit greatly.

The efficiency of bioconversion of a specific substrate depends on particle size in combination with suitable water content, nutritional balance, aeration and agitation. The structure of standard substrate used in presented experiments harmonised with water content of about 70%. For substrates composed of other raw materials the optimal water content may differ. The optimal water content should be determined for various substrates in combination with aeration and agitation. In some cases "balls" of various sizes can be built in the treated substrate. Inside them processes of the transformation are not the same as at their surface or in the remaining substrate. When balls appear the homogeneity and quality of the final product will probably be lowered.

The nutrient content of the standard substrate was suitable for the conducted experiments, but not yet for cultivation. Unfortunately, most of the cultivation experiments that were carried out on final products (not published) were less successful. There is a great need to increase the level of composting technology and this was beyond our resources. Without improvements in technology it is neither possible to achieve high precision in processing nor produce biofertilisers of desired quality. By these experiments on composting, only little progress towards better understanding of the complexity of the whole system was made.

The importance of thermal insulation of bioreactors became obvious when temperature curves from simultaneously running well and less well insulated, bioreactors were shown. There is no doubt that thermal insulation of bioreactors (or other vessels) is unavoidable for achieving high temperature in the whole substrate, which is necessary for inactivation of pathogens and seeds. Therefore standard substrate was treated in well insulated, rotated and aerated bioreactors.

The final product which was produced during the relatively short retention time (mostly two weeks) can be called 'raw compost' or 'biofertiliser for special purposes'. For example (1) for fertilising well rooted plants (Gajdos, 1987), (2) for mixing into soil where container grown well rooted plants will be replanted or (3) for mulching of well rooted plants (ornamental and fruit trees, bushes, roses, fuel plants, etc.). In mulching it can be effective against weed seeds, plant pathogens, and also against drying of the soil surface. The soluble nutrients and humic substances from raw compost can enter the soil during rain or irrigation, improve its properties, activate soil microorganisms, and thus positively stimulate plant roots.

When the active phase of the composting process terminates (i.e. when temperature declines but water content is nearly the same as at the start of processing), bioreactors should be emptied and the next important phase, active post-processing, should start in closed equipment. The most active phase of aerobic bioconversion can terminate after six to ten days (Paper II), depending on chemical and physical characteristics of substrate and on composting method used. The 'raw compost' has to be improved (upgraded) to biofertilisers which will fit cultivation demands better than current composts do. Post-processing includes either only packaging or blending for achieving more stabilised product (to minimise losses of nitrogen and further decomposition before entering rooting media) before packaging and several storage methods. As the bioconversion will be carried out

even during winter time, most of the biofertilisers have to be stored and therefore various alternative methods of preserving the quality should be tested, such as storing in cold environment, blending with dry materials and/or materials with low pH. To avoid nitrogen losses as ammonia, peat can be added (Kirchman, 1986).

During maturation of the traditionally made compost, losses of nutrient elements and energy still appear. Therefore maturation should be replaced by the new treatments described above, which will be focused on preserving plant nutrients and energy which is bound in the raw compost produced during short retention time in bioreactors. By mixing raw compost with various additives, and/or using special packing methods, losses and thus pollution can be avoided even during application.

Present open composting systems produced compost of neither high nor reproducible quality. Composting as "get rid of" method is still practised and, unfortunately, there are companies today selling equipment for large scale plants with the argument that each 100 kg of raw material will be turned to 30 kg compost. We have to be more concerned about the 70 kg which are biochemically bound in the OM and which are lost by present methods. Most of the elements and energy could be used in a more profitable way than turning them into emissions. When processed in bioreactors the output of the standard substrate was 70 to 80% end-product by fresh weight.

Standardised substrates for composting experiments are used by many other investigators. For example spruce-bark with sewage sludge was used by Bågstam and Svensson (1976) and Solbraa (1979*c*). Unfortunately, sewage sludge which is often mixed with solid waste is already partly processed. The challenge in this investigation was to use mostly non-processed OM i.e. raw material as fresh as possible to use the biologically bound water. It is important for avoiding emissions from collection and transport as well as for better control of material and energy flow during processing. Thus the results form presented experiments can easily be implemented in the novel methods of treatment of organic waste which normally appears in everyday life. Therefore the results can be useful for building up a pool of references that are needed as a base for technical improvement of bioconversion.

In well insulated bioreactors, the temperature reached peaks above 55°C in the whole mass. This is of high importance for hygienisation of the product which means inactivation of pathogens and seeds. Thermal insulation of bioreactors will prevent microbial population collapse shortly after the thermopile phase, and higher temperature levels can be reached. In the less well insulated bioreactors the temperature in the composted substrate started to decrease already after some hours when a peak of 40-42°C was achieved, while in the well insulated ones the temperature continued to raise up to above 60°C (Gajdos, 1995*a,b*). The duration of high temperature depended on the amount of readily available compounds which support the active microorganisms with energy and nutrients. Degradability of various components is described by Grainger (1987).

Zucconi and de Bertoldi (1987) stated that composting today is not an effective way of recycling organic matter because composting plants are costly, inefficient and fail to offer consistently good quality products. Glass, metals, plastics, and various chemicals are common contaminants in composts made from municipal solid wastes. Composting systems of simple design result in poor hygienisation of the compost (Denecke *et al.*, 1995). Unfortunately there are still tendencies to keep composting at technological level which do not optimise factors supporting microbial activity and which cause unhealthy working conditions with negative impact on the local and global environment.

In both laboratory systems described in Paper II not only experiments on reproducible standard substrate can be carried out, but also many substrates of various organic materials can be processed and the efficiency of processing evaluated. In static bioreactors (3 L) only small amounts of substrate can be treated, otherwise layers with different levels of microbial transformation can appear. Thus the final product from static bioreactors (and also from heaps, windrows, and bins) can not be of such uniform quality as from the rotated bioreactors. The large rotated bioreactors (18 L) can be used for investigations when large amount of end-products is needed for cultivation tests. In the future the improved bioreactors of various sizes may be adapted to both small and large scale decentralised facilities.

Already in 1977 la Rivière wrote that biological waste treatment is changing from a technology for defensive disposal of waste materials towards a technology for using waste. He also brought up the idea that knowledge of the ecology of the traditional system is important for improving the existing methods, as well as for guiding their change into more profitable waste utilisation. Unfortunately we are still, 20 years later, in this phase of development and mostly describe, investigate and analyse impact of the traditional systems on the environment instead of intensifying empirical experimentation needed for development of new methods. By modification of practices in management of organic waste and in soil it can be possible to eliminate pollution, increase economic benefits and achieve a healthy environment. The quality should always be adjusted to the purpose for which crop and/or soil the biofertilisers from a particular "batch" will be used. The quality can be improved by addition of various activators and additives, or by use of various processing and post-processing methods.

The process of microbial transformation has to be managed with suitable control

strategies to guarantee the desired results. Such process, called bioconversion of OM, will be provided in closed systems. Products should not be called composts but biofertilisers by definition.

Regarding changes in temperature and pH during all runs it can be stated that methods based on short retention time in batch systems have to be preferred. New methods may speed up processes of bioconversion and will lead to increased efficiency. Only acting within the biological frame and going deeply into the essential facts and principles on biological processes can induce the approach leading to sustainable development. Waksman *et al.* (1938) published a study on composting of horse manure and wrote that "it has now been established that microorganisms are largely, if not entirely, responsible for these processes, which finally lead to the transformation of the manure and of the plant materials into a uniform, dark coloured mass, generally known as humus." The value of humus achieved by an efficient bioconversion have to be understood.

The study on processing standard substrate in static 'well' and 'less well' insulated bioreactors was supplemented by investigation on the decomposition of carcass (Eriksson, 1991), on survival of weed seeds (Ekenroth, 1994) and by the study of the microbial populations (Robertsson, 1994).

What kind of trends can we see in composting? In these days only a little amount of plant nutrients from organic waste is recycled and used in cultivation systems. Therefore there appears a great need for the use of synthetic fertilisers. Composts produced from unsorted or centrally sorted municipal solid waste (MSW) with addition of sewage sludge can seldom be used on soils where plants for food production are grown, because of high amounts of unexpected impurities such as heavy metals and different chemicals. The wrong balance of plant nutrients and other compounds may also be undesirable for the root environment. Most of the present municipal composting facilities do not act with respect for either microorganisms, plant nutrients, humus or emissions affecting our common environment.

Results from experiments in open systems probably have a lower relevance than results from closed ones. Unfortunately, many investigators still use piles and windrows as research methods for composting. Some recently provided experiments are listed as examples: The goal was to develop design procedures for passively aerated compost piles (Lynch & Cherry, 1996). The composting study on cattle manure and straw represent three levels of process control: (i) composting by windrowing, (ii) composting by forced aeration, and (iii) stockpiling (Lopez-Real and Baptista, 1996). The leaf compost was produced in a passive pile turned two to three times yearly (Maynard, 1997). Two piles, each containing about 10 tonnes of feedstock material, were formed outside, on a paved ground (Sesay *et al.*, 1997). Seen from a holistic point of view, the results from open systems can be misleading and can stimulate the use of methods which are less efficient and pollute the environment.

Definitions, which show how compost is still classified as rubbish, are written for example in Bonniers dictionary 1990 (Swedish): "COMPOST - an arranged heap of garden residues or the like, which have to be decomposed" and in Oxford Advanced Learner's Dictionary (1995): "Compost (noun) - a mixture of decayed plant matter, manure, etc. added to soil to improve the growth of plants. Compost (verb) - (a) to make something into compost; composting the kitchen waste. (b) - to put compost on or in something."

In a report from the Swedish Association of Waste Management (RVF, 1994) trends in Europe which go towards composting in bioreactors are described. In this report is mentioned that in Germany "open" composting is not allowed when more than 2 000 metric tons per year are treated. The current composting plants, equipped with large and expensive buildings and machines, give high profit to engineers but seldom to those who carry out composting process (Jonathan Collinson, 1995, personal communication). Cost-efficient technology for "open" composting is not available (and probably never will be) due to emissions. The aerobic processes of microbial transformation can be managed efficiently only in closed systems. It should be possible to use co-processing methods, i.e. aerobic processing in combination with anaerobic one, and achieve even higher economical and environmental benefits than from methods based on aerobic or anaerobic processing only.

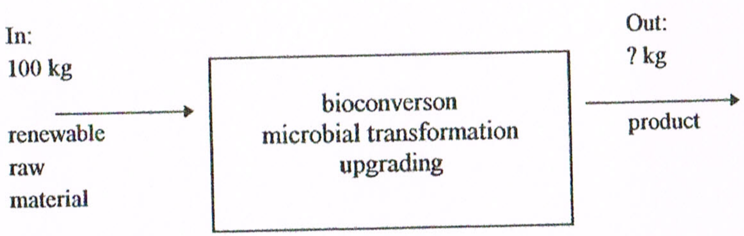

Figure 8. Proper processing in closed systems will lead to increased amount of product.

Bioconversion

Paper III contains a thought-provoking comparison of an economical estimation of the present organic waste management with future bioconversion for 1 000 households in Sweden. The possibilities of economic and sustainable recycling of plant nutrients by microbial transformation of organic waste in closed, decentralised plants are examined.

Experiences from experiments on bioreactors are used to design and describe the novel bioconversion systems named G&G. It include subsystems for collection in closed vessels (both solid and liquid organic waste), fast transport of the raw material to equipment for pre-processing, automated processing in bioreactors, equipment for post-processing and packaging, storage facility, and improved system for application of products. The processes in the bioreactors will be in the future the 'engine' and all sub-systems will be controlled by computers. Bioreactors of different kinds and of various size can be used for bioconversion of all kinds of organic waste, residues, by-products, and fuel crops.

Assumptions made for 1 000 families in Sweden show that costs for transport of MSW can be replaced by costs for building up a novel, locally situated, bioconversion system. Up to 85% of the MSW, which is of organic origin, will be treated and upgraded to valuable products. The bioconversion systems can be in small or large plants depending on the amount of raw material concentrated in the specific area. Expensive and polluting transports can thus be avoided.

The system of bioconversion is a device with many potential applications. The technology used now will be re-engineered to "bio"-technology (act for the living organisms) and will manage efficient microbial transformation on the conditions suitable for those microorganisms which are beneficial for humans. Using the newest technology, and working with that precision which is practised in other industrial processes, the sustainable development of the bioconversion, resulting in maximum of return and minimum of pollution, can take place.

The bioconversion can be carried out by two methods. By one step method biofertilisers of specific quality to match the requirements of different cultivated crops and various soils will be produced. In three step method the end products are methane (in biogas) and biofertilisers.

To minimise transportation costs it may be desirable to locate plants for bioconversion of OM near the facilities where OM such as organic wastes, residues, and by-products appear (in settlements, food industries, agriculture, horticulture, forestry). The biogas or both biogas and biofertilisers can be used directly or upgraded. Bioconversion facilities can also be situated on the border between urban and rural areas. Then biogas can be used as fuel in buses in the town and biofertilisers in crop production on the fields. Some facilities can be built in big cities directly under the buildings, where biogas can be used as a source of renewable energy and biofertilisers in parks, gardens, public areas, or for cultivation purposes in urban horti- and agriculture.

Bioconversion is better, from an environmental point of view, than burning or dumping organic waste. However, only using completely closed systems can we speed up the natural process of microbial transformation, get excellent products, improve working conditions, save energy, protect the environment, support the cultivation systems with excellent biofertilisers, maintain or increase productivity of cultivated soils, increase quality of food, stimulate biodiversity, and work for the sustainable development in the long term.

There is a big gap between what is known about efficient bioconversion and what is practised. The bottleneck for successful product-oriented processing of organic waste is still the lack of techniques for efficient collection (source separation), transport and pre-processing (disintegration, mixing, use of additives and activators) of most organic wastes. Biologically usable compounds are not protected from contamination from the nonfermentable fraction of wastes. Organic waste is not treated in time. The right time depends mainly on the readily decomposable fraction of organic waste and its water content. OM with high water content has to be treated while it is still fresh, i.e. not degraded by unwanted microbial conversion. Thus the biologically bound water can be utilised for effective processing and emissions can be avoided.

Composting, anaerobic digestion for biogas production, and combined process have to be compared and evaluated from energetic point of view. Leege (1993) defined infrastructure needs to follow key elements on waste organics recovery through composting: scientific research, standards, marketing legislation, regulation, and public education which all are important for social, political, and market acceptance for composting. He mentioned that in 1995 the compostable fraction will be 62 to 63% by weight. Stentiford (1993) stated that site specific solutions are to prefer. Ford (1987) wrote that the 'development of microbe technology' could allow us to obtain a proportion of our fuel from the chemical energy stored in refuse.

The diversity in the composition of raw material for composting and the used composting methods results in great variability in the composition of composts. That makes the transfer of information from composting, as well as from cultivation experiments, very difficult. There are plenty of factors which are important for creating products of high quality, especially when a combination of

aerobic and anaerobic microbial transformation is used. For example: origin of waste, its moisture, nitrogen content, readily available carbon, and optimal content of all nutrient elements which are necessary for optimal activity of microorganisms during processing.

The main advantages of closed systems, such as in-vessel or high-rate composting, over open systems in windrows or aerated static piles are described by Viel *et al.* (1987). The closed methods reduce the retention time, have a higher efficiency, and cause a decrease of active pathogens. It results in safer and more valuable end products. Unfortunately, the most suitable environmental conditions for efficient bioconversion require well constructed hardware, as well as suitable software for precise control and regulation of the systems.

By expanding the agricultural use of biofertilisers, produced from solid and liquid organic urban waste in decentralised bioconversion plants, several million SEK could be saved annually. These savings would come from:

- lower landfill, incineration, and waste water treatment costs
- lower transport costs
- increased yields of cultivated crops
- reduced use of fossil-based fertiliser, pesticides, and herbicides
- water savings
- energy savings.

Beyond the financial savings made by use of bioconversion of organic waste lie a multitude of environmental benefits such as:

- Improving the physical, chemical and biological properties of soil in the long term, resulting in reduced soil erosion, increasing crop yields and improving quality, higher resistance of the cultivated crops to weeds, parasites and disease, reducing harmful agricultural run-off by cutting the use of fossil-based pesticides, herbicides and fertilisers, conservation of water by increasing the water holding capacity of the soil and therefore decreasing percolation, evaporation and runoff of plant nutrients.

- Energy saving by using a part of the bioenergy as biogas and partly as energy-rich compounds in biofertilisers (used by microorganisms in soils or transferred to humus) as well as lower energy demand for irrigation.

- Decrease of emissions which lowers workers' exposure to unhealthy conditions during collection (novel sanitation methods), transport and discharge, during processing of organic waste with ancient methods of composting and rotting, on landfills, incineration plants, and waste water treatment plants as well as by decreased use of agro-chemicals in conventional cultivation systems.

Eriksson (1993) described problems connected with repairing of old infrastructures which were modern at the beginning of this century and questioned if these technical solutions need re-engineering in the near future. As organic waste management is closely connected to water and energy managements, improvement of systems and methods is of high priority.

Demuynck and Nyns (1986) wrote that anaerobic stabilisation of domestic waste results in a conversion of 40% of total solids and one third of the energy. The amount of energy which can be recovered by incineration of domestic waste, can be recovered by bioconversion as methane in biogas and thus used in an environmentally more friendly form.

The principal goals for combined aerobic and anaerobic bioconversion are (a) control of speed of the microbial transformation of the substrate, (b) an efficient production of the energy rich intermediate methane, (c) conservation of the soluble nutrient elements essential for plant growth (especially nitrogen), (d) formation of humic substances, (e) inactivation of plant, animal and human pathogens and seeds, and (f) avoidance of pollution. Then the ecologically sustainable loop (Fig. 9) which starts when plant nutrients are taken up by plants, assimilated in plant biomass, consumed, and became organic waste, which are upgraded by microbial transformation to biofertilisers - can be closed. Bioenergy from organic compounds can be transformed to energy-rich methane in biogas.

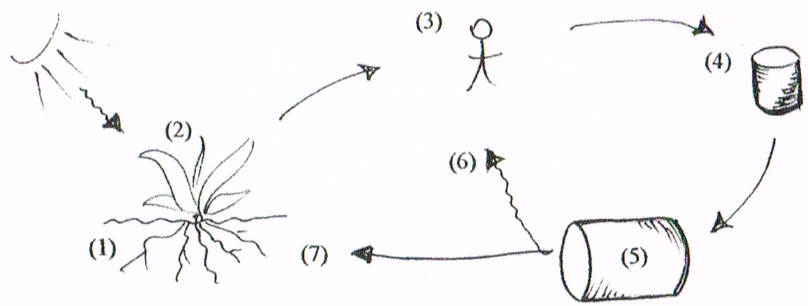

Figure 9. In the (1) cultivation systems elements are assimilated by the suns energy into (2) plant biomass then (3) consumed by humans, animals, and microorganisms and transformed to (4) organic wastes and residues, which are through (5) controlled microbial transformation in completely closed bioconversion systems upgraded to (6) valuable products such as (7) biogas and (8) biofertilisers. Elements return to air, water, and soil to enter the new loop.

Systems

Paper IV describe the necessity to develop new waste treatment strategies for an efficient recycling of plant nutrients in systems, based on the use of solid and liquid organic waste as renewable raw materials. The evolution of composting methods is developing from heaps, windrows and bins to air-tight well insulated bioreactors equipped with systems for aeration and agitation. The evaluation of current methods compared with future ones was made with consideration to quality of final products (Fig. 10). In the novel systems equipment is adjusted to methods of bioconversion based on combined aerobic and anaerobic microbial transformation processes described in Paper III.

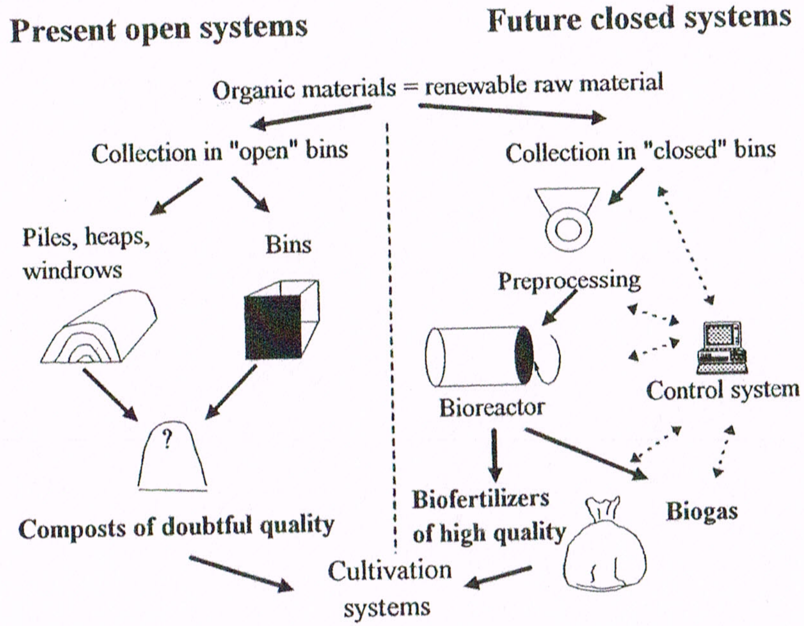

Figure 10. Products from "old-fashioned" methods of composting and from future combined aerobic and anaerobic methods vary in quality.

Wilson (1977) described the potential hazard when wastes are produced, or they may be hazardous by reason of their location or the method of processing used. The increased awareness of problems associated with generation of waste which appear during collection, transport, and treatment lead to an increased interest from many actors to find appropriate alternatives. Neither organic fraction municipal solid waste, nor human excreta is today treated in ecologically right and environmentally sound methods. There is not only an enormous need to prevent pollution and losses of plant nutrients, but there is also a great economical potential in increased utilisation of SOW and LOW as renewable raw material.

A long-held theory that biologically based methods (composting) are suitable only to decrease volume and weight of the waste, and that incineration is the best way to recover energy from the OMs which are a renewable source, have to be re-examined.

Hygienically safe biofertilisers without infectious pathogens, having a good compatibility with plants and absence of weed seeds and/or other seeds, are some of the expectations which have the cultivation systems. The operations processing organic materials which are intended for disposal or will be used as energy rich raw material (fuel crops) can be designed with respect to consumer friendly methodologies. A part of the energy, converted biologically from organic materials, can be used to power the bioconversion units.

The user friendly and environmentally sound technologies have to be adapted to the microorganisms which transform the substrate to desired products. The novel ecologically sound waste management system, could be implemented in whole society by the year 2010. In local bioconversion systems the separated organic fraction of MSW could be treated together with hygienically collected human excreta (Fig. 11). It will result in increased recycling of plant nutrients, reuse of bioenergy, increase of the amount of microorganisms beneficial for cultivation (biological control of pathogens), while it will decrease the amount of used and polluted water, costs for waste and wastewater management, costs for synthetic agrochemicals. This way the environmental damage will be avoided.

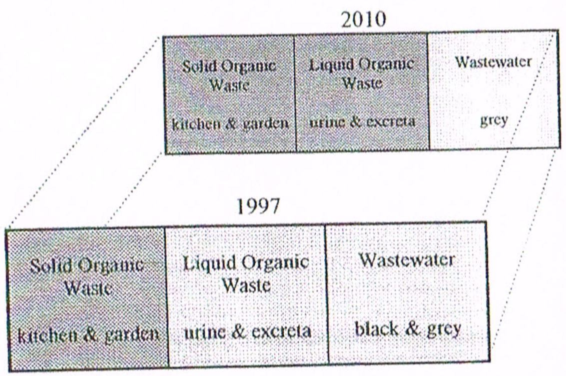

Figure 11. Management organic waste. 1997 - in modern urban areas solid organic waste are treated separately from the liquid, 2010 - in all countries both in urban and rural areas solid and liquid waste can be upgraded to valuable products.

Back to basics and forward to basics

Nothing can disappear, it will only disperse, due to physical laws. In biology only we can find systems assimilating dispersed elements or compounds and building up new structures. Plants utilise energy from the sun and bind a part of it. Meanwhile the diluted compounds are formed into energy rich structures which are the fundamental building blocks for all organic matter. Plants are only some of the critical players in the cycle of life where biological transformation processes (bioconversion) are active. It is well known that there are no plants, animals or humans living without influence from both beneficial and disturbing microorganisms. All living organisms are consumers and producers at the same time. On the simple cell level they consume compounds or elements (in the food) for building up the biomass. Simultaneously each cell produces compounds or elements (as metabolites) which sooner or later can be utilised by other cells or organisms.

When plants become digested (by humans, animals, and microorganisms), the biochemically bound energy and elements are partly transformed to new biological structures, partly remain in excreta, and some elements are discharged. Therefore, during microbial transformation, elements can be immobilised which means that they are bound in microbial biomass. Then, when biofertilisers are applied to soil and microorganisms die, elements are released and can be taken up by the roots.

During decomposition of plant matter, complex compounds are broken down to simple compounds that can be utilised by the microflora. Much of the material never breaks down completely, but remains as metabolic by-products and intermediate compounds that chemically combine to produce more resistant compounds (Smith *et al.*, 1992). Unfortunately, the potentialities for use of microorganisms for bioconversion and/or for biological control of pathogens are not fully accepted.

Goldstein (1988) stated that there is no question that recycling is highly compatible with composting. Unfortunately there are others who are not concerned about biological processes from the holistic point of view. For example Hogan *et al.* (1989) defended the idea that composting is not seen primarily as a means of producing any particular product, but rather as a treatment component of an overall waste management. It is obvious that the costly methods of treating organic matter causes increased emissions, which leads to an unhealthy environment as well as great economical losses when expensive processing does not create products of value, but instead pollutes the environment.

We should go back to basics and increase our knowledge of the microbial processes during bioconversion, and move forward to basics when this knowledge will be used as a springboard for design and implementation of advanced technology. By efficient processing of solid and liquid organic wastes, and by using the products - biogas as the source of renewable energy and biofertilisers for locally produced high value food - we can improve sanitation, reduce waste and pollution, and bring profits. This can additionally create jobs and development of a sustainable society.

The foundations presented here, upon which far-reaching scientific conclusions are built are based on experience from isolated observations, experimental measurements and results combined with those described by others. Suggestions are made for new investigations on one of many alternative systems which should be compared with other systems.

My hope is that presented work will excite many investigators to further research and also open the way for new, practical applications of the results. This thesis should be stimulating reading for all interested in reusing organic waste which has potential as a renewable raw material. Commercial applications of the biochemical activities of microorganisms can contribute to environmentally sound recycling of plant nutrients, use of bioenergy, protect plants against pathogens, maintain or increase microbial diversity and soil productivity and ecological sustainability. The challenge is to permit the system to evolve and fulfil the real needs.

Concluding remarks

Bioconversion in closed systems can replace the open ones

The cultivation experiments, where composts from source separated and centrally sorted municipal solid waste were investigated, showed the potential hidden in properly made composts. It is important to consider the impact on product quality and on the technology of processing by improvement of bioconversion methods. For example one important alternative is three phase bioconversion, which includes production of biogas and biofertilisers. The new approach has to promote not only strictly controlled process conditions but also improvement in methods of collection of raw material (including sanitation), pre-processing, as well as product management, including storage, transport, and improvement of various methods of end products application.

In composting experiments the need of precision in all steps of the processing was confirmed. The investigation carried out in laboratory bioreactors pointed out some of the factors necessary for achieving fast, hygienic and efficient treatment of organic materials and for minimising pollution and losses. Therefore increased knowledge on interactions between microbial necessities and equipment design is essential. The quality of biofertilisers has to be adjusted to the cultivated crop, the cultivated soil demands (including the demands of soil microorganisms), and also human demands on proper sanitation, clean working conditions, and healthy food have to be taken into consideration. The fully controlled combined processes of bioconversion will lead towards ecological sustainability.

To achieve successful organic waste management, biological limits have to be respected and both equipment and methods adjusted to them. Decision-makers, designers, and engineers need relevant information from researchers involved in microbial processes. They all have to understand the connection between ecologically sustainable development and processes of bioconversion of organic waste. More collaboration is needed especially within areas of aerobic and anaerobic microbial transformation of organic waste. In all levels of society it is necessary to intensify the education in microbial ecology and on the impact of microbial activity on everyday life.

One alternative way for utilisation of organic solid and liquid waste is drawn here. It links elements and energy circulation between the human consumption system and the agricultural production system. It is a new pattern for ecological engineering which can lead to sustainable development of safer food, cleaner air, cleaner water, and a better environment as a whole.

Further research

There is a great need to develop new strategies for efficient recycling of plant nutrients, using humic substances (which are essential for soil fertility and productivity), and bioenergy bound in organic waste. At the same time there is a strong interest in developing new waste treatment strategies to address the quality concerns of air, soil, water and cultivated crops. Therefore bioconversion of organic materials is the approach which should be studied intensively and evaluated from an economic point of view, inclusive of environmental benefits which are important for human health and survival.

Problems to be solved refer mainly to the development of proper procedures for collecting, pre-processing and treating the renewable raw materials intended for bioconversion which are organic waste, residues, by-products, and fuel crops. The main goal of bioconversion should be a rapid production of an hygienised, odour-free, and for cultivation needs well adapted biofertilisers with reasonable expense.

In R&D bioconversion facilities the studies should be conducted both in laboratory conditions and in the pilot plants which are similar to natural environment. To form the complete understanding of requirements for processes on microbial transformation of organic materials, it is necessary to continue studies on minimising losses of plant nutrients and energy. Preliminary results can be used for building models which can be an useful complement to the empirical experiments. By modelling the most relevant additional experiments can be pointed out. Each model can only gain credibility when it has been fully tested experimentally.

The comparison between various technical methods of bioconversion can be made by preparing identical feedstocks processed in different bioreactors and by various methods. In order to test the technology under diverse geographic and socio-economic environments (encountered across the selected area) several prototypes will be required. Techno-ecologic-economic advantages offered, by the state of the art technology, should promote concept both in developed and developing countries.

Where the results will lead in terms of action

The experiments on backyard composters (Gajdos, 1992*a*) resulted in increased public interest in composting in Sweden.

The cultivation experiments (Paper I) led to increased interest for studies on crop response to various composts, and also to a search for novel methods. The laboratory equipment with bioreactors and the standard substrate (Paper II) was

used with or without modifications by other researchers.

The results obtained from this research will be useful in many ways, such as:

• in everyday life - when all people will be conscious of the importance of recycling plant nutrients and reusing energy which is bound in organic matter

• in waste management - when not only organic waste but all OM (intended for disposal) will be treated in decentralised closed systems with methods adjusted to biological frames, so that health problems (caused by poor sanitation) and environmental damage can be avoided

• in the sphere of industry - when environmentally friendly equipment for bioconversion of solid and liquid organic waste will be constructed

• in cultivation systems - when biofertilisers can and will be used not only in ecological but also in commercial systems with the aim to return to soils as much as possible of the nutrient elements which today are thrown away in organic waste ending up on landfills, in incineration plants, and in waste water treatment plants (as emissions in the air and in sewage sludge)

• in education systems - both in developed and developing countries

• in research - where other researchers can improve the methods and make them suitable for various purposes.

This thesis should stimulate the reuse of organic waste, which has a potential as renewable raw material. Commercial applications of the biochemical activities of microorganisms can contribute to environmentally sound recycling of plant nutrients, better use of bioenergy, plant protection by biological methods, maintain or increase microbial diversity, productivity of soil, and to achieve ecological sustainability. The next challenge is to investigate how to permit the system to evolve and fulfil the real needs.

Glossary

Acid deposition - occurs by emissions of sulphur dioxide and nitrogen oxides from combustion at rates which exceed the neutralising capacity (Firth *et al.*, 1995).

Aerobic bioconversion (composting) - biological (microbial) transformation in presence of air oxygen. Aerobic microorganisms transform organic substances to carbon dioxide, water, heat, and their own biomass while some residues became humus.

Anaerobic bioconversion (digestion) - biological (microbial) transformation in absence of air oxygen. Anaerobic microorganisms transform organic substances to carbon dioxide, methane, very little heat, and their own biomass while some residues became humus.

Biomass - living or dead organisms.

Bioenergy - suns energy which is biochemically bound in organic compounds.

Biological transformation - changes in the molecular structure of a compound in which the free energy barrier for the reaction is lowered by enzymes in or from living matter (EEC's Draft).

Decomposition - the initial stage in the degradation of an organic substrate. It is characterised by processes of destabilisation of the preexisting structures. In properly conducted composting, decomposition is conductive to a subsequent stage of stabilisation (humification and mineralization) (Zucconi and de Bertoldi, 1987). Decomposition or degradation by microbial transformation of organic waste can be synonymous to upgrading when end-products of value are obtained.

Compost classification - division into fresh, mature and cured compost, according to degree of stabilisation (Zucconi and de Bertoldi, 1987).

Compost grade - division into very fine, fine, medium, and coarse compost according to its physical and chemical characteristics (Zucconi and de Bertoldi, 1987).

Cured compost - a highly stabilised product which results from exposing compost (fresh) to prolonged period of humification and mineralization beyond the stage of maturity (Zucconi and de Bertoldi, 1987). Cured synonymous with maturated.

Fresh compost - organic matter that has gone through the thermophilic stage of composting and achieved sanitation. It has undergone a partial decomposition but it has not yet stabilised (Zucconi and de Bertoldi, 1987). Fresh compost synonymous with raw compost.

Hazardous compounds - any organic or inorganic compound that may endanger life or health. Poisons, heavy metals, pesticides, etc. which may be found in waste belong to this group (Zucconi and de Bertoldi, 1987).

Humification - the microbial synthesis of three-dimensional polymers of saccharides and phenols resembling gums and lignin. It is a process of storing organic energy into compounds of high molecular weight which are slowly degradable (Zucconi and de Bertoldi, 1987).

Industrial waste - waste (organic or inorganic) formed in industrial processes.

Mesophilic phase - phase of composting during which the temperature of the mass is between 30 and 45°C.

Microbial transformation - biological transformation provided by microorganisms.

Mixed material waste - waste from products containing a mixture of substances, at least one being xenobiotic, or waste from manufacture of such products, and where the substances may not be separated by simple sorting (EEC's Draft).

Municipal solid waste (MSW) - waste from households, commerce, administration and service companies and which is disposed of through the public waste management system (EEC's Draft).

Organic compounds - compounds, which are building blocks of organic material (carbohydrates, proteins, fats, vaxes, and many others)

Organic material (OM) - material, which originate from (a) organisms (biomass), (b) man-made products (paper, wooden furniture, processed food and feed products), and which is (c) naturally composed from biomass (humus).

Organic waste - 1) waste which originates from plant and animal kingdom, as well as man-made artificial products based on organic compounds from plant and animal kingdom.

Organic waste - 2) organic material, which consists of living organisms (biomass), their excreta, and non-living residues (bark, straw, old leaves, branches, roots, and include food, feed, paper, furniture, and other 'used' man-made products).

Sanitization - the reduction of disease-producing organisms below the level of health risk (Zucconi and de Bertoldi, 1987). Synonymous with hygienisation.

Substance - a chemical element or molecule formed from different chemical elements (EEC's Draft).

Sustainable development - is a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development and institutional change are all in harmony, and enhance both current and future potential to meet human needs and aspirations (EEC's Draft).

Thermal transformation - a chemical transformation where the driving force for the transformation is increased by the use of an elevated temperature or a combination of an elevated temperature and an elevated pressure (EEC's Draft).

Thermophilic phase - phase of composting during which the temperature of the mass exceeds 45°C.

Waste - substances or objects which are disposed of, or are intended to be disposed of, or are required to be disposed of by the provisions or national law (Basel Conv., 1989).

Waste management - actions to solve waste problems (EEC's Draft).

Sludge - waste material deriving from the treatment of sewage (Zucconi and de Bertoldi, 1987). Synonymous with sewage sludge.

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Abbreviations

cs	centrally sorted
MSW	municipal solid waste
OM	organic material
OLW	organic liquid waste
OSW	organic solid waste
OW	organic waste
ss	source separated
v/v	volume/volume