High Quality In-Vessel Composting

The sustainable solution to the management of biodegradable solid waste and sewage sludge

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by:

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Executive Summary

The European Union is coming under increasing pressure from population growth, increased demands on food supply and climate change. All three of these factors are inextricably linked, through the Carbon Cycle, to the soil. The soil forms an important part of the biosphere in which we all live. Soil is the basis for 90% of all human food, livestock feed, fibre and fuel, it also facilitates half of the Carbon Cycle.

To sustain the increasing European population requires a reduction of atmospheric carbon, sustainable maintenance of soil fertility and a reversal of the degradation of marginal and abandoned soils throughout Europe.

Soil structure and fertility can be improved and desertification halted and even reversed by increasing the organic content of the soil. Nearly 90% of all European soils have an organic content of less than 5% and could be improved by the annual application of 10-20 tonnes/ha/yr of organic matter. Currently there is only sufficient organic material available from animal manures and cereal straw to achieve a 6.6 tonnes/ha/yr application rate across all European soils. The 3.4-13.4 tonnes/ha/yr shortfall equates to a total shortfall of $231*10^6$ - $911*10^6$ tonnes/yr of organic material. Some of this material shortfall could be sourced from the organic fraction of the solid waste stream and some from sewage sludge.

Section 3 clearly demonstrates the significant benefits of increasing the organic content of agricultural land while section 4 demonstrates that we need to utilize all available organic material to help maintain Europe's agricultural land in a sustainable manner. Therefore it is essential that wherever practicable, and safe, all high grade organic wastes (biowastes) are composted.

By the use of the latest composting technology it would be possible to safely generate an additional $90*10^6$ tonnes/yr of reliable high-quality compost for application to European soils. The use of modern in-vessel composting systems that maintain a temperature of 70°C for a period of 24 hours can ensure sanitation of the compost by reducing pathogenic bacteria and viruses by a factor of 10^{125}. These systems also offer an effective way of destroying some of the most virulent diseases including Foot and Mouth Disease Virus (FMDV).

It is often advantageous to compost mixed wastes including paper and cardboard. Such composting enables the maximum amount of organic carbon to be recycled back to the soil and also offers recycling solutions for composite materials and low value materials.

The annual application of 10-20 tonnes/ha/yr of compost will raise the soil organic content (SOC) by 0.32% - 0.71% per year. This carbon will be removed from the atmosphere thereby reducing the concentration of the greenhouse gas carbon dioxide. This will help to stabilise global climate change and thereby act to reduce soil degradation in Europe.

In addition to adding carbon to the soil, compost also adds essential macro and micro-nutrients needed to support plant life. These nutrients are required to replace those stripped from the land by successive crop harvests. All of the macro-nutrient requirements for a 5400 litre/ha wheat crop could be supplied by a single application of 15.7 tonnes/ha of good quality compost. Increased organic matter content and the replacement of macro and micro-nutrients will result in increased soil fertility. This increased fertility will result in increased yields of commercial crops and forestry plantations, as reported in section 3. This increased production can be achieved with reduced quantities of inorganic chemical fertilisers thereby reducing environmental pollution, eutrophication of ground water and energy demands.

Phosphorous is an essential macro-nutrient required to promote healthy plant growth and improve soil fertility. To protect and conserve scarce phosphorous reserves it is essential to recycle the phosphorous content of sewage sludge back to agricultural land.

The bio-availability of trace elements within compost is only a small percentage of the total elemental content except for nickel. This bio-availability also decreases with the maturity of the compost. The evidence therefore suggests that the total elemental content of compost does not correlate well with the fraction of the elements that are environmentally available. To attempt to set a Europe-wide limit for trace element concentrations in compost, based solely on the total elemental content, would also have limited applicability due to the diverse range of trace element concentrations in European soils. A more flexible approach needs to be implemented to allow for the many varied soil types and conditions throughout Europe.

To improve and protect the European environment it is essential that the four Priority Areas of the European Community Sixth Environmental Action Programme: Tackling Climate Change; Nature and Bio-diversity; Environment and Health; and Sustainable use of natural resources and management of wastes, are implemented across all European policies. Composting the organic fraction of the European waste stream will substantially contribute to each of these areas and provide an environmentally beneficial way of managing both biowastes.

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1. Introduction

The European Union is coming under increasing pressure from population growth, increased demands on food supply and climate change. All three of these factors are inextricably linked, through the Carbon Cycle, to the soil. As the population grows, so more land area is required for housing and more food is required to feed the growing population. The growing population is using more and more fossil fuels for energy supply which results in increased atmospheric carbon content. This is in turn causing global climate change through the Greenhouse Effect. Rising global temperatures are increasing desertification in areas of southern Europe while heavier rainfall in some areas of northern Europe is increasing soil erosion, further reducing the land available for food production. Reducing the amount of productive land increases the pressures on the remaining fertile soils to produce more. This increasing demand, if not managed in a sustainable manner, will further increase soil degradation resulting in the European environment entering a spiral of decline.

To support the increasing European population requires a reduction of atmospheric carbon, sustainable maintenance of soil fertility and a reversal of the degradation of marginal and abandoned soils throughout Europe.

There are currently two EC Draft Working Documents that are preparing the way for two major initiatives on the treatment of biodegradable wastes. The first working document is on sludge management[1] and the second on biowaste management[2]. The objectives of both of these documents are to promote the sustainable use of biowastes in the environment while protecting European ecosystems and human health.

Sewage sludge and other biowastes offer important sources of organic materials. It is important for Europe to maximise the amount of organic materials that are recycled back to the productive land thereby completing the organic Ecocycle. However, this must not be undertaken at risk to human health or the environment. Therefore it will be necessary to establish quality control and monitoring systems to ensure that adequate protection is provided at all times.

The following sections of this document identify some of the main areas in which composting can benefit the European environment and help to sustain agriculture to enable increasing food demands to be met.

This document is organised as follows:

[1] ENV.E.3/LM, Working Document on Sludge - 3rd Draft, Brussels, 27 April 2000.

[2] DG Env A.2/LM, Working Document on Biological Treatment of Biowaste – 2nd Draft, Brussels 12 February 2001.

2. Agronomic, Environmental & Economic Considerations

2.1. Introduction

The soil forms an important part of the biosphere in which we all live. Soil is the basis for 90% of all human food, livestock feed, fibre and fuel[3]. It also facilitates half of the Carbon Cycle.

The plants that the soil supports absorb atmospheric carbon in the form of carbon dioxide and convert it by photo-synthesis into carbon based materials within the plant and its root system. As the plants grow they continue to absorb more atmospheric carbon. When the plant dies and falls to the soil, micro-organisms convert the plant materials into nutrients for the next crop and carbon dioxide which is released from the soil back into the atmosphere. Therefore soil should not simply be considered a medium in which to hold plant nutrients but also a reservoir for organic carbon.

There is a similar water-based Carbon Cycle associated with the chemistry and biota of the world's oceans but man has little control over this and therefore it will not be considered further within this document.

In 1986 Stevenson[4] reported that the atmosphere contained $712*10^9$ tonnes of carbon and that this level was increasing at a rate of $3*10^9$ tonnes per year. It was also estimated that the amount of carbon in the world's soils, $1500*10^9$ tonnes, was approximately equal to the total of all land-based biota and the atmosphere combined.

There is significant scientific debate over the impacts that increasing atmospheric carbon levels will have on the planet's ecosystems but most agree that there will be a resultant undesirable climate change and that this is already manifesting itself in the extreme weather conditions experienced throughout the world over the last decade.

The flux of carbon from atmospheric reservoir, to plant biota reservoir, to soil reservoir and back to atmospheric reservoir needs to be balanced to halt the annual increase ($3*10^9$ t/yr) in atmospheric carbon. This balance could be achieved and the trend even reversed if we could make significant savings in the flux of carbon due to deforestation ($1\text{-}2*10^9$ t/yr), fossil fuel burning ($5*10^9$ t/yr) and reduction of soil organic content ($2\text{-}5*10^9$ t/yr).

Deforestation and fossil fuel burning account for some $7*10^9$ t/yr of atmospheric carbon increase and so need to be targeted urgently. Agricultural practices also need to be targeted, to reduce the loss of soil organic content (SOC) due to tillage, and to increase SOC by the application of organic materials. Because of the large size of the soil reservoir, increasing SOC by only a few percent could effect a significant improvement in atmospheric carbon levels. One important way of sequestrating carbon from the atmosphere is to incorporate organic matter into agricultural land. This can be done by ploughing in animal manures, straw stubble and other carbon-rich materials such as compost. Incorporation of organic matter increases SOC which also improves the fertility and structure of the soil.

Organic farming is based on the use of soil organic matter, rather than inorganic fertilisers, to provide plant nutrients. Organic farming therefore involves increasing and maintaining a high level of soil organic matter through various means including the incorporation of compost and animal manures. This farming technique offers major potential to reduce emissions of agricultural greenhouse gases (carbon dioxide, nitrous oxide and methane) and also their annual external costs. Numerous studies have shown that CO_2 emissions from organic farming are 40-60% lower per hectare than conventional systems. This is mainly because organic farmers do not rely on inorganic chemical fertilisers to supply the nitrogen requirements for their crops.

2.2. Soil Degradation

Globally, nearly 2 billion hectares of land are affected by human-induced degradation of soils[3]. Each year an additional 20 million hectares of agricultural land become too degraded for crop production, or are lost to urban sprawl.

Only a thin layer of soil, the topsoil, can adequately support plant life[5]. In most places the soil favourable to plant growth extends down about 15 centimetres. The fertility of this thin layer must be protected by preventing erosion and by replacing the nutrients that crops remove from the soil. At present, the risk of soil erosion is high to very high in one-third[6] of Europe. Erosion can strip soil from unprotected land at an alarming rate.

Human activities are increasing the rate of soil erosion by up to 50 times[6] that of naturally induced erosion. Current farming practices and global climate change are combining to produce a significant risk of water erosion in southern and central Europe, the Caucasus region, the Balkan Peninsula, the countries surrounding the Black Sea, the Czech Republic and the Slovak Republic.

Working on calcareous soils in 50 m² plots in Tunisia, Dumas showed that soil erodibility depends on the amount of pebbles, the amount of organic matter, and the equivalent humidity of the soil, which depends in turn on its texture[7]. Organic matter plays an important role in soil aggregate stability[8] and is, in fact, the primary stabilizing agent for aggregates in temperate-area soils. This stabilization process is accomplished mainly through the by-products of organic matter decomposition (microbial gums and mucilages). Roose[7] has shown that in the case of Mediterranean calcareous soil an increase of 1% in the amount of organic matter reduces soil erodibility by 5%.

Soils are also being degraded chemically due to exhaustion (nutrient depletion). Currently it is estimated that there is a 10% surplus of agricultural land across Europe but as the European population grows, increasing food production demands will be placed on all agricultural land. The resultant intensification of farming practices will, unless managed in a sustainable manner, strip organic matter and nutrients from agricultural land faster than they are replaced.

Continual cropping of a soil will lead to loss of fertility due to the year on year removal of nutrients by each successive crop.

Table 1: Nutrient demands of 5400 l/ha wheat crop

Nutrient	Nutrients Removed (kg/ha)	
	Grain	Straw
Nitrogen	85	34
Phosphate	45	10
Potash	27	74
Sulphur	6	8
Calcium	2	10
Magnesium	10	5.5
Boron	0.07	0.02
Copper	0.05	0.03
Iron	0.54	0.17
Manganese	0.16	0.30
Zinc	0.23	0.09
Note: If the straw is not removed but ploughed in then only the grain nutrients will be lost to the soil.		

Table 1 shows the amount of nutrients removed by a typical 5400 litre/ha crop of wheat producing 4 t/ha of grain and 5 t/ha of straw[9]. These nutrients must be replenished to prevent a gradual reduction in soil fertility.

As well as degradation due to lack of fertility, current global climate change is hastening desertification processes. Desertification is currently affecting southern parts of the EU including Spain, Greece, Portugal, Italy and France (Corsica)[10]. Extensive areas in the Mediteranean region have been so severely degraded that they are no longer capable of supporting any profitable cultivation, resulting in land abandonment and depopulation.

Soil must be considered a finite, non-renewable resource. The replacement of erosion losses is very slow. Nature takes from 500 to 1,000 years to make 2.5 centimetres of topsoil and from 2,000 to 5,000 years to replace a loss of 13 to 25 centimetres[5].

2.3. Economic Considerations

There is a huge diversity of livestock systems in marginal areas within Europe[11], producing milk, meat, wool and hides from a large number of breeds of cattle, sheep and goats. Those systems all, however, rely to a large extent on pasture resources to supply most of the feed.

In many marginal areas soil conditions are such as to limit the supply of nutrients to plants. During winter in Northern Europe and in summer in Southern Europe the nutritive value of available fodder crops (in terms of energy and protein) is generally very low and often insufficient to provide animals with even maintenance levels of intake. Often animals have to browse shrubs, which tend to have a low digestibility and a low protein content. In addition many contain secondary plant compounds such as tannins that impair digestion. The low levels of nutrition generally limit the physiological processes of reproduction, lactation and growth, well below the potential achievable by the animals. Consequently, the levels of animal performance and total output from livestock systems in the marginal areas of Europe fall considerably below that of comparable systems in more favoured areas. In areas of southern Europe and the Canaries it is becoming increasingly difficult to produce food crops due to desertification.

These marginal soils could be brought back into profitable production through the addition of compost. The application of a top dressing of compost at rates of 10–50 t/ha has been shown to improve grass coverage (density), growth and colour[12]. Tests on Egyptian soils have shown that the addition of high levels of compost would benefit these degraded soils by improving soil fertility and structure with resultant reduced erosion and increased yields making the land financially viable again.

At the global level, combating soil degradation by the incorporation of compost will help offset greenhouse gas emissions, provide a better environment, guarantee more food to an increasing population and contribute to the economic progress of future generations.

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3. Benefits of Using Compost

3.1. Improving Soil Fertility and Structure

Soil fertility depends upon many factors including soil type, availability of chemical nutrients, organic matter and the micro-organisms present in the root zone.

In moist sand loams, plant nutrients are generally more accessible than in silt or clay soils although clay soils contain higher fertility resources. In very wet or very dry soils nutrients become restricted or unavailable for obvious physical reasons such as a lack of root absorption by most crops.

Plants require both macro-nutrients and micro-nutrients which must be water soluble in order to enter plant root systems. Macro-nutrients are nitrogen (N), phosphate (P), potash (K), sulphur (S), calcium (Ca) and magnesium (Mg). Oxygen (O), hydrogen (H) and carbon (C) come from air and water and make up 95% to 99% of a plant's weight.

Micro-nutrients are needed in only very small quantities but are every bit as essential as macro-nutrients to normal plant growth. Plant essential micro-nutrients include boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo) and zinc (Zn).

Organic matter is essential to support the micro-organisms in the root zone, to provide plant nutrients and to help stabilise the soil structure. The decomposition of soil organic matter is an important mechanism whereby nutrients such as nitrogen and phosphorus are supplied to growing crops. Organic matter also has a strong, positive effect on infiltration of water into soils. This effect is due mainly to a decrease in bulk density, and improvements in aggregation. Increased organic matter content also has a beneficial effect on the retention and *availability* of water in soil.

Table 2: Typical Nutrient Content of Compost made from MSW and Sewage Sludge

Nutrient	Percentage % (by dry weight)	
	MSW only	MSW plus Sludge
Nitrogen (N)	1.7%	1.8%
Phosphorus (P)	0.66%	1.6%
Potassium (K)	0.66%	0.4%
Calcium (Ca)	2.8%	4.1%
Magnesium (Mg)	0.16%	0.27%

The addition of organic matter to soils, in the form of compost, not only increases the soil organic content but also adds essential macro and micro-nutrients. Table 2 shows the macro-nutrient content of a typical good quality compost manufactured from Municipal Solid Waste (MSW) with and without the addition of sewage sludge.

3.2. Reducing Eutrophication of Groundwaters

Water pollution is a major problem in agriculture. Nitrates in groundwater often exceed the standard for drinking water. In the UK, 20% of sampled groundwater sites exceeded drinking water standards for pesticides in 1998[13] and 75% of lake SSSIs (Sites of Special Scientific Interest) are affected by eutrophication. Agriculture is a major source of bacterial contamination and causes 17% - 28% of major pollution incidents (previous three years). Sedimentation, caused by run-off, is a problem for fisheries. The total external costs of water contamination by agriculture in the UK alone are estimated to be £220 million annually.

The Nitrates Directive 91/676/EEC was introduced in 1991 to bring about a reduction in water pollution caused or induced by nitrates from agricultural sources and to prevent further nitrate pollution. It requires every member state to operate a fertiliser application limit of 210 kg N/ha/yr (nitrogen per hectare per year) from 1998 up to the end of 2001 and 170 kg N/ha/yr from 2002. It also requires a balance to be achieved between the supply of nitrogen and the requirements of the crop throughout the growing period.

Inorganic nitrate fertiliser, used for plant nutrition in chemical intensive farming systems, is the most mobile form of nitrogen and results in the loss of approximately 20% of the applied nitrogen. In soils with high SOC, water retention is improved and the addition of organic matter also provides some, if not all, of the nutrient requirements. The amount of inorganic N and P fertiliser applied can be substantially reduced as plant nutrients are instead supplied by the biological life, bacteria and fungi, in the soil. Bacteria and fungi are the least leachable sources of N, and this considerably reduces the nutrient leaching potential. Higher SOC levels also increase water retention and drainage, further reducing leaching and run-off. Anecdotal evidence supports the significance of this effect (farmers report a reduced risk of drought).

The use of compost to supply a crop's nitrogen requirements will result in reduced eutrophication and will ensure that the supply of nitrogen is matched to the demands of the plants as required by Directive 91/676/EEC. This is due to the microbial action that releases the nitrogen from the organic matter within the compost, being stimulated by the same climatic conditions that stimulate plant growth.

3.3. Increased Production Using Compost

Adding compost to soils increases the organic content of the soil, adds nutrients and also increases water retention and availability. This results in better soil structure and nutrient content and thereby improves its fertility, as previously discussed. This increased fertility translates into increased yields that can be measured by carefully controlled crop trials.

Table 3 presents the results[14] of some of the tests that have been carried out in America on commercially available compost made from co-composted sewage sludge and Municipal Solid Waste.

Table 3: Increased Crop Yields from Composting

Research Organisation	Crop Type	Compost Rate (t/ha)	Results
University of Tennessee 1996 (Field Trial)	Snap Peas	12.4	+100% yield (t/ha)
University of Florida 1996 (Field Plots)	Citrus Trees	247	52% plant weight
University of South Carolina 1995 (2 year Field Trial)	Cotton	37	+8% (yr 1) +23% (yr 2) lint weight
University of Georgia 1995 (Field Plots)	Peanuts	24.7	+39% unshelled peanuts weight
University of Tennessee 1996 (Field Plots)	Tomatoes	6.9	+51% yield/ha
University of Florida 1996 (Field Plots)	Water Melons	99	+37% marketable yield
University of Florida 1989 (Field)	Bahia Grass	74 top dressed	+34% marketable yield
University of Florida 1989 (Field)	Papaya	74 tilled in	+31% diameter
Note 1: Original application rates and results measured in tons and acres and converted to tonnes and hectares respectively for this table.			

The results in Table 3 demonstrate the beneficial effect of adding loose compost to soils at varying rates. The actual increased yields obtained in any location will be dependent on many factors including crop, soil type, existing soil fertility, availability of water and climatic conditions. However, it is observed from Table 3 that in all of the trial conditions the addition of compost resulted in an increase in crop production.

Commercial trials have also been conducted with pelletised compost on pine trees grown for harvesting. These trials were conducted in Sweden in conjunction with AssiDoman, one of the worlds largest forestry companies.

Table 4: Increased Tree Growth from Composting

Research Organisation	Crop Type	Compost Rate (t/ha)	Results
AssiDoman 1991 (7 year Field Trial)	Pine Trees	3 6 12	+23% +12.5% +23% (year 1 growth of top sprout)
AssiDoman 1991 (7 year Field Trial)	Pine Trees	3 6 12	+41% +18% +55% (year 2 growth of top sprout)
AssiDoman 1991 (7 year Field Trial)	Pine Trees	3 6 12	+40% +51% +30% (year 7 growth of top sprout)
AssiDoman 1991 (7 year Field Trial)	Pine Trees	3 6 12	+1% +2% +2% (year 1 total height of seedling)
AssiDoman 1991 (7 year Field Trial)	Pine Trees	3 6 12	+7.5% +2% +7.5% (year 2 total height of seedling)
AssiDoman 1991 (7 year Field Trial)	Pine Trees	3 6 12	+17% +19% +19% (year 7 total height of seedling)

Table 4 presents the results of one of the AssiDoman tests which was conducted over a period of seven years. The pelletised compost was applied in one single application at rates of 3, 6 and 12 tonnes per hectare. The resultant tree growth was monitored by:

1. Measuring annual growth of the top shoot
2. Measuring overall height of tree

Table 4 shows that at all rates of application the compost produced beneficial results. The results also show that there was a continued benefit throughout the 7 year trial from a single application of compost pellets at the start of the trial. The increased growth reported in these trials will result in increased productivity either from an increased harvest or from a reduced time to market.

3.4. Reduced Need for Inorganic Fertilisers

When adding compost to soils to increase their SOC and improve their structure beneficial nutrients are also added. Table 5 shows the typical macro-nutrient and trace element content of a commercial pelletised compost made by composting organic waste with and without sewage sludge.

Table 5: Typical Nutrient and Trace Element Content of Commercial Pelletised Compost

Nutrient	Percentage % (by dry weight)	
	Organic only	Organic plus Sludge
Nitrogen (N)	1.3%	1.8%
Phosphorus (P)	0.66%	1.6%
Potassium (K)	0.66%	0.4%
Calcium (Ca)	2.8%	4.1%
Magnesium (Mg)	0.16%	0.27%
Sulphur (S)	0.32%	Not Available
Iron (Fe)	0.7%	Not Available
Copper (Cu)	0.011%	0.020%
Zinc (Zn)	0.017%	0.034%
Manganese (Mn)	0.13%	Not Available
Chlorine (Cl)	0.88%	Not Available
Boron (B)	Not Available	Not Available

With reference to Table 1 "Nutrient demands of 5400 litre/ha wheat crop", it can be seen that the nitrogen requirement for the wheat crop could be supplied by a single application of compost at a rate of 15.7 t/ha of compost made from MSW and sewage sludge. Such an application would typically release 30% of its nitrogen content per year thereby providing 85 kg/ha of nitrogen in the first year to supply the wheat crop. This same application of compost will also provide for all the other macro-nutrient and trace element requirements of the crop.

Alternatively a lower compost application rate could be used to maintain the SOC, provide the trace elements and to provide a proportion of the nitrogen requirements. This could then be supplemented with a reduced amount of inorganic nitrogenous fertiliser. The exact ratios of compost to inorganic fertiliser would be dependent upon many factors including: soil type; compost quality; fertilizer type; and land management scheme.

3.5. Use of Compost to Increase Soil Organic Content

The preceding subsections have identified many benefits of increasing soil organic content:

- Improved soil structure
- Reduced erosion
- Reduced desertification
- Increased fertility
- Improved crop yields
- Reduced chemical fertiliser requirements
- Slow release of nutrients matched to crop requirements
- Reduced eutrophication

However, it is important to ensure that carbon is added in the correct manner. The utilization of vegetable and animal wastes in crop production involves two definite steps:

(1) the formation of humus and its incorporation into the soil and

(2) the slow oxidation of the humus accompanied by the production of available nitrogen.

Both of these stages are brought about by micro-organisms for which suitable environmental conditions are essential. However, the requirements of the first phase, the preparation of humus and its incorporation into the soil mass, are so intense that if the process takes place in the soil itself, it will interfere with the development of the crop. The second phase, the utilization of humus, is much less intense and can proceed in the soil without harm to the growing plant. From the point of view of crop production therefore, it is a distinct advantage to separate these two stages and to prepare the humus outside the soil.

Composting is the aerobic process of preparing humus from plant and animal remains. It is usually undertaken away from, or on top of, the soil. There are various different techniques for composting which range from low-technology windrows to high-technology in-vessel composting systems.

The composting process is performed by micro-organisms which attack the fresh remains of plants and animals. A rapid and intense aerobic decomposition ensues. As soon as the readily decomposable constituents of the plant and animal remains (sugars, starches, pectins, celluloses, proteins, amino-acids) have disappeared, the speed of decomposition diminishes and a condition of equilibrium tends to become established. At this stage only those constituents of the original organic matter, such as the lignins, that decompose very slowly, are left. At this stage the compost is mature and ready for application to the soil. Under favourable conditions mature compost can be prepared ready for agricultural application in about 6 weeks.

Once the compost is applied, the lignins and the new substances, synthesized by the micro-organisms during composting, are incorporated into the soil to form the soil humus. After the production of humus and its incorporation into the soil mass, follows its utilization by the crop. Micro-organisms present in the soil, slowly transform the soil humus during which a moderate but constant stream of carbon dioxide is liberated. At the same time the nitrogen of the soil humus is converted into ammonia which, under favourable conditions, is then transformed into nitrate.

The CO_2 liberated during the transformation of the soil humus forms part of the Carbon Cycle as outlined in section 2.1. However, not all of the applied carbon is converted into CO_2. Work reported by Smith[15] shows that SOC is also increased by repeated application of organic matter. Although there appears to be no data for the increase in SOC as a result of the application of compost, much work has been carried out with animal manure. Smith reports that the percentage change in SOC can be calculated from:

$$y = 0.038x - 0.0538$$

where y = % change in SOC per year
and x = animal manure added (t/ha/yr)

Assuming that mature animal manure and mature compost act in a not too dissimilar manner, the potential SOC accumulation rates range from 0.14% per year (at 5 t/ha/yr) to 0.71% per year (at 20 t/ha/yr).

3.6. Additional Benefits

The application of compost has been found to provide additional benefits such as the suppression of plant pathogens. There are many references in the literature to trials conducted with compost amended soil and potting mixtures that have resulted in suppressed plant pathogens. Some typical trials are reported by Kannangara[16], Boulter[17], Tuitert G.[18], Zhang[19] and SerraWittling C .[20] amongst others.

The use of composts that successfully suppress plant pathogens will permit a reduction in the use of chemical controls, and slow the development of pesticide and fungicide resistance.

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4. Availability of Organic Materials in Europe

More sustainable farming methods, based on the incorporation of organic matter into the soil, rely on a steady supply of organic matter from compost and animal manures. In addition, the improvement of all marginal soils and the reduction of soil erosion across Europe will require a substantial and reliable supply of organic material.

4.1. European Land Benefiting from Increased Organic Content

No figures are currently available for the area of European land that is considered marginal or under threat of desertification. However, as the amount of land that is currently managed by organic farming techniques in Europe is small, it can be assumed that most European agricultural land would benefit from the annual application of at least a maintenance level of organic soil amendment.

The CORINE Landcover database contains detailed information on land use within the 27 European states covered by the European Environment Agency. From this and additional information from Sweden it is calculated that the member states of the European Economic Area EEA contain:

$68*10^6$ha of arable land
$73*10^6$ha of forests
$29*10^6$ha of pasture

Smith[21] calculates that 89% of Europe's land has an organic matter content of less than 5%.

4.2. Application Rate Required to Maintain Soil Organic Matter

Organic farming systems utilize crop rotation, mixed arable and livestock systems and set-aside or fallow years to provide a balance that maintains the soil's fertility and structure. Therefore it is safe to assume that almost all of Europe's agricultural land would benefit from the application of organic matter at a similar rate to that used on an average organic farm. Minister[22] runs a 320 ha organic farm in the UK with a mixture of arable, livestock and 10% set-aside. To maintain the current level of soil fertility, Minister requires an average of 3200 tonnes of compost per annum. This gives an average annual application rate of 10 t/ha/yr taking into account crop rotation systems and set-aside. This figure can therefore be used as the basis for a maintenance level application rate averaged across European agricultural soils.

Smith[23] estimates that if all animal manure produced in Europe was spread evenly across all agricultural land the achievable application rate would be 6.6 t/ha/yr.

In order to apply a maintenance level of 10 t/ha/yr would require an additional $231*10^6$ t/yr of organic material and to achieve the 15-20 t/ha/yr, to provide sufficient macro-nutrients for an average crop, would require an $911*10^6$ t/yr of organic material. There is therefore a substantial shortfall of available agricultural organic material across Europe.

4.3. Other Sources of Organic Material for Compost

Section 4.2 shows that to maintain current soil conditions across Europe requires the application of at least an additional $231*10^6$ t/yr of organic matter but where is this organic matter to come from. Part of the answer is to return to the land the organic matter that has been harvested from it. Most of the harvested materials end up being consumed within large urban conurbations and then discarded as either solid waste or sewage.

The amount of waste produced in the EEA countries in the year 2000 has been reported by the European Environment Agency as:

$182 *10^6$ t/yr MSW[24]
$7.2 *10^6$ t/yr (dry matter) sewage sludge in 1998[25]
$338 *10^6$ t/yr of commercial & industrial waste[24]

From the above amounts of total waste there will be approximately:

$101 *10^6$ t/yr of biodegradable MSW[26].
$7.2 *10^6$ t/yr (dry matter) sewage sludge in 1998
$60 *10^6$ t/yr of biodegradable commercial & industrial waste[26]

This biodegradable material is a valuable resource that could be recovered and safely returned to the land by use of suitable composting systems.

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21 Smith P. et al, Potential for carbon sequestration in European soils: preliminary estimates for five scenarios using results from long-term experiments, Global Change Biology (1997) 3, 67-69

22 Minister G, Average Annual Organic Requirements of 320 ha UK Organic Farm, Personal Communication, 1996.

23 Smith P et al, Meeting Europe's climate change commitments: quantitative estimates of the potential for carbon mitigation by agriculture, Global Change Biology (2000) 6, 525-539

24 Environmental Signals 2001, European Environment Agency, pp100

25 Environmental Signals 2001, European Environment Agency, pp103

[26] Based on UK average biodegradable waste fractions as reported in Waste Strategy 2000: Part 2 pp13, British Government - Department of Environment Transport and the Regions

5. Benefits of Composting Waste

5.1. Why Compost Biodegradable Wastes?

Section 3 clearly demonstrates the significant benefits of increasing the organic content of agricultural land while section 4 demonstrates that we need to utilize all available organic material to help maintain Europe's agricultural land in a sustainable manner. Therefore it is essential that wherever practicable, and safe, all high grade organic wastes (biowastes) are composted.

As previously discussed, the EEA member states currently produce an estimated:

101 $*10^6$ t/yr[27] of biodegradable MSW.
7.2 $*10^6$ t/yr (dry matter) sewage sludge in 1998
60 $*10^6$ t/yr[26] of biodegradable commercial & industrial waste

Currently much of this waste is landfilled or incinerated with more emphasis being placed on incineration since the adoption of the EU Landfill Directive 1999/31/EC. Both of these technologies are designed to dispose of an unwanted waste product but as shown in the previous sections biodegradable waste should be regarded as a beneficial source of organic material. The biowaste produced within the EEA could, with suitable safeguards, be converted into $90*10^6$ t/yr of compost that would contribute a significant proportion of the $231*10^6$ t/yr shortfall previously identified.

5.2. Biowastes for Composting

Much attention is currently focused on the disposal of Europe's biodegradable waste streams. The European Commission is currently consulting on two draft Directives: Working Document on Sludge – 3rd Draft; and Working Document Biological Treatment of Biowaste – 2nd Draft. The thrust of both of these documents is the environmentally beneficial use of both waste streams in an way which does not pose a threat to human, plant and animal health.

It has been shown that both sewage sludge and the organic fractions of our solid waste streams are required to help maintain European agriculture in a sustainable manner. The two working documents from the European Commission, by setting stringent targets, have made it clear that Europe is no longer prepared to accept the land-spreading of untreated sewage sludge nor the application of compost contaminated with plastics and glass or containing high levels of heavy metals. The challenge therefore, is to find a way in which the maximum amount of biowaste can be incorporated back into the soil, safely and in a socially acceptable manner.

High quality composting offers a combined solution for both organic waste and sewage sludge. By co-composting these materials the high carbon content of the drier solid waste is complemented by the high nitrogen content of the wetter sewage sludge. The combination of these two waste streams, in the correct quantities, using good process control, allows ideal composting conditions to be achieved and maintained. The process of composting, providing it is carefully controlled and monitored, also sanitises the wastes and produces a product that can be land-spread without posing a threat to human, plant or animal health. The composting process also produces a product that is pleasant to handle and full of natural, beneficial organisms that promote plant growth. Furthermore, good compost can be land-spread without any odour problems.

5.3. Separation of the Organics

Sewage sludge is already a well separated waste stream but in many European countries it can contain unacceptable levels of heavy metals from industrial effluent. In many instances this is not caused by accidental pollution but is a deliberate action by the water companies to dilute industrial effluent. Disposal of these effluents is a very lucrative business. This practice must be outlawed by European legislation to maximise the availability of organic resources from sewage sludge.

Unlike sewage sludge, solid waste streams are not usually well sorted and they too suffer from contamination problems. In order to produce a good quality of compost from biowaste requires careful control of the composted waste stream. It is important to avoid hazardous waste becoming mixed with the biowaste. The best way to achieve this is through separate collections (source separation) of the organic fractions of the solid waste streams. This is relatively simple and reliable when dealing with commercial and industrial wastes. However, the largest source of organic material comes from the domestic Municipal Solid Waste (MSW) stream. This is the waste generated by each and every one of us during the course of our daily lives. Source separation schemes are currently employed for some of this waste stream but cannot be relied upon to generate a 100% clean stream of organics for composting.

5.4. Problems Encountered with Source Separation of Domestic Waste

Many EU member states, the UK for example, do not yet have separate collections for biowaste. The EU Landfill Directive requires all member states to very substantially reduce the amount of biodegradable waste going to landfill. The EC working document on biowaste also proposes the separate collection of organic wastes. However, it will take many years to fully implement this due to existing long-term waste disposal contracts.

In other EU member states where source separation schemes already exist they do not guarantee a 100%

contaminant-free stream of organics. In tests carried out in Sweden in 1996, supervised by an independent group of researchers, the composition of waste received from households in three different Swedish municipalities was examined. Each of the municipalities used different source separation schemes but all were instructed to place their biodegradable waste into one bin ready for composting. However, even the best source separated waste was discovered to contain between 15% and 25% of inorganic materials and physical contaminants. The municipality that produced this waste had more than ten years experience in source separation of waste.

Since the 1996 tests the composting facility at Stora Vika, Sweden, has been composting household waste from different Swedish municipalities and large source separation errors are still found in the waste from all municipalities. This shows that any composting plant, dealing with domestic wastes, needs equipment for pre-sorting, screening and cleaning because source separation and separate collection does not **guarantee** a clean stream of biowaste.

With suitable screening and cleaning systems it is possible to produce a large quantity of high quality compost from European household waste. At the Stora Vika facility, they have implemented a sophisticated system of screening equipment both before and after the composting stage. This screening removes metals, plastics, glass and small items such as needles, sharp splinters of glass, etc. from the final compost. The Stora Vika facility also includes on-site analysis of incoming waste streams, curing compost and final shipped product. In this way it is possible to produce a consistently high quality compost from Municipal Solid Waste with the addition of sewage sludge if required.

5.5. Maximising Availability of Organics

A significant amount of organic material cannot be easily separated from inorganic wastes by conventional techniques. Examples of problem materials are:

- Staples from magazines
- Paperclips from letters, documents etc.
- Plastic windows from envelopes
- Glue from magazine bindings and envelopes
- Composite materials like Tetra-Packs
- Waxed cardboard cartons

A suitable composting process can cost-effectively separate the valuable organic materials from such wastes and even sort out the inorganics for further recycling or energy recovery. Figure 1 shows the results of composting a tetra-pack for three days in an in-vessel composting system. During the process the organic cardboard outer layer has been stripped away by the microbes and turned into a rough compost. The plastic inner layer remains, cleaned and ready for recycling or recovery.

Other materials can present problems due to their wildly fluctuating market driven value. Newspaper and cardboard are two such examples where their market value can actually become negative, making their recycling expensive and erratic. Both of these materials are valuable sources of organic carbon and represent approximately one quarter of the domestic waste stream. These materials can benefit the composting process by absorbing excess moisture released from food waste. Composting paper and cardboard enables their organic carbon content to be economically recycled back to the producing soils at a stable and financially viable market rate.

After Day 1 **After Day 2** **After Day 3**

Figure 1: Results of Composting a Tetra-Pack

5.6. Advantages of Composting Mixed Waste

During the test composting described in section 5.4 it was discovered that the nutrient content of the compost decreased with increasing degree of source separation. This was attributable to the associated reduction of sewage sludge that was required to compensate for the increased moisture content of the better source separated waste streams. The best source separated household waste, without cardboard and paper, contained more moisture, therefore the sewage sludge had to be reduced to maintain the optimum moisture level for composting.

Analysis shows that sewage sludge normally contains a higher nutrient content than household waste and also contributes to 50%–80% of the phosphorus in the composting process. Phosphorous for agricultural use is normally derived from rock phosphate of which there is an acute shortage in many areas of Europe. Therefore the composting of sewage sludge will help to preserve the phosphorous content of the agricultural soils.

For optimum composting, the C:N ratio and the moisture content are very critical parameters. Paper and cardboard are both dry and carbon-rich and can therefore be used to control the C:N ratio and moisture content. This permits incorporation of increased levels of sewage sludge to raise the compost nutrient content, as demonstrated in Table 5.

There are also often logistical problems when collecting source separated household waste. In these situations the collection of paper and cardboard together with other fractions of biowaste can offer logistical advantages which should be exploited to maximise the amount of organics collected.

Composting of mixed waste in a carefully controlled manner, utilising the micro-organisms within the composting process to recover all of the organic content, can result in very economic solutions to the separation of wastes for recycling and energy recovery.

Figure 2 shows what could be achieved using advanced in-vessel composting systems on typical UK mixed Municipal Solid Waste (MSW). Mixing 100 tonnes of MSW with 50 tonnes of good quality sewage sludge would result in 32 tonnes per day of pelletised compost, 7 tonnes per day of metals for recycling and 18 tonnes per day of combustibles which would be mainly plastics. These plastics, which would be clean and free of organic residues, could then either be sent for energy recovery using the cleanest technologies or utilised in a range of new construction materials like Plascrete. Use of such a system would result in the maximum recovery of organic material and sanitation of the waste materials, with only 18 tonnes per day of inert reject material requiring landfill.

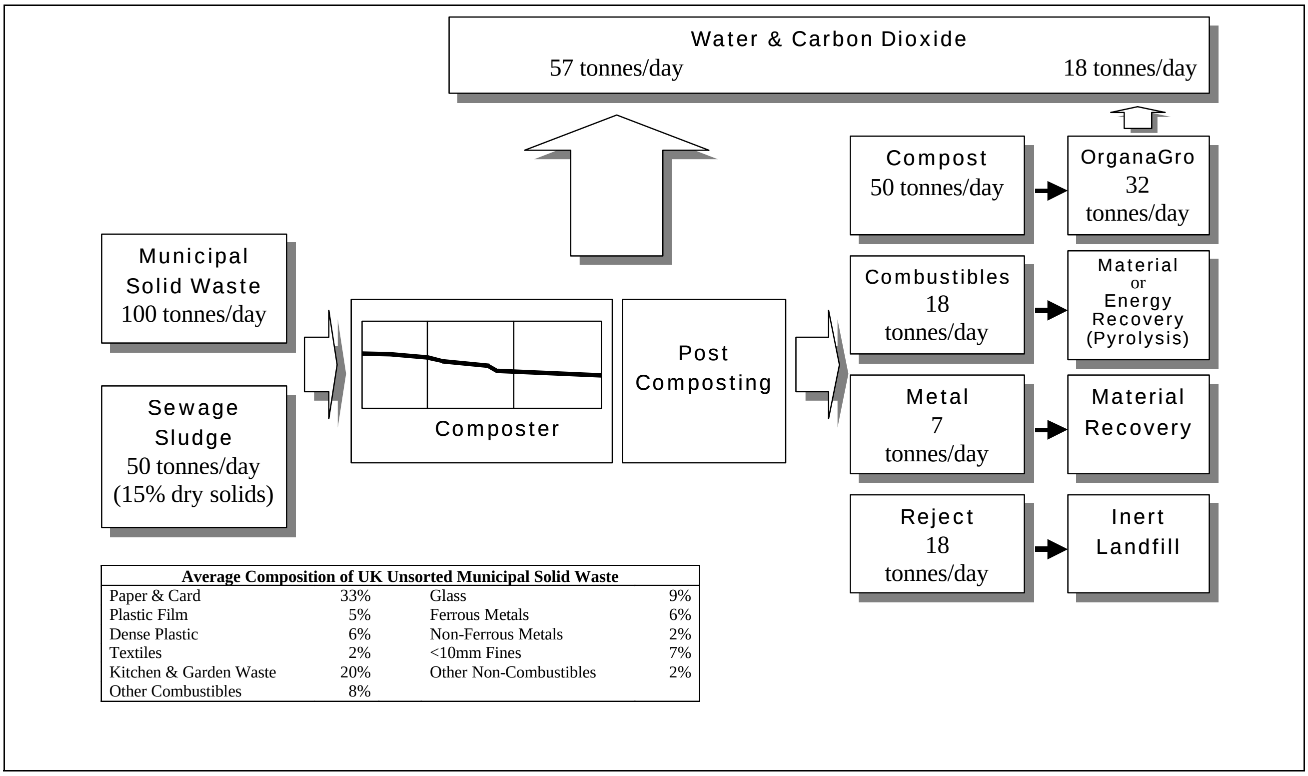

Figure 2: Typical Mass Balance from Composting and Recycling of UK MSW

5.7. Recovery of Packaging Waste

The Packaging & Packaging Waste Directive 94/62/EC places a requirement on all member states to recycle packaging waste and hence reduce the final disposal of such waste. Over one quarter of the municipal waste stream is packaging waste which can be readily recycled or composted once separated. Figure 1 shows how composting waste can help to maximise this recycling rate.

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[27] Based on UK average biodegradable waste fractions as reported in Waste Strategy 2000: Part 2 pp13, British Government - Department of Environment Transport and the Regions

6. Compost Quality Issues

Two of the most important properties of any product are its quality and reliability. The recent past has seen many inferior composts enter the marketplace with poor consistency, poor maturity and sometimes containing a large amount of physical contaminants. Many of these products carried no information on the nutrient content or the level of heavy metal contamination. This might not pose a problem for the home user who only applies a small amount of compost to an area of land on an irregular basis. However, the professional farmer, horticulturist or landscaper, demands a consistent product with known nutrient and contaminant levels, and which is of dependable quality.

To ensure the quality of compost made from variable waste streams a composting plant needs a quality assurance programme that includes:

- monitoring and screening of the incoming material
- monitoring and control of the composting process
- sanitation of the compost
- destruction of viable weed seeds
- screening and cleaning of the final compost
- analysis and certification of every batch of compost produced.

6.1. Monitoring and Screening Systems

These need to be capable of detecting and removing most metals prior to composting, as the acidic conditions during composting will leach metals from any exposed surface.

6.2. Control of the Composting Process

To produce the best possible compost requires careful control of C:N ratio, moisture content and airflow throughout the entire process. It is also very important to ensure that all of the composting material reaches a sufficiently high temperature to ensure complete pathogen destruction. This amount of monitoring and control can usually only be provided by commercial in-vessel composting systems. The quality control monitoring points of one such system are shown in Figure 3.

6.3. Compost Sanitatiion

The safety of compost depends upon many factors including:

- removal of physical contaminants like glass and needles
- destruction of pathogenic bacteria and viruses
- limitation of heavy metals
- control of nutrient loading

The sanitation of compost made from biowaste, with or without sewage sludge, is a two-stage process. The first stage is the destruction of pathogens by temperature and time.

Much research has been conducted on the sanitation of sewage sludge and co-composted sewage sludge with MSW. Burge[28] has studied the amount of time required to sanitise co-composted MSW and sewage sludge. Burge chose to use an indicator organism (f2 bacteriophage) which has a higher resistance to destruction by heat than most enteric pathogens including Salmonella Senftenberg 775W, Adenovirus, 12

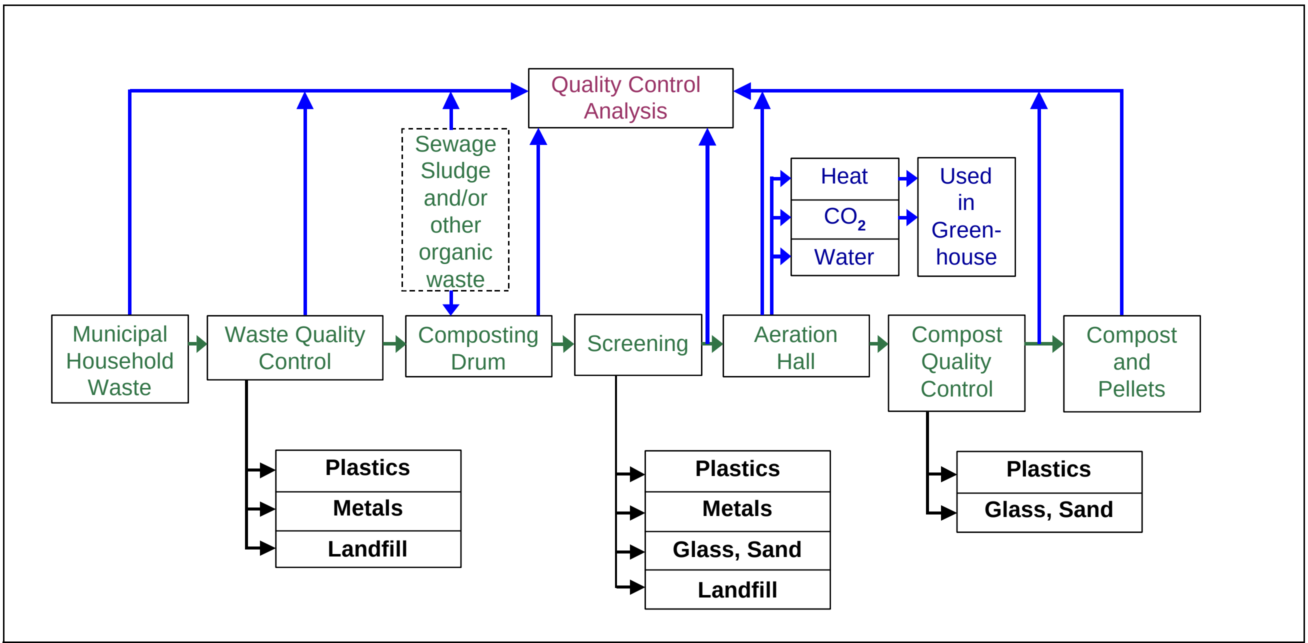

Figure 3: Process Flow and Quality Control

NIAID, Poliovirus type 1, Ascaris ova and Histolytica cysts. Burge monitored the time required to deactivate various percentages of the indicator organism and from these results was able to produce a set of curves showing the temperature-by-time regimes necessary to deactivate the desired number of f2 bacteriopharge. The Burge temperature-by-time curve for 125log deactivation (a reduction of 10^{125} in the number of viable organisms) shows that sanitation will be achieved within 0.3 days at 70°C, 1 day at 65°C, 5 days at 60°C and approximately 15 days at 55°C.

The work carried out by Burge is also supported by more recent work carried out by the Swedish University of Agricultural Sciences[29]. The Swedish report considered the deactivation of the following pathogens: Vibrio Cholerae, Entamoeba Histolytica, Taenia, Salmonella, Shigella, Ascaris, and Entero-Virus. The report establishes a 'Safe Zone' characterised by the following temperature/time periods: ≥62°C for 1 hour, ≥ 50°C for 1 day, ≥ 46°C for 1 week.

The second stage of the sanitation process is prevention of re-growth of pathogens in the compost due to competition from the micro-flora present in cured compost. Work conducted by Burge and Millner[30] showed that salmonellae inoculated into compost samples died out unless the compost had been previously sterilised to kill all the indigenous micro-flora. It was found that compost from curing piles at or near ambient temperature were completely suppressive of salmonellae growth.

Therefore using the most conservative 125log deactivation curve of Burge to define the sanitation limit, the temperature/time periods required to ensure sanitation are as shown in Table 6. Should the composting be undertaken in windrows then a safety factor must be added as recommended in the EC working document on biowaste.

Table 6: Temperature/time required to sanitise compost

Min. Temp. (C)	In-Vessel Composting		Windrow Composting	
	Treatment Time	Turnings	Treatment Time	Turnings
70	8 hours	N/A	-	-
67.5	14 hours	N/A	1 week	2
65	1 day	N/A	1 week	2
62.5	1.5 days	N/A	10 days	4
60	4 days	N/A	2 weeks	5
57.5	9 days	N/A	3 weeks	8
55	2 weeks	N/A	4 weeks	10

Using appropriate temperature/time regimes in in-vessel composting systems, where all of the composting material is guaranteed to reach the working temperature for the whole residence time, will ensure the destruction of viruses including Foot and Mouth Disease Virus (FMDV)[31]. In-vessel composting can therefore provide, safe, effective control of some of our most infectious diseases.

6.4. Trace Element Levels

Heavy metal, or trace element, contamination in compost must be kept at a level that will not cause harm to human health or the environment. However, the issue of trace element levels in compost is not as straightforward as sanitation. In the case of sanitation the ideal limit is for there to be zero pathogenic bacteria or viruses present in the compost. However, there is no such ideal zero limit for the trace element content of compost.

Some metals such as zinc, copper and iron are essential micro-nutrients. Other metals are not considered essential to plant growth but are nevertheless present in the background soils, to a greater or lesser extent, dependent upon location. Therefore what can be considered an acceptable level of trace elements in compost will be dependent upon many factors including bio-availability, soil type, location and land use. In some areas it may be beneficial to increase zinc and copper levels to improve plant health and reduce plant diseases. In other areas with low background levels of cadmium and arsenic it would be unacceptable to apply compost with high levels of these elements over a prolonged period.

One approach would be to ensure that soils are not polluted with sufficient heavy metals to cause an increased intake in human diets either directly from crops or through accumulation in the meat of farmed animals feeding on composted pastures. However, the availability of metals is not just a function of their concentration in the soil. Many factors including cationic exchange mechanisms determine the actual availability of heavy metals to the growing plants. These factors vary with soil type and organic content and can therefore not only vary across a nation but also at a more local level from field to field across a single farm.

For trace elements to be available for uptake by the growing plants they need to be water soluble. The amount of an element that is water soluble depends upon its form, the pH of the soil and rainwater and the organic content of the soil. Many studies have been conducted for the US EPA during the 1980's and 1990's. Most studies use the Sequential Chemical Extraction (SCE) process as reported by Tisdell & Breslin[32]. This process seeks to partition the elements into five phases: exchangeable, carbonate, iron & manganese oxide, organic and residual with only the exchangeable fraction expected to be readily available for leaching. In the studies reported by Tisdell & Breslin, the exchangeable fraction of Pb, Cr, Cu, Ni, Zn and Fe were <4% with the exchangeable fraction of Cd being around 11% of the total elemental content.

Tests using the Synthetic Acid Rainwater Cascade (SRC) method, conducted by Tisdell & Breslin, Henry & Westcott[33], Simms & Kline[34] show that the water solubility of trace elements decreases in order Ni>Cu>Zn>Cd>Cr>Pb=Fe with the solubility of Fe being approximately the same as for Pb. All of the reported SRC tests show that with the exception of Ni only small percentages of the elements present in the compost are actually leachable. Nickel is the most leachable element with reported availability ranging from 8.1% -56%.

Further tests Leita & De Nobili[35] show that the water-soluble fraction of elements substantially decreases with increasing maturity of the compost. This is despite the fact that the concentrations of the elements actually increase with increasing maturity due to organic matter loss.

The evidence therefore suggests that the total elemental content of compost does not correlate well with the fraction of the elements that are environmentally available. These reported results have been obtained by testing composts, therefore further tests would need to be conducted to determine the behaviour in compost amended soils.

Another approach would be to limit the amount of trace elements in compost to a level that ensures that the amounts of available trace elements in the soil are not increased through multiple applications of the compost. There is however a fundamental problem with this approach also. Pendias and Pendias[36] have compiled trace element data on soils from over 1000 global sources. Trace element concentrations are due to many factors including the natural underlying geology of an area. The work of Pendias and Pendias demonstrates that across Europe, average levels of copper vary from 6ppm to 37ppm and zinc from 24ppm to 125ppm. Comparing the range of these metals within individual European states reveals an even greater variation in concentrations with maximum levels in excess of 50 – 100 times that of the lowest concentrations. Similar variations are noted for all trace elements.

With such diverse concentrations across Europe and indeed within individual member states, it is not practicable, nor indeed desirable, to set a standard for trace element concentration in compost for the whole of Europe. What might be too high and cause an increase in trace elements in one country's soils might actually be so low that it causes a reduction in naturally occurring levels in another country. Such changes could impact on local crops and could conceivably lead to reduced biodiversity.

There is however a very real need to set some sort of upper limit on the acceptable concentration of trace elements in compost to prevent unscrupulous producers dumping heavily contaminated products on the land. A reasonable approach might be to set an absolute limit on the permitted trace element levels in compost for food and fodder crop production and another higher level for use for land reclamation, sports pitches, etc. These levels could be set to ensure that application of the compost over a given period would not dramatically increase the highest naturally occurring levels across Europe.

The above postulated maximum limit should then be supplemented by application limits designed to control the trace element loading applied to individual fields/farms. This would need to be supported by analysis of local background trace element levels prior to application of the compost.

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28 Burge W.D., Monitoring Pathogen Destruction, Biological Waste Management and Organic Resources Laboratory, Agricultural Research Service, USDA, Beltsville, Maryland.

29 Report 10/1997, Swedish University of Agricultural Sciences

30 Burge W.D. Millner P.D. et al, Regrowth of Salmonellae in Composted Sewage Sludge, US EPA, Water Engineering Research Laboratory, Cincinnati

31 Garland AJM, Acting Head, Department of Exotic Disease, Institute for Animal Health, Pirbright Laboratory, UK. 27/06/2001 - Personal Communication

32 Tisdell & Breslin, Characterisation and Leaching of Elements from Municipal Solid Waste Compost Compost, J.Environ. Qual. 24:827-833 (1995)

33 Henry C.L. & Westcott H. Assessing the toxicity and uptake of trace metals by plants grown in compost-amended soil., Proceedings of Composting Council's 3rd National Conference: Technical Symposium Washington DC – 1992

34 Sims J.T. and Kline J.S. Chemical fractionation and plant uptake of heavy metals in soils amended with co-composted sewage sludge , J.Environ. Qual. 13(3):344-349

35 Leita L. and De Nobili M., Water-soluble fractions of heavy metals during composting of municipal solid waste. J. Environ. Qual.20:73-78

36 Kabata-Pendias A. and Pendias H., Trace Elements in Soils and Plants 2nd Edition, CRC Press 1992, ISBN 0-8493-6643-7

7. Conclusions

1) European agricultural land is coming under pressure from other land use requirements, desertification and erosion. This is happening at a time when the increasing human population requires more food and fodder crop production from the land. To increase production from existing land in a sustainable manner and to reclaim degraded land throughout Europe requires the soil organic content to be increased by the regular addition of organic material at a rate of 10-20 t/ha/yr.

2) There is insufficient organic material available from animal manures and cereal straw to maintain Europe's agricultural land. Additional organic material is available from the organic fraction of commercial, industrial and domestic waste. This waste derived organic matter could be safely composted to return up to $90*10^6$ tonnes of organic compost per year to agricultural land.

3) Source separation schemes cannot be relied upon to guarantee safe and reliable compost from domestic waste streams. To ensure safety and to enable post-consumer wastes to be reliably composted requires screening and cleaning of all waste streams, however collected, prior to composting. In-vessel composting systems with good process and quality control can produce high quality, safe and reliable compost, for beneficial use within agriculture, from mixed waste streams.

4) Analysis of every batch of compost for contaminant levels, including heavy metals and physical contaminants, together with closely monitored sanitation temperature-time regimes, will guarantee protection for human health and the environment. Compost can be produced that is free of pathogenic organisms and viruses that might be present in the incoming waste streams and low contamination levels can be guaranteed. In-vessel composting systems where all the material is subjected to a temperature of 70°C for 24 hours, provide protection against the spread of some of the most virulent diseases including Foot and Mouth Disease Virus.

5) Trace element levels within European soils vary so greatly that it is impracticable to set a European wide limit for trace metal concentrations within compost.

6) The regular application of compost to European soils will increase their productivity, help suppress plant pathogens and reduce the need for chemical fertilisers, fungicides and pesticides.

7) The use of compost to supply the nitrogen demands of crops will reduce the need for nitrate fertilisers that are the prime cause of eutrophication of ground water, rivers and lakes. The release of nitrogen from compost will always be matched to the demands of the crops as required by the Nitrates Directive 91/676/EEC.

8) The soil forms an important carbon reservoir within the land-based Carbon Cycle accounting for approximately half of all the carbon within the land-based carbon cycle. Due to chemical intensive farming practices and/or lack of organic fertilisation, nearly 90% of Europe's soils now contain less than 5% organic matter. The annual application of organic materials to these soils will increase the Soil Organic Content (SOC) by 0.32%/yr at an application rate of 10t/ha/yr and by 0.7%/yr at the higher application rate of 20t/ha/yr.

9) Increasing the organic content of European soils will remove carbon from the atmosphere thereby helping to stabilise concentrations of CO_2.

10) Increasing soil organic content will help to improve the structure of the soil reducing soil erosion, desertification and degradation.

11) The European Community Sixth Environmental Action Programme highlights four Priority Areas for action. Composting the organic fraction of the European waste stream will help implement each of these Priority Areas as shown:

    Tackling Climate Change:
    Objective **-** *to stabilise the atmospheric concentrations of greenhouse gases at a level that will not cause unnatural variations of the earth's climate.*

    Regular application of compost to European soils will increase their organic content and remove a substantial amount of carbon from the atmosphere.

    Nature and Bio-diversity – protecting a unique resource:
    Objective – to protect and restore the functioning of natural systems and halt the loss of bio-diversity in the European Union and globally. To protect soils against erosion and pollution.

Increased soil organic content through the application of compost will improve the structure of European soils thereby reducing erosion and desertification. The composting of MSW and sewage sludge by tightly controlled in-vessel composting systems will protect the soil from pollution and pathogens.

Environment and Health:
Objective – to achieve a quality of the environment where the levels of man-made contaminants, including different types of radiation, do not give rise to significant impacts on, or risks to, human health.

The use of compost on European soils will substantially reduce the need for agro-chemical fertilisers, fungicides and pesticides thereby reducing environmental pollution.

Sustainable use of natural resources and management of wastes:
Objective – to ensure the consumption of renewable and non-renewable resources does not exceed the carrying capacity of the environment. To achieve a de-coupling of resource use from economic growth through significantly improved resource efficiency, dematerialisation of the economy, and waste prevention.

Composting solid waste and sewage sludge provides an environmentally beneficial way of managing both biowastes. It recycles organic carbon back to the producing land from where over 90% of all human food, livestock feed, fibre and fuel originate. The application of compost protects the soil which is a non-renewable resource. Using compost to replace inorganic chemical fertilisers reduces energy consumption and the use of minerals.

8. Recommendations

1) The European Community Sixth Environmental Action Programme highlights four Priority Areas for action. The organic fraction of domestic, commercial and industrial wastes and sewage sludge must be composted to implement all four Priority Areas of the EC Sixth Environmental Action Programme and in so doing make a significant contribution to the improvement of the European environment.

2) The amount of sewage sludge and biodegradable waste that is recycled back to agricultural land must be maximised to sustain agriculture and reduce atmospheric carbon. This should be undertaken as a matter of priority to reduce global climate change. European Directives need to reflect this and treat both sewage sludge and biodegradable solid wastes as a valuable resource. Serious consideration must be given to unifying the management of sewage sludge and the management of biodegradable waste into a single Composting Directive that incorporates both.

3) Sewage sludge must be protected by European legislation against deliberate pollution during disposal of commercial and industrial effluents.

4) All high quality sewage sludge must be composted and returned to the land to conserve scarce phosphorous reserves.

5) Compost should be used to supply the nitrogen demands of agricultural crops at the rate required by the growing crops. This will meet the requirements of the Nitrate Directive 91/676/EEC and reduce eutrophication and nitrate pollution of drinking waters.

6) A unified Composting Directive should be produced which sets practicable limits on acceptable concentrations of contaminants in compost. Such maximum limits should be set sufficiently high to accommodate the diverse range of trace elements in European soils. The maximum limits must be supported by limits on application rates designed to prevent excessive increases in naturally occurring and available trace element levels. These application rate limits must be implemented at a local level after analysis of the background levels in the soils to which compost is to be applied.

7) All composting systems should **not** be considered equal. High technology in-vessel systems offer safe solutions to the composting of mixed waste, including food waste and sewage sludge, whereas lower technology systems such as windrows can probably only be considered safe for source separated green wastes.

8) Some in-vessel composting systems promote a very rapid and intense aerobic decomposition phase, usually within the first 3 days. During this intense composting phase, micro-organisms attack the readily decomposable constituents of the plant and animal remains (sugars, starches, pectins, celluloses, **proteins**, amino-acids) which are converted into new compounds. Research should be conducted to establish whether such systems can convert and render harmless the prions associated with Bovine Spongiform Encephalopathy (BSE).