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A review of solid waste management by composting in Europe

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ABSTRACT

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A survey of the waste disposal situation in the Federal Republic of Germany and the role of composting is given. A description of the technique of composting, and a representation of the Duisburg-Huckingen composting plant as an example for the application of composting technique follow. Other aspects of this review are the economics of composting as well as marketing and sales, distribution and pricing criteria for compost.

WASTE DISPOSAL IN THE FEDERAL REPUBLIC OF GERMANY

The amount of wastes generated in the Federal Republic of Germany (F.R.G.) has increased from 64.4 million tonnes (Mg) in 1977 to 86.1 million tonnes in 1984 [1]. More than 50% of the total is taken up by construction and demolition waste. The second largest category relates to municipal solid wastes (MSW) including household, trade and market wastes, individual household items and street cleanings. MSW accounts for 36% of the total quantity of generated wastes.

Wastes for disposal are collected both by public sanitation departments and private waste disposal companies, who collect both domestic and industrial refuse. Whereas all of the construction waste goes to landfill sites, MSW is disposed of as follows: sanitary landfill 75%; incinerators 22%; composting 1.6%; other methods 1.4%.

Composting plays only a small part in waste management at the present time, although, interest is growing. In the F.R.G., there are at present 16 composting plants processing domestic refuse. In addition, there are research plants and those restricted to composting of garden waste, totaling another 25. Traditional domestic refuse composting plants treat the waste generated by 2.5

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million people, i.e., 4% of the population of the F.R.G. Due to the lack of verified informations on composting plants in other parts of Europe, further data on operating composting plants are not available.

THE TECHNIQUE OF COMPOSTING

Composting is a fundamental natural decomposition process. Treatment of agricultural and animal wastes is as old as farming and animal husbandry. Practical experience in producing good compost goes back some thousands of years. However, a scientific understanding of the biological, and particularly the microbiological processes involved, has only come about in the last sixty years. The decomposition and fermentation processes involved when refuse is artificially treated with air in composting windrows are similar to those involved in the decomposition of organic matter in nature: similar micro-organisms are involved. In the ultimate this leads to complete mineralization (i.e. production of water, carbon dioxide and inorganic salts).

Not all kinds of waste are suitable for composting. An examination of the composition of household waste in the F.R.G. from 1979 to 1985 concluded that only 68% was suitable for composting, and this reduced to 56% after separation of paper and cardboard. Typical composition data and compostable contents of MSW are given in Table 1. Wastes with a high content of organic matter are particularly suited, such as from domestic refuse, sewage

TABLE 1

Average composition of municipal solid wastes in the Federal Republic of Germany, 1985 [10]

Fraction	% by weight
Organic material (putrescribles)[a]	29.9
Paper[a]	12.0
Cardboard	4.0
Packaging material compound	1.9
Ferrous metals	2.8
Non-ferrous metals	0.4
Glass	9.2
Plastics	5.4
Textiles	2.0
Minerals	2.0
Material compound	1.1
Disposable napkins	2.8
Problematic wastes	0.4
Fraction sized 8 mm[a]	10.1
Fraction sized 8 to 40 mm[a]	16.0
Total	100.0

[a]Material suitable for composting.

sludge, leaf, grass, hedge trimmings, manure from stables, market waste and agricultural surpluses.

The processing procedure is divided into stages: (1) preliminary treatment of feedstock, with separation of undesirable contents; (2) fermentation with aeration and turning; and (3) grinding, screening and final separation of undesirable items from the product.

Several methods of composting are in use which differ primarily in the fermentation process employed: (1) static fermentation in naturally or artificially aerated windrows, artificially aerated composting drums and hangars, naturally aerated piles and windrows moved in regular intervals; or (2) dynamic fermentation in artificially aerated fermentation towers with one or more stories or artificially aerated rotating composting drums.

EXAMPLE FOR AN EARLY COMPOSTING PLANT: DUISBURG–HUCKINGEN

Feedstock to the plant

An example of composting in practice is the plant at Duisburg–Huckingen, the oldest in the F.R.G., which has been in operation for thirty years. It was originally constructed to compost the waste generated by 150 000 inhabitants of the city of Duisburg. Nowadays, for nine months of the year, the domestic waste of 95 000 residents is treated. In the remaining three months of the year, during the fall, the plant treats fallen leaves collected in the city. Leaf composting is carried out with the equipment used at other times of the year for domestic waste. Technically it would be possible to process waste and leaves together, but this is not recommended because of particles of glass and plastics in the domestic waste. Instead, garden wastes and manure from the city's zoological gardens and slaughter house are mixed and composted with the leaves. This combination also enables the heavy metal contents of the compost to be minimized. The Duisburg plant is also used to compost separately collected paper if market conditions do not allow an economical production of recycling paper products.

The processing of only selected materials is possible because the city of Duisburg has access to an incineration plant maintained and operated by the city of Duisburg and other nearby cities of the region.

Plant operation

A diagrammatic representation of the Duisburg plant is shown in Fig. 1. Collection vehicles are weighed, then unloaded in a bunker. A steel plate conveyor on the floor of the bunker moves the waste towards a rubber belt conveyor, at the end of which a magnet separated ferrous metal scrap. Ferrous metal separation is followed by a sorting conveyor supporting the manual sep-

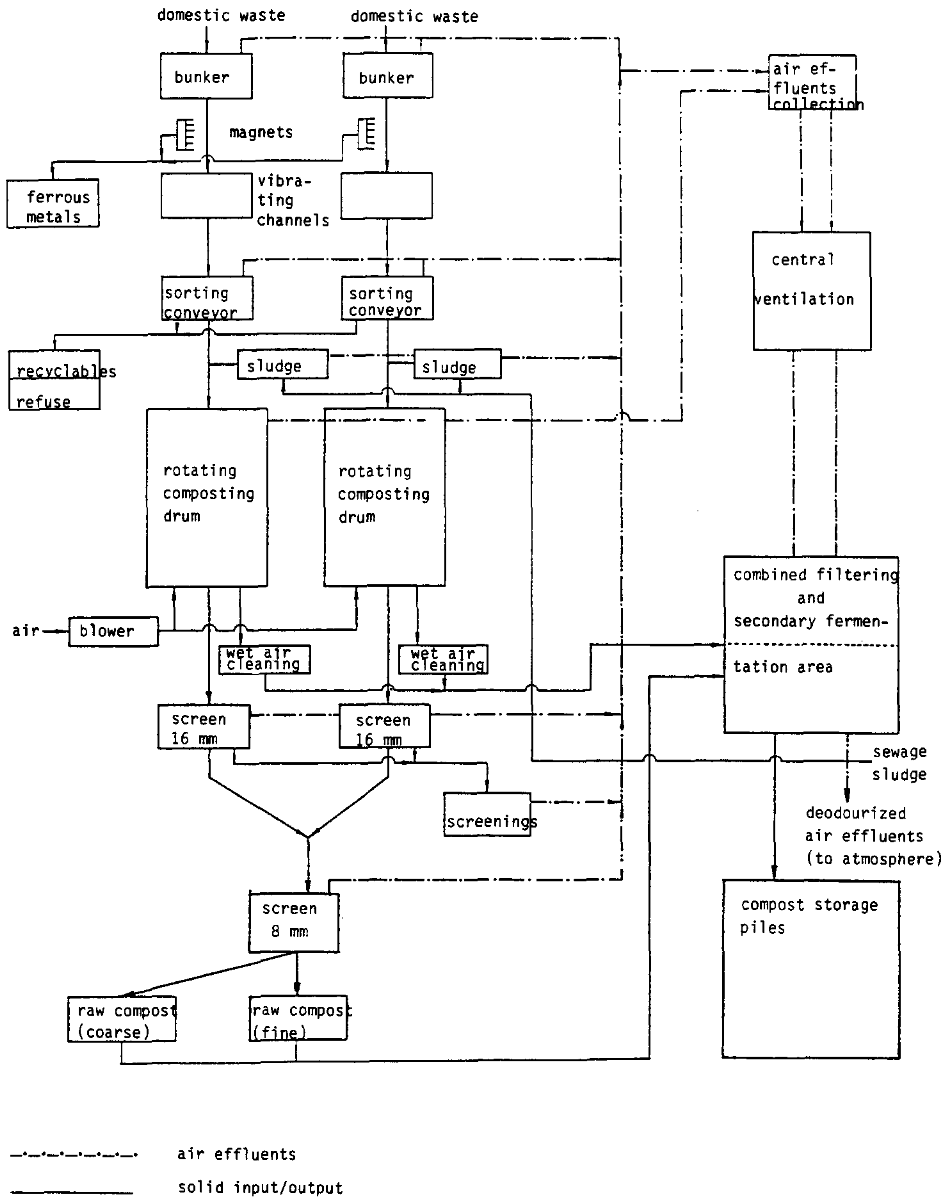

Fig. 1. Diagrammatic representation of the Duisburg–Huckingen composting plant.

aration of bulky waste, glass bottles and non-ferrous metals. Separated bulky waste, such as plastic film and covers, hard plastic and wood, are taken to an incineration plant. Separated glass, ferrous and non-ferrous metals are sold to the recycling industry according to market conditions.

Following the sorting conveyor, the waste goes to a rotating composting drum, called a "bio-stabilizer", responsible for grinding, mixing and rendering hygienic the incoming material. The Duisburg plant has two drums, each 26 m long and 3.5 m in diameter. The drums are filled to two-third of their volume. Effective grinding and homogenization is achieved by the action generated by the weight of the waste, the moisture content and the rotation. If the moisture content is not high enough, water or sewage sludge is added.

Long term tests on grain size have shown that after 36 h retention time and subsequent sieving at 18 mm, more than 74% of the material processed in the drum has a size less than 7 mm (average of 36 tests) [2].

For optimum development of micro-organisms, a temperature of about 70°C is maintained inside the drum. This temperature is high enough to eliminate pathogenic bacteria as well as weed seed during the 36 h retention. After this time, the material is sieved on a flip–flow screen with slit widths of 16 mm. At this stage of the process, the moisture content is about 50%. Oversize screenings, amounting to about 40% of the screen input, are incinerated. The remaining raw compost is screened a second time to achieve a final particle size of 8 mm.

The two product fractions – "raw compost" (particle size 8 mm or more) and "fine raw compost" (particle size less than 8 mm) – are then spread on a combined filtering and secondary fermentation area. The material is aerated using odour-contaminated air effluents from the composting plant itself. In this way, the compost removes odiferous substances from the air, whilst further aerobic digestion proceeds.

After three weeks of aeration, with controlled addition of water, the compost is moved to an intermediate storage area until sold to a customer. Here it is stored in piles 2.5 m high. The base of the storage area consists of a firm solidified surface. To avoid local anaerobic conditions, the piles are drilled after two days of storage with a special 250 mm drill. Drillings at intervals of 1 m ensure adequate aeration so that further moving or turning of the storage piles is not necessary.

THE ECONOMICS OF COMPOSTING

Investment criteria

The production of compost from MSW does not require extensive equipment, although this depends to some extent on the customer's quality demands. Simple but efficient equipment means low investment and operating costs. A recent survey shows that operating costs for composting lie in a range from DM 30 to DM 110 per ton of processed waste, equivalent to US$ 16 to

TABLE 2

Investment costs for composting plants

Investment	Costs (US$)
Machinery, electrical equipment	2 590 000
Buildings	2 440 000
Plant supplies	580 000
Total Investment Costs	5 610 000

TABLE 3

Operating costs for composting plants

Item	Unit	Costs/unit[a]	Units/yr	Total costs[a]
Electricity	kWh	0.08	950 000	75 500
Personnel				
preliminary sorting	person	32 000/yr	10	320 000
no preliminary sorting	person	32 000/yr	6	192 000
Depreciation, maintenance, repair	2.5% of investment costs for machinery and electrical equipment per year	–	–	64 750
Building maintenance	0.5% of investment costs for buildings	–	–	12 200
Operational supplies, fuels, lubricants, etc.	–	–	–	15 900
Contingency	–	–	–	6300
Total for plant				
with preliminary sorting				494 650
without preliminary sorting				366 650

[a]All costs in US$.

US$ 58 per ton*. The wide range reflects the need to study each potential plant location separately.

Variation in costs is caused for example, by the chosen method of preliminary treatment and composting, additional steps of compost processing, disposal of screenings at landfills or incinerators and safety standards and envi-

*In this and all subsequent conversions, an exchange rate of DM 1.90 = US$ 1 is used.

TABLE 4

Operating costs per Mg (US$)

Plant capacity	Presorting option	Operating costs
30 000 Mg/yr	No	12.20
	Yes, 10 persons	16.50
40 000 Mg/yr	No	9.15
	Yes, 10 persons	12.35
	14 persons	15.50

ronmental pollution control. Today and in future, environmental standards often require significant investment on treatment of leachates and on noise and odour control.

Costs

For the purpose of economic evaluation, it is proposed to take as an example a plant with a capacity of 30 000 tonnes (Mg) of domestic waste and 10 000 tonnes of sewage sludge per year. This is reckoned to be the maximum capacity available for most composting plants. Initial capital investment costs and operating costs are listed in Tables 2 and 3. Because the given calculation is based on presentation data, real costs may differ from those calculated by ± 10%. Operating costs per tonne, are shown in Table 4.

MARKETS FOR COMPOST

Technical considerations

Good quality compost is important, since composting is only suitable as a waste management tool if a useful distribution of the generated compost is achieved.

In 1985, 225 290 tonnes of compost were produced in the F.R.G. About three quarters of this was actually distributed. Of the total production, 45% was sold and 30% distributed free. Thus, distribution of the compost does not necessarily imply a sales credit to the plant. Table 5 gives data over ten years for the F.R.G.

When the first composting plants were designed and built in Europe, there was little experience in compost application. A wide range of possibilities had to be investigated. Standards had to be set. Then as experimentation proceeded, more and more applications were opened up.

Originally, the main use of compost was envisaged as agricultural, with its value determined mainly according to the presence of nutrients and the aim

TABLE 5

Distribution of compost in the Federal Republic of Germany [11]

Year	Plants in operation	Compost			Breakdown of distribution			
		Produced	Distributed		Compost sold		Distributed free	
		(Mg)	(Mg)	(% of total)	(Mg)	(% of total)	(Mg)	(% of total)
1975	18	206.685	114.225	55.2	52.733	25.5	61.492	29.7
1976	16	181.812	149.450	82.2	64.163	35.3	85.287	46.9
1977	17	229.743	173.070	75.3	78.281	34.1	94.789	41.2
1978	16	206.764	148.363	71.7	119.592	57.8	28.771	13.9
1979	16	196.558	162.736	82.8	94.341	48.0	68.295	34.8
1980	16	207.724	173.098	83.3	105.722	50.9	67.376	32.4
1981	14	212.816	145.151	68.2	86.779	40.8	58.372	27.4
1982	14	217.717	153.018	70.3	96.825	44.5	56.193	25.8
1983	15	221.318	171.349	77.5	94.207	42.6	77.142	34.9
1984	16	222.741	152.610	68.5	91.610	41.1	61.000	27.4
1985	15	225.291	169.381	75.2	101.843	45.2	67.538	30.0

of an increase of crop rates. With further development however, this has lost much of its former importance. Initially, the recommended application quantity was 20 Mg/ha. Nowadays, a standard application of 100–200 Mg/ha can be considered appropriate. Even extremely high levels of 1800 Mg/ha and more do not show any retardation of growth or decreasing crop rates.

Scientific tests show that compost can be an effective fertilizer, though, compared to mineral fertilizers, the nutritive value of compost is less important.

The organic component, presence of macro and micro nutrients and of essential trace elements add to the value. On the other hand, there are impurities, inert materials and weed seed. Moreover, attention must be directed towards heavy metals like lead, cadmium, mercury and chromium, present in varying amounts in solid waste derived compost. Nevertheless, it appears that the application of compost is possible in some degree wherever land is used to grow crops.

General agriculture

Agriculture in the broadest aspects is still considered to be the main potential user of compost, yet in spite of much effort, farming interest in compost remains at a low level. The following are among reasons for this: lack of information on specific compost applications, production and application of indigenous farm wastes like slurry or manure as fertilizers, methods of green manuring, ploughing in of crop wastes, price of compost and its transportation and application costs. Despite this, biases against solid waste compost should be minimized by producing a simple, well processed compost of good appearance with a high organic content and a low level of heavy metals. Plant operators should consider paying the user for transportation and application of compost. It should be possible to build composting plants in agricultural areas without having problems of disposal of the compost. Many tests show good advantages and increasing crop productivity. Particular advantages are found in the cultivation of cereals, feeding plants and grasslands.

Vineyards

Vineyards are the largest outlet for compost. Besides providing the soil with humus, compost has an ability to prevent soil erosion even on steep sites. To protect against the latter, an initial application of 200–300 Mg/ha may be followed by applications of 100 Mg/ha every two years [3]. More recent is the application of compost in the cultivation of new vineyards. Here an application of 1000 Mg/ha will ensure humus supply for about 15 years, thus saving money otherwise needed for intensive cultivation efforts.

Horticulture

Horticulture is the most intensive land cultivation technique and includes the cultivation of flowers and decorative plants as well as vegetable and fruit growing. Horticulture, with its special disciplines is, apart from vineyards, the field of compost application with the best chance of expansion. Cultivation of flowers involves several periods of growth almost all year. Humus and nutrient supply by compost at rates of 200 to 500 Mg/ha in greenhouses and cold frames leads to higher yielding and earlier blossom times [3].

In this regard, the use of compost as an energy source must be cited. The idea of employing the heat generated during the composting process is not new. Initially, plant beds were filled with compost in the beginning of the growing season to use the generated heat. Results were disappointing due to the minor energetic value of the compost. Minor energetic value refers to the minor organic content of the compost during the times of experimentation. For example, in 1960 the organic content of compost was only 31% (dry basis) whereas 25 years later the organic content is more than doubled at 65% (dry basis). Hence, the technique is being reexamined [4].

Proposals to gardeners to store raw compost in their own land instead of buying matured compost, thus employing the heat of the maturing process, led to the development of the "Compo-Therm-System" [2], in order to minimize labour and land requirements, special containers of capacities of 20–40 m^3 were constructed. The value of energy released in this way depends on general energy prices. However, the technique could support a wider distribution of compost.

Vegetable growing is divided into glass-covered and open-land cultivation. The distinction is important because of the limited possibilities for spreading out compost mechanically under glass. For vegetables, an application of 50–100 Mg/ha every two years is recommended [3]. Due to heavy-metal content of solid waste derived compost, only limited quantities may be employed.

Fruit orchards lack their own generated humus, so a humus supply has to be ensured. All fruit growing areas are suitable for compost application. Quantities of 100–200 Mg/ha every three years are recommended [3]. However, the presence of heavy metals is likely to lead to restrictions of application in this field too.

Gardens and landscaping

This field offers the largest variety of safe methods of compost application. There are, for example, green belts in and around housing areas, public greens and parks, sports grounds, verges along roads and motorways and reclamation of colliery spoils and waste tips. Application may lie in a range 300–600 Mg/ha, rising in some cases to 1000 Mg/ha [3].

No problems exist either in application or use, yet the use of compost in this field is decreasing. Reasons for this may include the economies by local and public authorities, offers and use of alternative materials and use of compost generated in-house.

Tree plantations could be important users, yet very little compost goes to this application. Reasons are believed to be the loose-packed structure of soils obtained using compost, which causes problems in marketing of root-bales and the fact that different trees and shrubs have different requirements for soil conditions that cannot always be met with compost.

In the outdoor cultivation of roses, application may rise to 300 Mg/ha [3]. Compost may be mixed with soil or peat to achieve the special needs of some plants.

Allotment gardens need an external humus supply, so are considered to be potential users.

Forestry

Forestry hardly appears among the statistics of compost application. There are, however, uses in the reclamation and recultivation of waste land, particularly land with poor soils, including alkaline soils. Recommended quantities are 200–300 Mg/ha [3].

Special crops

Compost may be recommended for use in mushroom growing and asparagus culture. For mushrooms, compost is employed, mixed with horse manure, as covering. Such mixtures support the process of fermentation and result in increasing yields. However, recent tests have shown that the crop takes up significant quantities of heavy metals when this method is employed. Accordingly, an improved technique has been developed, which involves the use of a mixture of matured compost, peat, clay and marl. It has been demonstrated that mushrooms no longer take up significant quantities of heavy metals if this mixture is employed [5].

The opportunities for marketing compost for mushroom growing are good if a standardized and supervised blend is developed which is introduced to individual growers and delivered promptly according to their needs. The potential is quite large since the covering material for mushrooms is usually changed three times a year [6].

Asparagus growing is restricted to certain areas because of special soil requirements. Asparagus needs intensive cultivation, and compost could be used as a source of humus. Initial and subsequent applications of compost should be carried out with quantities similar to those in vegetable growing, i.e., 50–100 Mg/ha every two years [3].

Flower growing, potting compost

Flower growing soils often employ solid waste compost mixed with other materials. Such mixtures are marketed in bags or sacks. For optimum conditions for plant nourishment the solid waste compost component should not be higher than one third of the mix.

Fillers

Organic fibre material from solid waste compost has been used as filler in the production of artificial fibre-boards, often mixed with crushed wood. This use has been abandoned because of high processing costs and low yield. Alternative materials are now employed.

Absorption of liquids

The high organic fibre content of compost renders it suitable for the absorption of contaminating liquids such as mineral oils and sludges from the surface of rivers, lakes and sewage treatment plant basins. It may also be used to protect plastic film laid down as a base for a newly built landfill site.

Noise absorption

A recent use of compost is its application in noise absorption walls due to its ability to absorb noise and resist erosion. Depending on the local situation, earth walls are built and covered with 20–30 cm of compost. The wall is then covered with plants. Alternatively, in more constricted areas, concrete containers may be filled with compost and covered with plants.

Filter material

The use of solid waste compost as a filtering material to minimize odours is of great interest [7]. In this way, air effluents from composting plants, sewage water treatment plants, abattoirs, animal breeding sites, food processing plants, sugar refineries and other industrial plants emitting noxious air effluents can be deodourised. Compost may also be used as a filtering material to purify gaseous effluents from agricultural straw burning, crematoria and the combustion of landfill gas [8]. Recommended application is 1 Mg/m^2 of filter surface each four years, based on a filtering capacity of 50–250 m^3 of air per hour and m^2 of filter surface. Effectiveness is about 95–98% removal [8].

Decontamination of polluted soils

Since solid waste compost has high biological activity it can be used to decontaminate polluted or diseased soils. Tests show that the decomposition of detergents, diesel oil, herbicides and some pesticides may be achieved. Much oil-polluted soil is cleaned up using Duisburg compost at the present time. The soil may be disposed of in normal landfill sites rather than on tips for hazardous waste, thus conserving the latter and reducing disposal costs. Further possibilities in the decontamination field are being examined.

SALES, DISTRIBUTION AND PRICING CRITERIA

Effective distribution and marketing of compost are essential for the effectiveness of waste management by composting. The product must be marketed to certain quality standards. Moreover, since requirements are becoming more specific, it is recommended that two or four grades of compost are offered [9].

Solid waste compost may be categorised as "raw" (or fresh) and "matured" compost according to the stage of fermentation reached and "fine" or "special" compost according to the degree of fineness and the glass and plastics content. Clearly the higher the quality, the more processing steps are needed and hence the higher the sales price. Table 6 shows quality of compost distributed in the F.R.G. from 1976 to 1985.

TABLE 6

Quality of compost distributed in the Federal Republic of Germany [11]

Year[a]	Condition of fermentation				Grading					
	Fresh		Matured		Coarse particles <20 mm		Medium particles 8–20 mm		Fine particles <8 mm	
	(Mg)	(%)	(Mg)	(%)	(Mg)	(%)	(Mg)	(%)	(Mg)	(%)
1976	46.329	31.0	103.121	69.0	101.626	68.0	29.591	19.8	18.233	12.2
1977	58.667	33.9	114.403	66.1	109.480	63.2	37.138	21.5	26.452	15.3
1978	49.952	33.7	98.411	66.3	77.409	52.2	58.059	39.1	12.895	8.7
1979	28.235	17.3	134.501	82.7	93.067	57.2	49.472	30.4	20.197	12.4
1980	36.416	21.0	136.682	79.0	94.173	54.4	58.848	34.0	20.077	11.6
1981	29.245	20.1	115.908	79.9	72.432	49.9	38.153	26.3	34.566	23.8
1982	33.867	22.1	119.151	79.9	72.796	47.6	42.862	28.0	37.360	24.4
1983	55.036	32.1	116.313	67.9	70.914	41.4	52.036	30.4	48.399	28.2
1984	56.010	36.7	96.600	63.3	71.343	46.8	31.950	20.9	49.317	32.3
1985	62.854	37.1	106.527	62.9	84.337	49.8	34.863	20.6	50.181	29.6

[a]Values for 1975 not available.

In Europe, prices for solid waste compost range from US$ 0 to US$ 80 per tonne excluding transportation costs. As a specific example, prices for various grades of compost produced at Duisburg are as follows:

Raw compost	US$ 13.00/tonne
Matured compost	US$ 13.00/tonne
Fine matured compost (bulk)	US$16.00/tonne
Fine matured compost (40 kg sacks)	US$ 3.20/sack
Leaf compost	US$ 10.60/tonne
Leaf compost soil (mature)	US$ 16.00/tonne

All prices valid since January 1987 and exclude transportation which is always paid for by the customers.

Prices should not be higher than the market price for other organic fertilizers of equivalent quality. The basis of calculation is the price for manure which is sold for US$ 10.60 per tonne. During the start-up of a composting plant, the product should be the cheapest organic fertilizer available.

Pricing policy must depend on local conditions, local farming conditions and crop rates, and application needs and costs. Compost should be sold by weight and not by volume.

An effective distribution organisation is necessary. This involves good information and consultation with users, and well organised cooperation of neighboured composting plants. The product must be advertised as any other sales product. Potential users must be informed of its properties and effects.

Solid waste compost is always in competition with other organic fertilizers. Good information leads to self-advertising after a time, which should be supported by regular visits to users. To achieve successful application and to avoid failures, consultation of users should be carried out by specialists in agriculture or horticulture.

Application possibilities and sales and revenue considerations described above are based on practical experience and can be replicated. It is clear that the revenues achieved from the sale of compost cannot completely match the costs of the operation. However, they serve to minimize the overall costs of waste handling and disposal as a whole.

CONCLUSIONS

Composting involves the aerobic digestion of waste with micro-organisms to generate a final product with a high humus content. It achieves both a reduction of waste volume and a hygienization of the waste. Composting technology has been developed to optimize technical and economical conditions. The introduction of controlled composting has reduced fermentation times significantly.

Waste management cannot rely on composting one, since not all wastes are compostable. Some part of the waste still has to go to landfill or be burnt in incenerators.

In the 1960's, composting was carried out in all European countries. Compost was expected to act as a soil conditioner and a source of humus, thus increasing crop rates and food production. Later, expectations concentrated on soil conditioning coupled with a reduction of waste volumes.

Improved processing technology now makes it possible to produce almost any quality of compost required by the user. Recommendations regarding quality and application as well as firm standards have been worked out in some European countries. As far as quality aspects are concerned, there should be no problems.

Marketing problems may well arise because of the expected growth of quantities of waste in comparison with possible solid waste compost outlets. Compost will meet hard competition from the wide range of other organic fertilizers, leading to a very narrow market in the immediate future.

In Western and Central Europe it will be difficult to distribute adequate quantities of compost, bearing in mind that normal marketing channels do not support the distribution of compost; soil conditions, particularly humus content, are better than expected; existing agricultural surpluses give no incentives for higher crop rates; the use of own-generated farm wastes and effluents reduces application rates; and the forthcoming regulations will not allow the application of larger quantities of compost anymore. For these reasons, new fields of compost application have to be investigated and are being examined. In future years, the emphasis on the field of waste management by composting will be the reduction of waste volume.

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