

## CHAPTER 3

### HISTORICAL DEVELOPMENT

Farmers and gardeners for many centuries have practised composting in some of its primitive forms. Night-soil, vegetable matter, animal manure, refuse, etc., were placed in piles or pits located in some convenient place and allowed to decompose as conditions would permit until the material was ready for the soil or the farmers were ready to apply it to the land. This process involved little or no control, required long periods in the pile to provide a good humus, might or might not conserve maximum nitrogen, and certainly did not provide sanitary treatment.

The first important advance in the practice of composting was made by Howard<sup>32, 33, 35</sup> almost 30 years ago in India, where in collaboration with Jackson & Wad,<sup>42</sup> and other workers,<sup>4, 17, 30</sup> he systematized the traditional procedures into a composting method known as the Indore process, because of the locality in which it was developed. This process when first developed used only animal manure, but later it involved stacking on open ground alternate layers of readily putrescible materials, such as night-soil, animal manure, sewage sludge, and garbage and relatively stable organic matter, such as straw, leaves, municipal refuse, and types of stable wastes. This material was stocked to a height of about 5 feet (1.5 m), or was placed in specially constructed pits 2 or 3 feet (0.6-0.9 m) deep. The original procedure was to turn the material only twice during the composting period of six months or longer; the liquor draining from the decomposing mass was recirculated to moisten the pile or was added to other, drier piles. It is probable, therefore, that the composting stacks were aerobic for a short period after piling and after each turn, and were anaerobic during most of the remainder of the composting period. The Indore process, with modifications, has been used widely in India by Howard,<sup>33</sup> Acharya,<sup>1</sup> and others.<sup>39</sup> The Indian Council of Agricultural Research at Bangalore further improved the method under the name Bangalore process, while developing extensive composting programmes in India. Scharff<sup>66</sup> in Malaya, Wilson<sup>91</sup> in East Africa, and others in various parts of the world<sup>4, 56, 57, 89, 93, 94</sup> have used the Indore method with modifications. Van Vuren,<sup>81</sup> of South Africa, has made extensive studies of modifications of the Indore method and of the use of compost as a fertilizer. An important innovation has been more frequent turning to maintain aerobic or facultatively aerobic conditions, thus providing more

rapid decomposition and shortening the composting period (see page 70).

In 1935, Scott and others started comprehensive studies of composting in relation to agricultural sanitation in Northern China. Their work was halted in 1941 because of the Second World War, but fortunately the results of their studies were published in 1951.<sup>68</sup> Night-soil was used in practically all of their studies, and the investigation dealt with :

(1) the effect on health of the reclamation of wastes by primitive and insanitary methods ;

(2) the sanitary problems involved in collecting and handling the faecal material ;

(3) the chemical losses accompanying primitive methods of waste utilization ;

(4) the results obtained by different techniques of aerobic and anaerobic composting with respect to the destruction of pathogenic organisms ;

(5) the reclamation of nitrogen in different methods of composting and storing of the compost ;

(6) fly control in composting operations ;

(7) the effect on composting of varying the amounts of the different types of waste materials ;

(8) the effect of compost on crop yields ;

(9) the problem of fitting composting into the scheme of the individual farm or village.

These studies yielded important data on problems of composting faeces and wastes in rural areas.

During the period 1926-41, Waksman and his associates carried out fundamental research on aerobic decomposition of vegetable residues and stable manure. They made and reported important discoveries regarding the influence of temperature on the rate of decomposition,<sup>86</sup> the role of individual groups of micro-organisms,<sup>85</sup> and the effect of mixed cultures as compared with pure cultures<sup>85, 87</sup> on organic breakdown.

From 1950 to 1952, Gotaas and his associates<sup>23, 24, 49, 81</sup> conducted research on some of the basic aspects of composting mixed municipal refuse containing garbage, both with and without additions of sewage sludge. Their investigations have furnished some basic information on the effects of some of the different variables encountered in aerobic composting, namely : (1) temperature ; (2) moisture ; (3) aeration by turning and by other means ; (4) the C/N ratio of the organic materials ; (5) the use of special biological inocula ; and (6) grinding or shredding the material.

Their studies also yielded data on the types of organisms present in composting, techniques for judging the condition of the compost during and after the operation, the insulating and heat-retention characteristics of compost materials, and process-design considerations.

During the period that the early composting practices were being refined in India, China, Malaya, and elsewhere, other investigators, notably in Europe, were devoting considerable effort to mechanizing the composting process, particularly for use as a method for the treatment and sanitary disposal of the garbage and refuse from cities. These efforts resulted in various mechanical innovations, usually with the objectives of improving the aesthetics of the process by enclosing the material in some type of structure, of speeding it up, and of making it more economical.

The mechanized and enclosed processes are primarily designed for cities, but they are also valuable in rural and village composting.

One of the most widely used<sup>11, 18, 36, 60, 78</sup> of the early patented processes was developed by Beccari,<sup>7</sup> of Florence, Italy, and is known by his name. In this process, which used initial anaerobic fermentation followed by a final aerobic stage, the material was stacked in an enclosed cell to prevent the escape of foul odours associated with the putrefactive breakdown of organic matter. As originally designed, the Beccari cell consisted of a simple cell-type structure with a loading hatch on top and an unloading door in the front. Air vents were included which, when opened for the final stage, permitted composting to proceed under partially aerobic conditions. A modification of the Beccari process, providing for recirculation of the drainage liquors or of gases and possibly providing more aeration, is known as the Verdier process.

Bordas,<sup>77</sup> in 1931, further modified the Beccari process, his aim being to eliminate the anaerobic stage by introducing forced air into a fermentation silo through a central pipe and along the walls. A grate divides the silo into an upper and a lower section. Compost is produced on a batch basis with maximum use of the silo, accomplished by dropping the charge through the grate into the lower chamber when it has lost much of its volume by decomposition.

A silo-type multiple-grate digester for producing compost under aerobic conditions, using rotary ploughs and forced air for aeration, was patented by Earp-Thomas of Hampton, N.J., in 1939. An essential feature of the process is the use of special bacterial cultures supplied by Earp-Thomas.

A variation of the digester-type enclosed cell, consisting of a double-walled silo with multiple floors, was recently designed by the Ralph W. Kiker Company of Lansing, Mich. The organic material is in the inner silo, which is aerated internally and externally while being continuously

sprayed with drainage liquor pumped from a collecting sump. A special inoculum is reported to be involved in this process.

The Frazer process,<sup>19</sup> patented in the USA in 1949, uses an enclosed, fully mechanized, aerobic digester in which shredded organic matter is kept continuously agitated as it moves downwards from one level to another and is also brought into contact with the gases of decomposition—a salient aspect of the patent. The composted material is screened as it leaves the bottom of the digester and the tailings from the screen are re-cycled.

The Hardy digester is a large round vat containing conveyor screws, mounted perpendicular to the floor, for aerating and agitating the material. The bottom of the vat is porous to permit air to enter and the drainage to flow out. This mixing vat, in which aerobic decomposition takes place, operates on a continuous basis, discharging finished compost as raw material is added. There are other patented digesters which have some different features for aerating and handling the material.

Snell<sup>71</sup> has carried out experimental studies on composting in a silo-type digester using mechanical stirring. His reports indicate that considerable attention has been given to developing more efficient mechanical stirring and to the solution of mechanical problems associated with digester operations.

It appears that silo digesters have been used primarily in small installations for segregated garbage with a high organic-matter content. They are highly mechanized to provide continuous aeration, and the thermophilic temperatures effect rapid composting. Rapid composting reduces the size of plant and land area required, but the economic significance of this is less than it is sometimes considered to be, since the finished compost is utilized seasonally and raw material for composting is received at a more or less uniform rate. Also, the economics of composting segregated garbage alone may be questioned. Garbage with a high food-content can be cooked and fed to hogs economically. The nitrogen loss in composting this type of garbage, which has a low C/N ratio, is very great. But, on the other hand, if the garbage is composted with organic rubbish as a mixed refuse with a higher C/N ratio, the time required to reduce the C/N ratio to 20 is increased—a fact of economic importance when mechanized digesters are used.

The first Dano process, developed in Denmark, is usually referred to as a composting process, but it is essentially a refuse-separating and grinding operation, the product of which can be composted by any recognized procedure. The garbage and refuse are fed into a slowly rotating cylinder, with the axis sloping slightly downwards from the horizontal, where the material is aerated to remove odours, mixed, and partly

broken up into smaller particles. The ferrous metals and other salvable materials are removed by a magnetic separator and hand sorting as the material passes to a grinding and homogenizing machine, known as the Egsetor. Grinding to a desired size of particle is accomplished by friction between the particles of refuse and between the refuse and the roughened walls of the rotating Egsetor. It may take 4 to 6 hours for the material to go through the grinding machine. The actual composting takes place in piles placed on the ground to heights of 5-6 feet (1.5-1.8 m).

The Dano Corporation<sup>15</sup> has recently developed a mechanical silo-type digester, known as the Bio-stabilizer, which has been in operation on a pilot-plant scale, composting about 20 tons of refuse per day. The Bio-stabilizer unit is essentially a long cylinder, somewhat similar to a cement kiln, which slowly rotates (one revolution in five minutes) and is tilted slightly downwards from the horizontal. Refuse, with or without sewage sludge, is added to the digester, which will hold about 100 tons and is kept substantially full. As the digester rotates the wastes are moved slowly forward. Water can be added to the digester to increase the moisture content of the refuse. Aeration is achieved by means of two rows of air jets fixed along the length of the cylinder. Disintegration of wastes is obtained by the abrasion of the rotating particles and by biological action. The refuse is retained in the digester for three to five days, according to the character of the material, the temperature of the material being in the thermophilic range during most of this time. The compost is passed through a 3/8-inch (1 cm) mesh screen at the discharge end of the digester, and is then stabilized further, if necessary, by stacking it in piles prior to preparing it for the market. A small Bio-stabilizer plant is in operation at Rüschnikon, Zürich, Switzerland, a larger plant is being built at Edinburgh, Scotland, and an experimental plant is to be built near Los Angeles, Calif.

The VAM<sup>89, 96</sup> processing procedure—utilized in the Netherlands since 1932 by N. V. Vuilafvoer Maatschappij (VAM), a non-profit utility company formed by the Government for the disposal of city refuse—is essentially an adaptation of the Indore process for composting large quantities of municipal refuse, which contains little garbage or readily putrescible food materials. In the original process, unground refuse was placed in long high piles which, during composting, were sprinkled periodically with recirculated drainage liquor; the decomposed material was then shredded by a hammer-mill and sold as a soil humus. In new installations, however, the refuse is first shredded in a special grinder developed by Weststrate,<sup>90</sup> the director of VAM. This grinder resembles a rimless wheel with U-section spokes pin-hinged at the hub, and rotating above a horizontal base with a diameter of about 15 feet (4.5 m) or more and with alternate rough rasp plates and sieve plates. The shredding is accomplished by the revolving

hinged spokes' rasping over the roughened plates. Salvable materials are segregated and picked out before the shredding is begun; non-shreddable materials are removed twice a day from the shredder. The shredded refuse, as it falls through the sieve plates, is picked up on a moving belt and conveyed to a place where it can be readily sprinkled to control the moisture, and turned from time to time to provide aeration, during the composting period.

Stovroff and his associates of the Compost Corporation of America<sup>74, 75</sup> have carried out extensive pilot-plant operations, and have studied the economics of composting municipal and industrial refuse from larger communities to produce fertilizer. These pilot plants incorporate modern materials-handling equipment designed for the large daily volumes generated by cities. Such mechanization permits profitable sales of bulk compost at prices below that of stable or barn-yard manure.

The plant planned for erection in Oakland, Calif., as a private enterprise, is designed to compost 300 tons of mixed garbage and refuse on an 8-hour-a-day basis or 600 tons on a two-shift 16-hour-a-day basis. The operation is entirely aerobic, using the windrowed-pile method, and is, in effect, a modern mechanization of the basic Indore technique.

It is a continuous-flow operation, beginning at a large concrete receiving area where refuse is fed to conveyors. Separation of the inorganic and non-compostable portions of the refuse is accomplished in a multi-stage operation, utilizing mechanical, pneumatic, magnetic, and centrifugal equipment and, finally, a manual check. The materials removed are further processed for sale to industry. Equipment and operations are planned so that environmental conditions conducive to desired biological action are maintained in the windrowed fermentation piles. Composting requires approximately three weeks, during which time moisture, air, and temperature are controlled. As the material reaches stabilization the windrows are combined to form large stock-piles for storage or are submitted to final market preparation. This consists in screening material for uniformity prior to shipment in bulk truck-loads or supplementing with additional chemical elements and then bagging. The extent of final processing depends upon the market, the season, and the purpose for which the product is required.

In connexion with composting developments, it may be desirable to indicate some of the many places where the different procedures are practised on a large municipal scale. Where water-carried sewage disposal exists, the practice of utilizing human excrement or sludge with garbage and refuse in composts has been considerable, but not extensive. In some places sewage sludge has been composted with other organic wastes, but generally the sludge is digested anaerobically and spread on the soil with no further treatment except dewatering.

The Beccari process is used in over fifty cities in Italy and France for garbage disposal, and the Verdier process has been employed in several towns of southern France. Dano grinding plants, which pile the material on the site or on individual farms for composting, are used in several communities in Denmark and Sweden. In some of these installations sewage sludge or night-soil is mixed with the refuse just as it leaves the grinder to be composted.

Various modifications of the Indore process have been used in the Netherlands, Germany, Austria, England, Africa, Australia, New Zealand, India, Malaya, Central America, and the USA.

The Netherlands has the most extensive composting operations in Europe, many thousands of tons of compost being produced annually from municipal refuse by VAM, and by several individual cities, for sale to farmers.<sup>89</sup> The refuse from The Hague, Groningen, and Zandvoort is transported in specially constructed railway trucks to the disposal site at Wijster, where the trucks are run on to one of the several viaducts 20 feet (6 m) high and 1600 feet (488 m) long, and the refuse is discharged in successive mechanically levelled layers below the viaduct and sprinkled with water. Four to eight months is required for composting, after which the material is pulverized and screened. It is probable that the decomposition is aerobic at first and then becomes anaerobic. At Schiedam, Flushing,<sup>90</sup> and other towns, refuse containing very little garbage is shredded and then placed in compost piles, which are turned to provide aeration. The time required for composting at these plants varies from three months for summer refuse to two months for winter refuse, which contains a considerable amount of ash.

A new compost plant is in operation at Baden-Baden, Germany. This plant has mechanized materials-handling equipment. Refuse is segregated by sieving, magnetic removal of metals, and hand sorting, and is then mixed with digested sewage sludge for composting in windrowed piles. After 4-6 months of decomposition the material is sieved and the large particles are pulverized in a hammer-mill. Municipal compost plants are reported to be planned or under construction in other cities in Germany. At Heidelberg, construction of a plant using the VAM rasping machine and windrows for composting was recently completed.

In London, the Borough of Southwark has composted street sweepings, market refuse, stable manure, and garbage since 1906.<sup>51</sup> Their method is a modification of the Indore technique using concrete bins of 70 tons' capacity. Leatherhead, Maidenhead, Dumfries, and the Northern Sewage Outfall Works of the County of London, have likewise composted sewage sludge, refuse, and garbage.<sup>51, 94</sup> The Dumfries plant takes refuse from several small towns, composts the material, and markets the product.

The composting is done in concrete bins, which are aerated so that thermophilic decomposition is obtained. The refuse is placed in the bins and liquid sewage sludge is allowed to flow on to it, leaving a film of sludge on the material as most of the water drains off. The material is mechanically handled in the process. Pilot-plant compost studies are in progress on the island of Jersey. A silo-type digester, which will compost mixed refuse and sewage sludge in 7 days—the composting period to be followed by a maturing period of 8-10 weeks in a stock-pile—is being investigated.

Various parts of Africa, particularly South Africa and Kenya, produce quantities of compost exceeding 500 000 cubic yards (382 000 m<sup>3</sup>) a year, using different modifications of the Indore process.<sup>62</sup> A recent survey shows that 14 municipalities in the Cape Province are producing compost.<sup>60</sup> Development in composting has also been taking place in rural areas. Refuse, vegetable matter, and manure are salvaged on a small scale—the more primitive methods generally being used—by farmers whose economic livelihood depends on the fertility of the soil or by people whose hobby is back-yard gardening.

In Central America the Government of Costa Rica created a corporation to conduct composting operations in urban centres. In El Salvador successful composting under private operation is being done profitably for the cities of Santa Ana and San Salvador. The refuse is segregated, shredded, mixed with sewage sludge and slaughterhouse wastes, stacked in pits, and turned. Five or six weeks are required to produce the finished compost.

Extensive pilot-plant composting, using windrowing and turning of the refuse, is in progress in Mexico in preparation for larger operations. Likewise, pilot-plant composting and comprehensive research investigations have been in progress under the supervision of an inter-departmental committee of the New Zealand Government.

There has been little interest in composting municipal wastes in the USA until recently, when several cities have recognized its possibilities for providing refuse disposal at a lower cost. This lack of interest was partly due to the fact that some of the patented processes proposed, but never developed to a practical state, were of doubtful scientific and economic feasibility, requiring elaborate and expensive installations, and a licence or royalty charges. Five Beccari process plants were installed in the late 1920's and early 1930's, but all were abandoned.<sup>77</sup> Recently a Frazer Products Inc. plant at Bayshore, Long Island, has been composting, on a small scale, selected garbage mixed with 25% sewage sludge.

Probably the greatest increase in the use of composting for the treatment and reclamation of wastes has taken place in India, where the number of municipal composting operations increased from 260 in 1944-45 to 1609

in 1951, and the annual tonnage of compost prepared increased from 182 610 to over 2 000 000.<sup>1, 40</sup> About 138 000 villages in rural areas are now composting their wastes. The Bangalore process is used.

There appears to be considerable interest in composting as an economical method for the disposal and reclamation of organic wastes in many parts of the world. The author's attention has been called to several places, not listed here, where composting operations are being planned.

There has been little new information on the use of anaerobic digestion of garbage, refuse, and night-soil in piles since the development of the Beccari process. There may be less tendency to lost nitrogen in anaerobic composting because of the lower temperatures, but the problems of odour nuisance, fly-breeding, and poorer destruction of pathogens are important disadvantages of anaerobic composting in piles.

There is voluminous literature on anaerobic digestion of sewage sludge and industrial wastes, where the organic matter is digested in a liquid suspension. The developments in this process are too extensive to discuss in detail here, but a way in which the method could be developed for use on farms and in small villages may be indicated. Since farms produce large quantities of carbonaceous materials, including manure of high nitrogen-content, and since methane gas is evolved in the anaerobic digestion of carbonaceous material, the use of digesters designed so that the evolved gas could be collected for fuel or power, and the remaining humus could be removed for fertilizer, would seem to offer excellent possibilities. Considerable progress has been made in this direction, particularly in France, Germany, Italy, and India where installations have been in operation for some time.<sup>37, 52, 54</sup> A great development has taken place in France, where there were 600 farm installations in 1950, and more than 1000 by 1952. Simple prefabricated tanks and gasometers are now being produced by French factories. These installations, discussed fully in Chapter 9, can be particularly effective in areas where both fuel and plant nutrients are scarce.

## CHAPTER 4

### RAW MATERIAL : QUANTITY AND COMPOSITION

The quantity, characteristics, and composition of wastes available for composting vary widely with the season and in different localities. On farms and in villages the compostable material will depend upon the climate, the number of people, the size of the farms, the type of agriculture, the animals utilized and whether or not they are stabled, the facilities for collecting the wastes, the social and dietary customs, the use of organic wastes for fuel, and the economic conditions in the area. In municipalities and cities, in addition to depending on most of the foregoing items, the quantity and quality of compostable material are affected by: waste products from industry; trimmings from lawns and gardens, street sweepings, and ash; the extent to which incinerators are used in the homes and commercial establishments; whether separate or combined collection of refuse<sup>a</sup> is practised; the frequency of refuse collection; the amount of material salvaged; the use of garbage for feeding livestock; and the use of household garbage-grinders.

The multiplicity and complexity of the factors affecting the quality and quantity of compostable refuse prohibits the use of any formula or rule-of-thumb method for determining the amount of waste material to be expected at any given place. Either a study of the particular place or the use of information obtained from studies of places with very similar characteristics is necessary for estimating the quality and quantity of refuse for a given population. There is, however, some basic information which can be useful in supplementing local data in analysing a particular composting operation.

#### Rural Areas and Agricultural Villages

In rural areas and agricultural villages which do not have water-carried sewage disposal, and in which night-soil is collected, the following basic quantity and quality data will be useful in studying a compost operation.

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<sup>a</sup> The term "refuse" is used here to include edible garbage, combustible and non-combustible rubbish, trash litter, and other materials which are commonly present in the mixed collection of community wastes. Sewage sludge, night-soil, and industrial wastes are not included in the term "refuse".

*Human faeces without urine*

*Approximate quantity*

0.3-0.6 pound (135-270 g) per capita per day moist weight  
 0.08-0.16 pound (35-70 g) per capita per day dry weight

*Approximate composition*

Moisture content . . . . .	66-80%
Organic-matter content (dry basis) <sup>a</sup> . . . . .	88-97%
Nitrogen " " . . . . .	5.0-7.0%
Phosphorus (as P <sub>2</sub> O <sub>5</sub> ) " " . . . . .	3.0-5.4%
Potassium (as K <sub>2</sub> O) " " . . . . .	1.0-2.5%
Carbon " " . . . . .	40-55%
Calcium (as CaO) " " . . . . .	4-5%
C/N ratio " " . . . . .	5-10

*Human urine*

*Approximate quantity*

Volume : 1<sup>3</sup>/<sub>4</sub>-2<sup>1</sup>/<sub>4</sub> pints (1.0-1.3 litres) per capita per day  
 Dry solids : 0.12-0.16 pound (50-70 g) per capita per day

*Approximate composition*

Moisture content . . . . .	93-96%
Organic-matter content (dry basis) . . . . .	65-85%
Nitrogen " " . . . . .	15-19%
Phosphorus (as P <sub>2</sub> O <sub>5</sub> ) " " . . . . .	2.5-5%
Potassium (as K <sub>2</sub> O) " " . . . . .	3.0-4.5%
Carbon " " . . . . .	11-17%
Calcium (as CaO) " " . . . . .	4.5-6%

*Animal manure*

*Approximate quantity.* The quantity of animal manure varies widely with different conditions of feeding and stabling. Van Slyke (quoted by Millar & Turk <sup>55</sup>) gives the information shown in Table I on animal-excrement production. To these quantities would be added the weight of straw, bedding, and litter when determining the total quantity of animal manure.

Mignotte <sup>54</sup> estimates the amount of manure produced per year by the following animals as : horses and oxen, 10 metric tons ; beef cattle, 15 metric tons ; milk cows, 12 metric tons ; sheep, 0.5 metric ton ; pigs, 1.5 metric tons.

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<sup>a</sup> In this monograph the quantities of organic matter are based on the loss in weight on ignition of the dry material.

**TABLE I. QUANTITIES OF ANIMAL EXCREMENT**

Animal	Tons per year per 1000 lb. live weight	Nitrogen (lb. per year per 1000 lb. live weight)		
		liquid	solid	total
Horse	9.0	5.4	8.8	14.2
Cow	13.5	4.8	4.9	9.7
Pig	15.3	4.0	3.6	7.6
Sheep	6.3	9.9	10.7	20.6
Poultry	4.3	—	20.0	20.0

From *Fertilizers and Crop Production* by Van Slyke (quoted by Millar & Turk <sup>55</sup>)

The nitrogen voided per year has been variously estimated at around 20 pounds (9 kg) for horses and oxen ; 15 pounds (7 kg) for cows ; and 12.5 pounds (5.6 kg) for sheep and goats.

*Approximate composition.* Stable manure is made up of three main components : (a) bedding or vegetable-matter litter ; (b) solid excreta ; and (c) urine. The characteristics and relative concentration of these components vary widely, depending on the type of animal, the stable feeding and handling, and the use to which the animal is put. Straw and plant residues used for bedding usually contain large amounts of carbon, particularly in the form of cellulose, and small amounts of nitrogen and minerals. Considerable amounts of protein are present in the solid excreta, which provide a more balanced nutrient material for the growth of micro-organisms. The proportions of some of the chemical constituents in fresh manure from different animals, as shown by Waksman,<sup>84</sup> are indicated in Table II.

**TABLE II. CHEMICAL COMPOSITION OF FRESH MANURE FROM VARIOUS ANIMALS \***

Chemical constituents	Sheep manure <sup>a</sup>	Horse manure <sup>b</sup>	Cow manure <sup>a</sup>
	%	%	%
Ether-soluble substances	2.8	1.9	2.8
Cold-water-soluble organic matter	19.2	3.2	5.0
Hot-water-soluble organic matter	5.7	2.4	5.3
Hemicelluloses	18.5	23.5	18.6
Cellulose	18.7	27.5	25.2
Lignin	20.7	14.2	20.2
Total protein	25.5	6.8	14.9
Ash	17.2	9.1	13.0

\* On the basis of dry, litter-free material

<sup>a</sup> Solid and liquid excreta

<sup>b</sup> Solid excreta only

Reproduced from Waksman <sup>84</sup> by kind permission of John Wiley & Sons, Inc., New York

Table III further shows the chemical nature of different types of manure as found by Jenkins.<sup>44</sup>

**TABLE III. CHEMICAL NATURE OF DIFFERENT TYPES OF MANURE**

Manure	Moisture (%)	Composition of dry matter		
		nitrogen (%)	P <sub>2</sub> O <sub>5</sub> (%)	K <sub>2</sub> O (%)
Cattle	80	1.67	1.11	0.56
Horse	75	2.29	1.25	1.38
Sheep	68	3.75	1.87	1.25
Pig	82	3.75	3.13	2.50
Hen	56	6.27	5.92	3.27
Pigeon	52	5.68	5.74	3.23

Reproduced from Waksman<sup>84</sup> by kind permission of John Wiley & Sons, Inc., New York

The results of numerous analyses<sup>68, 84</sup> indicate that stable manure in a fresh state contains about 70%-80% moisture, 0.3%-1.9% nitrogen, 0.1%-0.6% phosphorus (as P<sub>2</sub>O<sub>5</sub>), and 0.3%-1.2% potassium (as K<sub>2</sub>O). Hence, a ton of fresh manure has about 400-600 pounds (180-270 kg) of dry matter, around 8-12 pounds (3.5-5 kg) of nitrogen, 5-7 pounds (2-3 kg) of P<sub>2</sub>O<sub>5</sub>, and 9-12 pounds (4-5 kg) of potash. In composting manure, the moisture and dry matter will be considerably reduced but most of the nutrients can be retained in the finished compost.

It should be pointed out that human and animal urine contain considerably larger amounts of nitrogen than do faeces. Therefore, from the standpoint of reclamation, every effort should be made to collect the urine. Straw, sawdust, and other cellulose litter used in soakage pits or as stable bedding will absorb the urine.

#### *Refuse (garbage, rubbish, and other litter)*

*Approximate quantity.* The quantities of garbage, organic rubbish, and dead vegetation available for composting on farms and in villages are extremely variable. Most garbage and food wastes are fed to animals, and hence the amount of garbage is limited to very small quantities of non-edible vegetable products rich in cellulose. There is also little waste-paper, rags, etc. in the refuse. Ash, particularly in cold climates, street sweepings, and trash, constitute a major portion of the waste. In warm areas with a high rainfall, much waste vegetation finds its way into the refuse. However, in many villages the amount of such refuse is insufficient in quantity to provide a satisfactory compostable mass when mixed with

the night-soil. The addition of animal manure is necessary. Although there are considerable variations, the quantity of garbage and rubbish in villages is usually 0.5-0.75 pounds (220-340 g) per capita per day.

*Approximate composition*

Moisture content . . . . .	10-60%
Organic content (dry basis) . . . . .	25-35%
Nitrogen " " . . . . .	0.4-0.8%
Phosphorus (as $P_2O_5$ ) " " . . . . .	0.2-0.5%
Potassium (as $K_2O$ ) " " . . . . .	0.8-1.5%
Carbon " " . . . . .	12-17%
Calcium (as $CaO$ ) " " . . . . .	4.0-7.5%

*Slaughterhouse wastes*

*Approximate quantity.* The amount of these wastes is extremely variable, depending on the extent of processing. It is estimated that for small slaughterhouses with no by-product processing the compostable wastes will be as much as 50-80 pounds (22-36 kg), dry basis, per ton of meat processed, while in large plants which utilize wastes for by-product production, the waste will be as little as 25-40 pounds (11-18 kg), dry basis, per ton. The amounts of these liquid or solid wastes will also vary with the plant. In large modern plants most of the wastes are in the form of a liquid sewage.

*Approximate composition.* The composition varies according to the size of the operation and the extent of utilization of wastes for the manufacture of by-products. Most rural slaughterhouses have primitive recovery processes, and the wastes consist of blood, unsaleable meat, intestines, offal, paunch manure, hoofs, etc. and have the following average composition :

Moisture content . . . . .	75-80%
Organic matter (dry basis) . . . . .	80-95%
Nitrogen " " . . . . .	8-11%
Phosphorus (as $P_2O_5$ ) " " . . . . .	3.0-3.5%
Potassium (as $K_2O$ ) " " . . . . .	2.0-2.5%
Carbon " " . . . . .	14-17%
Calcium (as $CaO$ ) " " . . . . .	3.0-3.5%

**Cities and Urban Centres**

Compostable urban wastes probably vary as to quantity and composition almost as much as do rural wastes. However, considerable information from cities in different parts of the world has been published. Some basic data pertaining to cities with water-carried sewage collection

and regularly operated garbage and refuse collection systems, that can supplement local information in analysing municipal composting operations, will be shown.

### *Sewage sludge*

The approximate quantities and composition of sewage solids and of the sludge resulting from different methods of treatment are shown in Table IV. Sewage sludge, either fresh or digested, can satisfactorily be composted with garbage and other refuse. As will be shown later, if the sludge is not partially dewatered, large amounts of dry refuse are necessary to absorb the moisture so that the mass will compost aerobically.

### *Industrial wastes*

The quantities and composition of compostable industrial wastes are highly variable and must be estimated from available data on the industries in a particular place. Wastes from food-processing industries—for example, vegetable wastes, feathers, and slaughterhouse wastes—can provide considerable quantities of solid or semi-solid compostable material. Lumber-mill sawdust and wood chips, which usually have a moisture content of 40%-65%, are satisfactory for inclusion in composts, particularly when mixed with materials of high nitrogen-content, such as sewage sludge, night-soil, or slaughterhouse wastes. Liquid industrial wastes, such as those from dairies, breweries, etc., will often appear in the sewage and will be reflected in the quantity and composition of the sewage sludge.

### *Refuse (garbage, rubbish, and other litter)*

The quantities of compostable domestic and food-establishment wastes, which constitute garbage, depend upon climate, the food-preservation facilities, the types of food used, the utilization of garbage for stock food, the use of home garbage-grinders, and the economic status of the community. The quantity of domestic and commercial garbage, which is made up largely of waste food and vegetable trimmings, varies from 0.2 to 0.9 pound (90-400 g) per capita per day; these wastes contain 60%-85% moisture and 65%-85% organic matter on a dry basis. In a few instances as much as 1.3 pounds (600 g) per capita per day have been recorded in cities. When there is reasonable saving of food and refrigeration facilities are available, the quantity of garbage in an urban community will be between 0.2 and 0.6 pounds (90-270 g) per capita per day. Such garbage will weigh between 800 and 1000 pounds per cubic yard (460-590 kg per m<sup>3</sup>).

TABLE IV. APPROXIMATE QUANTITY AND COMPOSITION OF SEWAGE AND SEWAGE SLUDGE

	Quantity of solids, dry basis lb./head/day	Liquid sludge (% solids)	Drying-bed cake (% solids)	Vacuum-filter cake (% solids)	Composition on dry basis (%)				
					organic	mineral	nitrogen (N)	phosphate (P <sub>2</sub> O <sub>5</sub> )	potash (K <sub>2</sub> O)
1. Fresh domestic sewage	0.18-0.22	0.04-0.15	—	—	60-85	15-40	5.0-10.0	2.5-4.5	3.0-4.5
2. Imhoff tank, well digested	0.05-0.08	8.0-12.0	35-50	—	30-45	55-70	2.0-3.0	1.2-3.5	0.1-0.5
3. Primary, fresh	0.1-0.14	2.5-5.0	28-45	22-34	60-80	20-35	1.5-4.0	0.8-4.0	0.1-0.5
4. Primary, digested	0.06-0.09	5.0-12.0	35-50	26-34	35-60	40-65	1.0-3.5	1.2-4.0	0.1-0.5
5. Primary and trickling-filter humus, fresh	0.13-0.17	3.5-6.5	26-40	23-34	50-75	25-50	2.0-4.5	0.8-3.6	0.1-0.5
6. Primary and trickling-filter humus, digested	0.08-0.11	5.0-12.0	35-50	25-35	35-60	40-65	1.0-3.5	1.0-3.8	0.1-0.5
7. Primary and activated sludge, fresh	0.16-0.20	3.0-6.0	26-40	20-24	50-80	20-50	2.3-5.2	1.2-4.0	0.2-0.6
8. Primary and activated sludge, digested	0.10-0.13	4.5-8.5	28-50	22-26	35-55	45-65	2.0-4.8	1.3-4.0	0.2-0.6
9. Primary sludge, digested, and fresh activated sludge	0.12-0.16	2.5-4.5	28-45	20-24	40-60	40-60	2.2-5.0	1.3-4.0	0.3-0.8

The quantities of combustible rubbish in urban areas depend upon the economic conditions, the extent of incineration on the local premises, the population density, the salvage of rubbish, and the extent of home gardening. Usually, from 0.25 to 3.0 pounds (0.1-1.3 kg) per capita per day of combustible refuse, with a moisture content of 35%-60% and an organic-matter content of 55%-80% on a dry basis, are produced. Long-established residential areas and estates may have a combustible refuse as large as 4-5 pounds (1.8-2.2 kg) per capita per day. New residential areas, apartment areas, and places that have facilities for incineration or home composting, will produce less than 1.5 pounds (700 g), and often less than 1.0 pound (450 g), per capita per day. Combustible rubbish under average compaction weighs 200-400 pounds per cubic yard (115-230 kg per m<sup>3</sup>), and may be compacted to weigh 600-700 pounds per cubic yard (345-400 kg per m<sup>3</sup>). This high degree of compaction, however, is seldom achieved in the usual type of municipal collection truck.

Quantities of non-combustible and non-compostable rubbish, such as cans, bottles, china, and metal, will vary from 0.1 to 1.1 pounds (45-500 g) per capita per day. Usually the quantity will be between 0.3 and 0.8 pounds (135-350 g), but if ash and cinders are included, it will be much greater. The ash can be mixed with the compostable material, or mixed with sewage sludge to absorb moisture, or spread directly on the soil.

The various kinds of refuse, i.e., garbage and combustible and non-combustible rubbish, are often not segregated for collection. The quantities of mixed refuse produced in urban communities will vary between 0.7 and 4.5 pounds (0.3-2 kg) per capita per day, and the more common range will be between 0.8 and 3.0 pounds (0.35-1.3 kg), averaging below 2.0 pounds (0.9 kg).

Refuse-quantity data are available for certain towns in different parts of the world. An investigation<sup>59, 80</sup> of 13 cities in California shows a variation in mixed refuse of from 1.03 to 4.14 pounds (0.47-1.88 kg) per capita per day, with an average of 2.05 pounds (0.93 kg).

In Berkeley, Calif., an average of 1.25 pounds (0.57 kg) per capita per day of mixed refuse is collected; this refuse has the average physical and chemical composition shown in Table V.

In Long Beach, Calif.—a community of many individual homes, with yards and no coal-heating—the total amount of refuse averages 3.1 pounds (1.4 kg) per capita per day, of which 0.6 pound (0.3 kg) is garbage, 1.6 pounds (0.7 kg) is combustible rubbish, and 0.9 pound (0.4 kg) is non-combustible rubbish.<sup>79</sup> Hence, assuming that practically all the garbage and combustible refuse is compostable, i.e., about 70% of the total refuse, the quantity of compostable material is about 2.2 pounds (1 kg) per capita per day or 0.4 ton (400 kg) per capita per year.

**TABLE V. AVERAGE PHYSICAL AND CHEMICAL COMPOSITION OF MIXED REFUSE FROM BERKELEY, CALIF.<sup>81</sup>**

Physical composition		Chemical composition	
characteristic	percentage, by weight, as collected	characteristic <sup>a</sup>	percentage
Tin cans	9.8	Moisture (as collected)	49.3
Bottles and broken glass	11.7	Ash (dry basis)	28.5
Rags <sup>b</sup>	1.6	Carbon (dry basis)	35.7
Metals	0.9	Nitrogen (dry basis)	1.07
Miscellaneous non-compostable waste of no value	7.6	Phosphorus, as P <sub>2</sub> O <sub>5</sub> (dry basis)	1.16
Compostable material <sup>c</sup> (garbage, vegetable matter, paper, etc.)	68.4	Potassium, as K <sub>2</sub> O (dry basis)	0.83

<sup>a</sup> C/N ratio = 33.8

<sup>b</sup> Compostable material = 0.85 pound (380 g) per capita per day = 0.155 ton (157 kg) per capita per year

<sup>c</sup> Rags and clean paper are compostable but have a higher salvage value.

The Compost Corporation of America made analyses in 1952 of a large tonnage of mixed refuse from Oakland, Calif., in connexion with pilot-plant composting studies to determine the amounts of salvable material, compostable material, and inorganic waste, to serve as the basis for design and economic estimates in planning a large composting plant. From these findings, they have used the following average percentage composition, on a weight basis, for their estimates :

Tin cans . . . . .	10
Paper (mixed clean) . . . . .	7
Rags (mixed) . . . . .	1.5
Non-ferrous metals . . . . .	0.5
Ferrous metals . . . . .	0.7
Wire . . . . .	0.3
Amber glass . . . . .	4
White glass . . . . .	5
Bottles (salvable and saleable as bottles) . . . . .	1
Inorganic matter (some of which must be wasted) . . . . .	15
Compostable material . . . . .	55

These figures show that this particular refuse contains a large amount of salvable material, and indicate that salvage would be profitable.

The average moisture content and the weight per cubic foot (determined by measuring the truck-box volume of weighed loads) of refuse in the different stages of processing are as follows :

<i>Material</i>	<i>Moisture (%)</i>	<i>Weight (lb. per cubic foot) *</i>
Unsorted refuse . . . . .	—	18 to 20
Sorted refuse . . . . .	40 to 50	25
Pulverized mixed refuse (10%, by weight, soil added) . . . . .	50 to 60	60
Compost (unscreened) . . . . .	10 to 20	52
Compost (screened) . . . . .	10+	45 to 50

\* 1 lb. per cubic foot = 16 g per dm<sup>3</sup>

No information is available on the degree of compaction of the materials.

Data for seven suburban communities in Detroit, Mich.,<sup>56</sup> show on a weighted-average basis as pounds per capita per day : garbage, 0.45 ; rubbish, 0.79 ; and total refuse, 1.24 (200, 360, and 560 g per capita per day, respectively). All of the garbage and the organic fraction of the rubbish is compostable. At East Lansing, Mich., the collected garbage averages 0.66 pound (300 g) per capita per day.

The Institute of Public Cleansing, in Great Britain,<sup>56</sup> gives the quantity of mixed refuse collected as 1.56 pounds (710 g) per capita per day or 0.275 ton (280 kg) per capita per year, with the following physical composition :

Dust and cinders . . . . .	60.2%
Vegetable and putrescible matter	12.5%
Paper . . . . .	12.6%
Metal . . . . .	3.7%
Textiles . . . . .	1.8%
Glass . . . . .	2.8%
Bones . . . . .	0.5%
Combustible debris . . . . .	2.2%
Non-combustible debris . . . . .	3.7%

This refuse analysis is from an area where coal is used for heating, where considerable quantities of paper are salvaged, and where home gardeners utilize some of the lawn and garden trimmings for the soil. Hence, the proportion of dust and cinders is high. The dust and cinders, which contain phosphates and potash, could be included in the compost but they would not undergo biological decomposition. It is probable that the C/N ratio of this refuse is such that, if it were not for the public-health aspects, it could be put on the soil uncomposted, since it would not rob the soil of its nitrogen. Assuming that the vegetable matter, paper, textiles,

**TABLE VI. APPROXIMATE NITROGEN CONTENT AND C/N RATIOS OF SOME COMPOSTABLE MATERIALS (DRY BASIS)**

Material	N (%)	C/N
Urine	15-18	0.8
Blood	10-14	3
Fish scrap	6.5-10	—
Poultry manure	6.3	—
Mixed slaughterhouse wastes	7-10	2
Night-soil	5.5-6.5	6-10
Activated sludge	5.0-6.0	6
Meat scraps	5.1	—
Purslane	4.5	8
Young grass clippings	4.0	12
Sheep manure	3.75	—
Pig manure	3.75	—
Amaranthus	3.6	11
Lettuce	3.7	—
Cabbage	3.6	12
Tomato	3.3	12
Tobacco	3.0	13
Onion	2.65	15
Pepper	2.6	15
Cocksfoot	2.55	19
Lucerne	2.4-3.0	16-20
Kentucky blue grass	2.4	19
Grass clippings (average mixed)	2.4	19
Horse manure	2.3	—
Turnip tops	2.3	19
Buttercup	2.2	23
Raw garbage	2.15	25
Ragwort	2.15	21
Farmyard manure (average)	2.15	14
Bread	2.10	—
Seaweed	1.9	19
Red clover	1.8	27
Cow manure	1.7	—
Wheat flour	1.7	—
Whole carrot	1.6	27
Mustard	1.5	26
Potato tops	1.5	25
Fern	1.15	43
Combined refuse, Berkeley, Calif. (average)	1.05	34
Oat straw	1.05	48
Whole turnip	1.0	44
Flax waste (phormium)	0.95	58
Timothy	0.85	58
Brown top	0.85	55
Wheat straw	0.3	128
Rotted sawdust	0.25	208
Raw sawdust	0.11	511
Bread wrapper	nil	—
Newspaper	nil	—
Kraft paper	nil	—

bones, and combustible debris are compostable, 29.6% of the total or 0.081 ton (82 kg) per capita per year can be composted.

Lund Humphries<sup>56</sup> states that Great Britain's total collected refuse (not including liquid wastes) amounts to 1.68 pounds (760 g) per capita per day or 0.275 ton (280 kg) per capita per year, and contains 25%-55% moisture. The average analysis is given as: fine dust and cinders, 55%; organic garbage, 18%; paper and rags, 17%; metal, glass, etc., 9%; and bones, 1%. Probably 36% or 0.1 ton (100 kg) per capita per year would be compostable.

The city of Baden-Baden, Germany, is reported<sup>56</sup> to collect about 0.82 pound (370 g) per capita per day or 0.15 ton (152 kg) per capita per year of compostable refuse.

Acharya<sup>1</sup> estimates that the amount of compostable refuse, including dust, street sweepings, paper, garbage, and vegetation (katchra), may be as much as 1.5 pounds (700 g) per capita per day in cities like Bombay, while in small towns and villages the quantity is only 0.5-0.75 pound (220-340 g) per capita per day. He shows the organic-matter content to be about 25%-30%, and the moisture 10%-20% as collected.

Scott<sup>68</sup> found the mixed refuse from Tsinan, China, contained approximately 45%-60% organic matter and approximately 40%-55% ash on a dry basis. The nitrogen content was about 0.8%;  $P_2O_5$ , 0.35%; and  $K_2O$ , 0.6%. In the composting operations of van Vuren<sup>82</sup> in South Africa, the quantity of refuse was found to be about 0.5 pound per capita per day, the volume being 25 cubic feet (0.7 m<sup>3</sup>) per 1000 population.

The average amount of compostable refuse, excluding ash and dust, for all cities in New Zealand is estimated to be 0.11 ton (112 kg) per capita per year, with a volume of 4 cubic yards (3 m<sup>3</sup>) per ton.<sup>56</sup> Auckland and Wellington are estimated to produce 0.15 ton (152 kg) per capita per year. At Masterton, the compostable portion of the refuse, which is 60% of the total collected, is estimated to be 0.075 ton (76 kg) per capita per year.

### Nitrogen Content of Various Materials

Table VI gives data taken from various sources for the approximate nitrogen content<sup>1, 56, 59, 79, 83</sup> and the C/N ratios of some of the different materials which may be used in composting. The question of the C/N ratios is discussed more fully in Chapter 5 (see page 50).

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