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# COMPOSTING

## Sanitary Disposal and Reclamation of Organic Wastes

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## Sanitary Disposal and Reclamation of Organic Wastes

HAROLD B. GOTAAS

*Professor of Sanitary Engineering, Department of*
*Engineering, University of California, Berkeley,*
*Calif., USA*

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# PREFACE

Throughout most of the period of the recorded history of man some association between disease and man's waste products has been thought to exist. Since man began to plant in order to harvest needed foods, he has also associated these waste products with the fertility of the soil and the harvest. The use of wastes to improve soil fertility may have been a major factor contributing to the survival of some of the ancient civilizations. Yet, it is only a little more than a century since basic knowledge and a true understanding of the processes involved began to be acquired ; many of nature's secrets regarding health, food supply, and waste disposal are yet to be unlocked.

As small groups of people moved from place to place in their nomadic wanderings, contamination of the environment and the spread of disease therefrom did not have serious consequences. But when population densities increased and people remained in one area, the devastating effects of insanitary disposal of wastes—epidemic disease and debilitation—appeared. With the increasing demand for food and with decreasing soil fertility, the use of wastes to improve agricultural production became important in obtaining sufficient food for survival. Every farmer knows that disposal of waste organic matter on to the land will aid in the maintenance of agricultural production, but because of the lack of appreciation of the health aspects, insanitary utilization and disposal of these wastes are practised even today in many areas of the world.

Although population density in urban centres is high—which increases the possibilities of disease transmission—the rate at the present time for those communicable diseases spread through inadequate environmental sanitation, such as the enteric diseases, is highest among rural populations in most parts of the world. Insanitary disposal of wastes is the major contributing factor to this paradox.

Since in the animal body only a very small amount of the nitrogen, phosphorus, potash, and micro-nutrients is retained in comparison with the amount consumed, night-soil, sewage, and manure contain most of these plant nutrients that were in the food. Waste garbage and organic litter contain many nutrients taken from the soil, and these are worth reclaiming when this can be done in a sanitary and economical manner.

The purpose of this monograph is to present methods and processes by which organic waste materials, which constitute a health hazard and a source of disease communication, may be treated for sanitary disposal and utilization in agriculture. These important objectives—sanitary treatment for the protection of health, and preparation of wastes for utilization in agriculture—are compatible. By using proper techniques, it is often possible to increase considerably the reclamation of plant nutrients for the improvement of food production, while accomplishing sanitary treatment. The essential nutrients, nitrogen, phosphorus, potash, and trace elements, are important assets for agricultural production. Continued depletion of these assets leads to agricultural bankruptcy, and hunger, poverty, and debilitation for those whose welfare depends largely on production from the land. Also, in some places animal manure needed for soil fertilization is collected in an insanitary manner and used for fuel, with a consequent loss of plant nutrients and increase in disease hazards.

Problems of health, the spread of disease, hunger, the improvement of agriculture, the disposal of wastes, and fuel and power are often closely related in the economic development of an area. In areas of the world where the amount of food and power produced is often less than that required to sustain the population in a healthy condition, and where available power and other resources are insufficient to provide alternative fertilizers, the sanitary reclamation and utilization of nutrients in wastes can be an important factor in improving the nutrition, health, and economic status of the people. The return of the nutrients in wastes from the cities to poor agricultural land could change a continually decreasing agricultural production to a steadily increasing production.

This monograph will give little attention to the agricultural use of fertilizers or to the quality of organic or inorganic fertilizers, since the objective is to show how the nutrient and humus values of man's wastes can be conserved for agricultural use while at the same time sanitary disposal and protection of the environment are accomplished. Suffice it to say that in the waste products of animals and man there are still valuable nutrients which can often be profitably reclaimed.

The processes of nature involved in composting wastes are as old as nature itself, but as applied to sanitary composting and waste utilization they often have been misunderstood or not utilized. In fact, the basic aspects of some special and patented composting techniques have been veiled by a shroud of mysticism or magic. Hence, it has seemed important in developing a monograph on sanitary composting methods to bring together and discuss the fundamental aspects of composting, which are the basis for satisfactory practices. The author has attempted to consider the reported results of experience and research in composting and to focus the information on the present techniques. All the specific information available could not be included in a monograph of this size. However, an attempt has been made to cover most of the basic concepts and to support them by experience and the results of investigation. Extensive detail on many fundamental aspects has had to be omitted, but sufficient reference and bibliographical material is included to permit the reader to explore detailed scientific information should he wish to do so.

It is recognized that no one method or technique of composting can be recommended for all areas and conditions. Economic, climatic, social, and other factors will dictate the best procedures for different conditions. However, it is hoped that the methods described will aid in furthering the economic improvement of many areas by the sanitary disposal and utilization of wastes, and that this collection and analysis of fundamental information on composting may help composters to make their particular procedures more efficient.

* * *

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*H. B. GOTAAS*

# *INTRODUCTION*

*The diseases commonly transmitted by human excrement, particularly the parasitic diseases, are widespread and exact a serious toll of human lives and health. In areas where night-soil is commonly used for fertilizer it is not unusual to find 90% of the population infested with a single type of parasite, and the entire population affected by one or more of the several common intestinal infestations. WHO is concerned with the number of deaths arising from such diseases, which strike mainly at infants and small children, and with the general ill-health in all age-groups, which may not result in death but which does reduce vigour and working capacity.*

*Much has been written about the use of community and human wastes as fertilizers. There is little doubt that they are of value, and as processes are developed to improve their competitive position, their use will be extended more and more. While recognizing the necessity of maintaining soil fertility, WHO is interested that widespread agricultural practices should be consistent with acceptable principles of public health. There is an apparent conflict between the hazards of using community wastes and night-soil in agriculture on the one hand, and the need for organic fertilizers to improve crop production on the other. One possibility for a solution lies in making infectious material relatively innocuous by properly controlled composting.*

*The art of composting is very old, and some of the basic principles have been appreciated and used in practice for centuries. In recent years, however, rapid progress has been made in scientific studies of the underlying biological and chemical processes involved. These studies have served to clarify several factors which can act to produce a finished compost which is both valuable to agriculture and relatively safe from the viewpoint of public health. It is hoped that the publication of these principles will be a contribution towards a general improvement in this field.*

## CHAPTER 1

# DECOMPOSITION OF ORGANIC MATTER

The decomposition or stabilization of organic matter by biological action has been taking place in nature since life first appeared on our planet. In recent times, man has attempted to control and directly utilize the process for sanitary disposal and reclamation of organic waste material, and this process has been termed " composting " and the final product of composting has been called " compost ".

Generally speaking there are two processes : (*a*) aerobic decomposition and stabilization, and (*b*) anaerobic fermentation. In these processes, bacteria, fungi, moulds, and other saprophytic organisms feed upon organic materials such as vegetable matter, animal manure, night-soil,[a] and other organic refuse, and convert the wastes to a more stable form.

## Aerobic Decomposition

When organic material is decomposed in the presence of oxygen the process is called " aerobic ". In aerobic stabilization, living organisms, which utilize oxygen, feed upon the organic matter and develop cell protoplasm from the nitrogen, phosphorus, some of the carbon, and other required nutrients. Much of the carbon serves as a source of energy for the organisms and is burned up and respired as carbon dioxide ($CO_2$). Since carbon serves both as a source of energy and as an element in the cell protoplasm, much more carbon than nitrogen is needed. Generally about two-thirds of the carbon is respired as $CO_2$, while the other third is combined with nitrogen in the living cells. If the excess of carbon over nitrogen in organic materials being decomposed is too great, biological activity diminishes and several cycles of organisms may be required to burn up most of the carbon. When some of the organisms die, their stored nitrogen and carbon become available to other organisms. The utilization of the nitrogen from the dead cells by other organisms to form new cell material once more requires the burning of excess carbon to $CO_2$. Thus, the amount

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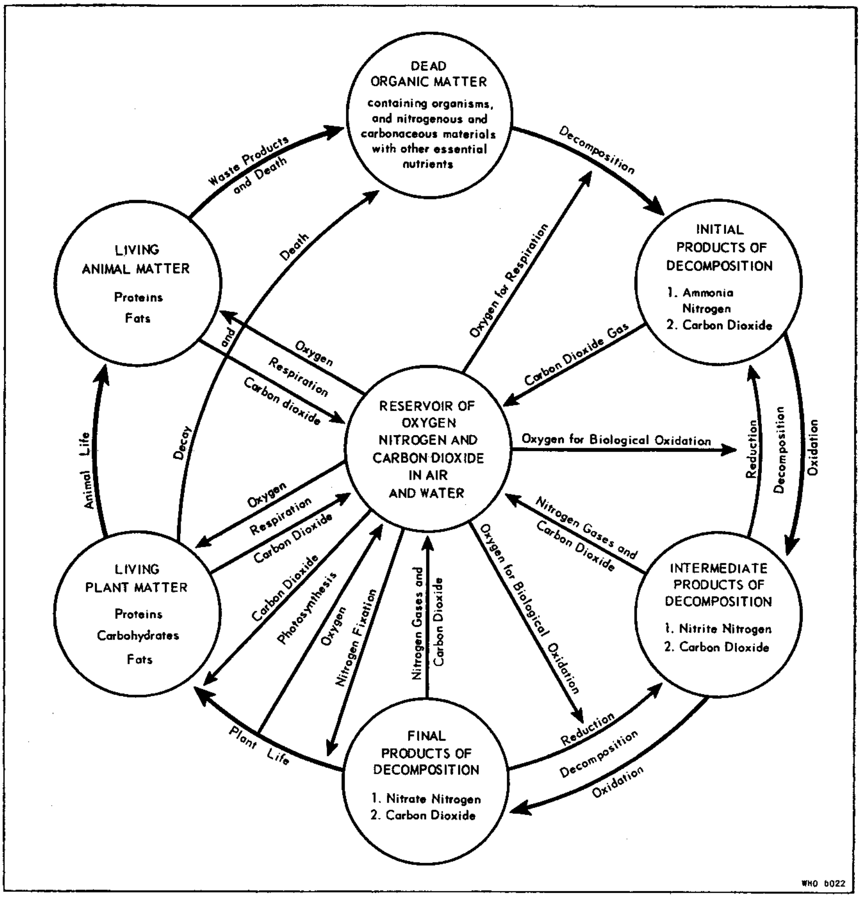
[a] In many places faeces and urine are collected, stored, and disposed of separately. In this monograph the term " night-soil " is used for the composite of faeces and urine ; the term " faeces " indicates faecal material without urine.

of carbon is reduced and the limited amount of nitrogen is re-cycled. Finally, when the ratio of available carbon to available nitrogen is sufficiently low, nitrogen is released as ammonia. Under favourable conditions some ammonia may be oxidized to nitrate. Phosphorus, potash, and various micro-nutrients are also essential for biological growth. These are normally present in more than adequate amounts in compostable materials and present no problem, hence a discussion of their metabolism by the biological cells will not be included.

Fig. 1 illustrates the cycles of carbon and nitrogen in the aerobic process. This is the process most common in nature and is the one which

FIG. 1. CYCLE OF NITROGEN AND CARBON IN AEROBIC DECOMPOSITION *



* After Imhoff & Fair,[37] by kind permission of John Wiley & Sons, Inc., New York

takes place on ground surfaces such as the forest floor, where droppings from trees and animals are converted into a relatively stable humus or soil manure. There is no accompanying nuisance when there is adequate oxygen present. A great deal of energy is released in the form of heat in the oxidation of the carbon to $CO_2$. For example, if a gram-molecule of glucose is dissimilated under aerobic conditions, 484-674 kilogram calories (kcal) of heat may be released. If the organic material is in a pile or is otherwise arranged to provide some insulation, the temperature of the material during fermentation will rise to over 70°C. If the temperature exceeds 65°-70°C, however, the bacterial activity is decreased and stabilization is slowed down. When the temperature exceeds about 45°C, thermophilic organisms, which grow and thrive in the temperature range 45°-65°C, develop and replace the mesophilic bacteria in fermenting the material. Only a few groups of thermophiles carry on any activity above 65°C. Oxidation at thermophilic temperatures takes place more rapidly than at mesophilic temperatures and, hence, a shorter time is required for stabilization. As will be shown in greater detail later (page 80), the high temperatures will destroy pathogenic bacteria and protozoa, hookworm eggs, and weed seeds which are detrimental to health and agriculture when the final compost is used on the land.

Aerobic oxidation of organic matter produces no objectionable odour. If odours are present, either the process is not entirely aerobic or there are materials present, arising from other sources than the oxidation, which have an odour. Aerobic decomposition or composting can be accomplished in silo digesters, pits, bins, stacks, or piles, if adequate oxygen is provided. Turning the material at intervals or other techniques for adding oxygen are necessary to maintain aerobic conditions.

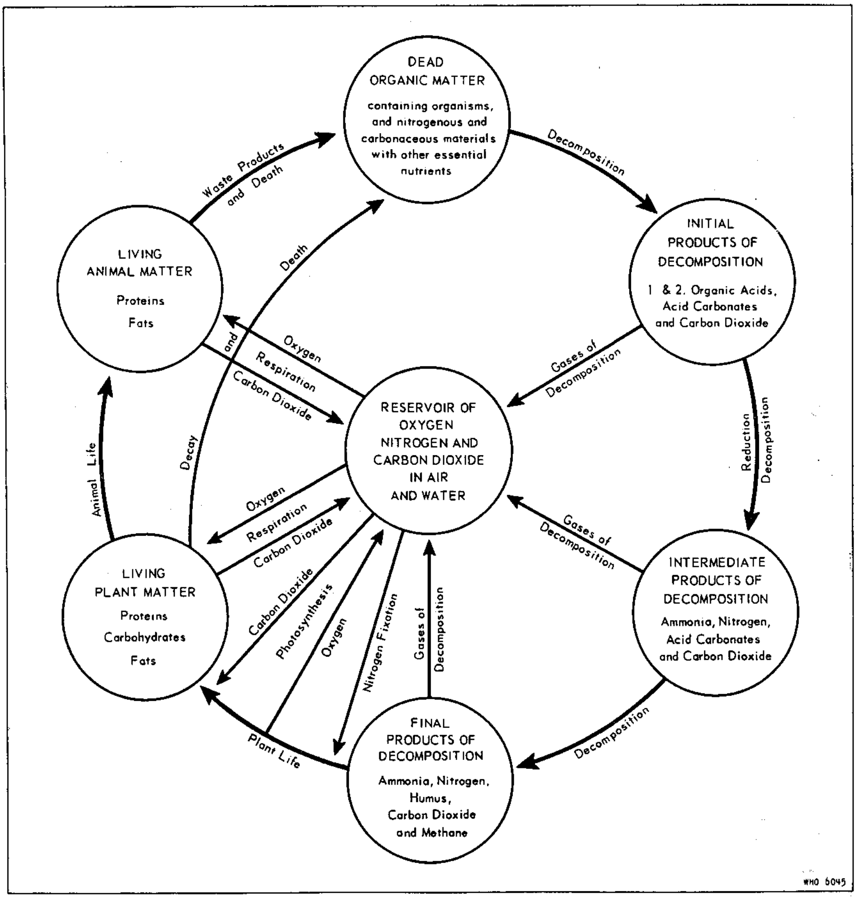
## Anaerobic Fermentation

Putrefactive breakdown of organic material takes place anaerobically. Anaerobic living organisms in metabolizing nutrients break down the organic compounds by a process of reduction. As in the aerobic process, the organisms use nitrogen, phosphorus, and other nutrients in developing cell protoplasm, but reduce the organic nitrogen to organic acids and ammonia. The carbon from the organic compounds which is not utilized in the cell protein is liberated mainly in the reduced form of methane, $CH_4$. A small portion of carbon may be respired as $CO_2$.

This process takes place in nature as in the decomposition of the organic muds at the bottom of marshes and in buried organic material to which oxygen does not have access. The marsh gas which rises is largely $CH_4$. Intensive reduction of organic matter by putrefaction is usually accompanied by disagreeable odours of hydrogen sulfide and of reduced organic compounds which contain sulfur, such as mercaptans.

Since anaerobic destruction of organic matter is a reduction process, the final product, humus, is subject to some aerobic oxidation when put on the soil. This oxidation is minor, takes place rapidly, and is of no consequence in the utilization of the material on the soil.

FIG. 2. CYCLE OF NITROGEN AND CARBON IN ANAEROBIC DECOMPOSITION *



* After Imhoff & Fair,[37] by kind permission of John Wiley & Sons, Inc., New York

Fig. 2 illustrates the cycles of carbon and nitrogen in the anaerobic process of decomposition. There is insufficient heat energy liberated in the process to raise significantly the temperature of the putrefying material.

In the anaerobic dissimilation of the glucose molecule, only about 26 kcal of the potential energy per gram-molecule of glucose are released as compared to 484-674 kcal for aerobic fermentation. The energy of the carbon is in the $CH_4$ released. If the $CH_4$ is burned to $CO_2$ large amounts of heat are involved. In many instances, the energy of the $CH_4$ from anaerobic destruction of organic matter is utilized in engines for power and burned for heat.

The lack of substantial release of heat to the mass being dissimilated in the anaerobic destruction of organic matter is a definite disadvantage in the treatment of night-soil and other contaminated materials, where for public-health reasons destruction of pathogens and parasites is necessary. High temperatures do not play a part in the destruction of pathogenic organisms in anaerobic composting. The pathogenic organisms do disappear in the organic mass, owing to being in an unfavourable environment and to biological antagonisms. The disappearance is slow and the material must be held for periods of six months to a year to ensure relatively complete destruction of *Ascaris* eggs, which are the most resistant of the faecal-borne disease parasites in wastes.

Anaerobic composting may be accomplished in large, well-packed stacks or pit cells containing 40%-75% moisture, into which little oxygen can penetrate, or in cells containing 80%-99% moisture so that the organic material is a suspension in the liquid. When the materials are composted anaerobically in stacks or pit cells without being covered with water, the odour nuisance may be quite severe. However, when the material is kept submerged, the odorous gases are dissolved in the water and are usually released slowly into the atmosphere. If the water is replaced from time to time when removing some of the material, no serious nuisance is created.

While the processes of composting are either aerobic or anaerobic, some bacteria are facultatively aerobic or facultatively anaerobic, i.e., they can grow under aerobic or anaerobic conditions but may grow better under one condition. This may partly account for the fact that it is difficult to reconcile the small amount of oxygen present in the voids of the volume of material, including the oxygen which might diffuse into the pile, with the degree of oxidation which takes place after placing the material in a pile and before turning or further aerating by other means. Compost piles under aerobic conditions attain a temperature of 55°-65°C in 1-5 days, depending upon the material and the conditions of the composting operation. This temperature can also be maintained for several days before further aeration. The heat necessary to produce and maintain these temperatures must come from aerobic decomposition, which requires oxygen. After a period of time the material will become anaerobic unless it is aerated. There is probably a period between the times when the oxygen is depleted and anaerobic conditions become evident, during which the process is facultatively aerobic.

In this monograph the term " aerobic composting " will be used in its commonly accepted meaning of that process which requires a considerable amount of oxygen and produces none of the characteristic features of anaerobic putrefaction. In its modern sense, aerobic composting can be defined as a process in which, under suitable environmental conditions, facultatively aerobic organisms, principally thermophilic, utilize considerable amounts of oxygen in decomposing organic matter to a fairly stable humus.

The term " anaerobic composting " will be used to describe putrefactive breakdown of the organic matter by reduction in the absence of oxygen where end products such as $CH_4$ and $H_2S$ are released.

## CHAPTER 2

# SANITARY AND AGRICULTURAL IMPORTANCE

There is an important relationship between sanitation and agriculture in all parts of the world. In agricultural areas, the utilization of human and animal wastes is of great importance from both the public health and the agricultural points of view.

The disposal and utilization of waste is also becoming of great importance in highly industrialized areas, because of: (*a*) the ever-increasing difficulties in disposing of great accumulations of wastes from cities in a sanitary and orderly manner; (*b*) the ever-increasing threat to soil fertility due to the great decrease in the amount of animal manure, formerly a by-product of the production and use of power; and (*c*) the ever-increasing and intensive demands being put on the agricultural lands to produce more food. The problem in highly industrialized countries is relatively new, but it is a very important one, which will require extensive future considerations to determine how these vast quantities of contaminated wastes from large cities can be satisfactorily disposed of and also utilized.

Modern composting, first suggested by Sir Albert Howard [32, 33, 35] and his associates [5, 41] from studies in India and carried forward there by Acharya and Subrahmanyan,[1, 3] has been investigated extensively by Scott [68] and van Vuren,[82] by Gotaas and his associates—McGauhey, Golueke, and Card—at the University of California,[23, 24, 49, 71, 81] and by many others in different parts of the world.

## Health Aspects

There are two important health aspects associated with the disposal and utilization of human and agricultural wastes. One is the high incidence of illness and death from faecal-borne disease which results from the insanitary disposal and utilization of wastes. The other is the improved nutrition, an important factor in the prevention of disease, which can be obtained when the wastes are returned to agricultural land to provide plant nutrients. Even with the best nutrition, however, destruction of the causative organisms of the faecal-borne diseases or their removal from the environment is necessary for the satisfactory control of these diseases. The faecal-borne disease rate is invariably high in agricultural areas where inadequate sanitation exists and insanitary use of wastes is practised.

The diseases for which the causative organisms are found in faecal wastes can be classified broadly as : *(a)* those caused by bacteria, *(b)* those caused by protozoa, and *(c)* those caused by helminths. The faecal-borne bacterial diseases are bacillary dysentery, typhoid fever, paratyphoid fevers A and B, enteritis, and cholera. Also the *Brucella* organisms, which produce undulant fever in man, can be present in animal faeces and the disease can be faecal-borne. Similarly *Coxiella burnetii*, the causative agent of Q fever, may be present in manure and the disease can thus be faecal-borne. The faecal-borne protozoan diseases are amoebic dysentery, balantidial diarrhoea, and flagellate diarrhoea. The faecal-borne helminth diseases are bilharziasis, fascioliasis, clonorchiasis, paragonimiasis, ankylostomiasis, ascariasis, trichuriasis, Cochin-China diarrhoea, and oxyuriasis.

Scott [68] has demonstrated, in experimental composting studies in China, that the causative organisms of faecal-borne diseases are destroyed by aerobic composting, if temperatures in the thermophilic range are maintained for a sufficient time and all of the material is subjected to these temperatures. The eggs of *Ascaris lumbricoides* were shown to be the most resistant to destruction by composting. It should be pointed out that although the eggs of *Oxyuris (Enterobius) vermicularis*, the pin or thread worm, are apparently destroyed by aerobic composting, the disease oxyuriasis, because of the personal hygiene factor, is not susceptible to control merely by proper methods of sanitary collection and disposal of faecal wastes.

That pathogenic bacteria will be rapidly destroyed when all parts of a compost pile are subjected to temperatures of about 60°C seems quite evident, since these organisms are unable to survive temperatures of 55°-60°C for longer than 30 minutes to 1 hour. *Entamoeba histolytica* has been shown to be destroyed when exposed to temperatures of 45°-55°C for an appreciable period. Scott,[68] however, found that both *Ent. histolytica* and *Ent. coli* survived in aerobic compost piles containing unusually large amounts of human faeces (70%) until about the 12th day, when the piles were turned on the 5th and 12th days. Similarly, his investigations showed the eggs of *A. lumbricoides* to be destroyed in aerobic compost piles before the fourth turn, when the piles were turned on the 5th, 12th, 22nd, and 36th days. Scharff [66] was unable to find eggs of *A. lumbricoides* after three weeks' composting of highly infected night-soil combined with refuse. More frequent turning, which keeps the mass more aerobic, maintains more uniformly high temperatures, and facilitates more rapid decomposition, would probably have shortened the survival period for both

*Ent. histolytica* and *A. lumbricoides* in Scott's and Scharff's composting operations. Later it will be shown that when the piles start to become anaerobic, the temperature falls, and aeration by turning or by other means is necessary to maintain more uniformly high temperatures.

It is probable that biological antagonisms in the composting material also affect the destruction of pathogenic organisms and parasites, but evidence indicates that high temperatures are the most important factor and that where thermophilic temperatures are maintained, destruction can be complete.

Van Vuren[82] was unable to demonstrate any health hazards in properly managed composting operations in South Africa. His findings are confirmed by Blair,[10] Union of South Africa Health Department; Loots,[48] Union of South Africa Department of Agriculture; Hamblin of Johannesburg,[82] Acharya[1] in India; Scharff[66] in Malaya; and others in Great Britain, Germany, Australia, the Netherlands, Denmark, and New Zealand.[56, 57, 60, 82]

In anaerobic composting involving no exothermic reactions which produce high temperatures, good destruction of the eggs of *A. lumbricoides* requires six months and complete destruction of the eggs cannot be assured in that period. The die-away of parasites in an unfavourable anaerobic environment will eliminate all but a small percentage of the resistant organisms and eggs. Scott[68] found that aerobic decomposition with accompanying high temperatures for about a week prior to anaerobic composting in pits or large stacks assured that *Ascaris* eggs would be destroyed.

In the case of anaerobic digestion of contaminated material in liquid suspension, such as sludge digestion, studies on the incidence and survival of pathogens and parasites have indicated that a considerable number of such organisms can remain viable for periods varying from less than a week to as long as six months, depending upon the organism, the nature of the digesting material, and the digestion conditions.[14, 58, 72, 92] Most reports show also the highly adverse effect of increased temperature on the survival of organisms. Ruchhoft[64] found that the survival of *Salmonella typhosa* in stored sludge was 80 days at 10°-16°C, and only 13-14 days at 20°-22°C. Newton et al.,[58] in a study on the effect of sewage-treatment processes on the ova and miracidia of *Schistosoma japonicum*, reported that at temperatures of 8°-18°C, storage periods of 2-3 months were needed to render ova non-viable, whereas at 18°-24°C only 3 weeks were needed. Keller[46] reports that although mesophilic digestion of sludge does not destroy the eggs of *A. lumbricoides*, thermophilic digestion at 53°-54°C is very effective. It is interesting that in areas where anaerobically digested sewage sludge has been used extensively as a fertilizer, there appear to be no recorded instances of faecal-borne disease caused by the sludge.

Flies, which are important in the transmission of faecal-borne diseases, can be controlled in aerobic composting if the compost piles are turned sufficiently often to subject the fly eggs to the high temperature before they have an opportunity to hatch. The Agricultural Research Council of Great Britain[26] noted that fly larvae were drastically curtailed in the compost operations in England. After the food in the organic wastes which is attractive to flies has undergone some decomposition and approaches being a humus, it ceases to be attractive to flies.

Good fly control is difficult, if not impossible, when food attractive to flies is composted anaerobically in stacks in warm weather. If organic matter is digested anaerobically in a liquid suspension in closed tanks, fly-breeding is satisfactorily controlled. Fly control is discussed in detail later (page 83) with special reference to its relationship to composting techniques.

From reported experiments it seems evident that adequate composting of faecal and other wastes, together with good sanitary practices, can control the faecal-borne diseases which are so widespread where faeces are used as a fertilizer without the practice of proper sanitary measures.

Special care must be exercised to safeguard the health of the compost-plant workers when night-soil or sewage sludge is added. Composting operations have been abandoned in some areas largely because of nuisances and health hazards resulting from carelessness in control of operations. In other instances there has been no difficulty concerning the health of the workers and little nuisance when composting raw faecal matter with refuse. Sufficient stand-by equipment should be available to prevent an accumulation of refuse in the case of a breakdown.

## Agricultural Aspects

Observers have often noted that, in areas of the world where town wastes are utilized for fertilizer, the land in the immediate vicinity of the towns is more fertile than the land further away, which is unable to procure these wastes. Humus from night-soil, manure, garbage, and other organic wastes has properties valuable to growing vegetation and to the soil itself. The wastes contain nitrogen, phosphorus, and potash, which are vital to the continuing fertility of the soil. In addition, they contain trace elements known to be essential for optimum plant growth. It is believed by many authorities that the susceptibility of crops to parasites and infectious diseases is increased by a shortage of the minor or trace elements. Thus humus may lessen the frequency of plant diseases in crops.

The humus resulting from composting organic materials has desirable characteristics in addition to the nutrients. When used with inorganic fertilizers, the organic acids resulting from metabolic breakdown of organic material form a complex with the inorganic phosphate. This form of phosphorus is more readily available to higher plants. Both phosphorus and nitrogen are involved in a storing effect which is peculiar to humus. The precipitation of phosphorus by calcium is inhibited, and nitrogen, which is converted to bacterial protoplasm, is rendered insoluble. This nitrogen thereafter becomes available as the bacteria die and decompose. The effect is to prevent leaching of soluble inorganic nitrogen and to make its rate of availability more nearly equal to the rate at which plants can utilize it. The gradual decomposition of insoluble organic matter provides continual liberation of nitrogen as ammonia, which is then oxidized to nitrites and nitrates.[63] The organic humus may also contribute to increased nitrogen-fixation in the soil from the nitrogen in the air.

Perhaps as important as the nutrient properties of humus are its physical effects on the soil. Soil fertility depends on soil structure as well as on nutrients. The degree of aggregation of the soil particles is very important, since on it depends the water-retention capacity of the soil. The higher the degree of aggregation of the particles, the greater is the soil's capacity to take in rain-water and, hence, the greater is the amount of water which can be stored against periods of low rainfall or drought. Aggregation is brought about by cellulose esters (cellulose acetate, methyl-cellulose, and ethyl-cellulose) resulting from bacterial metabolism;[62] consequently, the soil aggregation or crumbling property is promoted by humus. The modifications of soil structure effected by humus also encourage the more extensive development of the root systems of plants.

Intensely cultivated soils tend to become deficient in organic humus as do soils in tropical areas, where the higher temperatures promote rapid biological destruction of organic matter. A sufficient supply of organic matter helps to maintain the soil in the physical and biological condition required for healthy plant growth. Humus is especially important in heavy clay soils, in loose sandy soils, and in saline and alkaline soils. Humus and the bacterial metabolism associated with it increase the ability of the soil to buffer rapid changes in alkalinity and acidity, and to neutralize certain toxic wastes. Wind and water erosion are lessened by having sufficient humus in soils, as is also the difficulty of cultivating poorly aggregated soils. The chemistry and microbiology of humus, and its relationship to the soil, have been extensively described by Waksman,[83, 84] whose many researches have provided important information on the characteristics of humus in soils.

Most of the more primitive methods of utilizing wastes as fertilizer provide a continuous source of faecal-borne-disease infection and do not effect maximum conservation of nitrogen. Scott [68] found that considerable nitrogen was lost in the preparation and drying of faeces-cake for fertilizer. Similarly, when relatively fresh faecal material is put on the fields, a considerable amount of nitrogen may be lost through drying of the material, if the latter remains on the ground surface for some time before being worked into the soil. The burning of animal manure for fuel—a practice in some places—results in a complete loss of nitrogen. Modern composting to meet satisfactory sanitary standards can provide greater conservation of nitrogen than the more primitive insanitary methods. In using the safest sanitary technique, i.e., aerobic composting at high temperatures, nitrogen losses can be kept at a very low level, in fact, about as low as with anaerobic composting at low temperatures. This will be discussed more fully later with respect to composting procedures.

The propagation of weeds and other undesirable plants is increased when manure and other wastes are put on the land without adequate composting. The high temperatures of aerobic composting destroy the weed seed in a short period. This is not effectively accomplished in anaerobic composting. After six months the amount of fertile seed in anaerobically decomposing material is decreased, but is not entirely destroyed.

Composting, in addition to providing sanitary treatment of contaminated organic wastes, reduces the carbon-nitrogen (C/N) ratio of the wastes. This aspect is dealt with fully on page 50.