CHAPTER VII. USE OF WASTE-DERIVED ORGANIC MATTER AS A SOIL AMENDMENT

A. Introduction

Although the nitrogen (N), phosphorus (P), and potassium (K) contents of organic waste typically are insufficient to permit the waste to be legally termed "fertiliser",[1] the waste is a source of plant nutrients. When incorporated into the soil, the nutrients increase its fertility. The major utility of organic waste in agriculture is not its NPK content, however; it is its beneficial effect on the structure and other characteristics of the soil. Nevertheless, although the fertiliser aspect may be secondary, it should not be overlooked.

Organic wastes suitable for use in crop production fall into three broad groups: garden and crop debris, animal and human wastes,[2] and food preparation and food processing (e.g., cannery) wastes.

Raw organic wastes can be used either directly after they are generated, or they can be composted prior to application. Some preparation of the wastes, such as dehydration or shredding, may precede direct application. Each mode (i.e., direct vs. composted) has attendant advantages and disadvantages, the nature of which becomes apparent as this chapter advances.

The form in which fertiliser elements (NPK, and others) occur in processed and in raw, i.e., unprocessed, organic waste has an important bearing on the application of the waste. The elements are almost entirely in the form of organic molecules. In unprocessed waste, the elements are bound mostly in plant and animal cellular protoplasm. As the waste decomposes, the elements are gradually transformed into microbial protoplasm, and into intermediate and final breakdown products. Among the latter, ammonium and ammonia-nitrogen are especially important. The practical significance of the elements being bound in organic molecules is that upon the introduction of the waste into the ground, only a fraction of its nutrients immediately becomes available to a crop. For example, it is estimated that only about 30% to 35% of the nitrogen in compost is available for utilisation by crop plants during the first year after application. However, in succeeding years, the nitrogen and the other elements eventually become available.

B. Utilisation of raw organic waste

B1. PREPARATION

Type and extent of preparation depend upon several factors, among which four are particularly important. They are: 1) physical characteristics of the waste, 2) whether or not the waste can be incorporated into the soil in its present state, 3) time lapse between generation and application of the waste (storage time), and 4) distance to the site of use. Population density and proximity to the generation and application sites might be fifth and sixth factors.

B2. PARTICLE size

Particle size is one of the physical characteristics that serves as a decisive factor in the determination of the feasibility of direct application. The maximum permissible particle size is the largest at which a waste can be manipulated by the machine or by the labourer who spreads it on the land. Additionally, it is the size beyond which the waste cannot be completely covered with soil or would require an inordinately deep incorporation into the soil to do so. The dimensions of the maximum particle size probably can be larger if the material is to be incorporated manually. A machine has an inflexibly uniform depth tolerance, whereas a labourer can adjust his tilling to suit the size of the particles -- within reason.

The molecular composition of a waste particle also has a bearing on its maximum permissible dimensions. The particle size suited to a refractory material (difficult to decompose) is smaller than one suited to a material that can be readily decomposed. For example, woody material should have a maximum particle size of 1 or 2 cm; whereas most green (raw) vegetable trimmings and crop debris usually do not require size reduction. Of course, stalks of plants that are more or less a meter in length should be chopped into 30-cm sections -- mainly for convenience of handling. If the paper is removed, raw refuse, especially in the lesser industrialised countries, need not be size reduced. If an appreciable amount of paper is present, the paper should be shredded to a maximum particle size of about 12 cm.

Size reduction as a means of preparation for direct application of raw wastes should be avoided unless it is seriously needed. The reason is economic in nature. Generally, direct application is selected only because economic constraints rule out a more sophisticated approach (e.g., composting).

B3. DEHYDRATION

The potential generation of foul doors should be carefully considered, particularly in locations where there may be a high concentration of grass clippings and food residues. Dehydration is a preparatory step that could be done with much advantage. Dehydration is indicated in situations in which storage time and distance of transport are significantly long. It also might be required if the generation and collection areas, as well as the disposal sites, are in relatively densely populated areas.

The utility of dehydration comes from the fact that it leads to a more or less complete cessation of microbial activity responsible for odorous breakdown products. Microbial activity ceases completely when the moisture content drops to 12% (on a wet weight basis), and declines rapidly as that level is approached. Moreover, dehydration renders the material less attractive to vectors, makes the material easier to handle, minimises drainage during storage and transport, and decreases the weight and volume of the material to be transported. Loss in weight and volume is significant because the 85% to 95% moisture found in most living matter is reduced by 50% to 55%.

Dehydration should be limited to that which can be attained through air drying and exposure to the sun. Spreading on an exposed surface or placing on racks are two ways of bringing about dehydration; the cost of dehydration by means other than these two is prohibitive. Whatever the method of drying, appropriate precautions should be taken to prevent excess untreated liquid from harming the environment.

B4. EXAMPLE of direct application

Finally, as a point of interest, mention is made of an experiment to apply raw organic material that was tried first in the United States (Texas) and later in Israel [1]. In Texas, the attempt was unsuccessful; whereas in Israel, the attempt was very successful. In the attempt in Israel, 8 Mg of organic garbage (food preparation wastes) were spread upon a 0.25-ha plot of desert wasteland. The waste was sowed with seeds of a high-protein animal feed and a white wheat. Seeds and waste were covered with sand. The plot received no watering. Yield from the 0.25-ha plot was 4 Mg of animal feed. According to the author of the article, substantial yields were obtained over the ensuing ten years without resorting to watering or further reseeding.

C. Evaluation of direct application

C1. ADVANTAGES

The primary advantage of direct application of raw organic wastes is economic. The elimination of processing made possible because of direct application can reduce costly investment. The processing is costly because it involves the use of equipment. Another advantage is a probable reduction of the loss of nutrients that usually characterises processing. A common example is a loss of ammonia-nitrogen during composting. Another potential advantage is a reduction in the land area requirement because no land is involved in processing operations. In summary, most of the benefits arising from the incorporation of organic matter in soil can be attained with a smaller expenditure of effort, time, and money than is entailed in processing the waste prior to utilisation.

C2. DISADVANTAGES

Unfortunately, the advantages to be gained from the direct application of raw organic waste are strongly tempered by several limitations and constraints that pertain to crop production, maintenance of a quality environment, and safeguarding the public health. The site should be isolated and well managed; otherwise, the generation of foul doors alone will lead to numerous complaints.

C2.1. Crop production

Studies in Europe indicate that composted waste significantly surpasses raw organic waste in terms of promoting plant growth. Additionally, common gardening and farming experience demonstrates that the direct application of fresh manure can seriously damage plants and in general inhibit plant growth, unless precautionary measures are taken. The severity of the damage depends upon the degree of freshness and characteristics of the manure, which depend on the animal source. For example, damage from applying fresh cow manure, though significant, is not as severe as that from applying fresh chicken or swine manure. The adverse consequences from the use of fresh crop debris and urban refuse are much less drastic.

A severe form of the damage is the so-called “burning” that soon follows the application of a fresh raw waste. The burning is comparable to that which results from excessive application of chemical fertiliser (e.g., ammonium sulphate). In less severe cases, plant damage is manifested as a general stunting of plant growth.

The usual mechanism of the damage is the release of toxic concentrations of ammonia in the root zone. If the concentration is sufficiently great, plant roots are killed. Another possibility is the formation of toxic breakdown products. It should be noted that the application of incompletely composted material can have similar consequences.

One precautionary measure consists of spreading the material on the field in the autumn. However, in regions characterised by winter snows, there is the danger of eutrophic elements (e.g., NPK) being transported to receiving waters by way of the melting snow. The same possibility of polluting receiving waters applies in regions characterised by heavy rainfall during the period when the fields lie fallow. A second measure is to interpose a 10- to 20-cm layer of soil between the raw waste and the expected root zone. A third measure is to reduce the thickness of the layer of raw waste -- the assumption being that the waste will be sufficiently decomposed before plant seeds have germinated and the root system of the seedlings has developed.

The limitations described in the succeeding paragraphs apply only to raw wastes that are highly perishable in nature or are animal body wastes. Most types of field crop debris do not fit into the highly perishable classification.

C2.2. Public health hazard and environmental degradation

As was stated earlier, unless suitably protected during storage and transport, raw municipal organic wastes serve not only as attractants but also as sources of nutrient and as shelters for rodents and vectors. Rodents are attracted by wastes of plant origin and rarely, if at all, by manures. The potential of raw organic waste to attract and serve as a nutritional source for rodents and vectors was illustrated in an unpublished study conducted in the United States in the 1960s. (At that time, the organic content of United States refuse was much higher than it is at present.) The study demonstrated that an open dump containing municipal refuse can serve as a focal point for the spread of rat populations over an area with an 8-km radius. The spreading area of flies is about the same. The entire reproductive cycle of flies can and does take place in decaying organic matter. Major deterrents to flies are a low moisture content and either very low or very high temperatures.

Two other disadvantages are aesthetic in nature. One is the production of objectionable doors. Under an appropriate combination of conditions, the foul odour emission may become very intense. The second aesthetic affront is the unsightliness of raw wastes, especially of the garbage from the preparation of food.

Environmental and public health problems can be considerably lessened by preventing access by undesirable organisms (macro- and micro-) during storage and transport. In the field, they can be well controlled by incorporating the wastes into the soil as soon as is possible after the spreading.

D. Economics

If no preparation is required, the major cost prior to application is that of transportation. It is possible for transportation costs to become the key factor in the decision to utilise or not to utilise a raw waste. The existing economic situation is such that the economically permissible longest distance of transport is soon reached. Since the late 1960s, the unit cost for truck transport in the United States has doubled, and in some cases tripled. A similarly precipitous rise in costs prevails in developing countries.

If the material is to be stored, the cost of constructing a suitable enclosure becomes an important factor. Covering the material with screening would exclude flies and rodents. However, screening would do nothing about unsightliness or emission of doors.

Health authorities in the United States have concluded that beef and dairy cattle manures can be stored satisfactorily only in a concrete tank. Storage in a concrete tank or other durable container eliminates leachate formation, as well as wards off fly and rodent invasion. Despite these benefits, the cost involved in building concrete tanks is likely to exceed the economic capacity of most developing countries. On the other hand, the likelihood of prolonged storage in a developing country is remote.

E. Use of composted waste

E1. DESCRIPTION of product

Waksman defines humus as being a complex aggregate of amorphous substances resulting from the microbiological activity that takes place in the breakdown of plant and animal residues.

Properly composted waste fits Waksman's definition of humus [2,3]. In terms of chemical makeup, compost is a heterogeneous mixture of substances that includes a variety of compounds synthesised by the microbial populations of complexes resulting from decomposition, and of materials resistant to further breakdown. Thus, derivatives of lignins, proteins, certain hemicelluloses, and celluloses are compost's principal constituents. Inasmuch as it is a humus, compost is not in a biochemically static condition. Therefore, under appropriate conditions, compost will be further decomposed by microbes and to some extent by higher forms of life (e.g., earthworms and insects). Eventually, it is oxidised to mineral salts, carbon dioxide, and water. Because compost is a humus, it has an ample capacity for base exchange, with consequent swelling.

E2. APPEARANCE

The appearance of the compost product directly after the processing phase strongly depends upon the physical characteristics of the waste. However, regardless of origin, the product is dark brown to dark grey in colour. Unless the moisture content of the material is lower than 15%, decomposition continues. Decomposition is accompanied by change in appearance. If the compost product is stored sufficiently long, it eventually approaches the consistency of a fine dust. Because this eventual change in appearance also betokens a radical change in properties, all descriptions in this section refer to the compost product directly after it has been discharged from the compost facility.

Unless all newsprint and cardboard are removed in the pre-processing stage, composted mixed municipal refuse from industrialised countries will contain a sizeable amount of paper in the form of bits of recognisable paper. Similarly, straw, wood, or other resistant material may also be recognisable. Despite the fact that the bits of paper, wood, straw, etc. are recognisable, chemical and physical processes significantly alter their natures. For example, the bits are much more brittle than they were prior to composting. The change is manifested as a drastic increase in the ease with which the material can be further size reduced.

Glass shards and plastic film from composting mixed waste detract from the appearance, and to some extent from the utility of the product. Unfortunately, they are not easily removed; although screening may help to some extent. The visual attractiveness of the compost product can be enhanced by screening and shredding such that its particle size becomes relatively small and uniform. The alternative, of course, is to compost source-separated materials.

The composting material takes on an earthy odour toward the end of the processing phase, usually at the same time that fungi and actinomycetes make their appearance. The earthy odour mingled with slightly musty overtones continues to be a characteristic of the product long after the processing phase has been completed.

E3. PRODUCT specifications

Although the compost product does have a fertiliser value, as stated before, its nitrogen, phosphorus, and potassium (NPK) contents do not meet the usual legal definition of "fertiliser". Because the NPK of the product reflects that of the raw material, use of a high NPK raw waste results in a high NPK compost product. The converse is true for a low NPK raw waste.

Examples of nitrogen concentration (dry wt. basis) of municipal refuse typically encountered are as follows: United States, 0.5% to 1%; São Paulo, Brazil, approximately 2% to 4%; Mexico City, approximately 2% to 4%; and India, about 1% to 2%. The nitrogen content of composted cattle manure may be as little as 0.5% or as much as 2.5%. Composted fowl manure, pig manure, and sheep manure reflect the substantial nitrogen concentrations of the raw manures. The phosphorus content of composts generally is only slightly less than that of the nitrogen content. When municipal refuse is composted, the potassium (K) content generally is much lower, unless wood ash is present. The low potassium content is not a serious nutrient deficiency in areas where the soil is alkaline.

The carbon-to-nitrogen ratio (C:N) declines during the compost process, because carbon is lost by way of the carbon dioxide formed in microbial metabolism. However, the decline is not proportional to carbon dioxide formation, inasmuch as some nitrogen also may be lost in the form of ammonia. The final C:N may range from about 30:1 to about 20:1. Decline is not uniform. If the process is carried out properly, the C:N of the product does not exceed 20:1.

The C:N is critical to crop production. An excessively high C:N can lead to a nitrogen shortage for crop plants. The shortage ultimately is a result of the disparity between higher plants and soil microbiota for the available nitrogen. The microbes are more efficient in assimilating nitrogen than are higher plants. The upper critical C:N depends upon the availability of carbon to microbial assimilation and metabolism. The more difficultly available the carbon, the higher is the permissible C:N. Thus, if the major portion of the carbon is a substance that is difficult to decompose such as wood, straw, and paper, the upper level is about 35:1.

As is characteristic of all living cells, synthesis of new protoplasm (i.e., growth and proliferation) and metabolism occur with an inevitable simultaneity if nitrogen is available. If the supply of nitrogen is insufficient to fulfil the demands of all organisms present in the soil, the organisms compete with each other for the available nitrogen. Organisms that are the most efficient in nitrogen assimilation take up most of the available nitrogen -- at the expense of the less efficient organisms. The latter then exhibit symptoms of nitrogen deprivation -- namely, chlorosis and a general stunting of plant growth.

An excessively high C:N can be compensated by simultaneously applying a nitrogen-rich fertiliser with the compost.

If most of the carbon is readily available (e.g., green plants, food preparation waste), then the permissible C:N is lower -- namely, on the order of 20:1. If the C:N is too low, there is some danger of the occurrence of plant damage, i.e., “burning”.

E4. GRADING the product

The variations in visual and nutritive qualities of composts bring up the advisability of grading the product, either as a single mass, or as subdivided into fractions separated on the basis of differences in quality. In most cases, effective utilisation of the product depends upon the imposition of grading. The rationale for grading is in part the fact that applications differ among themselves with respect to the quality of compost required for them. For example, reclamation of land despoiled by strip mining can be satisfactorily accomplished with a relatively poor grade of compost; whereas, a very high-grade product would be needed for vegetable production.

Grading can be based upon: 1) NPK content; 2) particle size and uniformity of particles; 3) extent of contamination with glass and plastics; and 4) freedom from pathogens and toxic organics and metals. The data in Table VII-1 indicate allowable concentrations of individual heavy metals permitted in the marketing of European composts. A possible fifth basis might be degree of “maturity”, i.e., age of the compost product.

Table VII-1. Compost standards in some European countries (mg/kg, dry)[a]

Country	Pb	Ni	Cd	Hg	Cr	Cu	Zn
Netherlands	65 to 100	10 to 20	0.7 to 1	0.2 to 0.3	50	25 to 60	75 to 200
France	800	200	3	8	--	--	--
Austria	45 to 200	25 to 100	0.7 to 3	0.4 to 3	70 to 250	70 to 500	200 to 1,800
Germany	100 to 150	35 to 50	1 to 1.5	0.7 to 1	70 to 100	70 to 100	300 to 400
European Community	45 to 100	25 to 50	0.7 to 1	0.4 to 1	0.7 to 1	70 to 100	200 to 300

Source: Reference 8.

[a] Where two values are given, they denote compost meeting different regulatory conditions, classes of compost, or uses. If two values are indicated for a given metal, they reflect different limits based on specific class of compost, on allowable uses, or on different regulatory conditions.

Obviously, a top-grade (grade-1) product is one that is free of contaminants, is safe in terms of public health, has a uniformly small particle size, and has an NPK approaching that is legally expected of a fertiliser (about 6%). It would be suitable for the more demanding applications; as, for example, production of vegetables destined for human consumption, either with or without being cooked.

The following specifications are suggested for grade-2 and grade-3 composts. Grade-2 compost would be one that has a maximum particle size larger than that of the grade-1 product; a likely size would be 3 to 6 cm. Grade-2 compost could include some glass and plastic bits, have a C:N of at most 30:1, and would be free of pathogens. Grade-2 compost would be suitable for use in orchards and in raising field crops (e.g., forage, grain). Composts that do not meet specifications for grades 1 and 2 would be relegated to the grade-3 category. Grade-3 composts could be satisfactorily used in most land reclamation schemes. Other standards could be established to meet situations peculiar to the countries destined to use the compost products.

E5. METHOD of applying

Equipment for applying, i.e., using, compost is the same as that described for applying raw organic material. The principal difference between the use of raw organic material and the use of compost in the field is that the compost product can come into direct contact with the plants without harming them. This latitude makes it unnecessary to interpose a layer of soil between the root zone and the compost. Moreover, the compost can be used as a mulch without danger of generating a nuisance. In relatively small areas, compost can be applied manually. In larger applications, the material can be distributed by means of a manure spreader or vehicles specially made for that purpose. The spreaders range in capacity from about 4 to 13 m^3. The units are powered from a tractor's power take-off (PTO) and are capable of distributing the material at variable rates. The price of manure spreaders in the United States varies from about US$8,000 to US$11,000.

E6. LOADING rate

A prime constraint on the upper limit of the compost loading rate is the importance of not adding more plant nutrients (particularly NPK) than are required for crop production. Of the three elements, nitrogen is of the greatest concern. Consequently, the maximum amount of compost that can be applied without giving rise to a problem is that which contains no more nitrogen than is used by the crop during the growing season. For example, if the intended crop is corn (maize), the addition of about 224 kg of nitrogen per hectare would be permitted. If the compost has a nitrogen concentration of 2%, theoretically the maximum permissible loading would be about 11 Mg/ha. However, because only about 35% of the nitrogen in the compost is available to the plants in year-1, the loading could be about 30 Mg/ha. In determining the compost loading in the succeeding years, it should be remembered that the remaining nitrogen eventually becomes available to the plants, i.e., 30% to 35% in year-2, and the remainder in year-3. An indication of actual amounts released each year is given by the data in Table VII-2.

The importance of maintaining a balance between nitrogen added and that consumed arises from the fact that excess nitrogen is oxidised to nitrate by soil bacteria. Because the nitrate is soluble, it can be leached to the groundwater and thereby detract from the quality of the water. Amounts of NPK utilised by various crops are listed in Table VII-3.

The maximum permissible loading with composts that contain substances toxic to the plant, animal, and human members of the food chain is determined by multiplying the concentration of the objectionable substances in the compost by the number of Mg at which the upper permissible loading would be reached. Of course, the maximum amount that can be applied without damage is the difference between the amount at which damage occurs and that already in the soil. The quantity of compost per hectare is easily estimated according to the equation:

$$x = \frac{y}{z}$$

where:

- x = the total amount of compost per unit of area (Mg/ha),
- y = the permissible maximum amount (kg) of the objectionable substance per hectare minus the amount already in the soil, and
- z = the concentration of the substance per unit mass of compost (kg/Mg).

Table VII-2. Quantity of nitrogen released annually from compost incorporated into the soil

Organic-N in Compost (%)	Amount of Nitrogen Released (g/Mg compost added)		
	Year-1	Year-2	Year-3
2.0	454	408	408
2.5	544	544	499
3.0	635	635	590
3.5	771	726	680
4.0	862	816	771
4.5	998	952	907
5.0	1,088	1,043	998

Table VII-3. NPK requirements by various crops

Crop	Phosphorus (kg/ha)	Nitrogen (kg/ha)	Potassium (kg/ha)
Corn	39.2	207	199
	49.3	269	223
Corn silage	39.2	224	227
Soybeans	23.5	289	112
	32.5	376	134
Grain sorghum	45.0	280	186
Wheat	24.6	140	102
	26.9	208	150
Oats	26.9	168	140
Barley	26.9	168	140
Alfalfa	39.2	504	446
Orchard grass	49.3	336	348
Brome grass	32.5	186	236
Tall fescue	32.5	151	172
Bluegrass	26.9	224	167

Soil factors that determine the concentration in the soil at which a toxic element becomes inhibitory to a crop plant or hazardous to a consumer of the crop are pH, organic matter content, degree of aeration, structure and ion-exchange capacity, and amount of uptake of a toxic element by the plant. The mechanisms that make the factor effective are their impacts, combined and individually, on the solubility of the substance in question. Solubility becomes the ultimate factor in that a plant can assimilate substances that are in solution and the toxic substance can exert its harmful effect only if it is assimilated by the plant. The only exception is if the substance is physically destructive of plant tissue, as is ammonia with plant root hairs. Moreover, the substance becomes hazardous to humans only if the concentration of the substance in the edible portions of the plant is at a level toxic to the consumer.

Generally, heavy metals that are toxic to plants and potentially so to humans are insoluble at pH levels higher than 7.0 (alkaline soils). Increasing the organic concentration, promoting aeration, and ensuring a high exchange capacity in the soil magnifies the immobilisation or fixation accomplished by chelation, ion exchange, or by being rendered insoluble. The addition of compost amplifies all three factors. Consequently, the upper permissible limits are raised by incorporating compost into the soil. This fact should be taken into consideration in the determination of maximum permissible loadings. For a detailed discussion on the heavy metal problem, the book by Leeper [4] is an excellent reference.

Another important factor to consider is the concentration of salt in the compost. Based on their relative tolerance to salt, plants are divided into two general groups: halophytes and glycophytes. Halophytes are those plants native to saline environments and glycophytes are those species less tolerant to salts. Glycophytes have wide differences in sensitivity to saline conditions. Most crop species are glycophytes. Phytotoxic effects to plants are a function of both quantities and types of salts responsible for the saline conditions in the soil. Both leaf expansion rates and root growth are impacted by saline conditions. Reduction in plant growth has been attributed to the impacts of salts in the reduction of the water potential [6]. Some general guidelines on the salinity of soil and its effect on plant growth are presented in Table VII-4.

Table VII-4. Salt content and its impact on plant growth

EC (mS/cm)			Examples of Plant Species
Normal Yield	**Sharp Fall in Yield**	**Plant Reaction to Salt**	
< 2.0	> 4.0	sensitive	all seedlings, apples, peaches, beans
< 4.0	> 10.0	fairly tolerant	wheat, maize, alfalfa, vines
< 10.0	> 16.0	very tolerant	spinach, barley, sugarbeet
> 16.0		salt-loving	few saline plants grow

Source: Reference 7.

Nutrients and soluble ions such as nitrate, ammonium, calcium, potassium, magnesium, chloride, sodium, carbonates, and bicarbonates contribute to the soluble salt content of soil amendments and water. The concentration of soluble salts in compost should be measured periodically. Measurement can be accomplished by recording the electrical conductivity (EC) of the material. Electrical conductivity of a sample of compost can be obtained by preparing an extract of saturated compost. The extract can be prepared by mixing in a beaker about 500 mL of compost with enough distilled water to saturate the material. The mixture is allowed to stand for about 1 hour. After one hour, the suspension is filtered through filter paper (the authors have used coffee filters). The EC of the saturated solution is then measured. Conductivity is expressed in millisiemens per cm (mS/cm), or mmho/cm (1 mho = 1 S). A millisiemen is equal to a millimho. The relationships between electrical conductivity (EC) and salt concentrations are as follows:

- Total ion (anion and cation) concentration expressed in meq/L is equal to about 10 x EC (in mS/cm).

- The concentration of salt in mg/L (ppm) is equal to about 640 x EC (mS/cm).

Under certain conditions, such as is the case when compost is used as container medium, excessively high concentrations of salts can be reduced by leaching. If the application of compost is being considered in catchment areas for drinking water or in other protected areas for water supply, care must be taken to have a thorough understanding of the soluble salt concentration of the compost, typical rainfall, quality of the groundwater, and the conditions of the soil prior to application in order to prevent contamination of the water.

Desirable concentrations of soluble salts for compost for use in agricultural applications are within the range of 2.0 to 3.5 mS/cm.

In conclusion, loadings of about 10 Mg of compost/ha/yr, or from 20 to 30 Mg/ha/3-yr interval, generally are acceptable. Specifically, the latter alternative would involve incorporating 20 to 30 Mg in year-1 and no application in years 2 and 3. Lower loadings would be indicated for composts made from biosolids produced in an industrial sector, or from a waste that contains a sizeable amount of wood or coal ash, or an exceptionally heavy concentration of nitrogen.

F. Benefits from the application of compost to the soil

The benefits from the application of compost to the soil include those alluded to in preceding paragraphs and in the section on raw wastes. Among the benefits are enrichment of the NPK content of the soil, albeit not to the extent accomplished by the standard application of a chemical fertiliser. Nevertheless, because of the NPK in the compost, the amount of chemical fertiliser added can be reduced in proportion to the NPK concentration in the compost. Indeed, the amount of reduction in the required chemical fertiliser dosage is more than the simple difference between total amount required and that in the compost. Less chemical NPK is required because the presence of compost (or of any other biological organic matter) increases the efficiency of chemical NPK utilisation. The increased efficiency ultimately is the result of the conversion into microbial cellular mass of chemical fertiliser not used by the crop. NPK bound in microbial cellular mass is slowly released as the microbes die off. If organic matter had not been present, 30% to 35% of the nitrogen, 20% to 30% of the phosphorus, and a lesser fraction of the potassium added as chemical fertiliser would have been leached beyond the root zone, and thus could not have contributed to crop production.

The storage of phosphorus is accomplished through the agency of organic acids synthesised in the metabolic breakdown of organic matter. The acids form a complex with inorganic phosphates in the soil and thereby render the phosphorus more readily available to higher plants. Phosphorus as well as nitrogen are in effect "stored" in a manner peculiar to humus, in that precipitation of phosphorus by calcium is deterred and nitrogen is converted into microbial protoplasm. The conversion of nitrogen into microbial protoplasm interferes with the nitrogen mineralisation (nitrification) that would otherwise be the fate of nitrogen introduced into the soil and not rapidly assimilated by plants thereafter. Prevention of nitrification, in turn, protects the quality of groundwaters from being degraded. Not to be overlooked is the fact that compost is an excellent source of trace elements.

Another major benefit of the use of compost is a substantial improvement of soil structure. With respect to fertility, structure ranks with nutrient content. The improvement in soil structure results from the tendency of compost to bring about soil aggregation. Aggregation is accomplished through the agency of various cellulose esters formed in microbial metabolism. Aggregation imparts a crumb-like texture to soil, i.e., makes the soil friable. Friability is closely related with soil aeration and water-holding capacity. The more friable a soil becomes, the greater will be its water-holding capacity and its state of aeration. Because aeration and moisture are important factors in root system development, plants grown in compost-enriched soils characteristically have well developed root systems.

Another aspect of the water conservation potential of compost is the use of compost for mulching. A layer of compost mulch on the soil is a physical barrier to evaporation. The utility of compost as a mulch is furthered by the fact that eventually it can be incorporated into the soil and therein enhance its beneficial effects. The beneficial effects with respect to chelating and fixing heavy metals were described in the section on loading.

A final and important benefit is an accompanying increase in the resistance of crops to many plant diseases. Whether the increased resistance is due to the vigorous growth encouraged by the presence of compost or whether it is due to an actual development of an immunological response in the plant itself is immaterial; the result is the same. For example, Filipi and Pera have demonstrated that the use of mixes amended with composted pine bark can suppress *Fusarium* wilts of carnation [5].

G. Limitations to the application of compost to the soil

In this section, limitations are discussed related to public health that were not mentioned in the section on loading. Also covered are limitations pertaining to transport and to the mechanics of applying the compost on the field.

G1. PUBLIC health

Public health hazards arise when the product is composted human excrement or is composted industrial wastewater solids (i.e., sludge). Wastes from diseased animals could be ranked with human excrement as a hazard to public health, but perhaps to a lesser degree. Only those pathogens not exterminated during or after composting pose a hazard to public health.

It is important to keep in mind that passage through the compost process is not of itself a guarantee that all viable pathogens have been killed, and hence that the product is entirely free of viable pathogens. The reality is that the intervention of some factor may have prevented exposure of all pathogens to the bactericidal conditions associated with the compost process. Pathogens that escape these conditions can subsequently recontaminate "steriled" material. A single kilogram of insufficiently exposed infested or contaminated material can recontaminate an entire pile of compost.

For example, failure to expose all material in a composting pile to temperatures lethal to pathogens can result in pockets of contaminated material. Subsequent turning or other redistribution of material can lead to a recontamination of the entire composting mass. In systems that involve no turning, and in which sufficiently elevated temperatures seemingly should prevail throughout the composting mass, pockets of low temperatures might nevertheless exist.

A factor that amplifies the effects of high temperature and may even compensate for incomplete exposure to high temperature is the collection of inhibitory phenomena that begin in the composting mass at the time compost conditions are imposed and end when the process is terminated. Because the phenomena are time-dependent, loosely speaking it might be said that passage of time more or less compensates for shortcomings in exposure to high temperature. Thus, passage of time allows: 1) destruction of pathogens, 2) competition with non-pathogenic microorganisms, 3) antibiosis, and 4) the development of a less than favourable environment.

An important factor regarding pathogen survival and multiplication is the fact that the normal habitat of pathogens is the human body. Because of this, nutrient sources useful to pathogens are compounds usually found only in the human body. Therefore, only a relatively few compounds in a composting mass can be used as nutrient sources by pathogens. These compounds are rapidly destroyed under composting conditions.

Because they are adapted to the protective environment provided by their host, pathogens are at a disadvantage when competing with microbes indigenous to the habitat constituted by the composting material. Moreover, the presence of some antibiotics is ensured by the proliferation of actinomycetes and fungi normally characteristic of composting. For example, species of *Streptomyces* (actinomycete) and *Aspergillus* (fungus) appear in substantial numbers during composting. Therefore, all things considered, a year of storage should be ample for rendering a product safe for most uses.

G2. TRANSPORT and application mechanics

The bulky nature and low density of the dry compost product are responsible for most of the difficulties that pertain to transport and mechanics of applying the product. Because the volume-to-weight ratio is higher, a low-density product is more expensive to transport than is one of a high density. Inasmuch as compost generally is an uncompacted low-density product, the volumetric capacity of the transport vehicle is reached long before its weight capacity. The bulkiness and low density of compost necessitate the use of bulky equipment to spread it on the field. As previously indicated, a manure spreader can be used or adapted to apply compost to the field. With regard to manual application, more trips per unit mass of material are needed.

Nevertheless, these disadvantages are minor in comparison to the many benefits to be gained from the use of compost.

This chapter has provided the motivation for composting through a description of the many uses of the compost product. The efficient production of the product is the goal of Chapter VIII, Composting.

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Notes

[1] To legally qualify as a fertilizer in the United States, the NPK content must be at least 6%.

[2] Because of grave hazards to public health, human excreta must be treated in a manner such that pathogens and parasites are destroyed before applying in the field.