UTILIZATION OF NIGHT-SOIL, SEWAGE, AND SEWAGE SLUDGE IN AGRICULTURE

MILIVOJ PETRIK, Ing., M. S.
Professor, Faculty of Engineering, University of Zagreb, Yugoslavia

SYNOPSIS

The author reviews the agricultural use of night-soil, sewage, and sewage sludge from two points of view: the purely agricultural and the sanitary.

Knowledge of the chemistry and bacteriology of human faecal matter is still rather scant, and much further work has to be done to find practical ways of digesting night-soil in a short time into an end-product of high fertilizing value and free of pathogens, parasites, and weeds.

More is known about sewage and sewage sludge, but expert opinion is not unanimous as to the manner or the value of their use in agriculture. The author reviews a number of studies and experiments made in many countries of the world on the content, digestion, composting, agricultural value, and epidemiological importance of sewage and sewage sludge, but draws from these the conclusion that the chemistry, biology, and bacteriology of the various methods of treatment and use of waste matter need further investigation. He also considers that standards of quality might be set up for sludge and effluents used in agriculture and for water conservation.

Introduction

The origin of agriculture lies in prehistoric times. According to certain theories it started in regions subject to periodic flooding, such as Egypt and ancient Mesopotamia, where it gave rise to the first organization of fixed societies. In these regions it was nature itself which took care of a regular renewal of organic matter in the cultivated soil, exhausted by previous crops, and of supplying the soil with the necessary moisture. When in other regions, not so happily endowed, new peoples and tribes settled down to agriculture, this must have led to a more or less regular addition of organic matter to the soil. Such matter was, of course, waste matter, including human and animal faecal material.
The practice of adding such waste matter more or less regularly to the soil, in order to maintain and to raise its fertility, must be a very old procedure, almost as old as agriculture itself. Perhaps the most outstanding example of such use, consecrated by antiquity, is to be found in China, where night-soil, animal manure, and garbage have been used for this purpose from time immemorial. Equally old is the artificial wetting of the soil by irrigation water.

By the introduction of aqueducts and of the subsequent removal of waste matter by using water as a carrier, use of that most common organic waste as a fertilizer was made impossible. No wonder that many and continuous attempts have been made to use for agricultural purposes both the used water, for irrigation, and its content of organic matter, as fertilizer.

The spectacular development of chemistry in the 19th century led to the production of artificial manures, which caused a decrease of interest in organic fertilizers. The continuous use of chemical fertilizers increased the harvests beyond the possibilities of organic fertilizers, because far greater amounts of the main fertilizing agents—phosphates and compounds of nitrogen and potassium—can be introduced in a suitable form into the soil by means of artificial fertilizers than by the usual organic manures. But after a certain time some unexpected disadvantages became manifest in artificially fertilized soils, such as changes in the structure of the soil as revealed by a reduced water-holding capacity and lesser resistance to erosion owing to a greater dispersion of the soil particles, a decrease in bacterial activity in the soil, and the disappearance of minerals resulting in diseases of the plants. A study of such facts revealed successively the importance of organic fertilizers in their twin role as soil builders and fertilizers. At present it is believed that artificial fertilizers are as unrivalled in their capacity to furnish rich crops as are the organic manures in permanently maintaining the soil and the plants in good condition. This is the reason for the ever-increasing interest in the use of organic waste for fertilizing purposes, an interest very much alive on the European continent and to a considerable extent in Great Britain. It does not seem to be so great in the USA. The topic seems to be especially important in thickly populated countries where the smallness of individual farm holdings prohibits the production of sufficient quantities of stable manure, as, for instance, in India. In such conditions it is necessary to raise the fertility of the soil to the highest possible level and to maintain it there without any deterioration of the soil and at minimum cost. It is equally important to turn barren lands to agricultural use in order to secure food for the ever growing population. The same is true of the utilization of used water for purposes of irrigation. Hence the great importance of such wastes for the future of food production in densely populated countries.

The importance of such waste matter, however, is not restricted to its use in agriculture only. It has yet another, no less important, aspect: its
sanitary significance as a possible means of transmitting infectious disease and parasitic organisms. Both the agricultural and the sanitary significance must therefore be discussed in order to be able to make a clear appraisal of its suitability for agricultural use.

**Categories of Organic Waste Matter**

Before embarking upon a discussion of the properties of organic wastes, it is necessary to classify those categories of waste matter which come into consideration for agricultural use.

For fertilization alone the following are used: (a) partially fermented human excreta; (b) sewage sludge, both raw and digested, and wet and dry; (c) stable manure; and (d) fermented garbage.

For both fertilization and irrigation crude and partially treated sewage are used.

For purposes of irrigation alone effluents from sewage treatment are used. They are used also for purposes of water conservation or water reclamation in general.

These various categories may be applied to the soil either pure or mixed. Thus garbage is in some places applied alone, while in others it is fermented with stable manure, human faecal matter, or sewage sludge. Stable manure is at times fermented with human excreta.

Organic waste matter is unsuitable for fertilizing purposes in an unfermented state; it has to be broken down into relatively simple compounds capable of dissolving in water in order to enter the roots of the plants in solution if it is to serve as fertilizer, and into relatively stable and insoluble compounds if it has to serve as soil builder. The more complete such processes are, the more suitable is the transformed matter from both the agricultural and the sanitary standpoint, because the pathogenic and parasitic organisms in such matter are destroyed as the process of decomposition advances.

The main fertilizing agents are considered to be phosphates and compounds of nitrogen and potassium. Organic wastes usually contain much smaller amounts of such compounds than chemical fertilizers. On the other hand, in a digested state they contain stabilized organic matter which does not readily dissolve in water and is called humus. As it is not used by plants it remains in the soil and, in accumulating, changes its structure into a porous, well aired substance capable of retaining water and of offering a suitable medium for abundant bacterial growth.

**Human Faecal Matter**

Human excreta did not attract great scientific attention in the past, their removal forming but a multitude of minor local or household problems, each too insignificant in comparison with the broad problem of sewage
disposal to attract great attention. This is the reason for our still scant knowledge of the chemistry and bacteriology of faeces. It might therefore be of value to base the discussion of this problem upon one of the most recent research studies of the matter—that conducted by Snell at Harvard University.

Snell evaluated the daily production of excreta by the mixed population of the USA in 1930 as follows:

<table>
<thead>
<tr>
<th>Matter</th>
<th>Weight per day (in g)</th>
<th>Total residue (%)</th>
<th>Organic matter (%)</th>
<th>Nitrogen (%)</th>
<th>Phosphoric acid (%)</th>
<th>Potassium (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Faeces</td>
<td>86</td>
<td>22.8</td>
<td>19.8</td>
<td>1.00</td>
<td>1.10</td>
<td>0.25</td>
</tr>
<tr>
<td>Urine</td>
<td>1,055</td>
<td>3.7</td>
<td>2.4</td>
<td>0.60</td>
<td>0.17</td>
<td>0.20</td>
</tr>
<tr>
<td>Total excreta</td>
<td>1,141</td>
<td>5.15</td>
<td>3.7</td>
<td>0.63</td>
<td>0.24</td>
<td>0.20</td>
</tr>
</tbody>
</table>

In comparison the author cites China, which is believed to produce about 80% of the above amounts, the nitrogen content being but 60% owing to lower body-weight and food with less proteins. Wilson & Wang (cited by Scott) take the average weight of faeces in northern China to be around 60 g per person per day, calculated on a dry basis.

According to Snell’s experiments a mixture of faeces and urine does not digest quickly even if seeded. Seeded faeces alone digest normally and with a speed equal to that of sewage solids, but unseeded faeces take more than ten times as long. Urine, if properly seeded, decomposes quickly into carbonate and bicarbonate of ammonia, but when mixed with faeces the amounts of CO₂ produced are too small and result in a feeble production of bicarbonate; in consequence there is a lack of methane digestion of faeces, which instead break down into volatile acids. Snell succeeded in speeding up the digestion by adding to the excreta CO₂ in any form, such as cellulose, straw, starch, sucrose, and garbage.

As to the death-rate of pathogenic organisms in excreta, it was believed since Pettenkofer’s time that they practically disappear from the excreta in about four weeks. Snell found that in the anaerobic digestion of excreta the death-rate of coliform bacteria is about the same as in sewage sludge, i.e., between 10% and 15% per day at 25°C, which would leave, in the worst case, at the end of four weeks about 5% alive and at the end of eight weeks about 0.25%. The death-rate of the most resistant strains of *Bacillus typhosus* he found to be about twice that of coliform bacteria, which compares fairly well with Pettenkofer’s views.

Snell believes that at summer temperatures (20°-22°C) *Ascaris* eggs will not live in mixed stored excreta longer than two to three months, ova of *Ancylostoma* not more than two or three weeks, and causative organisms of typhoid, paratyphoid, and dysentery not more than fourteen days. In spring and autumn these times may be double (at 15°-17°C), and in winter (8°-10°C) about four to five times as long.
As the digestion of excreta in summer (at 25°C) takes between 60 and 80 days, digested material will be usually free of pathogens and ova of *Ancylostoma* and contain not more than 1% of the initial number of *Ascaris* eggs. In other seasons, digestion takes a longer time and the excreta may be expected to reach the same degree of sterility at the same degree of digestion.

That Snell is correct in assisting anaerobic digestion of excreta by adding CO₂ is borne out by other authors and by certain practices. Thus in Holland there is an old method of producing a kind of compost from excreta and garbage used mostly in small unsewered communities. In this method, sorted and sieved garbage is put in layers into composting ditches, each layer being covered by a layer of faecal matter. The heap is left to digest for 3 to 6 months. As there are in comparison large amounts of faecal matter which must be got rid of, and small amounts of garbage, the mixture is too wet (70% to 80% of water) and digests anaerobically at low temperatures (20°C-30°C) at which neither pathogens nor weed seeds can be eliminated. Aerobic digestion could be effected with a maximum moisture content of 60%, and that would in summer bring the weight relation of excreta to garbage to about one to five.

Another example is from the classical country of the agricultural use of excreta—China—in the rice-growing part of which faecal matter is mixed in pits or clay containers with rice straw, ashes, and garbage. The mixture contains about 90% of water and digests anaerobically with great loss of nitrogen, the nitrogen content being 0.62% in fresh mixtures of faeces and urine and only 0.26% in the digested mixture. Stone succeeded in Shaoyang, China, in controlling digestion in such a way as to lower the loss of ammonia nitrogen to such an extent that the higher fertilizing quality obtained covered expenses. Instead of anaerobic digestion he was able to establish aerobic digestion at between 60°C and 65°C (in a warm and moist climate at 22°C) by laying alternate layers of four parts of ground rice-straw, two parts of night-soil, and one part of powdered bone with enough lime to keep the pH at 7.1. The ratio of carbon to nitrogen was kept at 20 : 1. The first, uninoculated batches digested in 50 to 60 days and gave a semi-solid humus-like mass which, after 7 days of drying in a layer about 15 cm thick, had:

<table>
<thead>
<tr>
<th>Component</th>
<th>Weight %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total nitrogen</td>
<td>3.94%</td>
</tr>
<tr>
<td>Phosphates (as P₂O₅)</td>
<td>1.50%</td>
</tr>
<tr>
<td>Potassium (as K₂O)</td>
<td>2.27%</td>
</tr>
<tr>
<td>Moisture</td>
<td>42%</td>
</tr>
</tbody>
</table>

Similar results were obtained at Hongkong.

Stone had to discontinue his work because of the troubles in China but believes that with good inoculation and care the digestion could be reduced in that climate to 20 or even 15 days, which seems rather too optimistic.
Owing to the high temperatures of digestion (60°-65°C in the first days and 49°C or less in the next 15 days), the product was practically free from pathogenic germs and *Ascaris* eggs.

In another densely populated part of Asia—India—a similar, simple method of digesting emulsified night-soil with rubbish in alternate layers in wide ditches has been developed at Lalur, according to George. The particulars of the digestion are not known. Fly breeding is prevented by covering the ditches with tarpaulins. The digestion is completed in 8 weeks.

Hamlin found in South Africa that excreta of the non-European population, which lives on carbohydrates, were almost indigestible but could be digested when mixed with the excreta of the European population, which lives on a different diet.

A comprehensive study on the composting of human excreta with other kinds of organic refuse was carried out in Northern China by Scott and his collaborators in Cheeleeo and Yenching universities just before the war, in order to find methods capable of producing a better final product from the agricultural point of view and to eliminate the dissemination of pathogenic organisms and intestinal parasites. The methods were evaluated from the standpoint of sanitary efficiency on the basis of the temperatures developed and of the survival of *Ascaris* eggs, protozoan cysts, and flies; from the standpoint of agricultural efficiency on the basis of the conservation of nutrient constituents (N, P₂O₅, K₂O), of the C:N ratio, and of the crops obtained; and from the standpoint of economic efficiency on the basis of the expenses incurred and the profits derived from crops.

Both aerobic and anaerobic methods were studied. Aerobic conditions were obtained by composting in shallow pits in dry weather and on the surface of the ground in wet weather, and by turning over the stacks several times in the course of composting. The anaerobic procedure comprised a few days of initial aerobic fermentation followed by anaerobic treatment in deep pits without turning.

Faecal matter was composted with vegetable matter in mixtures of varying proportions, with the addition of some soil and small quantities of vegetable ash. Another series of tests was made on vegetable matter to which was added a mixture of faeces with horse and cow manure in varying proportions, also with the addition of some soil and ash.

Aerobic composting took about two months. It was definitely found that the temperature in a well built stack would rise to 55°C in the first few days and after the first turning even to 60°C, at which level it would stay for three weeks, except immediately after the subsequent turnings. After that time practically all the *Ascaris* eggs were dead, while protozoan cysts were eliminated before then. The optimal microbiological action was obtained at a moisture content of between 50% and 60%. The nitrogen conservation seemed to be better than in the usual stacks of stable manure.
but tended to decrease at higher temperatures, which seems to argue for controlling the temperature in the stack. The optimum nitrogen conservation seemed to be obtained at initial C:N ratios of around 40 with mixtures of vegetable matter and faeces alone, and around 20 if faeces were replaced by a mixture of faeces with horse and cow manure. Fly breeding was insignificant and the best C:N ratios gave also the smallest numbers of flies.

Anaerobic composting took a little longer than three months and showed a better nitrogen conservancy but a somewhat less destruction of *Ascaris* eggs.

As it seems that the principal loss of nitrogen occurs in the first two weeks of composting, a further study of the initial stages of composting appears desirable.

Scott’s results are clearly favourable from the sanitary point of view. Agriculturally, they ranked with the best methods of organic fertilization and seemed to have long-lasting residual effects.

The loss of nitrogen from the final product was small.

On basis of this study Scott considers the composting of excreta to be the best method of disposal in a dry or semi-dry climate. When the final product can be immediately utilized, aerobic composting is indicated; the anaerobic procedure is suitable when the final product is not to be used at once, if a better nitrogen conservancy is desired, or if a moist final product is preferred.

On the basis of their work in the University of California, Golueke, McGauhey & Gotaas in a recent summary (see page 307) define composting “broadly as the biological decomposition of organic matter to a relatively stable humus suitable for agricultural soils”. This decomposition “may take place under aerobic, partially aerobic, or anaerobic conditions, and at mesophilic or thermophilic temperatures”, the major part of the process usually being “carried on by the thermophilic micro-organisms under aerobic or partly aerobic conditions”. In their studies “sustained maximum temperatures of from 650-750°C were invariably attained”; these temperatures are above the thermal death points of *Salmonella, Shigella, E. coli, Entamoeba, Necator*, and other pathogens and parasites exposed to them for an hour or less. After a review of evidence collected in other places on the value of composting in the destruction of pathogenic and parasitic organisms, flies, and rodents, they state that aerobic and partially aerobic composting, as practised throughout the world, normally attains sufficiently high temperatures, and emphasize the necessity of exposing all parts of the stack to such temperatures, which can be achieved by proper turning. If the process is kept sufficiently aerobic, there will be no flies. In their view, “the economic value of compost is inestimable in areas where no other fertilizer is economically available and soil fertility must be maintained at a maximum”, while in areas using industrial fertilizers
"compost is used as a supplement and soil conditioner, and has been demonstrated to be saleable for at least the cost of production".

Scott's experience, as well as that obtained in California, applies to human excreta. With night-soil, which comprises excreta and urine, there appear to be difficulties which have not yet been overcome. It seems, therefore, that further studies are necessary to find good and practical methods of digesting night-soil in a short time into an end-product of a high fertilizing value and free of pathogens, parasites, and weeds. This also is the view of Snell.36

In spite of the fact that there is not much sympathy among sanitarians for the agricultural utilization of human excreta and night-soil, it seems that such use is in many agricultural countries not only highly important economically but also a good method of ultimate disposal. Therefore both the agricultural and the sanitary aspects of such disposal deserve further study.

This view was taken by the WHO Expert Committee on Environmental Sanitation at its third session, when it was stated: "The committee recognizes the widespread use, in many parts of the world, of human excreta as fertilizer... With the growing world population and the limited extent of world resources, all efforts to utilize sanitary by-products and return them to the soil should be encouraged. The necessity of controlling these activities in such a way as to reduce to an absolute minimum their inherent public-health hazards cannot be too strongly emphasized".47

**Sewage Sludge**

Much more is known about the digestion and agricultural utilization of sewage sludge. This is to be expected because the final disposal of sludge creates similar and often grave difficulties in most sewage-treatment plants the world over—a circumstance which has in many places stimulated studies on its utilization.

Agricultural utilization of sewage sludge meets with all shades of reception among sanitary engineers, from an unreserved acceptance to a disinterested or disapproving attitude. It is characteristic, however, that the number of its advocates increases, even in the USA, which for a long time seemed to look upon sludge more as an embarrassment than as a potentially useful or desirable article. In a summary, Rudolfs 27 explains the unfavourable attitude towards sludge utilization by the fact that sanitary engineers in general have looked at the sludge problem "as a question of destruction of noxious matter rather than conservation of values". Furthermore, insufficient knowledge of its value, unsuitable methods for its use and preparation, as well as exaggerated propaganda and little interest on the part of the sellers have retarded its use.
The present attitude of the most prominent members of the profession may be represented by the views of Imhoff, Fair, and Rudolfs.

The first two authors consider fresh sewage-sludge undesirable for fertilizing purposes on account of its content of fats, seeds, and pathogenic organisms, and its objectionable odour. It may be tolerated only if used as fertilizer for fodder crops and if ploughed in immediately. Composting of fresh sewage-sludge has rarely succeeded in American practice.

Digested sludge contains from 0.5% to 3.0% of nitrogen on a dry basis and has about the same value as fresh stable manure. Wet sludge may be used with advantage close to the production point, air-dried sludge may be used as far as 30 km from the point of production, while heat-dried sludge, if rich in nitrogen, may be transported with advantage over even greater distances. It loses about 40% of nitrogen in digestion, but the authors believe that a similar loss of nitrogen occurs in undigested sludge during decomposition in the soil. They do not recommend the use of digested sludge during the vegetative period on root crops or on low leafy vegetables.

Heat-dried activated sludge contains between 3% and 6% of nitrogen on a dry basis and appreciable amounts of phosphate, has no seeds, mixes easily with soil, and is safe from the hygienic point of view. It can easily be enriched by chemicals and serves in that case as fertilizer base. Heat-drying is, however, economically justifiable in big plants only.

On the whole, they consider the use of sludge for fertilizer as a good and economical method of sludge disposal.

Rudolfs studied various aspects of the use of sludge as fertilizer. He considers sewage sludge a good soil-builder with some fertilizing value and containing relatively small amounts of the main fertilizing matter and minor elements and material advancing the growth of plants, which may be of advantage in some soils. It increases the humus in the soil and generally improves soil structure—and especially its water capacity and the circulation of air, which results in a better oxidation of organic matter. It also brings into the soil large numbers of bacteria and protozoa which speed up the rate of oxidation of organic matter into compounds easily used as plant food. Fats make it lumpy, interfere with its distribution in the soil, and make the soil acid. To counteract the acidifying action lime must be added. As an additional disadvantage, he points out that sludge may bring into the soil toxic matter which might be present in some industrial wastes. It also "burns out" the plants by the products of acid decomposition. Raw, digested, and activated sludge contain, besides nitrogen and phosphates, relatively small amounts of potassium and, in addition, micronutrient elements such as boron, copper, manganese, and zinc. Further, they contain scatole, indole, ascorbic acid, carotene, benzoic acid, and thyrosine, which are all favourable to plant growth. Such material gives to sludge a greater fertilizing value than would appear judging by the presence of the
main fertilizing matter—nitrogen, phosphate and potassium. Its fertility value is greater than its fertilizer value. Many plants and crops thrive on sludge—for instance, tomatoes, beet, carrots, onions, beans, lettuce, spinach, wheat, rye, potatoes, cotton, strawberries, apples, various trees and shrubbery, roses, carnations, and especially grass. Primary sludge is to be ploughed in in autumn, while heat-dried, activated, and air-dried sludge may be used safely in agriculture, horticulture, and floriculture. Sludge prevents the exhaustion of the soil and can augment its fertility. It is especially good for sandy soils.

In a recent discussion of the use of sludge, Rudolf's decided agricultural utilization as against other methods of disposal but warned that it should be considered as a fertilizer base only and not as a complete fertilizer. Use of more than about 4.0 kg per m² may create difficulties. It is advisable to add lime once in four years to neutralize acids originating in the soil from the decomposition of fats, otherwise the harvests may decline even if soil building proceeds.

Niles, on the basis of experiments made at Toledo, Ohio, and in Texas, thinks that sludge is always better than artificial manure on account of the great quantities of nitrogen-fixing bacteria it contains which replace the nitrogen in the manured soil from the atmosphere. This view, expressed in 1944, does not seem to have found further confirmation.

Harper thinks the prolonged effect to be due to slow oxidation.

The Agricultural Research Council of Great Britain published in 1948 the conclusions drawn from more than 80 experiments with sewage sludge. They showed the sludge to be of moderate but positive agricultural value as a slow source of nitrogen and phosphate. Its crop-producing faculty is less than that of the same weight of stable manure, as has also been said by many others. As it is deficient in potassium, it is not good for crops with a great demand for this element. On account of transport costs, only dewatered sludge with less than 50% of moisture is generally useful. Digestion improves the physical condition of the sludge. So far the most useful form is a digested, air-dried, and ground activated-sludge. Some industrial wastes contain metallic and other matter which may prohibit the utilization of the phosphate in sludge and cause harm to crops.

In England again, experiments made by the Rothamsted Agricultural Experiment Station with sludge from domestic and industrial sewage did not give encouraging results.

In the USA, indifferent results were obtained in North Carolina and Baltimore, Md. On the other hand, good results were obtained in, among other places, Ohio; Connecticut; Schenectady, N.Y., on tomato crops; Florida, on grass; Milwaukee, Wis., on meadows; Indiana, where it is used on crops other than root crops; Wisconsin; Arizona; Chicago; Texas; California; Illinois; and New Brunswick, N.J.
There have also been good results in the Union of South Africa, Germany during the war, and in Ontario, Canada, where sludge may be used only with the approval of the sanitary inspector.

The origin and nature of the sludge used was different in the various places. Fresh primary sludge, undigested and digested sludge, activated sludge, and dewatered, air-dried, and heat-dried sludge were all used.

The agricultural effects are not the same with all kinds of sludge, as the process of sewage treatment and the digestion of sludge changes its nature. Rudolfs gives the values shown in table I for the average contents of sludge on a dry basis (in %).

<table>
<thead>
<tr>
<th>Sludge contents</th>
<th>Fresh sludge</th>
<th>Digested sludge</th>
<th>Activated sludge</th>
</tr>
</thead>
<tbody>
<tr>
<td>Organic matter</td>
<td>60-80</td>
<td>45-60</td>
<td>65-75</td>
</tr>
<tr>
<td>Protein</td>
<td>22-28</td>
<td>16-21</td>
<td>37.5</td>
</tr>
<tr>
<td>Fats</td>
<td>7-35</td>
<td>3.5-17</td>
<td>5-12</td>
</tr>
<tr>
<td>Total ash</td>
<td>20-40</td>
<td>40-55</td>
<td>25-38</td>
</tr>
<tr>
<td>Total nitrogen</td>
<td>4.50</td>
<td>2.25</td>
<td>6.20</td>
</tr>
<tr>
<td>Phosphate (P₂O₅)</td>
<td>2.25</td>
<td>1.50</td>
<td>2.50</td>
</tr>
<tr>
<td>Potassium (K₂O)</td>
<td>0.50</td>
<td>0.50</td>
<td>0.75</td>
</tr>
<tr>
<td>Silica (SiO₂)</td>
<td>13.80</td>
<td>27.60</td>
<td>8.50</td>
</tr>
<tr>
<td>Iron (Fe₂O₃)</td>
<td>3.20</td>
<td>6.00</td>
<td>7.20</td>
</tr>
<tr>
<td>Manganese (MnO)</td>
<td>0.02</td>
<td>0.04</td>
<td>0.03</td>
</tr>
<tr>
<td>Calcium (CaO)</td>
<td>2.70</td>
<td>5.70</td>
<td>1.70</td>
</tr>
<tr>
<td>Copper (CuO)</td>
<td>0.02</td>
<td>0.05</td>
<td>0.05</td>
</tr>
<tr>
<td>Zinc (ZnO)</td>
<td>0.01</td>
<td>0.04</td>
<td>0.03</td>
</tr>
</tbody>
</table>

It is evident that to dose an area with a given amount of organic matter a larger volume of raw sludge must be applied than of digested and especially of activated sludge. In addition the organic matter in digested and activated sludge is in a more advanced stage of decomposition or oxidation and represents, therefore, a smaller burden on the soil than does raw sludge. The fats in particular lead to acidification of the soil if they decompose in it, as they do in the case of raw sludge. Since it is easier to transport and since a smaller load is required per unit area, dried—and particularly air-dried—sludge is generally preferred to wet sludge. Air-drying in shallow lagoons seems to have economic advantages over drying on underdrained sand-beds, according to studies made in Los Angeles County.

Digested sludge has the further advantage of being safer; as a fertilizer for root crops or vegetables which are eaten raw it is therefore preferable.
Raw sludge may be applied if there is time enough for the mineralization of organic matter in the soil.

An interesting example of overburdening the soil with imperfectly decomposed organic matter by long and continuous application of raw sludge, with resulting deterioration of the soil structure and the grass grown on it, is given by Powell.\(^{29}\) The remedy is to switch from the application of undigested to that of digested sludge.

Recent years have shown an ever-increasing tendency towards composting sludge with other kinds of organic matter. At present a great deal of experimenting is going on with composting. The reason seems to be two-fold: first, to improve the fertilizing value of sludge, and, secondly, to find a profitable way of getting rid of other kinds of waste.

Ransome\(^ {22}\) succeeded in composting both dry and wet raw sludge with straw. The process is, of course, aerobic. With dry sludge he achieved in five days temperatures up to 70°C in a heap of alternating layers of 45 cm of straw and 5 cm of sludge. The straw was decomposed in five months. Four tons of straw and eight tons of dry sludge gave 24 tons of compost. With wet sludge he used equal layers of straw and dosed each ton of straw with 5,700 litres of sludge. The end-product was similar to stable manure but with more nitrogen and less potassium. In principle the same method of composting raw sludge with straw into a fertilizer equal to stable manure is given by the German agriculturist Stein.\(^ {37}\)

Another category of wastes used for composting with sewage sludge is garbage. It is, in fact, the most common combination of raw materials for composting. It is at present quite usual to couple the disposal of garbage with that of sewage. There are two ways of doing it. One is to pass garbage through comminutors into the sewerage system. In that case garbage is carried away with the sewage and passes through the treatment plant without any changes having to be made, save that the final amount of sludge will require digestion tanks of greater capacity.\(^ {26, 39}\) The second is to make compost of garbage and raw or digested sludge, which is achieved in aerated heaps composed of alternate layers or of a basic heap of garbage covered by sludge. The heap may be quite high; Brunt\(^ {3}\) allows as much as 4.5 m. Both sludge and screenings may be used. If the garbage is solid enough, the layer of garbage may act as a filter for the water in sludge. Brunt allows an amount of moisture in the whole heap up to 65%. On the basis of a garbage with 30% of moisture each ton of garbage will be able to receive one ton of sludge. The mixture is seeded and soon develops high temperatures which eliminate weeds and pathogenic germs. The latter also meet hostile organisms which help to eliminate them. According to Brunt the fermentation takes about 80 days, which is much shorter than in some other experiments.

Much thought and experiment has been devoted in Great Britain to composting sludge and garbage in order to save organic matter for agri-
cultural needs. The London County Council carried out extensive experiments in composting sewage sludge and screenings with ground municipal garbage but abandoned further work lately as an uneconomical proposition. A similar decision was arrived at in New Zealand by the Auckland Drainage Commission in 1949 on grounds that there was too much theoretical and practical uncertainty and risk.

At Maidenhead, England, 13 years of composting did not cover the costs, but the practice is still considered practical as long as it does not exceed in cost other methods of garbage disposal. This may be the reason why it is carried out in other towns of Great Britain, the Union of South Africa, and New Zealand. It certainly has ardent advocates as revealed in the Surveyor in an article by Burke and the discussion that followed the article.

It seems to have met with more success in Germany. H. Straub describes the procedure at Baden-Baden, where raw sludge with 75% of moisture is well mixed with garbage in the ratio of one weight of sludge to four weights of garbage, built up in large, aerated heaps, and, after seeding, left to ferment for 5 or 6 months. During the fermentation the heap is turned over. The final product is sieved. It is equal to stable manure and superior to dry artificial manures, especially for growing peas, potatoes, carrots, cabbage, etc. It is also cheaper than any other kind of fertilizer.

F. Pöpel describes the German procedure with digested sludge. Sieved garbage is mixed with dry digested sludge in such amounts that the ratio of carbon to nitrogen falls between 25:1 and 30:1. The mixture is built up into heaps with a maximum height of 6 m, precautions being taken to ensure proper access of air. The temperature of the heap is maintained between 45°C and 50°C by turning. The fermentation takes four months. The final product is sieved.

Another country which puts high hopes in composting is the Netherlands. At present the composting is rather restricted to garbage alone, but this is undertaken on an imposing scale and probably is to be much extended in the near future according to Weststrate. Among the composting plants, there is one at Amersfoort which produces compost from garbage and sewage sludge and there is soon to be another one at Schiedam. Such instances from a country with highly efficient agriculture may help to disperse some of the scepticism in the matter of composting.

As Niles put it, "the best part of sludge is drained away" as sludge water when sludge is dried on drained sand-beds.

As to the safety of sewage sludge from the epidemiological standpoint it is evident that undigested sludge is no safer than sewage in general. Digested sludge has been recently studied by Fuller & Litsky. They found that neither temperature, pH, moisture, antibiotics, nor bacteriophages are factors in the disappearance of coliform bacteria from digested sludge. *Escherichia coli* disappears from it at 37°C in seven weeks, and at about 22°C in barely two weeks, probably on account of the interaction of other organ-
isms. The absence of E. coli in dry sludge ought to give sufficient security from pathogenic intestinal organisms. The authors point out the need of further studies on other pathogenic organisms, such as the virus of poliomyelitis.

Cram⁵ studied the disappearance of helminthic ova and protozoan cysts from sewage and sludge. She did not find any proof of the survival of the cysts of Entamoeba histolytica in the process of sludge digestion. The eggs of both Ascaris and Ancylostoma, on the contrary, survived the digestion and the subsequent drying.

Newton and collaborators¹⁷ found that digestion at temperatures between 6.6⁰C and 18⁰C killed the eggs of Schistosoma japonicum in two or three months, but that the same eggs are killed in the process of drying sludge in about three weeks at 15.5⁰C to 24⁰C and in nine days at 30⁰C to 32⁰C.

P. Keller¹⁸ found that eggs of Ascaris would survive the digestion of sludge at temperatures below 53⁰C, but that exposure for two hours to the temperature of 55⁰C would kill or inactivate 100% of the eggs. This finding would impose the necessity of digestion at temperatures above 55⁰C for any sludge used as fertilizer.

In Johannesburg the utilization of digested sludge was restricted to areas managed by the municipality, as a safety measure, on account of an outbreak of poliomyelitis. A causal connexion between the outbreak of the epidemic and the use of sludge could not be established.⁸²

In this connexion, the suggestion in a report on the salvage of sewage in the Transactions of the American Society of Civil Engineers⁴⁰ in 1942 that solids from sewage which are used as fertilizer ought to be digested and dried before use, or—if not digested—kiln-dried at a temperature which will kill all the hostile pathogenic organisms, appears to be reasonable.

As far as composted sludge is concerned, Brunt³ states that in the 15 years of municipal composting in England not a single case of disease has been discovered which could be traced to it.

On the whole, it seems that our knowledge both of the epidemiology and of the bacteriology of sewage sludge is as incomplete as our information on the possibilities of its use in agriculture, especially for composting purposes.

The question of the safety of sludge will be touched on once more in the discussion of sewage.

**Sewage**

The use of sewage for agricultural purposes is probably as old as sewerage itself and has been practised in many countries, for both irrigation and fertilization. In the USA it seems that such use of sewage is at present more widespread than agricultural utilization of sludge, especially in regions which suffer from lack of water for irrigation. It is a common and
much valued practice in Germany and is used in France, the Union of South Africa, Australia, and many other countries of the world.

In the past—and nearly to our own days—crude sewage was used for irrigation, whereas at present it is the effluents from sewage-treatment plants which are used.

The use of sewage in agriculture has two aspects—the purely agricultural and the sanitary—which may conflict. The agricultural outlook is well represented by the German agricultural specialist Stein who wishes to retain in irrigation water as much suspended matter as will stay in it without settling in ducts, and who does not accept irrigation with clarified sewage. He looks upon sewage irrigation as a substitute for sewage treatment and claims that a drained irrigation surface gives a better effluent and consequently causes less contamination of surface waters than any sewage-treatment process. A similar outlook is revealed by S. Wierzbicki in Poland. That sanitary authorities in these countries do not necessarily share such views may be shown by citing W. Müller, who requires the sewage to be fully treated and freed from pathogenic organisms before use.

For agricultural purposes domestic sewage is usually good, while industrial wastes may contain matter which is harmful to crops. Wastes with a high mineral content are not acceptable. The usual contaminants are boron and sodium, but may also be salts of heavy metals, most bactericides, fungicides, insecticides, herbicides, and some plant hormones.

In many places, attempts have been made to establish some standards of quality for irrigation water, or at least some general principles which ought to be complied with. In general it can be stated that no untreated sewage is considered suitable for irrigation, and in most cases there is a tendency to admit only well oxidized and adequately disinfected effluents. The State of Oregon, for instance, requires the effluent used for irrigation to be well oxidized and to fulfil rigid bacteriological standards. The latter requirement is also imposed by the State of Colorado. California, which uses sewage to a great extent for irrigation, prohibits the use of effluents from septic, two-storey, and other settling-tanks, as well as of partially disinfected effluents from trickling filters and activated-sludge plants, for irrigation of vegetables in the vegetative period, garden truck, strawberries, low fruit, vineyards and orchards when any fruit lies on the soil, and their discharge into surface waters which may be used for similar irrigation purposes. It also prohibits the pasturing of cows on land irrigated with such effluents. Such restrictions do not apply to the use of well oxidized, non-putrescible, and reliably disinfected or filtered effluents if they constantly satisfy the following bacteriological requirements: in any 20 consecutive samples, each of which is examined in 10 portions of 10 ml, not more than 10 portions may show the presence of coliform bacteria, and in no single sample may more than 50% of the portions show their presence.
Sewage or effluent may be applied for irrigation in one of two ways: either through flow on the surface of the soil or by spraying. In the latter case it inevitably comes into contact with fruit, while in the former case it comes into direct contact only with edible roots, low fruit, or fruit lying on the soil. It is for this reason that M. Binamis believes the effluent from primary treatment to be best suited for irrigation and condemns any direct contact of such effluent with plants. A similar view was taken by K. Schulze.

The rate of dosage varies, of course, with the type of soil, the kind of crop, and the annual rainfall. It may correspond to as much as 800 mm of rain per year or more.37

There is a general and serious objection to the use of sewage or effluents for irrigation which is usually not mentioned by agricultural experts. Irrigation is designed to fulfil an agricultural aim and is therefore governed by agricultural considerations; consequently, sewage or effluents for irrigation must be applied at the time and in the quantity that will best satisfy the needs of a particular crop in a particular season. Irrigation must even be stopped if the crops do not demand, especially in periods of sufficient rainfall; in countries with rainy winters it may flood the ground and cause harm. The situation is aggravated by the fact that in winter there is no use of water by plants and little evaporation. As sewage cannot be stored it must be discharged in some other way if it is not to do damage. In this it differs from digested dry sludge, which can be stored when not needed. Irrigation cannot therefore be a permanent and exclusive method of disposal of sewage.

Another disadvantage is the risk of seeding the irrigated surfaces with weeds. Here again sludge digestion is superior since the seeds are destroyed in the digestion process.

Many crops can benefit from irrigation with sewage. Especially suitable are corn, beets and, in particular, grass. It is therefore to grasslands mainly that sewage or effluents are applied.35,37

Irrigation with sewage seems to be by no means innocuous. Wright 48 gives two examples of infection of beef with Cysticercus bovis and Taenia saginata, in Australia and Arizona, and mentions similar experience in South Africa. F. Reinhold reports on a roundworm plague at Darmstadt in 1947-8 with 350 infections due to the use of insufficiently treated sewage for the irrigation of vegetables. Stein,37 on the contrary, reports that decades of sanitary supervision of the sewage-irrigated fields of Berlin did not reveal any unusual morbidity, especially from infectious diseases, among the agricultural workers and the surrounding inhabitants. The literature, indeed, does not offer much evidence of morbidity and mortality due to sewage-irrigation practices, but among the hygienists there is a widespread and common belief, based on everyday experience, that vegetables irrigated in this way may transmit intestinal infections.48 Cram 5 reports from her own experiments that primary settling does not remove cysts of
Entamoeba histolytica from sewage but does remove a certain percentage of the eggs of Ancylostoma caninum and a still higher percentage of Ascaris eggs. She also found these forms in the effluent from trickling filters and from activated-sludge plants regardless of their efficiency as measured by reduction in the biochemical oxygen demand, but did not find them in the effluent from secondary settling-tanks in chemical precipitation with alum or in the effluent from sand filters 60 cm deep at a rate of filtration equal to 0.1 m per day. Newton and collaborators 17 could not find eggs of Schistosoma japonicum in the effluent from sand filters 30 cm deep (effective size of sand, 0.5 mm) at a rate of 1 m per day, or miracidia at a rate of filtration of 0.2 m per day (effective size of sand, 0.3 mm).

In long observations at Johannesburg cysts of Entamoeba and eggs of Ascaris, Taenia, and Ancylostoma were found in the effluent from fine screens, primary and secondary settling-tanks, trickling filters, and activated-sludge plants.48

Rudolfs and collaborators recently published the results of extensive experiments on contamination and decontamination of various vegetables, mainly tomatoes and lettuce, grown on experimental fields, with concentrations of coliform bacteria, strains of Salmonella and Shigella, cysts of Entamoeba, and eggs of Ascaris suum, applied by surface irrigation, spraying, and smearing.31 They arrived at a number of conclusions. The extent and seriousness of these capital experiments is such that a review of the main conclusions seems necessary at this place.

Vegetables grown on surfaces irrigated by sewage or fertilized by human excreta in years previous to the growing season are safe. Vegetables grown on soil irrigated on the surface by sewage do not show greater contamination by coliform bacteria than those grown on soil cultivated in the normal way, regardless of whether the soil was irrigated before or during the growth of the plants. If excreta or sewage sludge are applied to the surface of the soil or sprayed during the growth of vegetables, such application must be discontinued at least one month before the harvest. If this rule is followed, the vegetables will not show any greater contamination than would those to which stable manure or artificial manures were applied. Strains of Salmonella and Shigella do not survive on the surface of vegetables for longer than a week. Coliform bacteria may therefore be used as indicators of contamination with a considerable margin of safety. Bacteria applied on the surfaces of vegetables adhere tenaciously and are protected from the environment. This facilitates their survival under field conditions and explains the difficulties of their artificial removal. The resistance of Entamoeba cysts to environment depends almost entirely upon the amount of moisture present; immediately after drying they die out; in dry weather they survive less than three days on vegetables. In order to minimize the danger of transmission of amoebic dysentery the last application of the contaminating matter to the soil ought to be made at least a week in advance of the harvest in the
temperate zone and two weeks before in a warm and humid climate. *Ascaris* eggs were found on surfaces of vegetables in reduced numbers one month after application, but in a degenerate state; the danger of transmission is greatly reduced if fertilizing with faecal matter ceases a month before the harvest. The only successful method of decontamination of vegetables from bacteria, amoebae, and helminths is pasteurization for five minutes at 60°C, which can be accomplished by immersion in water of that temperature.

In view of the foregoing, irrigation of vegetables and fruit with sewage effluents is rather unpractical, even when very good effluents are used. This is particularly true of spraying, since it is no more feasible for a farmer to stop irrigating a month before harvest than it is for a cook to pasteurize raw food for five minutes in water heated to 60°C.

In view of the facts given it appears that either the practice of sewage irrigation is to be applied only to crops which are not eaten raw or that a technique must be developed which will secure effluents positively free from helminths and cysts of *Entamoeba histolytica*.

In either case the handling of both the sewage treatment and the irrigation is safest when done by public agencies.

Nowadays there is a tendency, most pronounced in some parts of the USA, to extend the utilization of sewage in order to reclaim used water, an item which is being increasingly considered in the planning of national resources in several parts of the world. Use of sewage in water conservation may require even higher standards for the quality of the effluent and more rigid enforcement.

In that matter the State of California seems the most advanced at present. The State legislature in 1947 provided the means for research into the State's water resources, as a basis for the establishment of the "California Water Plan". The inventory of water resources has to include significant effluents from sewage-treatment plants and industrial wastes. In connexion with that, the legislature adopted in 1949 a comprehensive programme for the control of water contamination. In 1949 there were already nine spreading-grounds with a capacity of nearly 31 m³ per second, intended to divert flood-water into the ground, in Los Angeles County. New spreading-grounds have been provided for the reclamation of used water, which is now discharged into the sea at the rate of 400,000 m³ per day. Experiments with trickling-filter effluents allow a rate of infiltration on spreading grounds equal to 0.3 m per day. On spreading-grounds nothing may be introduced but oxidized secondary effluent.

An analogous view was put forward in Germany in 1949 by Müller. The effluent from spreading-grounds may join the natural underground water and undergo subsequently the same exploitation. In this case it is very desirable for the water not to be heavily mineralized.
Conclusions

The agricultural use of stable manure and of municipal garbage does not come within the scope of this paper, but all other kinds of organic matter which are relevant have been discussed. It is time now to draw the necessary conclusions from this all too summary review.

In some parts of the world in general, and in Europe in particular, there is a shortage of organic fertilizers. The main reasons seem to be the growth of population with an increasing need of food; a multitude of small holdings incapable of producing sufficient fodder, and in consequence a shortage of stable manure; barren surfaces which cannot be made fit for agricultural exploitation by artificial manures; deterioration of the humus by reckless exploitation of soil; and exclusive use of chemical manure.

In other regions there is a shortage of water both for irrigation and for general use, as a result of a steady increase of demand and by natural causes.

In such regions man has turned for help to the organic waste produced and to the water wasted by his activity. With the tremendous development of the natural and medical sciences in the last hundred years he recognized the dangers inherent in the use of such matter, and, hence, tended to abandon the idea. But the present needs in many regions seem much too acute to allow such waste, and man has again turned to this question, looking for ways and means which may allow him to use these wastes without harm.

At the present time, certainly too little relevant knowledge has been accumulated, both from the agricultural and from the sanitary points of view. In the first place it seems necessary to investigate the epidemiology of the use of human wastes in agriculture more extensively than has so far been done and to accumulate an exhaustive body of epidemiological data. This seems particularly necessary where the use of excreta and of various kinds of sewage sludge for fertilization and of crude sewage and sewage effluents for irrigation is concerned.

In the second place, it seems necessary to investigate further the chemistry, biology, and bacteriology of the various processes of treatment and use of waste matter. The studies of Rudolfs and his collaborators mentioned previously stand as a fine example of this kind of work.

It appears desirable that new methods of treatment be investigated and experimented on—for instance, the still controversial composting of excreta and sewage sludge with other materials.

Finally, standards of quality for sludge and effluents used in agriculture and for water conservation purposes might be set up, based on the accumulated epidemiological information and the results of studies on the nature of such matter as well as standard methods of handling it.

As the problems have nationwide significance, they should be incorporated with national planning and, in practice, reserved for handling by public agencies alone.
RÉSUMÉ

Dans diverses parties du monde, en Europe particulièrement, il y a pénurie d’engrais organiques. Ce fait peut s’expliquer en grande partie par l’accroissement de la population et des besoins alimentaires, la production insuffisante de fourrage — et par conséquent de fumier — dans de nombreuses petites fermes, la destruction de l’humus par l’exploitation irrationnelle du sol, et l’usage exclusif des engrais chimiques qui aboutit à la détérioration du sol. On sait que, si les engrais chimiques — riches en azote, phosphate et potassium — permettent d’obtenir d’abondantes récoltes, les engrais naturels organiques sont indispensables au maintien du sol et des plantes dans de bonnes conditions, par la formation de l’humus qui retient l’eau et favorise le développement bactérien. Dans d’autres régions, c’est l’eau qui manque, que ce soit pour la consommation ou l’irrigation.

Pour remédier à ces déficits, l’homme a cherché à utiliser les déchets vitaux comme engrais (excréments humains partiellement fermentés, boues brutes ou digérées, fumier, ordures fermentées) et les eaux d’égouts pour l’irrigation. Mais l’hygiène moderne a révélé les dangers de ces méthodes, et l’on a été tenté de les abandonner. Or, certaines régions sont trop pauvres pour pouvoir renoncer à l’emploi de ces ressources, et l’on cherche actuellement les moyens de rendre ces déchets inoffensifs. Trop peu de recherches encore ont été faites dans ce domaine, fondées sur la bactériologie et la biochimie des engrais organiques naturels, leur transformation en peu de temps en engrais de valeur, débarrassé des germes pathogènes. Des études récentes ont montré, cependant, que, dans la digestion anaérobie des excréments, le taux de mortalité des bactéries coliformes est de 10-15 % par jour à 25°C. En été, les œufs d’Ascaris ne survivent pas plus de 2-3 mois, ceux d’Ankylostoma pas plus de 2-3 semaines et les agents de la typhoïde et de la dysenterie pas plus de 2 semaines. En automne et au printemps, le temps nécessaire à la destruction de ces organismes est double; en hiver, il est quadruple ou quintuple. Il y aurait lieu d’étudier, en particulier, les moyens de préparer des composts à partir des excréments et des boues, mélangés à d’autres matériaux. Quant aux boues, des analyses récentes ont montré qu’elles avaient une certaine valeur en agriculture, par l’apport lent au sol d’azote et de phosphate. Des résultats variables ont été obtenus aux Etats-Unis; ces boues ne conviennent pas à toutes les cultures.

L’auteur passe en revue un certain nombre d’études et d’expériences faites dans divers pays, relatives à la composition chimique, à la valeur agricole, et à l’importance épidémiologique des égouts et des boues. Il conclut que les diverses méthodes d’utilisation de ces substances doivent être mieux connues. Il estime que des normes pourraient être établies, assurant la qualité des boues et des égouts utilisés en agriculture. Ces problèmes, étant d’importance nationale, devraient être étudiés et les réalisations dirigées par les administrations publiques.

REFERENCES

1. Arnold, C. E., Hedger, H. E. & Rawn, A. M. (1949) Report upon the reclamation of water from sewage and industrial wastes in Los Angeles County, California, Los Angeles
5. Cram, E. B. (1943) Sewage Wks J. 15, 1119
19. Porter, J. P. (1948) *Report to Auckland, New Zealand, Metropolitain Drainage Board on sewerage, sewage treatment and sludge disposal schemes for the inner area of the Metropolitain Drainage Board's district*, Auckland
22. Ransome, F. H. (1944) *Surveyor (Lond.)*, 103, 525
29. Rudolfs, W. et al. (1949) *Sewage Wks J.*, 21, 228
32. Schrader, H. (1948) *Annual report of the City Engineer of Johannesburg, South Africa, for the year ending June 30, 1947*, Johannesburg
38. Stone, R. (1949) *Sewage Wks J.*, 21, 992
41. Warlow, W. P. & Regan, C. J. (1950) *Surveyor (Lond.)*, 109, 599
46. Wilcox, L. V. (1948) *Sewage Wks J.* 20, 24