Fig. 1. Turning of sewage sludge by machine at Los Angeles County Sanitation District. Material is turned daily for 30 to 40 days to facilitate composting.

Fig. 2. Growth of 3 trees initially of same size, planted near Las Vegas, Nevada in 1977. The 2 smaller trees grew in unamended soil, the larger one in soil amended with 33% by volume of composted sewage sludge ("Nitrohumus") and milled fir bark in a ratio of 1:1.

another very popular material, "Amend", is a composted blend of "Nitrohumus", shredded rice hulls, and micronutrients; it is used widely as a soil amendment. "Nitrohumus" is also used in formulating indoor planter mix and potting soil. For this use the mix also contains vermiculite, perlite, horticultural charcoal, and urea-formaldehyde. A final product, "pH Acidall" has acidifying agents and micronutrients added to the "Nitrohumus" and is used as a soil acidifier and as a topdressing for existing turfgrasses, ground cover, and landscape plantings.

UTILIZATION OF MUNICIPAL WASTEWATER FOR THE CULTURE OF HORTICULTURAL CROPS

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The use of municipal wastewater for horticultural production on the surface appears to be a very simple concept (2, 10, 12). In its simplest form it is the use of a waste product of one process as the raw material for a second process. However, if the best use of the combination of the 2 systems is to be made, it will be necessary to maximize the sum of the 2 systems rather than of each individual system. These 2 systems, horticulture and municipal wastewater, are interfaced by a number of mutual components which are mineral nutrients, CO_2, water and heat. The heat and CO_2 can only be taken advantage of under controlled environmental conditions, with a bare minimum being greenhouse conditions, while all horticultural operations can utilize the nutrients and water (5).

Characteristics of municipal wastewater

In order to make the best use of this wastewater it is necessary to understand the characteristics that make it desirable for horticultural use and also the characteristics that could limit its use.

Probably cost is the first characteristic of wastewater that makes it an attractive management alternative to many other water sources. However, the total cost of reclaimed water is very high but the actual cost of the treated water for irrigation often depends on whether the local sanitation people view it as a disposal operation or as the marketing of a natural resource. Recent environmental considerations such as the banning of ocean discharges and requiring increased treatment before wastewater can be disposed anywhere in the environment are rapidly increasing the cost and degree of wastewater processing. Thus, the additional degree of processing required to make wastewater suitable for reuse is being reduced to the same degree, which makes the cost that can be attributed directly to reuse or irrigation relatively small.

The physical characteristic of a given effluent water is primarily dependent upon 3 major variables. These are: 1) the quality of the original water source; 2) the type of use; and 3) the renovation treatment. Because of this, the term "effluent water" by itself is not sufficient to describe the quality of an effluent water. The quality can range anywhere from almost pure water to water so grossly polluted that it is not a fit source of water for any use. However, most of the renovated water considered for reuse can be defined in terms of the above 3 variables. The original source of the water supply should be of good drinking quality. with less than 500 ppm of total dissolved solids (TDS). It should come from a primarily urban area without significant industrial input and the level of treatment should be at least secondary. There is presently still a lot of domestic effluent available for reuse, and the industrial effluent which is more difficult to clean up need not be considered until the demand is much greater. In California less than 10% of the wastewater is being reused.

The real question when considering the reuse of effluent water for irrigation of crops is how it differs from the original water supply; the original water being the standard for the area, any problems associated with it should already be understood. Again there are 3 major categories of characteristics that are modified during use: 1) biological composition; 2) organic composition; and 3) dissolved inorganic salts. Although the biological composition of the effluent water is of great concern because of pathogenic bacteria and viruses, renovated waters are not released for irrigation without prior approval of the public health officials, usually at a level acceptable for full body contact. Renovated water should cause no public health problem after secondary treatment and disinfection, provided that the approved handling procedures are followed. For irrigation purposes, the organic portion of the effluent water is generally of minimal consequence unless nitrogen is included in this fraction. However, after the initial treatment, the wastewater is often held in ponds where algae can grow, therefore, it is necessary to include sufficient filters to protect irrigation equipment. The characteristic that is going to have the most influence on the use of effluent water for irrigation purposes is the added salt load which it picks up in use. This will be the most important in the arid west where the use of recycled water is most attractive.

Salt load

The salt load is comprised of the soluble material found in the water as the result of having been used once. For example, the water used in the home for dishwashing has soap dissolved in it which, in turn, dissolves whatever is found on the dishes as they are washed. A general rule of thumb is that water going through 1 cycle of use picks up about 300 parts per million TDS of inorganic salt. This is the average amount of material that would be dissolved in the water when all uses of water in the home are considered and averaged.

Plants in general do not grow very well under saline conditions. Only a few varieties of plants can tolerate the high salt conditions found right along the ocean or in the saline areas of the desert. Some plants, such as avocado, are so sensitive to dissolved salts that they can grow only when the best of water is used for irrigation.

If the dissolved material in the effluent water is looked at as just contribution to the total salt load or osmotic potential of the irrigation water, then this is of importance only when the total salt load from the original source is high. For example, if the original source was the Owens River (230 ppm of TDS), then an additional salt load of 300 ppm of TDS will be important only when growing very sensitive plants. However, if the original source is pure Colorado River water (800 ppm of TDS), then the additional 300 ppm of TDS could have a significant effect on many plants. Any water having a TDS greater than 1000 will have severe limitations as irrigation water unless a large portion of the cations are calcium.

The 300 ppm of added TDS is only part of the picture. Depending on the elemental composition of the added salts, both the specific effect and the magnitude of any effect on plants can be vastly altered. The salt load of a typical urban effluent can be characterized as containing the following 8 elements in approximately the following concentrations given as ppm: Sodium-70; potassium-10; calcium-15; magnesium-7; chlorine-75; sulfate-30; silicate-15; phosphate-25; and nitrogen-31.

However, both the form of the nitrogen, ammonium, nitrate or nitrite and the total amount of nitrogen will be a function of the particular treatment process used. This typical salt load is not very large and placed the typical urban effluent in a favorable total salt range for irrigation of horticultural plants if the only source of salt was that salt picked up when used once for domestic purposes. However, to emphasize a point, if the original source water has a significant amount of salt, then this added salt could become very important when considering effluent for use as irrigation water. Normal city sewage treatment, consisting of a primary sedimentation and secondary biological treatment, will not remove soluble salts. Only with the addition of some form of tertiary treatment will removal of some or all of the dissolved salts be possible.

The sodium absorption ratio (SAR) of this hypothetical mixture of inorganic salts is 6.8. The SAR is an index of the effect of sodium in reducing soil permeability (the rate which water passes through soil). A SAR of 6 or less is considered desirable. A SAR level of 6.8 indicates that a permeability problem could arise in some soil if not watched. The salt load just described does not account for an extensive use of self-recharging home water softeners. The self-recharging home water softeners use large amounts of common table salt, all of which eventually ends up in the sewage. If their use is common, the SAR would increase because of the increase in sodium and a permeability problem would be likely on any soil except coarse-textured ones. Along with sodium, the chloride is already high, and if increased with the use of water softeners, it could cause leaf burn on chloride-sensitive landscaping plants.

Plant nutrients

The concentration of the primary plant nutrients (N, P, K) added during a typical use cycle is low in terms of parts per million, but continued use of such effluent water for irrigation at high rates could add a significant amount of these plant nutrients. Each acre inch of effluent water used for irrigation in this example will add 4 lb. of nitrogen, 1.8 lb. phosphorus, and 2.3 lb. of potassium. Considering that approximately 40-acre inches of water per year are needed in Los Angeles basin just to replenish the water lost to evapotranspiration, this amount of effluent use would add 160 lb. of nitrogen, 72 lb. of phosphorus, and 92 lb. of potassium each year (180, 81, and 103 kg/ha of the 3 nutrients, respectively, for the same water application rate). In most instances this would supply more phosphorus and potassium than presently being recommended and needed for horticultural use and also most of the nitrogen. Therefore, the amount of fertilizer applied as part of the effluent will be a plus factor and must be accounted for when considering the fertilizer requirements of horticultural plants.

The chlorine used for disinfection could be a problem if used at abnormally high rates. Some plants will show injury when the residual chlorine is greater than 10 ppm. However, by the time most effluents are used, the residual chlorine is well below that level.

Effluent water also contains a wide array of elements in trace concentrations, all of which are potentially toxic if present and available in large excess over the normal concentrations at which they are found in the soil. The chemical characteristics of many of these trace elements, especially the heavy metals, are such that they tend to be concentrated in the upper horizons of the soils. Thus, when effluent water is used for irrigation over long periods of time, the concentrations of these trace elements in the upper soil horizons can build up to potentially toxic levels. It should be pointed out that most of the trace elements in treated effluent are associated with the small amount of particulate matter present. For most treatment processes the amount of particulate found is less than 10 ppm. Not only does the trace element concentration increase dramatically with increased particulate matter, but there is also an increased risk of incomplete disinfection.

Safety

The safety and suitability of effluent water for irrigation has to be judged not only on how it will affect our present crops or plants, but also on how it will affect the crops of our children. Keeping in mind that presently used effluent is generally derived from domestic wastewater, there does not appear to be any major problem with trace elements for plant growth. If, however, the wastewater came from heavy industrial areas or was combined with such wastewaters, then no such prediction could be made without a complete chemical analysis, and even then with no degree of certainty.

There are 5 trace elements in domestic effluent which could be present in amounts potentially toxic under certain conditions and should be periodically monitored. They are: boron, cadmium, copper, nickel, and zinc. Boron in many effluent waters will run between 0.5 and 1 mg per liter. The high concentration of boron presently found in domestic effluent can probably be attributed to the use of boron compounds in the home laundry rather than phosphate. When boron is in this concentration range, some boron-sensitive plants may show some injury. Fortunately, boron is very mobile in the soil and does not tend to build up on the soil as much as heavy metals, but is leached through the soil profile. This could lead to another problem, that of contaminated groundwater, which will have to be considered in any overall phase for water reuse.

The other 4 potentially toxic trace elements are heavy metals which in some instances are high in domestic wastewaters. However, a high concentration of zinc more often than not should be beneficial to turf. It is recommended that for continuous use as irrigation water, effluent should contain no greater than 0.005 ppm cadmium, 0.2 ppm copper, 0.5 ppm nickel, or 5.0 ppm zinc (11). Most renovated domestic wastewaters will meet these standards. But monitoring is essential to insure that this continues to be the case.

Interfacing systems

When considering the overall interfacing of the 2 systems, CO_2 and heat must also be considered. With our present energy crunch the advantage of utilizing any available heat source is very clear. In considering the use of heat from a wastewater treatment plant it is necessary to remember that although the amount is great, it is available at only a few degrees above ambient. Then it can only be efficiently utilized if both systems are fully integrated. The quality and quantity of the waste gases, such as CO_2 coming from wastewater treatment plants, varies with each process and represents an area which still needs to be explored.

In an interfaced system not only do the horticultural crops utilize the end products of the water treatment process, but they also are part of the wastewater treatment. One way that this can be done is by growing the plants hydroponically "on line" in the wastewater treatment stream where the plants can function on a limited tertiary treatment by removing mineral salts. This would improve the quality of the water which can then be used for additional beneficial purposes (4, 12).

The use of effluent for hydroponic culture is similar in many respects to the nutrient film technique (NFT) except that one has to be concerned about both the horticultural product and the wastewater produced. In each case one has both quality and quantity to worry about. Considering only the horticultural aspects, the limitations that apply to field irrigation with wastewater will still apply, but without the soil present to act as a filter and buffer, additional management controls may have to be applied.

The principal areas of concern are control of pH, dissolved oxygen and trace element composition (7). The trace element concentration that has been recommended for continuous use in irrigation water are too high when there is no soil present to ameliorate the toxicity (11). The biological oxygen demand (BOD) of the wastewater will vary at different stages of the treatment process and can be sufficiently high to limit root growth in plants (5, 6). The pH of the wastewater can also vary depending on the treatment process and can be sufficiently high to limit the availability of nutrient such as iron to plants (9).

If vegetable crops rather than ornamentals are to be grown in the wastewater, it is also necessary to consider the nutrient control of the edible portions of the crop. As noted previously, there are a number of trace elements such as cadmium, nickel, zinc, copper and cobalt that are present in urban domestic wastewater at concentrations of possible concern (1, 3, 8). We have grown a number of vegetables in such wastewater and followed the concentration of these trace elements in the various plant tissues (2, 12). It appears that for the more common vegetable crops such as tomato, cucumber, lettuce, etc. large concentrations of these elements are present in the roots. However, even under conditions of high root concentration, only a fraction of these trace elements are translocated to the tops with an even smaller fraction eventually reaching the fruit. Thus the root acts as a trap or filter which removes mineral nutrients and trace elements from the wastewater while translocating relatively little to the tops.

In summary, it is not easy to strictly define the quality of wastewater. It can vary from very good to very bad. But in general, wastewater from domestic sources is a good potential resource for irrigation water. In addition, horticultural crops can remove mineral nutrients and trace elements from wastewater, thus contributing to tertiary treatment.

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FACTORS AFFECTING QUALITY OF COMPOSTS FOR UTILIZATION IN CONTAINER MEDIA[1]

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A variety of publications from the United States (9, 10, 16, 22, 28), Norway (27), Belgium (4, 5, 6), Finland (18), and Japan (30) have discussed composting of tree barks for use in container media. Although differences in properties of bark from tree species are considerable, established methods for production of high quality composts are remarkably similar. The composting process comprises a complex series of biological events that remove mostly cellulose (wood and cambium) and various toxins (24, 29) from bark and leave humic acid, lignins and a variety of microorganisms as major end products. In this article, key factors are discussed that affect the composting rate of tree barks and quality of the end product. Information presented is based on research performed at the Ohio Agricultural Research and Development Center during the past 8 years as well as research at other institutions. Some guidelines were established in cooperation with various commercial operations that produce compost for container media.

Composting process

Composting has been defined as the biological decomposition of organic constituents in wastes under controlled conditions. An important term in this definition is "controlled" which distinguishes composting from natural rotting or putrefaction such as occurs in open dumps, manure heaps, or in field soil (11). Basically the process can be divided into 3 phases: 1) an initial phase of 1-2 days during which easily degradable soluble compounds are decomposed, 2) a thermophilic phase (possibly lasting several months) during which high temperatures occur and in which mostly cellulose is degraded, and 3) stabilization, a period during which the rate of decomposition decreases, temperatures decline, and antagonistic and other ambient temperature microorganisms recolonize the compost. For a detailed description of the composting process, the reader is referred to "Composting, A study of the process and its principles" (11).

Bark used for container media generally is composted in windrows (3-4 m wide, 2-2.5 m high). Since the process is aerobic, windrows should not be covered with polyethylene but may be under a roof in areas of high rainfall. The surface on which windrows are placed should provide adequate drainage to avoid anaerobic pockets in the base of windrows.

The oxygen concentration in the gas phase of a windrow should be maintained above 0.1% and preferably between 5-12% (8, 26). The optimum temperature for composting of hardwood bark is 40-55 C (4, 6). At high temperatures lower rates of decomposition occur (19). However to reach thermophilic conditions (>40C) throughout a windrow, temperatures in the center of a windrow usually reach 55-70 C (16).

The optimum pH for composting ranges from 6.5-8.5 (6, 21). The pH of fresh bark ranges from 4.0-5.5. Addition of ammonium nitrate does not raise the pH significantly, whereas addition of urea or anhydrous ammonia does (5, 16, 27). This is the primary cause for higher rates of decomposition observed in bark treated with ammonium N sources (4, 5, 6).

The optimum moisture content during composting is 50-65% on a wet weight basis (6, 20). Moisture contents below 40% significantly reduce the rate of decomposition (11). Higher levels may result in accumulation of free water in the bottom of windrows and yield a spoiled silage odor. Frequent turning after free standing water is removed usually corrects this problem due to drying of particles and aerobic decomposition of fermentation products. However, sour compost in which the pH has dropped below 4.0 is no longer usable. Readings as low as pH 1.9 have been encountered (2). These samples were extremely toxic and, when used, killed all vegetation.

Aeration, moisture content and particle size are interrelated. Coarse bark aerates better and can be stacked in higher windrows than finely ground bark. However, coarse bark dries out readily and water may have to be added to keep the moisture content at optimum levels. Equipment should not be driven onto stacks in the preparation of windrows since it causes compaction and subsequent fermentation (2, 16).

The length of time during which high temperature (thermophilic) decomposition occurs can be reduced significantly by careful control of optimum conditions for composting. Aeration with fans (negative pressure) attached to perforated drainage pipe (8, 26) reduced the composting period (Beltsville system) for hardwood bark from 6 months to 4 weeks if followed by 1 month of "stabilization". More sophisticated composting machines (mechanized aerated tanks or aerobic digestors) may reduce this period even further (to 2 weeks, followed by 1 month stabilization) thus reducing the acreage and heavy equipment needed.

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