MUNICIPAL SEWAGE EFFLUENT AS A SOURCE OF WATER AND NUTRIENTS FOR VEGETABLE CROPS

by

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LITERATURE REVIEW

Water pollution has long been a problem in the United States. The problem has largely been created and aggravated by the disposal of sewage effluent into streams, rivers, and lakes. In 1969, about 10% of the sewage effluent discharged from communities into surface waters was untreated--raw sewage (40,67). In 1972, over 26 billion gallons of effluent were discharged daily nationwide, the results of various degrees of treatment. Late in 1972, passage of the Federal Water Pollution Control Act Amendments (Public Law 92-500) was a major step "to restore and maintain the chemical, physical and biological integrity of the Nation's waters" (71). In order to eliminate pollutant discharge into navigable waters by 1985, the Act strongly recommended reclamation and recycling of effluent, and required the consideration of a land application system as one of the alternatives to present sewage treatment systems (58).

Land application of sewage effluent is the passage of primary or secondary effluent* through soil-plant systems (a "living filter") (63), providing a very advanced degree of treatment. The United States Environmental Protection Agency endorses land treatment of effluent as a form of tertiary treatment, recommending it as a way to "convert what was originally a wastewater into a valuable resource too good to throw away" (70). The history of land application of sewage effluent dates back to ancient Athens, and has been used for centuries

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*Primary treatment removes from incoming sewage only materials that settle or float, leaving all soluble constituents, and removing 35% of the biological oxygen demand (BOD). Secondary treatment removes 85% BOD, more of the soluble constituents and suspended solids, and kills most of the pathogenic bacteria, protozoa, and viruses. Tertiary treatment is any treatment beyond secondary treatment. It is considered advanced treatment, producing a very clean, odorless effluent (70).

in many parts of the world. However, it did not become widespread in the United States until the late 1800's (26,60). Though many land application systems in the U.S. were replaced by sewage treatment plants in the early 1900's, many communities continued to apply effluent to the land as a means of disposal, or as supplemental irrigation. Today, with government support evident through the 1972 legislation and further legislation in 1977 (the Clean Water Act) (61), recognition of the need to supplement declining groundwater supplies (19,61), and the economic savings gained by using land treatment rather than treatment in conventional facilities (47,61), there are numerous land application systems operating throughout the United States.

Land application sites in the United States

The growth of land treatment systems in the United States over the last decade is illustrated in Table 1 (21).

Table 1. Municipal land treatment systems 1972 and 1981.

Type of system	1972	1981
Slow rate	315	839
Rapid infiltration	256	323
Overland flow	0	18
Total	571	1180

Perhaps the largest and most recognized land treatment system in the nation is in Muskegon County, Michigan (59). Over 5300 acres, planted in field corn, are irrigated with secondary effluent. The Muskegon Metro Wastewater Management System is innovative in that it was the first system of its magnitude to be planned as a land application system from the start. Another system often referred to is the Flushing Meadows project west of Phoenix, Arizona (11, 12). Installed in the Salt River bed in 1967, the objective was to study the use of rapid infiltration to renovate treated effluent for unrestricted irrigation, recreation, and certain industrial uses. Based on the project's positive findings, a system was established near Phoenix to filter effluent through soil, then pump the renovated water up for irrigation of a large lettuce-producing area (4). Another irrigation district in Arizona, near Buckeye, mixes secondary effluent with excessively salt-laden well water to improve the well water's quality for irrigation (28).

A 1977 California State Department of Health Services survey reported effluent reclamation at over 200 treatment plants for application to more than 360 locations for fodder, fiber, and seed crop irrigation (2). Land application is thus recognized as a well-established practice in California, with sites at Santa Rosa, San Luis Obispo, Lodi, Modesto, Fresno, Bakersfield, and Petaluma (2,21). Palm Springs uses recycled secondary effluent to irrigate its golf courses (36).

Other land application systems include sites both on the mainland and off. In Hawaii, secondary effluent augments restricted natural water resources for the irrigation of sugarcane, bermudagrass golf courses, forage crops, tropical nuts and fruits, and commercial vanda orchid production (45). Nevada land application systems include the Las Vegas wash, where treated effluent transformed a dry desert wash to a marshy, attractive wetlands (69), and use of Lake Tahoe effluent for irrigation (24). Farmland near Toole, Utah, has received effluent since 1957 for crop irrigation (60). In Hayden, Colorado, mountain meadows have received effluent (62), and in Westminster, Colorado, farmers exchange portions of their irrigation water for equal amounts of the city's secondary effluent in order to expand significantly the domestic water supply (19). Bennett Spring State Park, in the Missouri Ozarks, keeps its waterway effluent-free for recreation use by applying its partially- treated effluent to a 5-acre forested area (5). Golf courses in Chicago and Bensonville, Illinois, use secondary effluent as irrigation to avoid competition for declining groundwater supplies, and to cut fertilization costs by 60-100% (61). Wetlands in Michigan receive treated effluent as irrigation, providing a substantial cost savings for the community while improving and protecting delicate natural marshland (72). Treated effluent has been applied to cropland and forest stands in the Penn State Wastewater Renovation and Conservation Project since 1963 to study land application principles and results (67). In the southern United States, 3500 acres of hilly woodlands are irrigated year-round with treated effluent in Clayton County, south of Atlanta, Georgia (48). In the mountains of north Georgia, the state government funded an effluent irrigation system in Unicoi State Park in 1973, in part to study effluent application to southern Appalachian forests; the system continues to operate successfully (3,57). And in Florida, effluent irrigation of forage crops has been conducted since 1970 near Tallahassee (54). Other systems using private land are in El Reno, Oklahoma; Vandalia, Missouri; and Lubbock, Texas (21).

Concerns regarding land application of sewage effluent

The land application systems listed above are successful examples of the "living filter" concept of effluent treatment and reclamation for beneficial use--but not without public apprehension. One public reaction to land application was noted by Dr. Wade L. Nutter, soil scientist and hydrologist at the University of Georgia, who has worked extensively on land application systems in Georgia: "When we first talked about spraying wastewater on forests, people got all kinds of weird ideas about what it would look like. I think they were expecting to find toilet paper hanging in the trees." (48). This indicates some of the ignorance surrounding effluent treatment with land systems, but not all concerns are unfounded. Sewage effluent does contain plant nutrients, but levels of these nutrients may be excessively high, and may be accompanied by unacceptable levels of heavy metals and other potentially toxic substances.

Effluent contains pathogenic bacteria, protozoa, and viruses, the levels depending on the extent of treatment and disinfection. Disease transmission by these pathogens is a legitimate public concern. Each of these factors may pose environmental and/or health hazards, directly or indirectly, if abnormally high levels accumulate in groundwater, soil, or vegetation. The public might also question methods of site selection and management, the Federal and State regulations that must be met, and the overall safety of the system. Obviously, the aspects of land application of sewage effluent are numerous, all worthy of separate discussion. This review will concentrate on the responses of soil and vegetation to effluent constituents.

Soil responses to land application of sewage effluent

> "The success of a land disposal site depends upon the ability of the soil to fix and store effluent constituents for use by plants and microbes and to prevent excessive migration of certain constituents to the ground water." (41)

Soil has long been recognized as an efficient purifying medium, acting as a complex filter with particle sizes ranging from over 500 microns to less than 1 micron (47). In the renovation of sewage effluent, soil acts as 3 filters: a physical filter, a chemical filter, and a biological filter.

Physical filter. Soil may be viewed as a maze of channels, and it is the size distribution and nature of these channels that controls the soil's capacity to filter suspended solids from effluents (68). In most soils, pore size distribution and nature of water movement channels are such that suspended solids are completely removed after effluent has traveled short distances through the soil.

Chemical filter. Many organic and inorganic reactions occur as effluent passes through a soil profile (33). These reactions include ion exchange, adsorption, and precipitation. An example is the rapid adsorption of P by most soils. In acid soils, removal of PO_4^{3-}, as well as Ca^{2+} and Mg^{2+}, from effluents may occur by formation of a complex gel with Fe, Al, and Si in the soil (38). Cations (K^+, Ca^{2+}, Mg^{2+}, Na^+) in effluent may complex with insoluble organic matter, precipitate as insoluble oxides, or be reversibly adsorbed on the soil surface (15,42,49).

Biological filter. The organisms comprising the soil biological filter are bacteria, actinomycetes, fungi, protozoa, algae, soil micro- and macro-animals, and higher plants (49). A very significant function of soil microbes is the degradation of organic compounds in effluents, reducing the biological oxygen demand (BOD) in the water by converting the organic materials to CO_2 (33,49). Equally important are microbial reactions involving effluent N. Nitrogen in the effluent is mineralized by soil microbes, and the mineralized NH_4^+-N as well as NH_4^+-N still in the effluent are held by soil exchange sites until nitrified by chemosynthetic bacteria (*Nitrosomonas* sp. and *Nitrobacter* sp.) (14,49). The NO_3^--N formed is very mobile and subject to leaching, presenting a hazard if excessive amounts reach groundwater. However, research indicates that application of effluent containing NO_3^- or a potential source of NO_3^- (organic N, NH_4^+) to soil surfaces will probably not result in unimpeded movement of that NO_3^- to the water table, due to interception by plant roots and denitrifying bacteria (39). Anaerobic heterotrophic bacteria denitrify 15-20% of the NO_3^- passing through the soil rhizosphere, converting it to innocuous N_2 gas. Therefore, denitrification is an ideal decontamination process, a very important factor in the soil biological filter.

Clearly, soil may act as a purifying filter, but true renovation efficiency is closely correlated with soil type. A study of 6 diverse Connecticut soils concluded that acid soils with relatively low permeability and medium to high clay and organic matter contents were the best effluent renovators, exhibiting an anion removal pattern of $PO_4^{3-} > SO_4^{2-} > NO_3^- = Cl^-$, and removing 85% K^+ and 75% Ca^{2+} and Mg^{2+} (38). The alkaline, calcareous soil studied removed low amounts of chemical constituents despite its high clay and organic matter content, allowing PO_4^{3-} to leach beyond the A horizon, removing 95% K^+, less than 50% Ca^{2+}, and was totally ineffective in removing SO_4^{2-} and Mg^{2+}. In a separate study, it was concluded that fine-textured soils have a greater ion removal capacity due to a greater number of adsorption sites (clay minerals, metal oxides, organic matter) (21). As for specific soil types, research at Pennsylvania State University has shown that Ultisols (Hublersburg silt loam and Morrison sandy loam), irrigated with 5 cm effluent/week, are suitable for effluent renovation. Studies in Arizona found a Mollisol (Grabe silt loam) still efficiently renovating effluent after 14 years of crop irrigation with effluent (30). Research in Florida has shown that Tavares sand is an effective remover of P from effluent, and that Spodosols (Immokalee fine sand and Pomello fine sand), under proper management to maintain soil aeration, may be used as disposal fields for the renovation of effluent (40).

The above discussion has focused on the effect soil has on effluent, but equally important is the effect effluent has on the soil. Continued application of sewage effluent may affect a soil's physical and chemical characteristics. Physical characteristics. There is a tendency in many land application systems to inundate and submerge the soil surface with effluent, concentrating on disposal of the effluent rather than on the consequences to the soil or vegetation. This failure to maintain adequate soil aeration intensifies clogging of the soil with microbial cells, polysaccharides, and ferrous and manganous sulfides (49). The zone of clogging is an impervious mat formed at the soil surface, plugging the soil channels through which effluent moves (68). The clogging zone can be removed by allowing the soil to dry, followed by better management to avoid anaerobic conditions that lead to the development of the clogging mat. Another instance of lowered soil infiltration rate due to effluent application was observed near Cortaro, Arizona, where crops had been irrigated with treated effluent for 14 years (30). The rate of infiltration of the effluent-irrigated soil (Grabe silt loam) was lower than that of near-by soil that had received well water as irrigation. Apparently, continued use of effluent as irrigation may result in some deterioration of surface soil structure, perhaps caused by accumulation of soluble salts. The researchers suggest that, to prevent effluent-irrigated soils from becoming more difficult to irrigate, consideration be given to mixing effluent with well water in proportions which provide adequate, but not excessive, amounts of plant nutrients for the specific crop grown.

The study in Arizona also examined the effect of 14 years of effluent application on soil bulk density and modulus of rupture. The bulk density was not affected by the effluent, but the modulus of rupture (a measure of the force required to disrupt a soil after it has been wet, then dried) was greater in the Ap horizon (plow layer, 0-25 cm) of the effluent-irrigated soil than in the control soil. This suggests that more power is needed to plow soil irrigated with effluent than for soil irrigated with well water. A higher concentration of Na^+ in the effluent-irrigated soil may be a partial explanation. Overall the study concluded that effluent irrigation for 14 years had no adverse effects on Grabe silt loam that could not be corrected with minor changes in field crop culture, specifically, the mixing of effluent with well water before use for irrigation.

Chemical characteristics. Soil pH may be affected by effluent application. Soil irrigated with effluent for 14 years in Arizona had pH similar to that of soil irrigated with well water for the Ap horizon, but the pH values for the C horizon (sub-soil, 38-51 cm) were higher in the effluent-irrigated soil (30). Soils planted in barley and irrigated with a 50:50 mixture of effluent and well water for 2 years in Arizona showed no significant pH difference from the control soil in the 0-30 cm depth (28). Effluent application in Muskegon, Michigan, increased soil pH from its previously acid condition because H^+ ions in the soil were replaced with Na^+, Ca^{2+}, and Mg^{2+} ions from the effluent (59).

Land application of effluent results, to some degree, in increased soil levels of various elements. Levels of NO_3^- are most often greater in soils receiving effluent than in soils, at the same site, irrigated with well water (12,28,30,59). High soil NO_3^- is cause for concern because it increases the danger of NO_3^- poisoning from food crops, such as in forage crops grown for livestock pasture (30). Also, since NO_3^- is subject to leaching, high soil NO_3^- may increase NO_3^- levels in surface or ground water to above 10 mg/liter, the U.S. Public Health Service standard for NO_3^- in drinking water (49). However, some researchers view the total N content of effluent as being sufficiently low to not warrant concern over excessive NO_3^- build-up in the soil or groundwater (33), feeling that what NO_3^- does accumulate in the soil is largely intercepted by plant roots, or denitrified.

Soils rapidly adsorb P until their adsorbing capacity is reached-- a situation not expected at the normal levels of P in effluent (approximately 10 mg/liter) (33). When land application systems are properly managed, most of the P added through effluent remains in the soil at the site or is removed as a nutrient in harvested crops (39). Toxic levels of P in soil have not been observed, but there is a danger of Zn deficiency when levels of P are high in the soil. Levels of K are generally so low in effluent that supplemental fertilization is necessary for crops irrigated with effluent (43,51,52,53), and what K does reach the soil is retained only by normal exchange reactions, not strongly complexed (49). Trace element concentrations in effluent are not high enough to cause any short-term acute effects in crop irrigation--in fact, a typical effluent may be applied for almost 100 years before any trace element accumulation in the soil may reach currently proposed upper limits for trace element-soil deposition (2).

Soluble salt levels in effluent vary from city to city and from time to time in the same facility, usually ranging from 300 to 700 ppm in concentration (7). These levels fall well within the recommended range for sewage treatment plants. In comparison, salt content of normal irrigation water ranges from 60 to 1000 ppm or more. Salt levels in irrigation well water near Buckeye, Arizona, were so high that phytotoxicities resulted. The farmers found that mixing effluent with the well water improved the quality of the irrigation water, thus improving crop yields (28). Accumulation of soluble salts in the soil from effluent application is of concern, but research suggests that soluble salts in the soil do not accumulate if adequate drainage and sufficient water is added to leach the ions from the root zone (7). Salt ions such as Na^+ are not complexed strongly in the soil, so leaching does occur (49).

The activity of heavy metals in soil has received much attention due to fear of heavy metal accumulation to phytotoxic levels, or movement of the metals into the groundwater, possibly creating a health hazard. Heavy metals are elements with a density greater than 5.0 g/cm^3, such as Zn, Cd, Co, Pb, Cu, Mn, Hg, and Cr. Most heavy metals are precipitated in the sludge of secondary sewage treatment, and, thus, are not present to great extent in effluent (6). Those metals found in effluent are usually soluble heavy metal chelates formed by the combination of heavy metals and organic materials in the effluent. When effluent is applied to soil, the behavior of the heavy metals present depends on the soil-plant-water relationships of the specific metal in question (16,35), but the availability of all heavy metals is generally dependent on certain soil factors. The cation exhange capacity (CEC) of a soil is an important factor in binding heavy metal ions--a soil with a high CEC is inherently safer for effluent disposal than soil with low CEC (35). Soil pH is another factor controlling heavy metal solubility. When soil pH is above 7.0, most heavy metals precipitate as hydroxides or carbonates, so that levels remaining in solution are quite low (33). As soil pH decreases, there is an increase in solubility and mobility of heavy metals, making them more available for plant uptake (35). However, if organic matter is present, metal availability is reduced at lower soil pH's due to the high cation-retention capacity of organic matter. Soil P limits metal availability by combining with metal ions to form soluble or insoluble complexes, in this way decreasing injury due to excessive levels of toxic metals. Other factors influencing the availability of heavy metals are soil aeration, moisture, and temperature. Whatever the influence of each of the above factors, mobility of heavy metals is restricted to the soil surface (0-12.7 cm) (16,66), remaining in proximity of plant roots. Thus, good management is needed with land application of effluent to minimize metal movement via soil erosion, and to use tillage for incorporation of metals throughout the plow layer, decreasing surface concentrations. Fortunately, toxic metals revert with time to unavailable forms--a process poorly understood, but known to be most rapid in calcareous soils (35). Soil pH, phosphate, organic matter, and the amounts of heavy metals added through effluent affect the reversion rate and extent.

The survival of pathogenic bacteria, protozoa, and viruses which reach soil through effluent application remains the subject of research and debate. Several research findings are presented in the literature (8,9,17,18,49,50).

Vegetative responses to land application of sewage effluent

> "Under the "living filter" concept the higher plants growing on the soil are an integral part of the system and assist the microbiological and physico-chemical activities occurring within the soil to renovate the sewage effluent through removal and utilization of the nutrients applied." (67)

The importance of vegetation at land application sites for increasing the efficiency of the total "soil filter" is well documented (38,49,65). Selection of vegetation must be based on the renovative capacity of the vegetation first, with potential economic returns a very close second; a regional approach to selection is essential, and selection cannot be made independently of the site selection or the system design chosen (1,67,73). Options for vegetative cover range from public and private landscaping to greenbelts, wildlife habitats, commercial forest plantings and natural forests, to agronomic and horticultural crops (perennial or annual, including intertilled crops) (73). Several research projects have determined the capacity of various plant species to renovate effluent, with emphasis on the removal of N and P.

A 5-year study at the Penn State Wastewater Renovation and Conservation Project determined reed canarygrass (Phalaris arundinacea L.) and corn (Zea mays L.) to be the most efficient crops tested for the renovation of effluent (67). Other studies disagree that corn is an efficient renovator of effluent, pointing out that the crop only removes extensive amounts of N from the soil during a 4-week period of rapid growth near maturity (1,34). Because of the inability of corn to remove/reduce effluent NO_3^- in the soil solution during much of the growing season, many researchers feel it cannot be recommended as the sole crop for land treatment systems. A study at Michigan State University suggested intercropping corn with forages such as ryegrass (Lolium perenne L.) for effective effluent renovation throughout the season (34). A separate study suggested using a corn field and an adjacent hay field to renovate effluent; the corn would receive the effluent when it would use both water and N, otherwise the effluent would be diverted to the hay (1). Forage crops alone have proven suitable for effluent renovation due to their long growing seasons, high nutrient requirements and uptake, and the capacity to stabilize the soil and prevent erosion during effluent application (10,52). Research has shown reed canarygrass, timothy (Phleum pratense L. var. 'Climax'), smooth bromegrass (Bromus inermis Leyss var. 'Lincoln'), and quackgrass (Agropyron repens L.) to remove suitably N and P from applied effluent (56), as does coastal bermudagrass (Cynodon dactylon (L.) Pers.) (51) and pearl millet (Pennisetum glaucum L.)(52).

Just as research has determined the capacity of vegetation to renovate effluent, much attention has also been given to the response of vegetation to effluent irrigation. A study near Tucson, Arizona, compared wheat (Triticum aestivum L.) irrigated with treated effluent to wheat irrigated with either well water plus recommended NPK or well water plus NPK levels equal to those found in effluent (31). With effluent irrigation no undesirable effect on plant growth or general quality of wheat grain for feed was noted. In fact, wheat irrigated with effluent produced a greater number of heads per unit area, had higher grain yields, more tillers per plant, and greater protein content than wheat in the other irrigation treatments. The study concluded that treated municipal effluent could be used for irrigation to produce high quality, high protein wheat grain for livestock consumption. In another study using wheat, near Buckeye, Arizona, the effects of irrigating wheat with a 50:50 mixture of effluent and well water were compared to irrigation with well water alone (26). Wheat irrigated with the effluent:well water mixture produced taller plants, a greater number of heads per unit area, heavier seeds, higher grain yields and higher straw yields than wheat receiving well water alone. However, due to greater vegetative growth, more lodging occurred in wheat irrigated with the effluent:well water mixture, and lower grain volume weights resulted, reducing the quality of the wheat in the marketplace. Therefore, the higher straw yields obtained with the effluent:well water mixture should be the focus of the grower, who could expect higher yields of pasture forage, green chopped feed, and hay from wheat irrigated in such a manner.

Further experiments near Buckeye, Arizona, examined the effect of a 50:50

mixture of effluent and well water on row crops other than wheat. Barley (*Hordeum vulgare* L.) irrigated with the mixture produced taller plants, more heads per unit area, heavier seeds, higher grain yields and higher straw yields (28). Drawbacks were just as with the wheat--more lodging and lower grain volume weights, the latter indicative of lower grain quality and marketability. However, if it were the grower's objective to produce barley as pasture forage, irrigation with effluent:well water would produce higher vegetative yields than irrigation with well water alone. Cotton (*Gossypium hirsutum* L.) was another crop irrigated with the effluent:well water mixture, resulting in more lint cotton, more seed cotton, higher seed weight, higher total number of seeds, and taller plants than cotton irrigated with well water alone (27,29). Though taller cotton plants are not desirable (promotes lodging, makes defoliation difficult, lowers fiber quality), the study concluded that treated municipal effluent mixed equally with well water could be an effective irrigation and plant nutrient source for the commercial production of cotton in Arizona.

Near Tucson, Arizona, municipal effluent alone was used to irrigate oats (*Avena sativa* L.) for pasture forage and grain (25). There were no differences between oats irrigated with effluent and oats irrigated with well water plus recommended NPK, leading the researchers to conclude that treated municipal effluent can be utilized to produce oats with grain yields and forage and grain protein contents approximately equal to those obtained from oats grown with well water plus recommended fertilization, but at lower cost.

Soybeans (*Glycine max* (L.) Merr.) irrigated with effluent were the subject of a field study in Michigan (23). Higher seed yields, due to a greater number of pods per plant, resulted from irrigation with effluent, as compared to soybeans receiving well water or no water.

Forage grasses have long been recognized for their ability to provide high levels of effluent renovation with less operational and maintenance costs than row crops such as corn and wheat, at the same time growing vigorously to produce high yields. Reed canarygrass is a good example, a primary choice for overland flow systems because of its water tolerance and vigorous growth (1,10,67). Quackgrass is another recommended recipient of effluent irrigation, removing large quantities of N while forming a thick sod (prevents erosion) and providing a good quality animal feed (1). Studies in Florida have shown ryegrass to respond positively to effluent irrigation (53). Commercial production of bermudagrass in Arizona can benefit from effluent irrigation, for the grass responds with more and longer stolons and greater yields (32).

Woody plants as well as herbaceous plants may respond positively to effluent irrigation. Christmas trees on a Michigan farm were irrigated with sewage treatment pond effluent, resulting in enhanced survival and growth of white spruce (_Picea glauca_ Moench Voss.), balsam fir (_Abies balsamea_ (L.) Mill.), and 3 varieties of Scotch pine (_Pinus sylvestris_ L.) (20). Studies using fruit trees showed that effluent irrigation can cut 25-30% from the production costs normally incurred for fertilizer, machinery, and labor (7). Cypress (_Taxodium distichum_ var. _nutans_ (Ait.) Sweet)-dominated wetlands in Florida have received effluent for as long as 70 years; secondary effluent enhances cypress tree productivity (46). Effluent application in the hardwood-pine forests of Unicoi State Park, near Helen, Georgia, has resulted in increased stem diameter growth in the overstory canopy [oaks (_Quercus_ sp.), white pine (_Pinus strobus_ L.), Virginia pine (_Pinus virginiana_ Mill.)] (13). Effluent irrigation caused a significant increase in upper stem diameter due to increased radial growth along the stem. Maximum radial increment on the stem of a tree occurs within the live crown, implying that effluent irrigation maintains a longer active crown in trees, and, hence, a greater crown biomass.

Clearly, irrigation with sewage effluent can have positive effects on the growth and productivity of some agronomic row crops, forages, grasses, and trees. This response is largely attributed to the presence of plant macronutrients and micronutrients in the effluent. Data from the Penn State Wastewater Renovation and Conservation Project best illustrates this fact. From 1963 to 1970, crop areas received 2 inches of effluent weekly for a total of 392 inches of effluent, resulting in a nutrient loading equivalent to applying 10,000 lbs. of a 13-6-15 commercial fertilizer (67). The annual crop yield increased over control plots from -8 to 346% for corn grain; 5-130% for corn silage; 85-91% for red clover (Trifolium pratense L.); and 79-139% for alfalfa (Medicago sativa L.).

A further explanation for the positive response plants have to effluent irrigation may be the presence of cytokinin-like substances in treated effluent (32,44). Researchers have isolated from municipal effluents ureido adenosine chromaphores which exhibit a moderate cytokinin-like activity. There may also be present in sewage effluent organic components which simulate certain aspects of RNA synthesis, which might explain increased protein content in wheat grain irrigated with effluent (31).

Research has shown that sewage effluent can serve well as a source of water and plant nutrients, but the user must realize that not all uses of effluent irrigation are without complications. When effluent is the sole source of irrigation, control over timing of fertilizer applications is lost, and this may result in toxic levels of plant nutrients. Decreased crop quality may result from excessive applications of N--orange trees produce grainy, pulpy fruit, apricots develop green shoulders, sugar beets contain less sugar, and apples experience color development problems (6). Total tons of yield may not decrease, but excessive vegetative growth due to excessive N may result in fewer fruit, of smaller size, thus reducing yield quality. Excessive vegetative growth may also result in production complications. Overfertilization and overwatering of tomatoes produces excess growth, causing excessive vine-clogging of harvest equipment. When melons, squash, and grapes are overfertilized, the excess growth shades fruit, keeping moisture high, resulting in fruit rot. Grain crops supplied with excessive levels of N and P lodge more severely, causing harvest problems (6,30).

Overfertilization due to continuous effluent applications is problematic in less apparent ways. Plant removal of K from soil increases as the amount of N increases (55). When the K/N ratio is low, plant uptake of K will exceed what the effluent supplies, reducing plant and soil concentrations of K to deficient levels. As nutrient deficiencies can occur, so can nutrient toxicities. High soil NO_3^- from continuous effluent application may increase the danger of NO_3^- poisoning to consumers of crops grown on that soil (6,30).

Toxicities of major concern are those that may stem from heavy metal accumulation in plant tissue. When soil factors are such that some heavy metals are available for plant uptake, certain plant factors determine the uptake and accumulation of the metals (35): 1) plant species and cultivar--vegetable crops are relatively sensitive, field crops are moderately tolerant, and grasses are tolerant to toxic heavy metals, 2) organs of the plant--grain and fruits accumulate less than leafy tissue, and 3) plant age and seasonal effects--older tissues contain greater amounts of heavy metals than do younger tissues. Research has shown that levels of heavy metals are somewhat higher in effluent-irrigated plants than in plants irrigated with well water, or receiving precipitation only. The metals most likely to be phytotoxic are Zn, Cu, and Ni (35,65). Cadmium can be extremely toxic to plants, as well as to consumers of those plants, but Zn levels greater than the levels of Cd suppress Cd uptake by plants (65), and Zn phytotoxicity is usually visible before the plants might be consumed. Since heavy metals are not present to a great extent in effluent as a whole, irrigation with effluent can proceed without undue concern as long as effluent monitoring and, if necessary, dilution, are accomplished.

The presence and survival upon vegetation of pathogenic bacteria, protozoa, and viruses present in effluent is of legitimate public concern, and the topic of several research projects (3,22,37,64).

Research findings in the literature present land application of sewage effluent as a means of disposing of effluent while simultaneously giving it further treatment, as a form of irrigation to supply moisture and plant nutrients for plant growth, and as a source to recharge ground water. Land application systems appear, on the whole, successful, and strongly supported. But research continues in order to fulfill several needs in the area of land application of effluent. Management techniques must be more clearly defined for each type of system (overland flow, slow-rate, rapid infiltration), and for systems in general--timing and rates of application, creation of buffer zones around irrigated areas, sludge application during effluent irrigation, determination of dilution needs, and effective use of monitoring of soil, plants, and ground water (8,21,34,73). Additional data are needed regarding possible public health hazards from long-term land application of effluent. Testing continues to identify species suitable for effluent irrigation, especially crops with high economic value (such as vegetables and other horticultural crops). Whatever the specific focus of further research on land application of effluent, it must always be accompanied by consideration of environmental pollution, soil pollution resulting in crop damage, and consequences to the human food chain (35). The answers to these questions will largely determine the continued growth of land application as a productive means of renovating and recycling sewage effluent in the United States.

LITERATURE CITED

1. Anonymous. 1981. Managing vegetation in wastewater application. BioCycle 22(6):30-35.
2. Anonymous. 1984. Optimizing crop production via wastewater irrigation. BioCycle 25(8):26-28.
3. Anonymous. 1981. Unicoi Land Treatment System, Unicoi State Park, Helen, Georgia. Dr. Wade L. Nutter, Principal Investigator.
4. Anonymous. 1973. Waste water to be recycled. American Vegetable Grower 14(4):67.
5. Anonymous. 1984. Spray irrigation method for park wastewater. BioCycle 25(5):26.
6. Baier, Dwight C. and Wilton B. Fryer. 1973. Undesirable plant responses with sewage irrigation. American Society of Civil Engineers Irrigation Drainage Division Journal 99:133-141.
7. Basiouny, Fouad M. 1982. Wastewater irrigation of fruit trees. BioCycle 23(2):51-53.
8. Bell, R.G. and J.B. Bole. 1978. Elimination of fecal coliform bacteria from soil irrigated with municipal sewage lagoon effluent. Journal of Environmental Quality 7(2):193-196.
9. Bitton, Gabriel. 1975. Adsorption of viruses onto surfaces in soil and water. Water Research 9:473-484.
10. Bole, J.B. and R.G. Bell. 1978. Land application of municipal sewage waste water: Yield and chemical composition of forage crops. Journal of Environmental Quality 7(2):222-226.
11. Bouwer, Herman, R.C. Rice, and E.D. Escarcega. 1974. High-rate land treatment I: Infiltration and hydraulic aspects of the Flushing Meadows project. Journal of the Water Pollution Control Federation 46(5):834-843.
12. Bouwer, Herman, J.C. Lance, and M.S. Riggs. 1974. High-rate land treatment II: Water quality and economic aspects of the Flushing Meadows project. Journal of the Water Pollution Control Federation 46(5):844-859.
13. Brister, G.H. and R.C. Schultz. 1981. The response of a southern Appalachian forest to waste water irrigation. Journal of Environmental Quality 10(2):148-153.
14. Broadbent, F.E. 1973. Factors affecting nitrification-denitrification in soils, pp. 232-244. In: William E. Sopper and Louis T. Kardos (eds.). Recycling treated municipal wastewater and sludge through forest and cropland. The Pennsylvania State University Press, University Park, Penn.

15. Brown, K.W., J.C. Thomas, and J.F. Slowey. 1984. Extractability of metals applied to soils in sewage effluent. Soil Science 138(6):423-431.

16. Brown, K.W., J.C. Thomas, and J.F. Slowey. 1983. The movement of metals applied to soils in sewage effluent. Water, Air, and Soil Pollution 19:43-54.

17. Bryan, Frank L. 1977. Disease transmitted by foods contaminated by wastewater. Journal of Food Protection 40(1):45-56.

18. Cairns, Annette, Mary E. Dutch, Esme M. Guy, and J.D. Stout. 1978. Effect of irrigation with municipal water or sewage effluent on the biology of soil cores. I. Introduction, total microbial populations, and respiratory activity. New Zealand Journal of Agricultural Research 21:1-9.

19. Christopher, Bill. 1980. Make sewage a valuable commodity. American City & County 95(7):47-48.

20. Cooley, John W. 1980. Christmas trees enhanced by sewage effluent. Compost Science/Land Utilization 21(6):28-30.

21. Crites, Ronald W. 1984. Land use of wastewater and sludge. Environmental Science and Technology 18(5):140A-147A.

22. Cooke, Wm. Bridge. 1956. Potential plant pathogenic fungi in sewage and polluted water. Plant Disease Reporter 40(8):681-686.

23. Cordonnier, M.J. and T.J. Johnston. 1983. Effects of wastewater irrigation and plant and row spacing on soybean yield and development. Agronomy Journal 75:908-913.

24. Culp, Gordon L., Russell Culp, Daniel Hinrichs, and Robert Williams. 1979. Land treatment and advanced wastewater treatment alternatives for South Tahoe. Journal of the Water Pollution Control Federation 51(10):2487-2498.

25. Day, A.D. and R.M. Kirkpatrick. 1973. Effects of treated municipal wastewater on oat forage and grain. Journal of Environmental Quality 2(2):282-284.

26. Day, A.D., J.A. McFadyen, T.C. Tucker, and C.B. Cluff. 1979. Commercial production of wheat grain irrigated with municipal wastewater and pump water. Journal of Environmental Quality 8(3):403-406.

27. Day, A.D., J.A McFadyen, T.C. Tucker, and C.B. Cluff. 1981. Effects of municipal waste water on the yield and quality of cotton. Journal of Environmental Quality 10(1):47-49.

28. Day, A.D., J.A. McFadyen, T.C. Tucker, and C.B. Cluff. 1979. Wastewater helps the barley grow! Water & Waste Engineering 16(8):26-28.

29. Day, A.D. and J.A. McFadyen. 1984. Yield and quality of cotton grown with wastewater. BioCycle 25(3):35-37.

30. Day, A.D., J.L. Stroehlein, and T.C. Tucker. 1972. Effects of treatment plant effluent on soil properties. Journal of the Water Pollution Control Federation 44(3):372-375.

31. Day, A.D., F.A. Taher, and F.R.H. Katterman. 1975. Influence of treated municipal wastewater on growth, fiber, acid-soluble nucleotides, protein, and amino acid content in wheat grain. Journal of Environmental Quality 4(2):167-169.

32. Day, A.D., J.R. Wilson, and F.R. Katterman. 1984. Bermudagrass grown with municipal wastewater. BioCycle 25(4):38-39.

33. Ellis, Boyd G. 1973. The soil as a chemical filter, pp. 46-67. In: William E. Sopper and Louis T. Kardos (eds.). Recycling treated municipal wastewater and sludge through forest and cropland. The Pennsylvania State University Press, University Park, Pennsylvania.

34. Ellis, Boyd G., A.E. Erickson, and Lowell E. Leach. 1981. Cropping systems for treatment and utilization of municipal wastewater and sludge. EPA-600/S2-81-065, Project Summary, United States Environmental Protection Agency, Washington, D.C.

35. Epstein, Eliot and Rufus L. Chaney. 1978. Land disposal of toxic substances and water-related problems. Journal of the Water Pollution Control Federation 50(8):2037-2042.

36. Fisichelli, Andrew P. 1984. Three-way recycling in Palm Springs, California. BioCycle 25(7):25-27.

37. Foster, D.H. and R.S. Engelbrecht. 1973. Microbial hazards of disposing of wastewater on soil, pp. 247-270. In: William E. Sopper and Louis T. Kardos (eds.). Recycling treated municipal wastewater and sludge through forest and cropland. The Pennsylvania State University Press, University Park, Pennsylvania.

38. Hill, D.E. 1972. Waste water renovation in Connecticut soils. Journal of Environmental Quality 1(2):163-167.

39. Hook, J.E., L.T. Kardos, and W.E. Sopper. 1973. Effect of land disposal of wastewaters on soil phosphorus relations, pp. 200-219. In: William E. Sopper and Louis T. Kardos (eds.). Recycling treated municipal wastewater and sludge through forest and cropland. The Pennsylvania State University Press, University Park, Pennsylvania.

40. Hortenstine, C.C. 1976. Chemical changes in the soil solution from a Spodosol irrigated with secondary-treated sewage effluent. Journal of Environmental Quality 5(3):335-338.

41. Kardos, L.T. and J.E. Hook. 1976. Phosphorus balance in sewage effluent treated soils. Journal of Environmental Quality 5(1):87-90.

42. Kardos, Louis T. and William E. Sopper. 1973. Effects of land disposal of wastewater on exchangeable cations and other chemical elements in the soil, pp. 220-231. In: William E. Sopper and Louis T. Kardos (eds.). Recycling treated municipal wastewater and sludge through forest and cropland. The Pennsylvania State University Press, University Park, Pennsylvania.

43. Karlen, D.L., M.L. Vitosh, and R.J. Kunze. 1976. Irrigation of corn with simulated municipal sewage effluent. Journal of Environmental Quality 5(3):269-273.

44. Katterman, F.R. and A.D. Day. 1980. Wastewater chemical affects plant growth. Water & Wastes Engineering 17(8):33-35.

45. Lau, L. Stephen. 1979. Water reuse from sewage effluent by irrigation: A perspective for Hawaii. American Water Resources Association Water Resources Bulletin 15(3):740-752.

46. Lemlich, Sandra K. and Katherine Carter Ewel. 1984. Effects of wastewater disposal on growth rates of cypress trees. Journal of Environmental Quality 13(4):602-604.

47. Michel, H.L., P.H. Gilbert, and H.K. Creed. 1974. Land disposal. . . what's the realistic view? Water & Wastes Engineering 11(6):30-35.

48. Miller, Julie Ann. 1981. Watering with waste. Science News 120:29.

49. Miller, R.H. 1973. The soil as a biological filter, pp. 71-94. In: William E. Sopper and Louis T. Kardos (eds.). Recycling treated municipal wastewater and sludge through forest and cropland. The Pennsylvania State University Press, University Park, Pennsylvania.

50. Overcash, Michael R. 1978. Research and development needs related to pathogens in pretreatment-land application systems. Transactions of the American Society of Agricultural Engineers 21(4):671-675, 681.

51. Overman, Allen R. 1979. Effluent irrigation of coastal bermuda grass. American Society of Civil Engineers Environmental Engineering Division Journal 105(EE1):55-60.

52. Overman, Allen R. 1975. Effluent irrigation of pearl millet. American Society of Civil Engineers Environmental Engineering Division Journal 101(EE2):193-199.

53. Overman, Allen R. 1976. Effluent irrigation of rye and ryegrass. American Society of Civil Engineers Environmental Engineering Division Journal 102(EE2):475-483.

54. Overman, Allen R. 1975. Growth response and nutrient uptake by forage crops under effluent irrigation. Communications in Soil Science and Plant Analysis 6(1):81-93.

55. Palazzo, A.J. and T.F. Jenkins. 1979. Land application of waste water: Effect on soil and plant potassium. Journal of Environmental Quality 8(3):309-311.

56. Palazzo, A.J. and H.L. McKim. 1977. The chemical analysis of forage grasses receiving four years of wastewater applications. Agronomy Abstracts, November 13-18, 1977, Los Angeles, California.

57. Personal interview with Glen Suggs, Superintendent, Unicoi State Park, Helen, Georgia, February 15, 1985.

58. Poloncsik, Stephen. 1978. Regulations, ordinances, and other restraints affecting wastes on recreational land, pp. 1-15. In: Proceedings of wastewater conference, Amer. Soc. of Golf Course Architects Found., Green Section of the U.S. Golf Assoc., National Golf Found,, and Golf Course Superintendents Assoc. of America, Chicago, Illinois.

59. Pound, Charles E., Y.A. Demirjian, and W. Henry Waggy. 1984. Wastewater recycling in Muskegon County. BioCycle 25(8):46-51.

60. Reynolds, James H., M.O. Braun, W.R. Campbell, R.W. Miller, and L.R. Anderson. 1980. Long-term effects of irrigation with wastewater. Journal of the Water Pollution Control Federation 52(4):672-687.

61. Rust, William G. 1978. Chicago case study: Wastewater as a golf course irrigant, pp. 57-63. In: Proceedings of wastewater conference, Amer. Soc. of Golf Course Architects Found., Green Section of the U.S. Golf Assoc., National Golf Found., and Golf Course Superintendents Assoc. of America, Chicago, Illinois.

62. Sabey, B.R., K.A. Barbarick, and N.A. Evans. 1981. Soil filtration of sewage effluent of a rural area. EPA-600/S2-81-151, Project Summary, United States Environmental Protection Agency, Washington, D.C.

63. Sanai, M. and J. Shayegan. 1980. Field experiments on application of treated municipal waste waters to vegetated lands. Water Pollution Control 79(1):126-135.

64. Sheikh, Bahman, Philip N. Stoirs, Thomas J. Jones, Joyce S. Hsiao, and William R. Kirkpatrick. 1981. Health and safety aspects of irrigation of raw-eaten food crops with reused water. Desalination 39:491-502.

65. Sidle, R.C., J.E. Hook, and L.T. Kardos. 1976. Heavy metals application and plant uptake in a land disposal system for waste water. Journal of Environmental Quality 5(1):97-101.

66. Sidle, R.C. and W.E. Sopper. 1976. Cadmium distribution in forest ecosystems irrigated with treated municipal wastewater and sludge. Journal of Environmental Quality 5(4):419-422.

67. Sopper, William E. and Louis T. Kardos. 1973. Vegetation responses to irrigation with treated municipal wastewater, pp. 271-294. In: William E. Sopper and Louis T. Kardos (eds.). Recycling treated municipal wastewater and sludge through forest and cropland. The Pennsylvania State University Press, University Park, Pennsylvania.

68. Thomas, Richard E. 1973. The soil as a physical filter, pp. 38-41. In: William E. Sopper and Louis T. Kardos (eds.). Recycling treated municipal wastewater and sludge through forest and cropland. The Pennsylvania State University Press, University Park, Pennsylvania.

69. Tusack-Gilmour, Donna. 1980. Effluent creates an oasis in Nevada. Water & Wastes Engineering 17(9):22-24.

70. United States Environmental Protection Agency. 1979. Environmental pollution control alternatives: Municipal wastewater (revised). EPA-625/5-79-012. United States Government Printing Office, Washington,D.C.

71. Walker, Robert D. 1977. Environmental quality standards, pp. 42-47. In: Utilizing municipal sewage wastewaters and sludges on land for agricultural production. North Central Regional Extension Publication No. 52.

72. Williams, T.C. 1980. Wetlands irrigation aids man and nature. Water and Wastes Engineering 17(11):28-31.

73. Wolcott, Arthur R. and Ray L. Cook. 1976. Crop and system management for wastewater application to agricultural land, pp. 7.1-7.12. In: Bernard D. Knezek and Robert H. Miller (eds.). Application of sludges and wastewaters on agricultural land: A planning and educational guide. North Central Regional Research Publication 235.

MANUSCRIPT

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Municipal Sewage Effluent as a Source of Water and Nutrients for Vegetable Crops

I. Soil Response: pH, electrical conductivity, and elemental composition

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Abstract. To determine the effect of secondary municipal sewage effluent on soil in which vegetables were grown, a 3:2 mixture of unsterilized Haynie very fine sandy loam (Mollic Udifluvent; coarse-silty, mixed, calcareous, mesic) and washed river sand was seeded, in a temperature-controlled greenhouse, with spring and fall crops of radish (*Raphanus sativus* L.), mustard (*Brassica perviridis*), or green beans (*Phaseolus vulgaris* L.). The soil:sand mixture was 1) fertilized, prior to seeding, with $(NH_4)_2HPO_4$ and KCl and irrigated with tap water, 2) fertilized, prior to seeding, with $(NH_4)_2HPO_4$ and KCl and irrigated with secondary municipal sewage effluent, or 3) not fertilized and irrigated with secondary municipal sewage effluent. Nitrate levels were the same or higher in effluent-irrigated soil as compared to soil fertilized and irrigated with tap water. Phosphorus and potassium in soil receiving only effluent were lower than in soil fertilized and irrigated with tap water or effluent. In

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general, levels of micronutrients Ca, Mg, Fe, and Zn in soils irrigated with effluent were similar or higher than micronutrient levels in soil that received fertilizer and tap water. Concentrations of Pb, Cd, and Mn in effluent-irrigated soil were not significantly different from heavy metal concentrations in soil fertilized and irrigated with tap water. Soil irrigated with effluent showed almost no difference in pH from that of soil irrigated with tap water. Effluent did not contribute to the salinity of the soil. Therefore, secondary municipal sewage effluent appears to be a good source of water and plant nutrients. The greatest increase in nutrient levels was in the fertilized soil that was irrigated throughout the season with effluent.

The Federal Water Pollution Control Act Amendments (Public Law 92-500) stongly recommend reclamation and recycling of treated sewage effluent, and require the consideration of a land application system as one of the alternatives to conventional sewage treatment systems (14). Since passage of this legislation in 1972, land application of municipal sewage effluents has become an accepted practice, with numerous land application systems operating throughout the United States. The United States Environmental Protection Agency's suggestion that "Land treatment of wastewaters can provide moisture and nutrients necessary for crop growth" (19) has led to the establishment of many successful irrigation systems. In Muskegon County, Michigan, over 5300 acres of field corn are irrigated with secondary municipal effluent (15). In Hawaii, secondary effluent augments restricted natural water resources for the irrigation of sugarcane, bermudagrass golf courses, forage crops, tropical nuts and fruits, and commercial vanda orchid production (8). Farmers in Westminster, Colorado, exchange portions of their irrigation water for equal portions of the city's secondary effluent (5). Over 3500 acres of hilly woodlands south of Atlanta, Georgia, are irrigated year-round with treated effluent (12). Golf courses in Chicago and Bensonville, Illinois, use secondary effluent as irrigation to avoid competition for declining groundwater supplies, and to cut fertilization costs by 60-100% (17).

Clearly, there are numerous reports of effluent irrigation, ranging from agronomic crops to forests to turf grasses. However, the literature is deficient in reports of effluent irrigation of horticultural crops, such as vegetables. It was the objective of this research to determine the extent to which irrigation of vegetables with secondary municipal sewage effluent is feasible. Since monitoring the effects of applying municipal effluents on the soil and on the vegetation is a necessary follow-up of such irrigation, the effects of effluent irrigation of vegetables were determined by recording

1) the soil response through pH, electrical conductivity, and elemental composition and 2) the plant response through growth, yield, and elemental composition. Because both the soil response and the plant response to effluent irrigation are equally important to the success of the system, they will be examined individually. This, the first article of a two-part series, will discuss the effect of effluent irrigation on the soil in which 3 vegetables were grown.

Materials and Methods

In a temperature-controlled greenhouse, 36 19-liter black plastic pots (45 cm tall, 37 cm upper diameter, 35 cm lower diameter) were filled with a 3:2 mixture of unsterilized Haynie very fine sandy loam (Mollic Udifluvent; coarse-silty, mixed, calcareous, mesic) and washed river sand. The pots were divided into 3 groups of 12 pots each, and each group was seeded with either radish (Raphanus sativus L. cv. Fancy Red), mustard (Brassica perviridis cv. Tendergreen II), or green beans (Phaseolus vulgaris L. cv. Bush Blue Lake). Pots within each group were divided equally into treatments:

Treatment 1 (control): recommended NPK fertilization, irrigated with tap water

Treatment 2: recommended NPK fertilization, irrigated with secondary municipal sewage effluent

Treatment 3: no fertilization, irrigated with secondary municipal sewage effluent

Within each crop the 3 treatments were replicated 4 times, then all 36 pots were arranged in a randomized complete block design.

Fertilizers applied to Treatments 1 and 2 were 2.3 g of 18-46-0 diammonium phosphate ($(NH_4)_2HPO_4$) (18% N, 20% P) and 2.3 g of 0-0-60 muriate of potash (KCl) (50% K) per pot. The fertilizers were worked into the upper 15.24 cm of soil. The amount of fertilizers was determined by converting the recommended rate in kg/ha to g/cm^3 after calculating the volume of the pot to a 15.24 cm depth. Though no fertilizer was applied to Treatment 3, soil in those pots was also hand-cultivated to a 15.24 cm depth.

Field capacity of the soil:sand mixture was estimated to guide the amount of irrigation to apply. One liter of the soil:sand mixture required 250 ml of water, or 25% by volume, to reach apparent field capacity. Therefore, 25% of the volume of the pot to a 10.16 cm depth was needed for irrigation to reach field capacity when the soil:sand was 100% dry. This amount was 2830 ml, but since the soil would not be allowed to become totally dry, it was decided only about 1/3 of this amount (900-1000 ml) would be used as the maximum amount per irrigation.

On 19 May 1984 the groups of pots were seeded with either radish, mustard, or green beans. A greenhouse tensiometer (Irrometer Moisture Indicator, Irrometer Company, Riverside, CA) was placed in the center of each pot to aid in scheduling irrigations. Irrigations occurred when soil moisture potential at 7.6 cm depth reached approximately -0.05 MPa. Irrigation began with 500 ml/pot. Treatment 1 received water from the Manhattan Municipal Water System through the faucet within the greenhouse. Treatments 2 and 3 received secondary municipal effluent from the Manhattan Municipal Wastewater Treatment Plant. The effluent was obtained periodically and stored in a greenhouse cooler at $4^{\circ}C$ to prevent bacterial reproduction. On the average, the crops were irrigated every other day, all pots included in each irrigation and receiving equal amounts. As the crops matured, irrigation reached a maximum of 1000 ml/pot. Drainage water never appeared from the bottom of the pots after irrigation.

The radishes were harvested on 18 June and 29 June, the mustard on 20 June, and the green beans on 19 July. Harvest involved pulling each plant up by the roots and rinsing the roots with water. After the last harvest, a soil sample was taken from the upper 15.24 cm of each pot and submitted for analysis to the

Soil Testing Laboratory of Kansas State University. Levels of NO_3 and NH_4 were determined by the 1 N KCl extract method, in which 2 g of soil were mixed with 20 ml of 1 N KCl, shaken for 2 hours, then filtered and analyzed colorimetrically with a Technicon Auto Analyzer II. Levels of P were determined by the Bray P1 test (2). Calcium, Mg, and K were analyzed by the 1 N NH_4OAc method(3). Levels of Zn, Fe, Mn, Cd, and Pb were determined with the DTPA soil test (9).

A fall crop of radishes, mustard, and green beans (same cultivars) was seeded on 1 September 1984. Materials and methods were the same as for the spring crop. The soil used was the soil:sand mixture in which the spring crop was grown. The same soil was used to determine possible accumulations of elements in the soil after irrigation of spring and fall crops with secondary effluent. The radishes were harvested on 2 October and 11 October, the mustard on 12 October, and the green beans on 27 October. At harvest, all plants were pulled up by the roots, and the roots rinsed with water. After the last harvest soil samples were again collected from the upper 15.24 cm of each pot and analyzed by the Soil Testing Laboratory. The same elements were analyzed by the same methods as the spring crop.

Soil pH and electrical conductivity were determined for the soil from each pot at the completion of the fall crop. Soil pH measurements followed the method outlined by McLean (11), using a 1:1 soil/water ratio and a Fisher Accumet Model 620 pH Meter. For measurement of soil electrical conductivity, a 1:5 extraction ratio was used according to the method described by Rhoades (16). Conductivity of the extracts was measured with soil sensors attached to a Salinity Bridge (Cat. No. 5500, Soil Moisture Equipment Corp., Santa Barbara, CA). Readings were plotted on the standard curves for each sensor to determine soil solution conductivity at 25^oC in mmhos/cm.

All data were subjected to analysis of variance to determine treatment differences within each vegetable crop. Statistical comparisons were not made between the different vegetables. Mean separations were by least significant difference (LSD) for soil pH and soil elements.

Results and Discussion

Irrigation water quality

Elemental composition, pH, and electrical conductivity of the municipal sewage effluent and the tap water used for irrigation are shown in Table 1 and Table 2, respectively. Tolerance limits for heavy metals in irrigation water include 0.005 mg/liter Cd, 5.0 mg/liter Pb, 2.0 mg/liter Mn, and 5.0 mg/liter Zn (13). Levels of these elements in the effluent and tap water conformed to these limits, with the possible exception of Cd.

Irrigation water having pH values 4.5 to 9.0 should not present any insurmountable problems in crop production (13). The pH of the sewage effluent fell within this range, as did that of the tap water. Irrigation water having an electrical conductivity between 1.5 and 3.0 mmhos/cm @ 25°C may have adverse effects on many crops and will require careful management practices (13). The EC of the effluent and tap water fell within this range. The municipal sewage effluent appeared to rank favorably as a source of irrigation water, containing nutrients (N, P, K, Ca, Mg, Zn, Fe) and being similar in quality to the water normally used for irrigation in the area as far as trace elements, pH, and EC were concerned.

Soil pH and electrical conductivity

The pH of the soil:sand mixture before treatments was 7.8. The soil pH after treatments, measured following the fall harvests, is shown in Table 3. Significant treatment differences for soil pH did not occur except for the soil of the radish crop, in which Treatment 3 had the highest pH and Treatments 1 and 2 were not significantly different. The lower pH in Treatments 1 and 2 was probably due to the fertilizers added to those treatments--diammonium phosphate is known to have an acidifying effect (18). Though the soil pH for each vegetable crop dropped after treatments were applied, the pH values were within the range recognized as best for most vegetable crops (10).

Soil electrical conductivity was measured as an indication of sewage effluent's effect on soil salinity. Measurements made following completion of fall harvests are shown in Table 3. Even though the tap water and effluent had electrical conductivities between 1.5 and 3.0 mmhos/cm, the electrical conductivity of each soil saturation extract was below the lowest point (1.15 mmhos/cm @ 25°C) on the standard curves of each salinity sensor used. At this level, salinity effects on vegetable crops are mostly negligible (10). Therefore, there was no salt build-up in the soil to a depth of 15.24 cm after 2 crops had been irrigated with effluent or tap water.

Soil elemental composition

Radish. Elemental composition before and after treatments applied to the radish crop is shown in Table 4. Since soil concentrations of the elements examined showed the same statistical relationships after the fall crop as after the spring crop, the following discussion applies to both crops.

Levels of NO_3 were highest in the soil that received both effluent irrigation and fertilization (Treatment 2). Soils that received effluent alone (Treatment 3) or fertilization and tap water irrigation (Treatment 1) had no significant difference between levels of NO_3. Ammonium added to Treatment 2 through fertilization may have undergone nitrification, helping explain the NO_3 levels in that treatment. Soil levels of NH_4 were not significantly different among the 3 treatments.

Significant differences occurred among all treatments for P levels in the soil. Phosphorus levels were highest in the soil of Treatment 2, with Treatment 1 having the next highest concentration and Treatment 3 the lowest. This may be attributed to the P fertilizer added to Treatments 1 and 2. The high levels of Ca in the effluent, as well as the calcareous nature of the soil, may have tied up some of the P added to Treatment 3 (1,6,17).

Significant differences also existed among all treatments for K levels in the soil, with Treatment 2 having the highest concentration, followed by Treatment 1, then Treatment 3. The addition of K fertilizer to Treatments 1 and 2 is an explanation for these differences.

The soil levels of Ca in Treatments 1 and 2 were not significantly different. Treatment 3 contained the highest Ca levels. The higher levels of K in Treatments 1 and 2 may have caused the loss of some Ca through leaching to lower levels of the soil (1).

Magnesium levels in Treatments 1 and 3 and in Treatments 2 and 3 were not significantly different. These levels may be expected from the levels of Mg applied through irrigation. Zinc levels in Treatments 2 and 3 were not significantly different, with Treatment 1 having the highest concentration. A possible explanation is the soil pH. If the soil pH is 6.5 or higher, Zn becomes less available (1). Treatment 1 had the lowest soil pH of the 3 treatments (Table 3), even though it was above pH 6.5.

The concentrations of Fe, Cd, Pb, and Mn in the 3 treatments were not significantly different.

Mustard. Table 5 shows the soil elemental composition before and after treatments to the mustard crop. After the spring crop there were no significant treatment differences for NO_3 levels in the soil, but after the fall crop all treatment means were significantly different. Treatments 2 and 3 had higher levels of NO_3 than did Treatment 1, probably due to amounts of NO_3 in the effluent.

After both crops, there were no significant differences between levels of NH_4 in Treatments 1 and 3, with Treatment 2 having the highest level. Treatment 2 received the largest amount of NH_4, through irrigation and fertilization. Though Treatment 1 appears to have had more NH_4 added than Treatment 3, it was added at one time, whereas Treatment 3 received some NH_4 at each irrigation, through the effluent.

The mean P levels in the soil of all treatments were significantly different, with Treatment 2 having the highest concentration, followed by Treatment 1, then Treatment 3. This was true after both crops, as it was for the soil from the radish crop, and is subject to the same explanations.

Following the spring crop there were significant differences among all treatments for K levels in the soil. Treatment 2 contained the highest K levels, with Treatment 1 having the next highest levels, both probably due to the K fertilizer added to those treatments. After the fall crop, the K levels in Treatments 1 and 2 were not significantly different, both treatments having higher levels than Treatment 3. Treatment 3 actually received more total K fertilizer, through effluent irrigation, than did Treatment 1, but it contained the lowest K levels for both crops.

Treatment means for Ca and Fe were not significantly different after either crop. Following the spring crop, Mg levels were not significantly different between Treatments 1 and 2, or between Treatments 2 and 3. The amount of Mg added to each treatment may be a partial explanation. After the fall crop, Mg levels were not significantly different among the treatments.

The soil levels of Zn, Cd, Pb, and Mn showed no significant treatment differences, after both crops.

Green bean. Soil elemental composition before and after treatments applied to the green bean crop is shown in Table 6. Soil concentrations of the elements examined after the spring and fall crops showed the same statistical relationships, so the following discussion applies to both crops.

Mean levels of NO_3 were not significantly different between Treatments 2 and 3, with Treatment 1 having the lowest levels. The levels can be attributed to the amount of NO_3 added to each treatment through effluent irrigation. There were no significant treatment differences for NH_4 in the soil.

Phosphorus levels differed significantly among all treatments, with Treatment 2 having the highest concentration, followed by Treatment 1, then Treatment 3. The same pattern was observed in the soil after the radish and mustard crops, and the same explanations apply.

Potassium levels in Treatments 1 and 2 were not significantly different, with Treatment 3 having the lowest levels. This was probably due to the addition of K fertilizer to Treatments 1 and 2.

Levels of Ca were highest in Treatment 3, with the levels in Treatments 1 and 2 not significantly different. The higher levels of K and P in Treatments 1 and 2 may have interacted with Ca in those treatments (1,17,18).

Magnesium levels were not significantly different between Treatments 1 and 2 or between Treatments 2 and 3. Levels of Fe in Treatments 1 and 2 were not significantly different, with Treatment 3 having the lowest levels. The high level of Ca in Treatment 3 may be the reason for low Fe availability; Fe deficiency occurs most often in calcareous soils (1,4,7,18).

Levels of Cd, Pb, and Mn showed no significant treatment differences.

Soil fertility

In Table 7, the rates of N, P, and K (kg/ha) suggested for each vegetable are compared to the kg/ha of N, P, and K resulting in the soil after treatments. The levels of N in each treatment fell well below the suggested rate for each vegetable. Foliage color reflected low levels of N in each treatment during the growth of both spring and fall crops. Chlorosis was most evident on the bean plants, with the leaves of the radish and mustard plants being pale to medium green in color. This observation suggests that the irrigation water, whether tap water or sewage effluent, could not supply all the N required by the vegetable crops, even when supplemented prior to seeding with inorganic N fertilizer (Treatments 1 and 2). However, the soil in Treatments 1 and 2 contained high to excess levels of P (10), while Treatment 3 contained medium to high levels of the nutrient. The P levels in each treatment exceeded the suggested rates of P for the vegetables. Potassium levels in each treatment also exceeded the suggested rates. Levels of K in the soil of Treatments 1 and 2 were sufficient for the growth of vegetable crops, so that, if additional K fertilizers were applied, no crop response would be observed (10). Levels of K in Treatment 3 were somewhat lower, so that a few susceptible crops might require additional K fertilization.

Additions of micronutrients to the soil were observed after each treatment. Magnesium levels remaining in the soil after harvests were such that only a few susceptible crops might benefit from fertilizer additions (10). Zinc levels in the soil fell within the range in critical levels (0.5-1.0 ppm) (10), so no Zn deficiencies were likely. In some cases, Zn levels exceeded the range (see Tables 4-6). In all treatments, Fe levels exceeded the range in critical levels (2.5-4.5 ppm) (10) below which deficiencies occur.

There was an abundance of Ca in the soil before treatments due to the calcareous nature of the very fine sandy loam. Treatments did not significantly increase the Ca levels in the soil. In fact, Ca levels dropped after most of the treatments, probably due to elemental interactions and leaching further into the soil (1,4,18). Slight, if any, increase in the levels of heavy metals Cd, Pb, and Mn occurred after each treatment, and there were no significant differences among the treatment means for these elements. This was anticipated, since the effluent used for irrigation contained low concentrations of heavy metals. A trend toward toxic accumulation of heavy metals in the soil was not indicated.

Conclusion

Nitrate levels were the same or higher in effluent-irrigated soil as compared to soil managed by the standard method of recommended fertilization and irrigation with tap water. Phosphorus and potassium levels in soil receiving only effluent were lower than in soil receiving inorganic fertilizer and irrigated with tap water or effluent. In general, levels of the micronutrients Ca, Mg, Fe, and Zn were similar and sometimes higher, than micronutrient levels in soil receiving inorganic fertilizer. Concentrations of the heavy metals Pb, Cd, and Mn in effluent-irrigated soil were not significantly different from heavy metal concentrations in the soil with inorganic fertilizer. Soil irrigated with effluent showed almost no difference in pH from that of soil irrigated with tap water. Effluent did not contribute to the salinity of the soil. Therefore, secondary municipal sewage effluent appears to be a good source of plant macro- and micronutrients, as well as an abundant source of water. The greatest increase in nutrient levels was in the soil fertilized once, prior to seeding, then irrigated throughout the season with effluent. Such an increase in plant nutrients in the soil could possibly mean a reduction in fertilizer costs for the vegetable grower.

Equally important in determining the feasibility of effluent irrigation of vegetables is consideration of the plant response to effluent. This topic is addressed in another paper (6).

Literature Cited

1. Brady, Nyle C. 1974. The nature and properties of soils. 8th ed. Macmillan Publishing Co., Inc., N.Y.
2. Bray, R.H. and L.T. Kurtz. 1945. Determination of total, organic, and available forms of phosphorus in soil. Soil Sci. 59:39-45.
3. Carson, P.L. 1980. Recommended potassium test, pp. 17-18. In: Recommended chemical soil tests procedures for the North Central Region. NCR Publication No. 221 (revised), Bull. No. 499 (revised).
4. Chapman, Homer D. (ed.). 1973. Diagnostic criteria for plants and soils. 2nd printing. Quality Printing Co., Inc., Abilene, Tex.
5. Christopher, Bill. 1980. Make sewage a valuable commodity. Amer. City & County 95(7):47-48.
6. Davis, Teresa L., J.K. Greig, and M.B. Kirkham. 1985. Municipal sewage effluent as a source of water and nutrients for vegetable crops. II. Plant response: growth, yield, and elemental composition. J. Amer. Soc. Hort. Sci. (submitted).
7. Ellis, Roscoe Jr. Chemical properties of soil, Agronomy 015-705. Dept. of Agronomy, Kansas State University, Manhattan, Kan.
8. Lau, L. Stephen. 1979. Water reuse from sewage effluent by irrigation: a perspective for Hawaii. Amer. Water Res. Assoc. Water Res. Bull. 15(3):740-752.
9. Lindsay, W.L. and W.A. Norvell. 1978. Development of a DTPA soil test for zinc, iron, manganese, and copper. Soil Sci. Soc. Amer. 42:421-428.
10. Lorenz, Oscar A. and Donald N. Maynard. 1980. Knott's handbook for vegetable growers. 2nd ed. John Wiley & Sons, N.Y. 390 p.
11. McLean, E.O. 1982. Soil pH and lime requirement, pp. 199-224. In: A.L. Page, R.H. Miller, and D.R. Keeney (eds.). Methods of soil analysis, Part 2: chemical and microbiological properties. 2nd ed.

Agron. No. 9 (Part 2). Amer. Soc. of Agron., Inc., and Soil Sci. Soc. Amer., Inc., Madison, Wis.

12. Miller, Julie Ann. 1981. Watering with waste. Sci. News 120:29.

13. National Technical Advisory Committee. 1968. Water quality criteria. Federal Water Pollution Control Administration, U.S. Dept. of Interior, Washington, D.C.

14. Poloncsik, Stephen. 1978. Regulations, ordinances and other restraints affecting wastes on recreational land, pp. 1-15. In: Proc. of wastewater conference. Amer. Soc. Golf Course Architects Found., Green Sect. U.S. Golf Assoc., Nat. Golf Found., and Golf Course Super. Assoc. Amer., Chicago, Illinois.

15. Pound, Charles E., Y.A. Demirjian, and W. Henry Waggy. 1984. Wastewater recycling in Muskegon County. BioCycle 25(8):46-51.

16. Rhoades, J.D. 1982. Soluble salts, pp. 167-170. In: A.L. Page, R.H. Miller, and D.R. Keeney (eds.). Methods of soil analysis, Part 2: chemical and microbiological properties. 2nd ed. Agron. No. 9 (Part 2). Amer. Soc. Agron., Inc., and Soil Sci. Soc. Amer., Inc., Madison, Wis.

17. Rust, William G. 1978. Chicago case study: wastewater as a golf course irrigant, pp. 57-63. In: Proc. of wastewater conference. Amer. Soc. Golf Course Architects Found., Green Sect. U.S. Golf Assoc., Nat. Golf Found., and Golf Course Super. Assoc. Amer., Chicago, Illinois.

18. Tisdale, Samuel L. and Werner L. Nelson. 1975. Soil fertility and fertilizers. 3rd ed. Macmillan Publishing Co., Inc., N.Y.

19. United States Environmental Protection Agency. 1979. Environmental pollution control alternatives: municipal wastewater (revised). EPA 625/5-79-012. U.S. Env. Prot. Agency, Washington, D.C.

Table 1. Elemental composition, pH, electrical conductivity of secondary municipal sewage effluent used to irrigate Treatments 2 and 3.[z]

NO_3[y]	NH_4[y]	P	K	Ca	Mg	Zn	Fe[x]	Cd[x]	Pb	Mn	pH[w]	EC[v]
μg/g												(mmhos/cm)
27.1	0.43	6.75	16.0	47.0	18.0	0.17	<0.11	<0.05	0.04	0.05	7.0	2.5

[z] Treatment 2 received 2.3 grams of $(NH_4)_2HPO_4$ and 2.3 grams KCl prior to spring and fall seeding. Treatment 3 received no fertilization.

[y] Mean values for NO_3 and NH_4 were obtained from 6 values and 5 values, respectively, provided by the Manhattan Municipal Wastewater Treatment Plant, Manhattan, Kansas. The values were the results of measurements taken over a period of 8 months. The measurements indicated that levels of elements in the effluent fluctuate little during the year, month to month. Therefore, mean values for the other elements were obtained from 2 effluent samples collected in the fall and analyzed by the Campus Emission Spectroscopy Laboratory, Kansas State University. All measurements and analyses were made in 1984.

[x] Values for Fe and Cd were below the detection limits shown.

[w] pH value given by the Manhattan Municipal Wastewater Treatment Plant, Manhattan, Kansas. Effluent pH ranges from 6.8 to 7.3, but usually lies close to 7.0.

[v] Electrical conductivity in mmhos/cm @ 25°C. The value is the mean of 8 measurements.

Table 2. Elemental composition, pH, electrical conductivity of municipal tap water used to irrigate Treatment 1[z].

NO_3[y]	NH_4[y]	P[x]	K	Ca	Mg	Zn[x]	Fe[x]	Cd[x]	Pb[x]	Mn[w]	pH[v]	EC[u]
μg/g												(mmhos/cm)
0.07	----	<0.58	8.10	30.0	13.5	<0.15	<0.05	<0.04	<0.04	----	6.8	1.7

[z] Treatment 1 received 2.3 grams of $(NH_4)_2HPO_4$ and 2.3 grams KCl prior to spring and fall seeding, and was irrigated with tap water.

[y] The value for NO_3 was from the 1984 Report of Inorganic Water Analysis of the State of Kansas Department of Health & Environment. The report provided no value for NH_4. Mean values for the other elements were obtained from 2 samples taken from the greenhouse faucet from which the plants were irrigated, collected in the fall (1984) and analyzed by the Campus Emission Spectroscopy Laboratory, Kansas State University.

[x] Values for P, Zn, Fe, Cd, and Pb were below the detection limits shown.

[w] A mean value for Mn could not be calculated because one sample was below the detection limit (0.015 μg/g).

[v] pH value was the mean of 7 measurements.

[u] Electrical conductivity in mmhos/cm @ 25°C. The value is the mean of 8 measurements.

Table 3. Soil pH and electrical conductivity after the fall crop of radishes, mustard, and green beans.

	Soil pH[z]			Soil electrical conductivity[y] (mmhos/cm)		
	Trt. 1[x]	Trt. 2[x]	Trt. 3[x]	Trt. 1[x]	Trt. 2[x]	Trt. 3[x]
Radish	6.84[b]	6.93[b]	7.24[a]	<1.15	<1.15	<1.15
Mustard	6.72[a]	6.66[a]	6.89[a]	<1.15	<1.15	<1.15
Green bean	6.89[a]	6.93[a]	7.07[a]	<1.15	<1.15	<1.15

[z] Mean separation by LSD, 5% level. Means with the same letter are not significantly different. Treatment means are compared within rows; means for the different vegetables are not compared.

[y] Soil electrical conductivity was below the lowest point on the salinity sensors' standard curves (1.15 mmhos/cm @ 25°C).

[x] Treatments 1 and 2 each received 2.3 grams $(NH_4)_2HPO_4$ and 2.3 grams KCl prior to spring and fall seeding. Trt. 1 was irrigated with municipal tap water and Trt. 2 was irrigated with secondary municipal sewage effluent. Trt. 3 was not fertilized, and was irrigated with secondary municipal sewage effluent.

Table 4. Soil elemental composition before and after treatments applied to the radish crop.

	Soil Before Trts.	$Spring^z$			$Fall^z$		
		Trt. 1^y	Trt. 2^y	Trt. 3^y	Trt. 1^y	Trt. 2^y	Trt. 3^y
	$\mu g/g$						
NO_3	17.0	1.28^b	2.38^a	1.58^b	3.60^b	5.75^a	4.28^b
NH_4	3.0	3.03^a	2.65^a	2.63^a	1.73^a	1.80^a	1.50^a
P	28.0	53.1^b	65.8^a	32.3^c	69.6^b	75.4^a	38.5^c
K	145.0	223.8^b	263.8^a	161.3^c	248.8^b	267.5^a	143.8^c
Ca	1330.0	1137.5^b	1175.0^b	1302.5^a	1100.0^b	1175.0^b	1250.0^a
Mg	60.0	74.5^b	91.3^a	83.5^{ab}	77.5^b	92.5^a	85.0^{ab}
Zn	0.7	0.95^a	0.73^b	0.63^b	0.65^a	0.60^b	0.63^b
Fe	5.0	5.00^a	5.00^a	5.00^a	7.00^a	6.25^a	6.50^a
Cd	0.07	0.07^a	0.08^a	0.07^a	0.10^a	0.10^a	0.10^a
Pb	0.6	0.68^a	0.68^a	0.68^a	0.98^a	0.98^a	0.90^a
Mn	6.0	5.75^a	5.25^a	5.50^a	3.00^a	2.75^a	2.75^a

[z] Mean separation by least sign. diff., 5% level. Treatment means are compared within rows. Means with the same letter are not significantly different. Values for the spring crop and the fall crop stand separately, and are not compared statistically.

[y] Trts. 1 and 2 each received 2.3 g $(NH_4)_2HPO_4$ and 2.3 g KCl prior to spring and fall seeding. Trt. 1 was irrigated with municipal tap water and Trt. 2 was irrigated with secondary municipal sewage effluent, both treatments receiving 17 liters (18,688 g) in the spring and 16.5 liters (18,138 g) in the fall. Trt. 3 was irrigated with effluent, receiving the same volumes as the other 2 treatments, but with no fertilization.

Table 5. Soil elemental composition before and after treatments applied to the mustard crop.

	Soil Before Trts.	Spring[z]			Fall[z]		
		Trt. 1[y]	Trt. 2[y]	Trt. 3[y]	Trt. 1[y]	Trt. 2[y]	Trt. 3[y]
	µg/g						
NO_3	17.0	4.18^a	4.68^a	4.30^a	4.68^c	7.20^a	6.23^b
NH_4	3.0	2.83^b	3.35^a	2.78^b	1.53^b	1.78^a	1.53^b
P	28.0	46.6^b	58.0^a	29.8^c	60.5^b	71.5^a	36.1^c
K	145.0	205.0^b	231.3^a	157.5^c	241.3^a	225.0^a	150.0^b
Ca	1330.0	1170.0^a	1190.0^a	1357.5^a	1250.0^a	1125.0^a	1325.0^a
Mg	60.0	74.3^b	86.0^{ab}	87.5^a	80.0^a	80.0^a	87.5^a
Zn	0.7	0.73^a	1.10^a	1.03^a	0.65^a	0.70^a	0.80^a
Fe	5.0	5.50^a	6.00^a	5.75^a	7.50^a	7.50^a	7.25^a
Cd	0.07	0.07^a	0.07^a	0.07^a	0.15^a	0.10^a	0.10^a
Pb	0.6	0.68^a	0.73^a	0.75^a	0.77^a	0.98^a	0.98^a
Mn	6.0	5.75^a	6.00^a	5.50^a	3.50^a	3.75^a	3.50^a

[z] Mean separation by least sign. diff., 5% level. Treatment means are compared within rows. Means with the same letter are not significantly different. Values for the spring crop and the fall crop stand separately, and are not compared statistically.

[y] Trts. 1 and 2 each received 2.3 g $(NH_4)_2HPO_4$ and 2.3 g KCl prior to spring and fall seeding. Trt. 1 was irrigated with municipal tap water and Trt. 2 was irrigated with secondary municipal sewage effluent, both treatments receiving 14.3 liters (15,719 g) in the spring and 17.4 liters (19,128 g) in the fall. Trt. 3 was irrigated with effluent, receiving the same volumes as the other 2 treatments, but with no fertilization.

Table 6. Soil elemental composition before and after treatments applied to the green bean crop.

	Soil Before Trts.	Spring^{z}			Fall^{z}		
		Trt. 1^{y}	Trt. 2^{y}	Trt. 3^{y}	Trt. 1^{y}	Trt. 2^{y}	Trt. 3^{y}
	μg/g						
NO_3	17.0	3.05^{b}	5.48^{a}	5.33^{a}	2.93^{b}	5.23^{a}	4.58^{a}
NH_4	3.0	2.73^{a}	2.53^{a}	2.80^{a}	1.70^{a}	1.85^{a}	1.65^{a}
P	28.0	42.5^{b}	50.8^{a}	30.3^{c}	63.9^{b}	84.4^{a}	42.4^{c}
K	145.0	201.3^{a}	192.5^{a}	132.5^{b}	232.5^{a}	247.5^{a}	147.5^{b}
Ca	1330.0	1117.5^{b}	1055.0^{b}	1202.5^{a}	1100.0^{b}	1150.0^{b}	1275.0^{a}
Mg	60.0	74.2^{b}	77.3^{ab}	80.5^{a}	87.5^{b}	102.5^{ab}	110.0^{b}
Zn	0.7	0.75^{a}	0.98^{a}	0.75^{a}	0.78^{a}	0.85^{a}	0.75^{a}
Fe	5.0	6.00^{a}	6.00^{a}	5.25^{b}	8.50^{a}	7.75^{a}	7.00^{b}
Cd	0.07	0.07^{a}	0.08^{a}	0.07^{a}	0.10^{a}	0.10^{a}	0.10^{a}
Pb	0.6	0.65^{a}	0.63^{a}	0.63^{a}	1.05^{a}	0.98^{a}	1.03^{a}
Mn	6.0	5.00^{a}	5.00^{a}	5.00^{a}	3.75^{a}	4.00^{a}	3.50^{a}

[z] Mean separation by least sign. diff., 5% level. Treatment means are compared within rows. Means with the same letter are not significantly different. Values for the spring crop and the fall crop stand separately, and are not compared statistically.

[y] Trts. 1 and 2 each received 2.3 g $(NH_4)_2HPO_4$ and 2.3 g KCl prior to spring and fall seeding. Trt. 1 was irrigated with municipal tap water and Trt. 2 was irrigated with secondary municipal sewage effluent, both treatments receiving 26.4 liters (29,021 g) in the spring and 22.8 liters (25,064 g) in the fall. Trt. 3 was irrigated with effluent, receiving the same volumes as the other 2 treatments, but with no fertilization.

Table 7. Suggested rates of N, P, and K for radish, mustard, and green bean compared to levels of N, P, and K in the soil after species were harvested.

			N	P	K
			kg/ha		
Radish		Sugg. Rates[z]	168.2	48.2	232.6
	Spring	Trt. 1	9.66	119.1	501.8
		Trt. 2	11.3	147.5	591.4
		Trt. 3	9.44	72.4	361.6
	Fall	Trt. 1	11.9	156.0	557.8
		Trt. 2	16.9	169.0	599.7
		Trt. 3	12.9	86.3	322.4
Mustard		Sugg. Rates[z]	168.2	48.2	139.6
	Spring	Trt. 1	15.7	104.5	459.6
		Trt. 2	18.0	130.0	518.6
		Trt. 3	15.9	66.8	353.1
	Fall	Trt. 1	13.9	135.6	540.9
		Trt. 2	20.1	160.3	504.5
		Trt. 3	17.4	80.9	336.3
Green bean		Sugg. Rates[z]	56.1	36.2	46.5
	Spring	Trt. 1	12.9	95.3	451.3
		Trt. 2	17.9	113.9	431.6
		Trt. 3	18.2	67.9	297.1
	Fall	Trt. 1	10.4	143.3	521.3
		Trt. 2	15.9	189.2	554.9
		Trt. 3	13.9	95.1	330.7

[z] Suggested rates from Knott's Handbook for Vegetable Growers (10), p. 111. Levels converted from lbs/acre to kg/hectare. Rates for P and K are percentages of the rates of P_2O_5 and K_2O given in the book. The rates are the levels of the elements suggested for addition to the soil--if not already present--prior to seeding.

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Municipal Sewage Effluent as a Source of Water and Nutrients for Vegetable Crops II. Plant Response: growth, yield, and elemental composition

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Additional index words: radish, mustard, green beans, heavy metals, nitrate

Abstract. Radish (*Raphanus sativus* L. cv. Fancy Red), mustard (*Brassica perviridis* cv. Tendergreen II), and green beans (*Phaseolus vulgaris* L. cv. Bush Blue Lake) were used in a greenhouse study to determine the response of a root vegetable crop, a leafy green vegetable crop, and a fruit-bearing crop to irrigation with secondary municipal sewage effluent. Spring and fall crops of the vegetables were seeded into a soil:sand mixture 1) fertilized, prior to seeding, with $(NH_4)_2HPO_4$ and KCl and irrigated with tap water, 2) fertilized prior to seeding, with $(NH_4)_2HPO4$ and KCl and irrigated with secondary municipal sewage effluent, or 3) not fertilized and irrigated with secondary municipal sewage effluent. Yields from radishes and beans irrigated with effluent were not significantly different from radishes and beans with fertilizer and tap water irrigation. Mustard irrigated with effluent produced higher yields than mustard irrigated with tap water. Effluent-irrigated plants and plants

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receiving fertilizer and tap water irrigation were not significantly different for most growth characteristics. Nitrogen levels in effluent-irrigated plants were similar, or higher, than levels in plants irrigated with tap water. Levels of P, K, Ca, Mg, Zn, and Fe were not significantly different between effluent-irrigated plants and plants receiving fertilizer and tap water irrigation. In the edible portions of each vegetable, concentrations of P and Fe were close to or above the published levels for each vegetable, but levels of Ca and K were low. There were no toxic accumulations of Zn, Mn, and Cd. Lead levels were within the expected range for vegetables, except for bean pods, in which levels were elevated. Overall, secondary municipal sewage effluent appeared to be a good source of water and nutrients for vegetable plant growth.

Vegetation is an integral part of the "living filter" concept recognized as a means of treatment and disposal of municipal sewage effluent. The response of vegetation to effluent irrigation is well documented. In Arizona, wheat (Triticum aestivum L.) irrigated with treated municipal effluent produced a greater number of heads per unit area, had higher grain yields, more tillers per plants, and greater protein content than wheat irrigated with well water and receiving NPK fertilization (13). Researchers near Tucson, Arizona, concluded that effluent can be used to produce oats (Avena sativa L.) with grain yields, and forage and grain protein contents, approximately equal to those obtained from oats grown with well water and recommended fertilization, but at less expense to the farmer (12). Irrigation of soybeans (Glycine max (L). Merr.) with effluent in Arizona resulted in higher seed yields than soybeans receiving well water or no water (10). Other studies in Arizona concluded that commercial production of bermudagrass (Cynodon dactylon (L.) pers.) benefited from effluent irrigation--the grass responded with more and longer stolons and greater yields (14). On a Michigan farm, Christmas trees irrigated with sewage treatment pond effluent demonstrated enhanced survival and growth of white spruce (Picea glauca Moench Voss.), balsam fir (Abies balsamea (L.) Mill.), and 3 varieties of Scotch pine (Pinus sylvestris L.) (9). Studies using fruit trees have shown that effluent irrigation can cut 25-30% from the production costs normally incurred for fertilizer, machinery, and labor (2).

Clearly, irrigation with municipal sewage effluent has had positive effects on the growth and productivity of some agronomic row crops, forages, grasses, and trees. However, the literature lacks reports concerning the response of vegetable crops to effluent irrigation. The objective of this research was to determine the extent to which irrigation of vegetables with secondary municipal sewage effluent is feasible in light of 1) the soil response through pH, electrical conductivity, and elemental composition, and

2) the plant response through growth, yield, and elemental composition. Soil response to effluent irrigation was discussed in the first article of this series (11), so that the following discussion will focus upon the plant response.

Materials and Methods

Radish (Raphanus sativus L. cv. Fancy Red), mustard (Brassica perviridis cv. Tendergreen II), and green bean (Phaseolus vulgaris L. cv. Bush Blue Lake) were chosen to represent a root vegetable crop, a leafy green vegetable crop, and a fruit-bearing vegetable crop. In preparation for seeding the vegetables, 36 19-liter black plastic pots were filled with a 3:2 mixture of unsterilized Haynie very fine sandy loam (Mollic Udifluvent; coarse-silty, mixed, calcareous, mesic) and washed river sand, and placed in a temperature-controlled greenhouse. Twelve pots were labeled for each of the 3 vegetable crops, and divided equally into treatments:

Treatment 1 (control): recommended NPK fertilization, irrigated with tap water

Treatment 2: recommended NPK fertilization, irrigated with secondary municipal sewage effluent

Treatment 3: no fertilization, irrigated with secondary municipal sewage effluent

Within each group of pots the 3 treatments were replicated 4 times, then all 36 pots were arranged in a randomized complete block design.

Prior to seeding, 2.3 g of 18-46-0 diammonium phosphate ($(NH_4)_2HPO_4$) (18% N, 20% P) and 2.3 g of 0-0-60 muriate of potash (KCl) (50% K) were worked into the upper 15.24 cm of the soil in each pot of Treatments 1 and 2. Though no fertilizer was added, the soil in pots of Treatment 3 was also hand-cultivated to a 15.24 cm depth.

On 19 May 1984 the vegetables were seeded and thinned to 35 radish plants/pot, 17 mustard plants/pot, and 10 green bean plants/pot. At the time of seeding, a greenhouse tensiometer (Irrometer Moisture Indicator, Irrometer Company, Riverside, CA) was placed in the center of each pot to aid irrigation scheduling. Irrigations occurred when soil moisture potential at 7.6 cm depth reached approximately -0.05 MPa. Irrigation began at seeding with 500 ml/pot, Treatment 1 receiving water from the Manhattan Municipal Water System through the greenhouse faucet and Treatments 2 and 3 receiving secondary municipal effluent from the Manhattan Municipal Wastewater Treatment Plant. Effluent was obtained periodically from the treatment plant and stored at 4°C in a greenhouse cooler to prevent bacterial reproduction. On the average, irrigations took place every other day, with all pots included in each irrigation and receiving equal amounts of water or effluent. As the plants matured, irrigation reached a maximum of 1000 ml/pot.

Poor germination necessitated reseeding the beans on 30 May. A severe infestation of aphids on all plants was controlled with 2 applications of endosulfan, sprayed according to label directions. After harvests of the radish and mustard crops, whiteflies appeared, and the bean plants were sprayed 4 times with resmethrin, following label directions.

Radishes were harvested on 18 June and 29 June, mustard on 20 June, and beans on 19 July. At harvest, plant heights were recorded, then all plants were pulled up by the roots. Fresh weights were taken of separated plant parts (leaves and stems, roots, pods). Leaf area was measured on 10 leaves/pot with a Li-Cor Model 3100 Area Meter (Li-Cor, Inc., Lincoln, Nebraska). The plant parts were rinsed thoroughly with distilled water and dried in a forced air oven (65°C) for 24 hours. Dry weights were recorded.

Radish leaves/stems and roots, mustard leaves/stems, and bean leaves/stems and pods were ground in a Wiley Mill to a 40 mesh. The ground tissue was mixed to a homogenous state, then analyzed by the micro-Kjeldahl method to determine total N content (18). The remainder of the ground sample was wet ashed (1) by the Kansas State University Animal Nutrition Laboratory, and the digest analyzed by the Campus Emission Spectroscopy Laboratory, Kansas State University. Analysis was by the inductively coupled plasma (ICP) method (16) for the elements P, K, Ca, Mg, Fe, Zn, Cd, Pb, and Mn.

A fall crop of radishes, mustard, and green beans (same cultivars and seed source) was seeded into the pots on 1 September 1984. The soil was the same as used in the spring crop, and materials and methods were the same as those used for the spring crop, except no pesticide applications were made. Radishes were harvested on 2 October and 11 October, mustard on 12 October, and beans on 27 October. Measurements were the same as for the spring crop: plant heights, fresh and dry weights, and leaf area. Tissue preparation for analysis, the analytical methods used, and the elements analyzed for were the same as those described above.

All data were subjected to analysis of variance to determine treatment differences within each vegetable crop. Responses of the different vegetables were not statistically compared. Mean separation for fresh weights, dry weights, leaf area, and plant heights was by Duncan's Multiple Range Test. Mean separation for levels of elements in the plants was by least significant difference (LSD).

Results and Discussion

Growth and yield

Growth characteristics of radishes, mustard, and green beans, spring and fall crops, separated by treatment, are shown in Table 1.

Radish. Plant growth reflected the same treatment responses in both the spring and fall crops. Treatments 1 and 2, both of which received inorganic fertilizers and were irrigated with tap water and sewage effluent, respectively, had greater leaf weights (fresh and dry) and leaf areas than did Treatment 3, which received sewage effluent as a source of water and the only source of nutrients. However, the treatments did not differ significantly for root fresh weights and root dry weights, so there were no yield differences among the 3 treatments. There were also no significant differences in plant heights.

Mustard. The plants exhibited the same treatment responses in both the spring and fall crops. Plants in Treatment 2 had the highest leaf weights and leaf area, and, thus, the highest yield. Treatment 3 had the lowest root fresh weight, and the shortest plants, but did not differ significantly from Treatment 1 in leaf fresh weights, root dry weights, or leaf area.

Green bean. The plants in each treatment did not adapt well to the greenhouse environment, and had poor leaf development and leaf scorch. Nevertheless, Treatment 2 produced greater leaf weights in both crops, and the greatest leaf area in the spring crop. Treatments were not significantly different for root weights and plant heights. Though there were some treatment differences for pod dry weights, the lack of significant treatment differences for pod fresh weights indicated no yield differences among the treatments.

Elemental composition

The elements added through irrigation and fertilization are shown in Table 2, and are the same for each crop.

Radish leaves. Table 3 shows the elemental composition of radish leaves after harvest. The following discussion applies to both spring and fall crops.

There were no significant differences between Treatments 1 and 2 for total N in the radish leaves, or between Treatments 1 and 3. The higher levels of N in Treatments 1 and 2 are probably due to the amounts of N added to those treatments through fertilization and irrigation, and to the cumulative amounts of NO_3-N and NH_4-N resulting in the soil (11).

There were no significant treatment differences for levels of P, K and Ca. Magnesium levels were not significantly different between Treatments 1 and 2, with Treatment 3 having the highest Mg concentrations. It is difficult to explain the levels of Mg in the leaves strictly by the amount of Mg added through irrigation. One possible explanation may be an ion interaction, or "antagonism," between Mg, K, and Ca, so that Mg absorption was depressed due to relatively high concentrations of K and Ca present in the soil before and after fertilization and/or irrigation (3,4,11,15).

There were no significant differences among treatments for leaf concentrations of Zn, Fe, Pb, or Mn. Cadmium levels were not significantly different between Treatments 1 and 2, or between Treatments 1 and 3. The higher levels of Cd in Treatments 1 and 2 may have resulted from Cd contamination of the P fertilizer added to these treatments, since Cd contamination often occurs in mining of phosphorus rock for phosphate fertilizers (6).

Radish roots. Table 4 shows the elemental composition of radish roots after harvest. The following discussion, except that of Cd and Mn levels, applies to both spring and fall crops.

There were significant differences among the 3 treatments for levels of total N in the radish roots. Treatment 2 contained the highest concentration of N, followed by Treatment 1, then Treatment 3. These levels may be attributed to the levels of N added to each treatment, and possibly to N accumulation in the soil (11).

Phosphorus levels were not significantly different between Treatments 1 and 3, with Treatment 2 having the lowest P levels. The apparent reduction/depression of P absorption in Treatment 2 may have resulted from the K fertilizer applied or the Ca levels in the soil (4,11,26).

There were no significant treatment differences for levels of K, Ca, Mg, and Zn in the radish roots. Levels of Fe were not significantly different between Treatments 1 and 3. Treatment 2 contained the lowest levels of Fe, possibly a result of reduced Fe absorption from the calcareous soil, to which additional Ca was applied through effluent irrigation (4,15,26).

Cadmium levels in Treatments 2 and 3 were not significantly different. Treatment 1 contained an unusually high level of Cd as compared to the other treatments. This level of Cd is difficult to explain by the amount of Cd in the soil or the Cd added through irrigation, and might best be attributed to lab contamination which easily occurs in trace element analysis (21).

There were no significant differences among treatments for Mn levels in the radish roots from the spring crop. Radish roots harvested in the fall showed no significant differences between Treatments 1 and 2, or between Treatments 2 and 3, for Mn. Lead levels in the spring crop of radish roots were not significantly different between Treatments 2 and 3, or between Treatments 1 and 2. In the fall, there were no significant treatment differences for Pb in the radish roots.

Mustard leaves. The elemental composition of the mustard leaves following spring and fall harvests is given in Table 5. With the exception of the discussion of N and P levels in the leaves, the following discussion applies to both the spring and fall crops.

Levels of total N were not significantly different between Treatments 1 and 3. Treatment 2 contained the highest levels of N, and this can be attributed to the amount of N added through fertilization and effluent irrigation.

Mustard leaves in Treatments 1 and 2 of the spring crop contained levels of P that were not significantly different, while leaves from Treatment 3 contained the highest levels of P. For the fall crop, P levels in Treatments 2 and 3 were not significantly different, with Treatment 1 having the lowest levels of P. The continual application of P through effluent irrigation may explain the higher levels of P in Treatments 2 and 3.

There were no significant treatment differences for levels of K and Ca in the mustard leaves. Magnesium levels were not significantly different between Treatments 1 and 2, or between Treatments 2 and 3. The same relationship was seen for Mg levels in the soil after the spring crop (11), and may be partially attributed to the amounts of Mg applied through the irrigation water.

There were no significant treatment differences for levels of Zn, Fe, Pb, and Mn. Cadmium levels differed significantly among the treatments, Treatment 3 having the highest levels, followed by Treatment 1, then Treatment 2. The Cd present in the irrigation water (tap water or effluent), though in trace amounts, is one possible explanation, for it is known that leaves are capable of accumulating even excessive amounts of Cd when the solution concentration is only of the order of a few tenths of μg/ml (23).

Bean leaves. The elemental composition of bean leaves is shown in Table 6. Levels of total N in the bean leaves from the spring and fall crops showed no significant treatment differences. Phosphorus levels in Treatments 1 and 2 in the spring crop were not significantly different, with Treatment 3 having the lowest P levels. The higher levels of P in Treatments 1 and 2 may have been due to the P fertilizer added to those treatments. In the fall crop, P levels were not significantly different between Treatments 2 and 3, with Treatment 1 having the lowest P levels. In this case, the continual application of P through sewage effluent irrigation might explain the P levels resulting in the leaves.

Potassium levels in the spring crop were not significantly different between Treatments 1 and 3, or between Treatments 2 and 3. The difference between K levels in Treatments 1 and 2 is puzzling in light of the fact that both treatments received K through fertilization and irrigation. It is possible that an ion interaction, most likely with Ca, took place, slightly reducing K absorption in Treatment 2 (3,22,29). In the fall crop, K levels were not significantly different between Treatments 1 and 2, and Treatment 3 contained the lowest K levels. The addition of K fertilizer to Treatments 1 and 2 may explain K levels in this case.

There were no significant treatment differences for Ca levels in the bean leaves from either the spring or fall crops. In bean leaves from the spring crop, Mg levels in Treatments 1 and 3 were not significantly different. Treatment 2 contained the lowest Mg concentration, possibly due to an ion interaction with K or Ca (15). In the fall-harvested bean leaves there were no significant treatment differences for Mg levels.

Zinc levels were not significantly different among treatments. Levels of Fe were not significantly different between Treatments 1 and 2 or between Treatments 1 and 3 in the spring crop. Perhaps the Ca levels in Treatment 3 induced a reduction in Fe uptake (4,15,26), resulting in the lower Fe levels in that treatment. Bean leaves from the fall crop showed no significant treatment differences for Fe content.

Cadmium levels in Treatments 1 and 3 were not significantly different. The high level of Cd in Treatment 2 as compared to Treatments 1 and 3 might be due to lab contamination (21), though it is possible for leaves to accumulate high amounts of Cd from trace amounts (23).

There were no significant treatment differences for Pb and Mn in bean leaves from either crop.

Bean pods. Table 7 lists the elemental composition of the bean pods from both the spring and fall crops. There were no significant treatment differences for total N and P in the bean pods from either the spring or fall crops. In the spring crop of bean pods, K levels were not significantly different among the treatments. In the fall-harvested bean pods, K levels were not significantly different between Treatments 1 and 3, or between Treatments 2 and 3. Perhaps the higher level of K in the sewage effluent used to irrigate Treatment 2, as compared to the K in the tap water used to irrigate Treatment 1, was the cause for the difference between those treatments.

There were no significant differences among treatments for Ca, Mg, Zn, Fe, and Mn in the bean pods. Cadmium levels in Treatments 1 and 2 were not significantly different. Levels of Cd in the irrigation waters appear to be the only explanation for the levels of Cd in the pods.

In bean pods from the spring crop, levels of Pb were not significantly different between Treatments 1 and 2, or between Treatments 2 and 3. In the fall crop of beans, there were no significant treatment differences for Pb levels in the pods.

Elemental composition of edible portions as compared to established and toxicity levels

One question arising from the irrigation/fertilization of vegetables with sewage effluent is whether or not the composition of the edible portions of vegetables receiving effluent applications differs from the composition established, and normally expected, for that vegetable. Table 8 lists levels of P, K, Ca, and Fe established for radish roots, mustard leaves, and bean pods (30) as compared to the levels resulting after treatments. Another concern with effluent irrigation is whether or not toxic concentrations of heavy metals accumulate in the edible portions of the vegetables. Table 9 is a comparison of toxic concentrations of the heavy metals Zn, Cd, and Mn to the heavy metal concentrations resulting after treatments, with a comparison of the expected levels of Pb in vegetables to the levels resulting after treatments.

Radish root. Radish roots from all treatments contained levels of P and Fe close to the levels established for radish root. This was true for roots from both the spring and fall crops. Phosphorus and Fe levels in Treatment 1, the control, and in Treatment 3, which received only effluent, were closest to the established level.

Potassium levels in roots from each treatment were noticeably lower than the established K level. Radish roots from the fall crop contained higher levels of K than those from the spring crop, but levels were still below the established level. The same trend was seen in Ca levels in the radish roots, with the exception of Treatment 1 in the fall crop, which contained Ca levels exceeding the established level. Levels from the other treatments fell below the level expected. Though K and Ca deficiencies were not evident during the growth of either the spring or fall crops, these findings suggest that the effluent used did not supply the amount of K and Ca apparently normally available to radish crops, or that the forms supplied were not readily available. However, it is important to note that K and Ca levels resulting from the control, Treatment 1, considered the standard method of fertilizing/irrigating a radish crop, also fell below the established K and Ca levels, except the results for Ca in the fall crop.

Concentrations of Zn and Mn in radish roots from each treatment, and both spring and fall crops, were well below levels recognized as toxic to adults. Cadmium levels in roots irrigated with effluent (Treatments 2 and 3) were below toxic levels, but roots from the control, Treatment 1, contained toxic levels of Cd. The concentration of Cd in this treatment is, as discussed in the preceding section on plant elemental composition, something of an anomaly.

Levels of Pb in radish roots from all treatments fell within the range of Pb normally seen in vegetables, and generally considered below excessive levels (20,25,27). As of 1980, the U.S. Food and Drug Administration had not published regulations/limits for Pb content in foods except for the foods and beverages of infants (8). The World Health Organization's recommended limit of Pb intake from food is 3 mg/week (17).

Mustard leaves. Mustard leaves in each treatment of the spring crop contained P levels exceeding the level established for the vegetable. Leaves from the fall crop contained P levels slightly below the established level.

Levels of Ca in mustard leaves from each treatment were well below the established level of Ca. Though Ca levels increased in leaves of the fall crop, levels were still below the established level. The same relationship was seen for Ca levels in the radish roots, and the comments made for that crop apply here. Calcium deficiencies were not noted in the mustard crop.

Spring-harvested mustard leaves contained Fe levels close to the level of Fe established for the vegetable. The treatments irrigated with effluent (Treatments 2 and 3) were closest to the established Fe level, with Treatment 3 exceeding the level. Iron content in mustard leaves from the fall crop exceeded the Fe level established for mustard leaves.

An established level of K for mustard leaves was not available. Mustard leaves are described by one source (24) as containing moderate to high amounts of potassium. The levels of K resulting from each treatment are provided for the reader's interpretation. Potassium deficiency was not noted during either the spring or fall crop.

Toxic concentrations of Zn, Cd, and Mn did not result in any treatment of the mustard crops. Levels of Pb in mustard leaves from each treatment fell within the range of Pb values expected in vegetables.

Bean pods. Phosphorus levels in bean pods from each treatment were close to the level of P established for bean pods. In the fall crop, treatments irrigated with effluent (Treatments 2 and 3) exceeded the established P level.

Bean pods from each treatment contained K levels below the established level of K. The fall crop of bean pods contained higher levels of K than those from the spring crop, with Treatments 2 and 3 having the highest levels, but still below the established concentration. Potassium deficiency was not evident in either crop of beans.

Levels of Ca in bean pods from each treatment of the spring crop were below the established level of Ca for the vegetable. Treatments 2 and 3 contained the highest levels of Ca, though still below the level expected. The fall crop of bean pods in each treatment contained Ca levels in excess of the established level of Ca.

Iron concentration in bean pods from each treatment were above the established level, in both crops.

Concentrations of Zn, Cd, and Mn in bean pods from each treatment, and both crops, fell below concentrations considered toxic to adults. Except for the spring crop of bean pods from Treatment 1, the concentration of Pb in bean pods from each treatment exceeded the range of Pb values expected in vegetables. By this standard, the levels of Pb would be considered excessive, and possibly harmful to the consumer. As stated before, the World Health Organization's recommended limit of Pb intake from food is 3 mg/week (17). An adult consuming bean pods with the highest level of Pb (3.38 μg/g fresh weight, Treatment 2, fall crop) would have to eat 888 g of bean pods in one week to ingest 3 mg of Pb. Consumption of bean pods from the lowest level of Pb still considered excessive (1.63 μg/g fresh weight, Treatment 2, spring crop) would require ingestion of 1840 g of pods to reach the 3 mg/week limit. The possibility of an individual consuming these volumes of bean pods within a week is dependent on the individual, but seems unlikely.

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Since municipal sewage effluent, on the whole, is regarded as a source of excessive amounts of NO_3-N, NO_3 accumulation in vegetables irrigated with effluent may be a concern. The effluent used in this study contained NO_3-N in excess of the U.S. Public Health Service's standard for drinking water (10 ppm) (28), but NO_3-N standards for irrigation water could not be located. Total N in the vegetables was measured as an indication of the level of N fertilizer supplied by sewage effluent, but the amount of free NO_3 in each plant was not determined. In general, the fraction of N in a plant present as free NO_3 ions is 10-20% or less (15). At this level, possible NO_3 levels in the radish roots, mustard leaves, and bean pods (as calculated from total N contents) are below the toxic daily dose to humans of 560 mg NO_3-N and the toxic single dose of 700 mg (19). Also, varying degrees of chlorosis were noted in each vegetable crop, indicating the level of N (as NO_3 or NH_4) supplied by the effluent was low. Nevertheless, the toxicity of NO_3-N to humans may warrant future studies as to the effect effluent irrigation of vegetables has on NO_3-N levels in the vegetables--especially leafy green vegetables and notorious NO_3 accumulators such as radishes.

Conclusions

There were no significant differences between yields from radishes and beans irrigated with municipal effluent compared to radishes and beans fertilized with inorganic fertilizer and irrigated with tap water. Mustard irrigated with effluent produced higher yields than mustard receiving tap water and fertilizer. Effluent-irrigated and control plants of the 3 vegetables did not differ significantly for most growth characteristics. Nitrogen levels in effluent-irrigated plants were similar, or higher, than levels in control plants. In general, levels of P, K, Ca, Mg, Zn, and Fe in plants irrigated with effluent did not differ significantly from levels in control plants. In the edible portions of the vegetables--radish roots, mustard leaves, and bean pods--concentrations of P and Fe were close to or above the published, established levels for each vegetable. Toxic accumulations of Zn, Mn, and Cd did not occur, and Pb levels were in the expected range of Pb values for vegetables except in bean pods, which had levels above the expected range. Overall, secondary municipal sewage effluent appeared to be a good source of nutrients. and water for vegetable plant growth, with radishes, mustard, and green beans responding well to effluent irrigation.

Literature Cited

1. Association of Official Analytical Chemists. 1984. Wet ashing method, Chapter 7.102. Official methods of analysis. 14th ed.
2. Basiouny, Fouad M. 1982. Wastewater irrigation of fruit trees. BioCycle 23(2):51-53.
3. Beeson, Kenneth C. 1941. The mineral composition of crops with particular references to the soils in which they were grown. U.S. Dept. of Agr. Misc. Publ. No. 369.
4. Beeson, Kenneth C. 1946. The effect of mineral supply on the mineral concentration and nutritional quality of plants. The Bot. Rev. XII:424-455.
5. Brown, J.R. and G.E. Smith. 1967. Nitrate accumulation in vegetable crops as influenced by soil fertility practices. Univ. of MO. Agr. Expt. Sta. Bul. 920.
6. Chaney, Rufus L. 1973. Crop and food chain effects of toxic elements in sludges and effluents, p. 129-141. In: The Env. Prot. Agency, the U.S. Dept. of Agr., the Nat. Assoc. of State Univ. and Land Grant Colleges. Proc. of the joint conference on recycling municipal sludges and effluents on land, July 9-13, 1973, Champaign, Illinois.
7. Committee on Food Protection, Food and Nutrition Board, and National Research Council. 1973. Toxicants occurring naturally in foods. National Academy of Sciences, Washington, D.C.
8. Committee on Lead in the Human Environment, Environmental Studies Board, Commission on Natural Resources, and National Research Council. 1980. Lead in the human environment. National Academy of Sci., Washington, D.C.
9. Cooley, John W. 1980. Christmas trees enhanced by sewage effluent. Compost Sci. Land Util. 21(6):28-30.
10. Cordonnier, M.J. and T.J. Johnston. 1983. Effects of wastewater irrigation and plant and row spacing on soybean yield and development. Agron. J. 75:908-913.

11. Davis, Teresa L., J.K. Greig, and M.B. Kirkham. 1985. Municipal sewage effluent as a source of water and nutrients for vegetable crops. I. Soil response: pH, electrical conductivity, and elemental composition. J. Amer. Soc. Hort. Sci. (submitted).

12. Day, A.D. and R.M. Kirkpatrick. 1973. Effects of treated municipal wastewater on oat forage and grain. J. Env. Quality 2(2):282-284.

13. Day, A.D., F.A. Taher, and F.R.H. Katterman. 1975. Influence of treated municipal wastewater on growth, fiber, acid-soluble nucleotides, protein, and amino acid content in wheat grain. J. Env. Quality 4(2):167-169.

14. Day, A.D., J.R. Wilson, and F.R. Katterman. 1984. Bermudagrass grown with municipal wastewater. BioCycle 25(4):38-39.

15. Epstein, Emmanuel. 1972. Mineral nutrition of plants: principles and perspectives. John Wiley & Sons, Inc., N.Y.

16. Fassiel, V.A. and R.N. Knisley. 1974. Inductively coupled plasma optical emission spectroscopy. Analy. Chem. 46:1110A-1120A, 1158A-1164A.

17. Lenihan, John and William W. Fletcher. 1977. The chemical environment. Vol. 6: Environment and Man. Academic Press, N.Y.

18. Ma, T.S. and G. Zuazaga. 1942. Micro-Kjeldahl determination of nitrogen. Ind. Eng. Chem, Anal. Ed. 14(3):280-282.

19. Maynard, D.N. and A.V. Barker. 1972. Nitrate content of vegetable crops. HortScience 7(3):224-226.

20. Monier-Williams, G.W. 1949. Trace elements in foods. John Wiley & Sons, Inc., N.Y.

21. O'Haver, T.C. 1975. Chemical aspects of elemental analysis, p. 63-77. In: J.D. Winefordner (ed). Trace analysis: spectroscopic methods for elements. John Wiley & Sons, Inc., N.Y.

22. Overstreet, Roy, Louis Jacobsen, and Raymond Handley. 1952. The effect of calcium on the absorption of potassium by barley roots. Plant Physiol. 27(3):583-590.

23. Page, A.L., F.T. Bingham, and C. Nelson. 1972. Cadmium absorption and growth of various plant species as influenced by solution cadmium concentration. J. Env. Quality 1(3):288-291.

24. Ryder, Edward J. 1979. Leafy salad vegetables. AVI Publishing Co., Inc.

25. Schroeder, H.A. and J.J. Balassa. 1961. Abnormal trace elements in man: lead. J. Chron. Dis. 14:408-425.

26. Sutcliffe, James F. and Dennis A. Baker. 1981. Plants and mineral salts. 2nd ed. Edward Arnold (Publishers) Ltd., London.

27. U.N. Environment Programme and World Health Organization. 1977. Environmental criteria 3: lead. World Health Organization, Geneva.

28. U.S. Public Health Service. 1962. Drinking water standards. U.S. Dept. of Health, Education, and Welfare, Washington, D.C.

29. Viets, Frank G. Jr. 1944. Calcium and other polyvalent cations as accelerators of ion accumulation by excised barley roots. Plant Physiol. 19(3):466-480.

30. Watt, Bernice K. and Annabel L. Merrill. 1963. Composition of foods. Agr. Handbook No. 8. Agr. Res. Ser., U.S. Dept. of Agr., Washington, D.C.

Table 1. Fresh weights, dry weights, leaf area, and plant height of radishes, mustard, and green beans, spring and fall crops, fertilized and irrigated with tap water (Trt. 1), fertilized and irrigated with secondary municipal effluent (Trt. 2), and not fertilized and irrigated with secondary municipal effluent (Trt. 3).

			Leaves[z]		Roots[z]		Leaf area[z]	Plant ht.[z]	Pods[z]	
			F.W.	D.W.	F.W.	D.W.			F.W.	D.W.
			g/pot				(cm^2)	(cm)	g/pot	
Radish	Spring	Trt. 1	116.2^{a}	8.68^{a}	177.6^{a}	12.2^{a}	30.1^{a}	10.6^{a}		
		Trt. 2	111.6^{a}	7.60^{a}	167.7^{a}	8.75^{a}	31.5^{a}	10.2^{a}		
		Trt. 3	90.2^{b}	5.90^{b}	156.9^{a}	10.6^{a}	21.5^{b}	9.83^{a}		
	Fall	Trt. 1	105.0^{a}	7.18^{a}	173.5^{a}	10.9^{a}	26.0^{a}	11.5^{a}		
		Trt. 2	123.1^{a}	7.93^{a}	175.4^{a}	10.1^{a}	26.6^{a}	11.7^{a}		
		Trt. 3	80.3^{b}	5.23^{b}	155.4^{a}	9.63^{a}	17.8^{b}	9.93^{a}		
Mustard	Spring	Trt. 1	210.3^{b}	24.8^{b}	13.9^{a}	0.93^{ab}	73.2^{b}	19.9^{a}		
		Trt. 2	227.5^{a}	29.6^{a}	14.6^{a}	2.93^{a}	82.7^{a}	19.1^{a}		
		Trt. 3	157.1^{b}	21.1^{c}	9.45^{b}	0.35^{b}	64.6^{b}	17.9^{b}		
	Fall	Trt. 1	130.8^{b}	19.1^{b}	16.5^{a}	2.05^{ab}	66.2^{b}	19.5^{a}		
		Trt. 2	248.9^{a}	23.2^{a}	15.9^{a}	2.23^{a}	93.3^{a}	22.1^{a}		
		Trt. 3	115.8^{b}	14.2^{c}	10.1^{b}	1.38^{b}	63.5^{b}	17.9^{b}		
Bean	Spring	Trt. 1	172.4^{b}	34.5^{b}	7.38^{a}	1.50^{a}	62.9^{b}	29.3^{a}	110.7^{a}	10.6^{b}
		Trt. 2	186.2^{a}	37.9^{a}	7.68^{a}	1.48^{a}	76.5^{a}	30.2^{a}	140.2^{a}	13.6^{ab}
		Trt. 3	155.2^{c}	32.5^{c}	7.20^{a}	1.53^{a}	63.6^{b}	31.3^{a}	149.2^{a}	16.4^{a}
	Fall	Trt. 1	165.1^{b}	27.9^{b}	7.38^{a}	3.13^{a}	59.1^{a}	33.1^{a}	95.1^{a}	6.85^{b}
		Trt. 2	197.9^{a}	33.4^{a}	9.25^{a}	2.08^{a}	59.7^{a}	35.9^{a}	106.0^{a}	9.80^{ab}
		Trt. 3	150.7^{c}	25.5^{c}	7.70^{a}	1.83^{a}	53.7^{a}	30.9^{a}	97.6^{a}	7.95^{a}

[z] Mean separation in columns by Duncan's Multiple Range Test, 5% level. The treatment means should be compared within the spring crop and within the fall crop--spring and fall crops are not statistically compared. The different vegetables are not statistically compared. Means with the same letter are not significantly different.

Table 2. Elements applied to each vegetable crop, spring and fall, through irrigation and fertilization.

	Applied via irrigation and fertilization[z]		
	Trt. 1[z]	Trt. 2[z]	Trt. 3[z]
		$\mu g/g$	
NO_3	0.07	27.1	27.1
NH_4 (irrig.)	----	0.43	0.43
NH_4 (fert.)	25.4	25.4	----
P (irrig.)	<0.58	6.75	6.75
P (fert.)	28.2	28.2	----
K (irrig.)	8.10	16.0	16.0
K (fert.)	70.4	70.4	----
Ca	30.0	47.0	47.0
Mg	13.5	18.0	18.0
Zn	< 0.15	0.17	0.17
Fe	<0.05	<0.11	<0.11
Cd	<0.04	<0.05	<0.05
Pb	<0.04	0.04	0.04
Mn	----	0.05	0.05

[z] Trts. 1 and 2 each received 2.3 g $(NH_4)_2HPO_4$ and 2.3 g KCl prior to spring and fall seeding. The $\mu g/g$ NH_4-N, P, and K from the fertilizers are labeled separately from the NH_4-N, P, and K added through irrigation. Trt. 1 was irrigated with municipal tap water and Trt. 2 was irrigated with secondary municipal sewage effluent, both treatments receiving total volumes of irrigation according to crop and season (Tables 3-7). Trt. 3 was irrigated with secondary municipal effluent, receiving the same volumes as the other 2 treatments, but with no fertilization.

Table 3. Elemental composition of radish leaves after harvest.

	Spring^{z}			Fall^{z}		
	Trt. 1^{y}	Trt. 2^{y}	Trt. 3^{y}	Trt. 1^{y}	Trt. 2^{y}	Trt. 3^{y}
	μg/g					
N	28.5^{ab}	29.6^{a}	23.6^{b}	30.0^{ab}	37.1^{a}	30.3^{b}
P	3000.0^{a}	2987.5^{a}	2962.5^{a}	3887.5^{a}	4212.5^{a}	3812.5^{a}
K	5787.5^{a}	6750.0^{a}	6275.0^{a}	19125.0^{a}	19375.0^{a}	16500.0^{a}
Ca	3645.0^{a}	1965.0^{a}	6337.5^{a}	24000.0^{a}	21337.5^{a}	19150.0^{a}
Mg	1083.8^{b}	933.8^{b}	2300.0^{a}	4387.5^{b}	3900.0^{b}	5112.5^{a}
Zn	68.5^{a}	38.6^{a}	62.4^{a}	48.5^{a}	35.3^{a}	42.4^{a}
Fe	245.0^{a}	227.5^{a}	211.3^{a}	1396.3^{a}	605.0^{a}	532.5^{a}
Cd^{x}	20.8^{ab}	32.3^{a}	8.9^{b}	-----	-----	-----
Pb	4.63^{a}	9.66^{a}	6.46^{a}	51.4^{a}	3.41^{a}	10.4^{a}
Mn	55.8^{a}	57.8^{a}	54.5^{a}	106.7^{a}	94.2^{a}	82.6^{a}

[z] Mean separation by least significant difference, 5% level. Treatment means are compared within rows. Means with the same letter are not significantly different. Treatment means in the spring crop and the fall crop are not statistically compared.

[y] Trts. 1 and 2 each received 2.3 g of (NH$_4$)$_2$HPO$_4$ and 2.3 g KCl prior to spring and fall seeding. Trt. 1 was irrigated with municipal tap water and Trt. 2 was irrigated with secondary municipal sewage effluent, both treatments receiving 17 liters (18,688 g) in the spring and 16.5 liters (18,138 g) in the fall. Trt. 3 was irrigated with secondary municipal sewage effluent, receiving the same volumes as the other 2 treatments, but with no fertilization.

[x] A large number of values below detection limits created an incomplete data set for Cd levels in the fall crop, and statistical analysis was not done. The detection limits ranged from 6.0 to 11.0 μg/g.

Table 4. Elemental composition of radish roots after harvest.

	Spring^{z}			Fall^{z}		
	Trt. 1^{y}	Trt. 2^{y}	Trt. 3^{y}	Trt. 1^{y}	Trt. 2^{y}	Trt. 3^{y}
	μg/g					
N	13.3^{b}	16.2^{a}	10.8^{c}	13.2^{b}	16.6^{a}	11.7^{c}
P	4162.5^{a}	3737.5^{b}	4212.5^{a}	4412.5^{a}	3825.0^{b}	4375.0^{a}
K	6175.0^{a}	6437.5^{a}	6212.5^{a}	14875.0^{a}	15000.0^{a}	15625.0^{a}
Ca	1692.5^{a}	1612.5^{a}	1673.8^{a}	6662.5^{a}	3171.3^{a}	3450.0^{a}
Mg	832.5^{b}	1120.0^{a}	1012.5^{a}	1325.0^{b}	1387.5^{a}	1575.0^{a}
Zn	45.5^{a}	34.1^{a}	35.4^{a}	25.6^{a}	24.0^{a}	30.3^{a}
Fe	206.3^{a}	148.8^{b}	165.0^{a}	173.4^{a}	155.0^{b}	191.3^{a}
Cd^{x}	18.4^{b}	7.59^{a}	6.9^{a}	-----	-----	-----
Pb	17.1^{a}	10.3^{ab}	7.00^{b}	13.2^{a}	12.6^{a}	18.1^{a}
Mn	17.0^{a}	14.1^{a}	13.6^{a}	13.1^{a}	17.0^{ab}	18.1^{b}

[z] Mean separation by least significant difference, 5% level. Treatment means are compared within rows. Means with the same letter are not significantly different. Treatment means in the spring crop and the fall crop are not statistically compared.

[y] Trts. 1 and 2 each received 2.3 g of $(NH_4)_2HPO_4$ and 2.3 g KCl prior to spring and fall seeding. Trt. 1 was irrigated with municipal tap water and Trt. 2 was irrigated with secondary municipal sewage effluent, both treatments receiving 17 liters (18,688 g) in the spring and 16.5 liters (18,138 g) in the fall. Trt. 3 was irrigated with secondary municipal sewage effluent, receiving the same volumes as the other 2 treatments, but with no fertilization.

[x] A large number of values below detection limits created an incomplete data set for Cd levels in the fall crop, and statistical analysis was not done. The detection limits ranged from 6.0 to 11.0 μg/g.

Table 5. Elemental composition of mustard leaves after harvest.

	Spring^{z}			Fall^{z}		
	Trt. 1^{y}	Trt. 2^{y}	Trt. 3^{y}	Trt. 1^{y}	Trt. 2^{y}	Trt. 3^{y}
	μg/g					
N	14.9^{b}	16.7^{a}	15.1^{b}	13.1^{b}	20.2^{a}	16.3^{b}
P	4737.5^{b}	4325.0^{b}	5362.5^{a}	1862.5^{b}	2550.0^{a}	2525.0^{a}
K	5600.0^{a}	6012.5^{a}	5812.5^{a}	6875.0^{a}	8925.0^{a}	8737.5^{a}
Ca	2930.0^{a}	3437.5^{a}	3175.0^{a}	6962.5^{a}	7600.0^{a}	7437.5^{a}
Mg	1212.5^{a}	1337.5^{ab}	1587.5^{b}	1512.5^{a}	1912.5^{ab}	2137.5^{b}
Zn	35.6^{a}	30.9^{a}	37.5^{a}	17.1^{a}	24.8^{a}	26.9^{a}
Fe	88.4^{a}	101.4^{a}	168.1^{a}	256.3^{a}	328.8^{a}	213.8^{a}
Cd^{x}	8.74^{b}	6.74^{c}	13.1^{a}	-----	-----	-----
Pb	7.20^{a}	4.93^{a}	7.35^{a}	7.59^{a}	10.7^{a}	8.63^{a}
Mn	54.9^{a}	58.4^{a}	55.0^{a}	42.0^{a}	62.4^{a}	56.4^{a}

[z] Mean separation by least significant difference, 5% level. Treatment means are compared within rows. Means with the same letter are not significantly different. Treatment means in the spring crop and the fall crop are not statistically compared.

[y] Trts. 1 and 2 each received 2.3 g of $(NH_4)_2HPO_4$ and 2.3 g KCl prior to spring and fall seeding. Trt. 1 was irrigated with municipal tap water and Trt. 2 was irrigated with secondary municipal sewage effluent, both treatments receiving 14 liters (15,719 g) in the spring and 17.4 liters (19,128 g) in the fall. Trt. 3 was irrigated with secondary municipal sewage effluent, receiving the same volumes as the other 2 treatments, but with no fertilization.

[x] A large number of values below detection limits created an incomplete data set for Cd levels in the fall crop, and statistical analysis was not done. The detection limits ranged from 6.0 to 11.0 μg/g.

Table 6. Elemental composition of bean leaves after harvest.

	Spring[z]			Fall[z]		
	Trt. 1[y]	Trt. 2[y]	Trt. 3[y]	Trt. 1[y]	Trt. 2[y]	Trt. 3[y]
	μg/g					
N	12.8^a	13.7^a	15.2^a	16.6^a	16.3^a	16.9^a
P	1862.5^a	1875.0^a	1612.5^b	2237.5^b	2537.5^a	2425.0^a
K	7012.5^a	6025.0^b	6450.0^{ab}	14500.0^a	14500.0^a	13125.0^b
Ca	2550.0^a	2712.5^a	6037.5^a	3450.0^a	4562.5^a	8512.5^a
Mg	1527.5^a	697.5^b	1231.3^a	2075.0^a	2375.0^a	2212.5^a
Zn	32.1^a	31.0^a	25.1^a	20.6^a	19.1^a	23.0^a
Fe	256.3^{ab}	333.8^b	166.3^a	108.3^a	63.4^a	100.6^a
Cd[x]	12.7^b	25.7^a	10.8^b	-----	-----	-----
Pb[x]	7.03^a	9.29^a	7.70^a	-----	-----	-----
Mn	71.6^a	65.3^a	57.5^a	48.5^a	52.8^a	53.0^a

[z] Mean separation by least significant difference, 5% level. Treatment means are compared within rows. Means with the same letter are not significantly different. Treatment means in the spring crop and the fall crop are not statistically compared.

[y] Trts. 1 and 2 each received 2.3 g $(NH_4)_2HPO_4$ and 2.3 g KCl prior to spring and fall seeding. Trt. 1 was irrigated with municipal tap water and Trt. 2 was irrigated with secondary municipal sewage effluent, both treatments receiving 26.4 liters (29,021 g) in the spring and 22.8 liters (25,064 g) in the fall. Trt. 3 was irrigated with effluent, receiving the same volumes as the other 2 treatments, but with no fertilization.

[x] A large number of values below detection limits created an incomplete data set for Cd levels in the fall crop, and statistical analysis was not done. This explanation also applies to Pb levels in the fall crop. The detection limits for Cd ranged from 6.0 to 11.0 μg/g. The detection limits for Pb ranged from 4.0 to 7.3 μg/g.

Table 7. Elemental composition of bean pods after harvest.

	Spring^{z}			Fall^{z}		
	Trt. 1^{y}	Trt. 2^{y}	Trt. 3^{y}	Trt. 1^{y}	Trt. 2^{y}	Trt. 3^{y}
	μg/g					
N	20.4^{a}	19.8^{a}	20.6^{a}	22.2^{a}	22.7^{a}	22.7^{a}
P	3900.0^{a}	3537.5^{a}	3825.0^{a}	4300.0^{a}	4837.5^{a}	4600.0^{a}
K	6475.0^{a}	6437.5^{a}	6012.5^{a}	15125.0^{a}	16000.0^{b}	15625.0^{ab}
Ca	1338.8^{a}	2343.8^{a}	3000.0^{a}	7296.3^{a}	7175.0^{a}	6087.5^{a}
Mg	1393.8^{a}	1712.5^{a}	1712.5^{a}	2675.0^{a}	2837.5^{a}	2737.5^{a}
Zn	36.1^{a}	32.5^{a}	34.5^{a}	39.3^{a}	39.3^{a}	40.1^{a}
Fe	185.0^{a}	121.0^{a}	167.3^{a}	146.3^{a}	135.0^{a}	138.8^{a}
Cd^{x}	8.39^{ab}	5.94^{a}	10.8^{b}	-----	-----	-----
Pb	11.7^{a}	16.3^{ab}	21.9^{b}	30.9^{a}	33.8^{a}	25.3^{a}
Mn	28.8^{a}	20.0^{a}	26.6^{a}	36.9^{a}	33.1^{a}	34.5^{a}

^{z}Mean separation by least significant difference, 5% level. Treatment means are compared within rows. Means with the same letter are not significantly different. Treatment means in the spring crop and the fall crop are not significantly compared.

^{y}Trts. 1 and 2 each received 2.3 g $(NH_4)_2HPO_4$ and 2.3 g KCl prior to spring and fall seeding. Trt. 1 was irrigated with municipal tap water and Trt. 2 was irrigated with secondary municipal sewage effluent, both treatments receiving 26.4 liters (29,021 g) in the spring and 22.8 liters (25,064 g) in the fall. Trt. 3 was irrigated with effluent, receiving the same volumes as the other 2 treatments, but with no fertilization.

^{x}A large number of values below detection limits created an incomplete data set for Cd levels in the fall crop, and statistical analysis was not done. The detection limits ranged from 6.0 to 11.0 μg/g.

Table 8. Levels of P, K, Ca, and Fe established for radish roots, mustard leaves, and bean pods as compared to levels of P, K, Ca, and Fe resulting from treatments.

		Publ. Comp.[z]	Spring[y]			Fall[y]		
			Trt. 1[x]	Trt. 2[x]	Trt. 3[x]	Trt. 1[x]	Trt. 2[x]	Trt. 3[x]
		mg/100 g (f.w.)[w]						
Radish Roots	P	31.0	25.0	22.4	25.3	26.5	22.9	26.3
	K	322.0	37.1	38.6	37.3	89.3	90.0	93.8
	Ca	30.0	10.2	9.7	10.0	40.0	19.0	20.7
	Fe	1.0	1.24	0.89	0.99	1.04	0.93	1.15
Mustard Leaves	P	28.0	52.1	47.6	59.0	20.5	28.1	27.8
	K	N.A.[v]	61.6	66.1	63.9	75.6	98.2	96.1
	Ca	210.0	32.2	37.8	34.9	76.6	83.6	81.8
	Fe	1.5	0.97	1.12	1.85	2.82	3.62	2.35
Bean Pods	P	44.0	39.0	35.4	38.3	43.0	48.4	46.0
	K	243.0	64.8	64.4	60.1	151.3	160.0	156.3
	Ca	56.0	13.4	23.4	30.0	72.9	71.8	60.9
	Fe	0.8	1.85	1.21	1.67	1.46	1.35	1.39

[z] Composition levels from Composition of Foods, Agriculture Handbook No. 8 (30).

[y] Emphasis in the table is on comparison of each treatment mean for P, K, Ca, and Fe to the established levels of those elements for each vegetable, not on comparison of treatment means. Treatment mean separation for P, K, Ca, and Fe can be found in Table 4, Table 5, and Table 7 for radish roots, mustard leaves, and bean pods, respectively.

[x] Trt. 1 was fertilized prior to spring and fall seeding and irrigated with municipal tap water. Trt. 2 was fertilized prior to spring and fall seeding and irrigated with secondary municipal sewage effluent. Trt. 3 was not fertilized, and irrigated with secondary municipal sewage effluent.

[w] Conversion of $\mu g/g$ dry weight (d.w.) to mg/100 g fresh weight (f.w.):

$$\frac{\mu g}{g} \times \frac{1 \text{ mg}}{1000 \ \mu g} = \frac{\text{mg}}{1000 \text{ g}} = \frac{0.1 \text{ mg}}{100 \text{ g d.w.}}$$

$$\frac{0.1 \text{ mg}}{100 \text{ g d.w.}} \times \frac{\% \text{ d.w.}}{\text{f.w.}} = \frac{0.1 \text{ mg}}{100 \text{ g f.w.}}$$

According to experimental results and Agriculture Handbook No. 8 (30):
In radish roots, 6% of the fresh wt. was dry wt.
In mustard leaves, 11% of the fresh wt. was dry wt.
In bean pods, 10% of the fresh wt. was dry wt.

Table 8 (continued)

[v] Not available. Levels of K established for mustard leaves were not available from Agriculture Handbook No. 8 (30).

Table 9. A comparison of toxic concentrations of Zn, Cd, and Mn, and of Pb levels most often seen in vegetables, to heavy metal concentrations after treatments.

		Concs. toxic to adults^{z}	Spring^{y}			Fall^{y}		
			Trt. 1^{x}	Trt. 2^{x}	Trt. 3^{x}	Trt. 1^{x}	Trt. 2^{x}	Trt. 3^{x}
		(ppm)	μg/g d.w.					
Radish Roots	Zn	5000–10000	45.5	34.1	35.4	25.6	24.0	30.3
	Cd^{w}	15	18.4	7.59	6.90	----	----	----
	Mn	1000–2000	17.0	14.1	13.6	13.1	17.0	18.1
Mustard Leaves	Zn	5000–10000	35.6	30.9	37.5	17.1	24.8	26.9
	Cd^{w}	15	8.74	6.74	13.1	----	----	----
	Mn	1000–2000	54.9	58.4	55.0	42.0	62.4	56.4
Bean Pods	Zn	5000–10000	36.1	32.5	34.5	39.3	39.3	40.1
	Cd^{w}	15	8.39	5.94	10.8	----	----	----
	Mn	1000–2000	28.8	20.0	26.6	36.9	33.1	34.5
		Expected Levels of Pb^{v}						
			μg/g f.w.					
Radish Roots		0.0–1.26	1.03	0.62	0.42	0.79	0.76	1.09
Mustard Leaves		0.0–1.26	0.79	0.54	0.81	0.83	1.18	0.95
Bean Pods		0.0–1.26	1.17	1.63	2.19	3.09	3.38	2.53

[z] Toxic concentrations in the dry diet from Toxicants Occurring Naturally in Foods (7).

[y] Emphasis in the table is on comparison of each treatment mean to toxic concentrations (Zn, Cd, Mn) or the range of expected levels (Pb). Treatment mean separation can be found in Table 4, Table 5, and Table 7 for radish roots, mustard leaves, and bean pods, respectively.

[x] Trt. 1 was fertilized prior to spring and fall seeding and irrigated with municipal tap water. Trt. 2 was fertilized prior to spring and fall seeding and irrigated with secondary municipal sewage effluent. Trt. 3 was not fertilized and irrigated with secondary municipal sewage effluent.

[w] Mild symptoms of Cd poisoning are first seen at 15 ppm. Due to incomplete data sets, statistical analysis was not done for Cd levels in the fall crop.

Table 9 (continued)

[v] Range of values most seen in vegetables from Schroeder and Balassa (25) and the U.N. Environment Programme (27).

[u] Conversion of μg/g dry weight (d.w.) to μg/g fresh weight (f.w.):

$$\frac{\mu\text{g}}{\text{g d.w.}} \times \frac{\%\text{ d.w.}}{\text{f.w.}} = \frac{\mu\text{g}}{\text{g f.w.}}$$

According to experimental results and Agriculture Handbook No. 8 (30):
In radish roots, 6% of the fresh weight was dry weight.
In mustard leaves, 11% of the fresh weight was dry weight.
In bean pods, 10% of the fresh weight was dry weight.

APPENDICES

The determination of fertilizer rate per pot.

The recommended rate of 18-46-0 diammonium phosphate and of 0-0-60 muriate of potash is 224.7 kg/ha. This rate was used to calculate the amount of each fertilizer to add to the upper 15.24 cm of soil/sand in each 19-liter pot.

Volume of pot to 15.24 cm depth = $\pi r^2 h$

$$V = 3.14(18.8\text{ cm})^2(15.24\text{ cm})$$

$$V = 16913.4\text{ cm}^3$$

Volume of 1 hectare to 15.24 cm depth:

$$\frac{9919.6\text{ m}^2}{\text{ha}} \times \frac{100\text{ cm}}{\text{m}} \times \frac{100\text{ cm}}{\text{m}} \times 15.24\text{ cm} = 1.51 \times 10^9\text{ cm}^3/\text{ha}$$

Therefore, the fertilizer rate per hectare may be expressed as $224.7\text{ kg}/\ 1.51 \times 10^9\text{ cm}^3$.

$$\frac{224.7\text{ kg}}{1.51 \times 10^9\text{ cm}^3} = \frac{?\text{ kg}}{16913.4\text{ cm}^3}$$

$$= .0025\text{ kg}$$

$$= 2.5\text{ g* of each fertilizer for addition to each pot}$$

*When the fertilizer rate was used in the above manner to calculate the amount of each of the 2 fertilizers to add to the upper 15.24 cm of soil/sand in each pot, values were kept in the units of the English system (ft, ft^2, in^3). The amount of each fertilizer to add was calculated as 2.3 g, and this was the amount of each fertilizer used in each pot (pp. 29, 52). The difference between this value and the value calculated above is attributed to round-off error.

The determination of field capacity of the 3:2 soil/sand mixture used in each pot.

The field capacity of the 3:2 mixture of Haynie very fine sandy loam (Mollic Udifluvent; coarse-silty, mixed, calcareous, mesic) and washed river sand was estimated as an indication of the amount of irrigation to apply to each 19-liter pot. Seven 1-liter containers (15.24 cm tall) were filled with the soil/sand mixture. The containers did not have drainage holes. The following amounts of H_2O were added to each container.

(1) 100 ml -- wet to 7.6 cm depth

(2) 150 ml -- wet to 10.2 cm depth

(3) 200 ml -- wet to the bottom of the container, with no excess water sitting in the bottom of the container

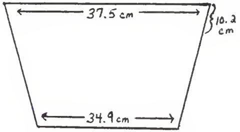
(4) 250 ml -- wet to the bottom of the container; more saturated than soil/sand wetted with 200 ml H_2O, with no excess water sitting in the bottom of the container

(5) 300 ml -- wet to the bottom of the container; "muddy"

(6) 350 ml -- wet to the bottom of the container; very wet, pasty

(7) 400 ml -- excess water, soil/sand would not hold structure

It was determined that 250 ml of H_2O were needed to reach apparent field capacity of the soil/sand mixture, or 25% by volume. The volume of the 19-liter pot to a 10.2 cm depth was determined.



$$V = \pi r^2 h$$

$$V = 3.14(18.8\ \text{cm})^2(10.2\ \text{cm})$$

$$V = 11{,}230\ \text{cm}^3$$

$$.25(11{,}230\ \text{cm}^3) = 2830\ \text{cm}^3,\ \text{or}\ 2830\ \text{ml}$$

To reach field capacity, 2830 ml would be needed per irrigation, assuming the soil/sand was 100% dry. Since the soil/sand was not allowed to become

100% dry, about 1/3 of the calculated amount, or 900-1000 ml, was used for the maximum amount of irrigation.

Micro-Kjeldahl determination of total nitrogen in plant tissue.

The following procedure is bascially that of Ma and Zuazaga (1) with minor modifications[1].

Materials

Micro-Kjeldahl digestion flasks

Micro-Kjeldahl digestion rack

Micro-Kjeldahl distillation unit

Glass beads

Catalyst-potassium sulfate mixture (96 g Na_2SO_4; 3.5 g $CuSO_4 \cdot 5H_2O$; 0.5 g SeO_2)

Concentrated sulfuric acid

Sodium hydroxide solution (40%) (4 g NaOH/100 mls H_2O)

Boric acid solution (2%) (2 g powdered boric acid/100 mls H_2O)

Standard hydrochloric acid solution (N/100) (10.0 mls of 1 N HCl mixed with 1000 mls H_2O, standardized with 5 mls of 0.02 N NaOH)

Screened indicator (5 parts of bromocresol green to 1 part of methyl red in ethanol, 0.1%)

Procedure

1. Forty mg of homogenous dried, ground plant tissue were weighed into a digestion flask. A glass bead, 0.5 g of catalyst, and 2 ml of conc. sulfuric acid were added to the flask. The flask and contents were placed on a digestion rack under a hood and heated gently at first,

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[1] Minor modifications according to advice of Dr. Mary Lewnes Albrecht from her laboratory experience as a student in Horticulture 603, Ohio State University, 1977. Dr. Albrecht is presently an Assistant Professor in the Department of Horticulture, Kansas State University.

then more vigorously until the solution became clear. Heating continued for a total of 2 hours.

2. The contents of the flask were washed into the chamber of the distillation unit. Distilled water was added until there were 5 ml of solution in the chamber. The solution was released into the unit, and 10 ml of 40% NaOH solution were added. Distillate was collected in a 50 ml beaker containing 5 ml of 2% boric acid solution with a few drops of mixed indicator. The tip of the condenser was kept below the surface of the liquid in the beaker for accurate results. Distillation continued for about 2 minutes or until 20-30 ml had accumulated in the beaker.
3. The contents of the beaker were titrated to a steel gray endpoint with N/100 HCl, with the mls of HCl used recorded (1 ml = 0.14 mg N).
4. The N content of the sample was calculated:

$$\text{mg N/g sample} = \frac{\text{ml HCl} \times 0.14}{\text{wt. of sample}}$$

Thirty-six plant samples (dried and ground) were analyzed for total N by the above procedure. The distillation unit was thoroughly rinsed between each sample. Five blanks were also analyzed for total N.

Literature Cited

1. Ma, T.S. and G. Zuazaga. 1942. Micro-Kjeldahl determination of nitrogen. Ind. Eng. Chem., Anal. Ed. 14(3):280-282.

Conversion of plant analysis data from dry weight basis to fresh weight basis.

The established levels of P, K, Ca, and Fe in edible portions of vegetable plants were given in mg/100 g fresh weight in the source used (2). In order to evaluate the levels of P, K, Ca, and Fe in radish roots, mustard leaves, and bean pods after treatments, it was necessary to convert the data from μg/g dry weight to mg/100 g fresh weight.

$$\frac{\mu g}{g} \times \frac{mg}{1000\ \mu g} = \frac{mg}{1000\ g} = \frac{0.1\ mg}{100\ \ g\ dry\ wt.}$$

$$\frac{0.1\ mg}{100\ \ g\ dry\ wt.} \times \frac{\%\ dry\ wt.}{fresh\ wt.} = \frac{0.1\ mg}{100\ g\ fresh\ wt.}$$

In radish roots, 6% of the fresh wt. was dry wt. (94% water). In mustard leaves, 11% of the fresh wt. was dry wt. (89% water). In bean pods, 10% of the fresh wt. was dry wt. (90% water). Watt and Merrill (2) reported these values, and the experimental results agreed with the findings.

The standard for Pb levels in vegetables was given in μg/g fresh wt. (1). Therefore, it was necessary to convert levels of Pb in radish roots, mustard leaves, and bean pods from μg/g dry wt. to μg/g fresh wt.

$$\frac{\mu g}{g\ dry\ wt.} \times \frac{\%\ dry\ wt.}{fresh\ wt.} = \frac{\mu g}{g\ fresh\ wt.}$$

Literature Cited

1. Committee on Food Protection, Food and Nutrition Board, and National Research Council. 1973. Toxicants occurring naturally in foods. National Academy of Sciences, Washington D.C.
2. Watt, Bernice K. and Annabel L. Merrill. 1963. Composition of foods. Agr. Handbook No. 8. Agr. Res. Ser., U.S. Dept. of Agr., Washington D.C.

Levels of copper in radish leaves and roots, mustard leaves, and bean leaves and pods, and in the soil in which they were grown.

Copper was initially one of the elements analyzed for in the soil samples from each crop. Laboratory confusion of "Co" (cobalt) for "Cu" (copper) led to a lengthy delay in analysis of the plant tissue for copper. Therefore, the data was omitted from the discussion of elemental composition of the soil and plants.

Table A-1. Levels of copper in soil in which radish, mustard, and green beans were grown and fertilized and irrigated with municipal tap water (Trt. 1), fertilized and irrigated with secondary municipal sewage effluent (Trt. 2), or not fertilized and irrigated with secondary municipal sewage effluent (Trt. 3).

	Spring[z]			Fall[z]		
	Trt. 1	Trt. 2	Trt. 3	Trt. 1	Trt. 2	Trt. 3
	µg/g					
Radish	1.03^{a}	1.03^{a}	0.98^{a}	0.90^{a}	0.90^{a}	0.88^{a}
Mustard	1.03^{a}	1.03^{a}	0.98^{a}	0.83^{a}	0.85^{a}	0.83^{a}
Green Bean	1.00^{a}	0.98^{a}	0.93^{a}	0.85^{a}	0.85^{a}	0.80^{a}

[z] Mean separation in rows by least sign. diff., 5% level. Means in the spring and fall crops are not statistically compared, nor are the different vegetables. The soil before treatments contained 1.10 µg/g copper.

(continued)

Table A-2. Levels of copper in radish leaves, radish roots, mustard leaves, bean leaves, and bean pods.

	Spring[z]			Fall[z]		
	Trt. 1	Trt. 2	Trt. 3	Trt. 1	Trt. 2	Trt. 3
	μg/g					
Radish leaves	16.7[a]	7.90[a]	13.2[a]	9.20[a]	9.03[a]	6.83[a]
Radish roots	7.60[a]	6.03[a]	5.53[a]	4.75[a]	5.00[a]	4.88[a]
Mustard leaves	7.90[a]	7.53[a]	8.08[a]	7.55[a]	8.53[a]	8.78[a]
Bean leaves	10.3[a]	8.73[a]	11.2[a]	7.10[a]	7.43[a]	7.68[a]
Bean pods	16.9[a]	9.58[a]	9.78[a]	10.3[a]	11.4[a]	10.9[a]

[z] Mean separation in rows by least sign. diff., 5% level. Means in the spring and fall crops are not statiscally compared, nor are the different vegetables.

The secondary municipal sewage effluent contained 0.06 mg/liter of copper, measured over a 7-month period by the Manhattan Municipal Wastewater Treatment Plant. The municipal tap water contained levels of copper below detection limits (0.01 μg/g), analyzed from 2 samples collected in the fall from the greenhouse in which the vegetables were grown, and analyzed by the Campus Emission Spectroscopy Laboratory of Kansas State University (1984).

Levels of cobalt in radish leaves and roots, mustard leaves, and bean leaves and pods.

Laboratory confusion of "Co" (cobalt) for "Cu" (copper) resulted in analysis of the plant samples for cobalt. The soil samples were not analyzed for cobalt.

Table A-3. Levels of cobalt in radish leaves, radish roots, mustard leaves, bean leaves, and bean pods.

	Spring[z]			Fall[z]		
	Trt. 1	Trt. 2	Trt. 3	Trt. 1	Trt. 2	Trt. 3
	μg/g					
Radish leaves	29.1[a]	32.5[a]	10.6[b]	------	------	------
Radish roots	24.0[a]	------	8.06[b]	------	------	------
Mustard leaves	------	7.19[b]	14.3[a]	------	------	------
Bean leaves	25.1[a]	33.7[a]	12.0[b]	------	------	------
Bean pods	18.5[a]	8.79[c]	11.2[b]	------	------	------

[z] Mean separation in rows by least sign. diff., 5% level. A large number of values below detection limits (3.00 μg/g in spring, 20.0 μg/g in fall) created an incomplete data set for the fall crops, and statistical analysis was not done. Means not shown in the spring crop could not be calculated because the majority of values were below detection limits.

Levels of cobalt in the secondary municipal sewage effluent used to irrigate Trts. 2 and 3 were below detection limits (0.30 μg/g) in the 2 samples collected in the fall, 1984, and analyzed by the Kansas State University Campus Emission Spectroscopy Laboratory. The levels of cobalt in the 2 samples of municipal tap water analyzed by the laboratory were below detection limits, but the laboratory did not provide the detection limits. The tap water samples were collected from the greenhouse in which the vegetables were grown, in the fall, 1984.

MUNICIPAL SEWAGE EFFLUENT AS A SOURCE OF WATER AND NUTRIENTS FOR VEGETABLE CROPS

by

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Research was conducted to determine the extent to which irrigation of vegetable crops with secondary municipal sewage effluent is feasible. The effects of effluent irrigation were determined by recording 1) the soil response through pH, electrial conductivity, and elemental composition and 2) the plant response through growth, yield, and elemental composition. Spring and fall crops of radishes (Raphanus sativus L. cv. Fancy Red), mustard (Brassica perviridis cv. Tendergreen II), and green beans (Phaseolus vulgaris L. cv. Bush Blue Lake) were grown in a greenhouse, seeded into a 3:2 mixture of Haynie very fine sandy loam and washed river sand. The plants and soil were 1) fertilized, prior to seeding, with $(NH_4)_2HPO_4$ and KCl and irrigated with tap water, 2) fertilized, prior to seeding, with $(NH_4)_2HPO_4$ and KCl and irrigated with secondary municipal sewage effluent, or 3) not fertilized and irrigated with secondary municipal sewage effluent.

Effluent-irrigated soils contained NO_3 levels the same or higher than levels in fertilized soil irrigated with tap water. Phosphorus and potassium in soil receiving only effluent were lower than in soil fertilized and irrigated with tap water or effluent. In general, levels of the micronutrients Ca, Mg, Fe, and Zn in soil irrigated with effluent were similar or higher than micronutrient levels in soil receiving fertilizer and tap water irrigation. Concentrations of Pb, Cd, and Mn in effluent-irrigated soil were not significantly different from heavy metal concentrations in fertilized soil irrigated with tap water. Soil irrigated with effluent showed almost no difference in pH from that of soil irrigated with tap water. Effluent did not contribute to the salinity of the soil.

Yields from radishes and beans irrigated with effluent were not significantly different from radishes and beans fertilized and irrigated with tap water. Effluent-irrigated plants and plants receiving fertilizer and tap water irrigation were not significantly different for most growth characteristics. Nitrogen levels in effluent-irrigated plants were similar, or higher, than

levels in plants irrigated with tap water. Levels of P, K, Ca, Mg, Zn, and Fe were not significantly different between effluent-irrigated plants and plants with fertilizer and tap water irrigation. In the edible portions of each vegetable, concentrations of P and Fe were close to or above the published levels for each vegetable, but levels of Ca and K were low. There were no toxic accumulations of Zn, Mn, and Cd, and Pb levels were within the expected range, except in bean pods, where levels were elevated.

Overall, secondary municipal sewage effluent appeared to be a good source of nutrients and water for vegetable plant growth. Radishes, mustard, and green beans responded well to effluent irrigation, and soil nutrient levels increased with no accumulations of toxic metals or increase in salinity.