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Quality Characteristics of New Yorker and Heinz 1350 Tomatoes Grown in Soil Amended with a Municipal Sewage Sludge

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Two varieties of tomatoes were grown in a control plot and in a plot of municipal sludge amended soil. Physiochemical and sensory measurements were performed to evaluate their quality characteristics. The sludge-grown tomatoes were smaller by weight, volume, height, and diameter. The control and sludge-grown tomatoes were not significantly different in color, a/b (redness/yellowness), percentage of locular material or moisture, flesh juiciness, overall juiciness, soluble solids, pH, off-odor, off-flavor, sweetness, or reduced ascorbic acid of the whole tomato or locular material. The sludge-grown tomatoes were lower in tissue firmness and titratable acidity. The sludge-grown tomatoes had more tender skins, less sourness, and less intense characteristic tomato flavor based on sensory evaluation. They were higher in soluble solids/titratable acidity ratios, reduced in ascorbic acid of the combined flesh and skin, and higher in cadmium concentration than the controls. In overall quality, the sludge-grown tomatoes were rated lower.

Proper management of sewage sludge disposal is the subject of much investigation by regulatory agencies, such as the Environmental Protection Agency, and others concerned about the wholesomeness of the food supply. Millions of tons of this material are produced annually in the United States (Hallenbeck, 1979). Present means of sludge disposal include incineration, ocean dumping, burying in sanitary landfills, and landspreading.

Land application of sludge can contaminate the soil with potentially phytotoxic heavy metals (e.g., copper, nickel, and lead) (Beckett, 1978), toxic organic compounds (e.g., polychlorinated biphenyls and pesticides) (Hansen et al., 1981), and pathogenic microorganisms (Hallenbeck, 1979). However, sludge also contains plant nutrients and organic matter, which are beneficial to plant growth (Ott and Forster, 1978). Various aspects of sludge application to land have received much attention, including the effects of sewage sludge–soil amendments on soil properties, plant yields, and chemical accumulation by plants. However, the quality (appearance, texture, odor, flavor, nutritional value, and toxicity) of crops grown on sludge-amended soil has received little study.

A limited number of studies have dealt with the flavor of crops grown in soil amended with sludge. McIntyre et al. (1977) grew plants in land fertilized with municipal wastewater sewage sludge and reported that sludge-grown sweet corn tasted better than the control corn but sludge-grown raw carrots had a sharp, undesirable aftertaste and string beans from the sludge-amended and control soils were similar in taste. Lee et al. (1980) reported that control carrots were substantially sweeter than carrots grown in a domestic sludge-amended soil and sludge-grown peas were preferred over control peas.

Very few studies have examined the effect of a sewage sludge–soil amendment on nutrient levels in plants. Lee et al. (1980) found that sludge-grown vegetables were higher in ascorbic acid and riboflavin than the control vegetables but results with niacin and thiamin were variable. The accumulation of mineral nutrients by plants grown in sludge-amended soil has been reviewed by a number of workers (Page, 1974; Lepp, 1981), but the translocation of accumulated mineral nutrients or the mineral status of edible plant parts has not been extensively studied.

The toxicity of crops grown in sludge-amended soil depends on their degree of contamination by heavy metals, toxic organic compounds, and pathogenic microorganisms. The accumulation, translocation, and levels of heavy metals in edible plant parts has been reviewed by Page (1974) and Lepp (1981), but less has been reported on organic compounds and pathogenic microorganisms. Cadmium is of particular concern to toxicologists because of its ease of accumulation by plants (Heffron et al., 1980), its efficient deposition in animal tissue (Browning, 1969), and its toxicity (Fox, 1979).

The increased use of sewage sludge on agricultural land has expanded the need for an understanding of sludge properties and the quality of crops that are grown in sludge-amended soil. It is possible that sewage sludge as a soil amendment might affect crop quality, since the quality characteristics are primarily affected by the plant's biosynthetic processes, which may be altered by the use of a sludge-amended growing medium. Therefore, this study was undertaken to examine the quality characteristics of two varieties of tomatoes, New Yorker and Heinz 1350, field grown on a soil amended with a municipal sewage sludge.

EXPERIMENTAL SECTION

Field Culture of Tomatoes. Anaerobically digested municipal sewage sludge was obtained from the Ley Creek Sewage Treatment Plant in Syracuse, New York. This plant receives domestic waste, as well as the effluents discharged by about 100 industries, including industries for welding, plating, printing, laundering, fat rendering, and the manufacture of bearings, die castings, gears, tools, steel and electrical products, china, paper board, chemicals, wood preservatives, and beverage, dairy, and food products. No lime or other chemicals are added during the treatment process. The sludge used in this study was produced during 1978 and was allowed to weather for 1 year to facilitate the removal of excess soluble salts and the decomposition of potentially phytotoxic organic constituents.

Two 13 × 80 ft plots were located in Ithaca, New York. The soil consisted of Hudson silt loam (fine, illitic, mesic glassaquic hapludalfs, pH 6.2, cation-exchange capacity 16 mequiv/100 g, 4.1% organic matter), which was plowed and disced. In Sept 1979 2.4 tons of sludge (pH 6.9, fertilizer equivalent 1.4–1.3–0.1% (N–P–K), 53.1% moisture, 69.0% ash) was applied to one plot. This was equivalent to an application rate of 100 dry tons of sludge/acre (224

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metric tons/ha) or a layer of sludge about 1 in. deep covering the soil prior to its incorporation.

The sludge was spread evenly on the surface of the soil and was incorporated into the soil with 50 pounds of 15–6.5–12.5% (N–P–K) granular fertilizer by rotary cultivation. The control plot had 50 pounds of the granular fertilizer plus 2.4 tons of bull manure (bull excreta plus wood shavings and sawdust bedding) (fertilizer equivalent 1.6–1.0–2.9 (N–P–K), 66% moisture, 65% ash) incorporated into it. The pH of the resultant plots was 6.6 for the control and 6.4 for the sludge-amended plot. The nutrient element and other analyses of the soil, sludge, and manure were performed using standard soil testing methods (Greweling and Peech, 1960).

Seeds for the New Yorker and Heinz 1350 tomato varieties were placed in flats containing Cornell Peat-Lite Mix (Boodley and Sheldrake, 1977), in the greenhouse. In May 1981, the plants were transplanted to the plots at the age of about 1 month. One row of each variety was planted in each plot.

The plants were allowed to grow undisturbed until about 1 week after they had been transplanted, at which time all tomatoes and flowers were pinched off. This was done to ensure that all tomatoes that were evaluated had initiated their growth when the plants were in the control or sludge-amended growing medium rather than in the Cornell Peat-Lite mix. The tomatoes were harvested at the light red stage of maturity. Harvests were made every 3 or 4 days for six harvests. The tomatoes were stored at approximately 13 °C (55 °F) for up to 3 days. During this time they reached the red stage of maturity.

Laboratory Analyses. Both physiochemical and sensory measurements were made, to ensure a thorough evaluation of tomato quality. Volume was measured by distilled water displacement. Height and diameter were measured by vernier caliper. Tomato color was measured with the Hunter color difference meter (HCDM), Model D-25, for L (lightness), a (redness), and b (yellowness). As recommended by Hunter (1976), the aliquots were taken from samples that had been blended for 15 s on high speed in a Waring blender, and deaerated by vacuum pump for 4 min, to eliminate the effects of nonuniformity of pigment distribution and air. The a/b ratios were calculated as an index of ripeness in the tomatoes.

Flesh firmness was measured with the Instron Universal Testing Machine (Model TM). Force–distance curves were obtained for punctures of the pericarp wall, radial wall, and core by using a full-scale load of 200 g and a small-diameter probe (1.4986 mm diameter drill blank, 69.5 mm long) traveling at a constant rate of 20 cm/min that was allowed to penetrate 1 cm into a 2-cm tomato slice. The Instron machine was also used to measure skin toughness, with the difference between force–distance measurements of a "skin-on" and an adjacent "skin-off" puncture taken as the measure of skin toughness. The full-scale load was 1000 g, and the drill blank and penetration rate were the same as for the flesh firmness measurements.

Percentage of locular material was calculated from the weight of the tomato and the weight of the locular material, including the seeds. Moisture concentration was determined on the whole tomato, locular material, and combined flesh and skin tissues by the use of a Fisher Isotemp oven (Senior Model/forced draft) at 70 °C, until a weight constant to 0.003 g was reached. (The whole tomato samples contained locular material, flesh, and skin tissues.)

The soluble solids measurements were made by using a Bausch & Lomb Abbe 3-L desk refractometer, maintained between 17 and 21 °C. Corrections for temperature deviations from 20 °C were made. Measurements of pH were made by means of a Corning Model 10 pH meter with a semimicro combination electrode. Titratable acidity was performed by the official methods of analysis of the Association of Official Analytical Chemists (AOAC, 1970).

Reduced ascorbic acid was determined on the whole tomatoes, locular materials, and combined flesh and skin tissues by using the colormetric method of Loeffler and Ponting (1942), modified for use with the Bausch & Lomb Spectronic 20 spectrophotometer set at 520 nm. For cadmium analysis, the samples were freeze-dried, and a 1-g sample was then wet-ashed by using nitric, sulfuric, and perchloric acids. Cadmium in the acid digests were determined by conventional stripping voltammetry (Gajan and Larry, 1972).

Sensory evaluation was performed by a taste panel, consisting of six members, trained to make discriminatory evaluations. A rating scale of 1–7 was used to evaluate skin color, flesh color, off-odor, skin toughness, flesh firmness, flesh juiciness, overall juiciness, sourness, sweetness, characteristic tomato flavor, off-flavor, and overall quality. Standard sensory evaluation practices were used for training panel members and making evaluations.

Size, percentage of moisture, and reduced ascorbic acid were measured for all six harvests, cadmium was measured for the sixth harvest only, and all other measurements were made for the first five harvests. Each of the above measurements was performed on fresh tomatoes, except for color, a/b ratio, pH, titratable acidity, soluble solids, and soluble solids/titratable acidity ratio, for which the analyses were performed on tomato blends that had been frozen approximately 1 month and allowed to thaw at room temperature.

A 2 × 2 factorial design (sludge level × variety) with blocking for harvest date was used for the experimental design and analysis of all but the cadmium and sensory data. Since cadmium data were obtained for only one harvest, no statistical analysis could be performed. Sensory scores were analyzed by using a 2 × 2 factorial design (sludge level × variety) with blocking for harvest date and panel member.

RESULTS AND DISCUSSION

A summary of the data is presented in Table I. Table II lists the analysis of variance results.

Size. The sludge treatment significantly decreased the weight ($p < 0.001$), volume ($p < 0.001$), height ($p < 0.01$), and diameter ($p < 0.0001$) of the tomatoes. The effect of a sewage sludge–soil amendment on plant yield is variable, depending on the sludge-amended soil, plant species, variety, and plant part. For example, Baerug and Martinsen (1977) reported that sewage sludge application to soil increased the yield of potatoes, while Giordano et al. (1975) found that the yield of mature bean pods decreased with sewage sludge application to soil. These studies may not be directly applicable to the results reported here, since changes in yield can develop not only from changes in the size of individual fruits or vegetables but also from the number of fruits or vegetables produced. Few or no studies have examined the relative size of fruits or vegetables grown in sludge-amended soil.

Color. No significant difference was found between the control and sludge-grown tomatoes for the L values (lightness), the a values (redness), or the b values (yellowness). There was a significant sludge × variety interaction ($p < 0.05$) for the b measurement, indicating a tendency for the two varieties to respond differently to the sludge treatment. The Heinz 1350 tomatoes decreased in yellowness with the sludge treatment, while the New

Table I. Summary of Values (Mean ± Standard Deviation) of Control and Sludge-Grown New Yorker and Heinz 1350 Tomatoes

dependent variables	treatment groups: control New Yorker	control Heinz 1350	sludge-grown New Yorker	sludge-grown Heinz 1350
physiochemical				
weight, g	105.93 ± 13.56	110.59 ± 17.73	90.08 ± 14.57	92.42 ± 22.56
volume, cm^3	109 ± 14	113 ± 19	94 ± 16	95 ± 25
weight, cm	4.99 ± 0.10	4.98 ± 0.17	4.85 ± 0.24	4.76 ± 0.31
diameter, cm	5.79 ± 0.32	5.81 ± 0.35	5.40 ± 0.29	5.43 ± 0.41
L color	31.47 ± 1.62	31.52 ± 1.44	32.28 ± 2.10	31.28 ± 1.05
a color	26.87 ± 1.39	26.88 ± 1.48	26.59 ± 1.22	26.14 ± 1.25
b color	11.01 ± 0.55	11.09 ± 0.29	11.46 ± 0.31	10.81 ± 0.33
a/b ratio	2.46 ± 0.23	2.43 ± 0.15	2.33 ± 0.12	2.42 ± 0.13
pericarp wall firmness (g-force)	90.6 ± 16.8	91.0 ± 5.6	71.8 ± 14.2	85.2 ± 18.4
radial wall firmness (g-force)	69.5 ± 16.2	70.7 ± 11.1	58.1 ± 14.1	68.5 ± 13.2
core firmness (g-force)	78.2 ± 16.3	83.9 ± 27.5	56.8 ± 15.1	62.1 ± 8.7
skin toughness (g-force)	504 ± 51	551 ± 58	516 ± 41	509 ± 23
percentage of locular material, % fresh weight	14.57 ± 0.64	14.87 ± 1.05	15.35 ± 0.90	13.68 ± 0.97
moisture concentration—whole tomatoes, % fresh weight	93.05 ± 0.24	92.92 ± 0.46	92.97 ± 0.22	92.97 ± 0.18
moisture concentration—locular material, % fresh weight	91.91 ± 0.74	91.29 ± 0.58	91.46 ± 0.37	91.73 ± 0.50
moisture concentration—combined flesh and skin, % fresh weight	93.41 ± 0.22	93.00 ± 0.38	93.31 ± 0.33	93.13 ± 0.25
soluble solids, %	5.84 ± 0.24	6.39 ± 0.33	5.97 ± 0.06	6.08 ± 0.14
pH	4.50 ± 0.07	4.50 ± 0.13	4.50 ± 0.07	4.51 ± 0.08
titratable acidity, % citric acid	0.4347 ± 0.0384	0.4609 ± 0.0155	0.4130 ± 0.0154	0.4205 ± 0.0217
soluble solids/titratable acidity ratio	13.59 ± 1.47	14.01 ± 1.16	14.58 ± 0.45	14.58 ± 0.77
reduced ascorbic acid—whole tomatoes, mg/100 g fresh wt	20.18 ± 6.87	19.44 ± 3.64	19.51 ± 2.77	20.65 ± 4.23
reduced ascorbic acid—locular material, mg/100 g fresh wt	23.85 ± 16.38	20.13 ± 3.11	24.13 ± 5.18	22.93 ± 5.56
reduced ascorbic acid—combined flesh and skin, mg/100 g fresh wt	14.99 ± 2.40	17.74 ± 2.33	19.36 ± 1.78	18.88 ± 3.59
sensory				
skin color (1 = faint; 7 = intense)	3.7 ± 1.2	3.9 ± 1.4	3.5 ± 1.2	3.7 ± 1.3
flesh color (1 = faint; 7 = intense)	4.3 ± 1.2	4.1 ± 0.3	4.0 ± 1.2	4.3 ± 1.3
flesh firmness (1 = very soft; 7 = very firm)	3.6 ± 1.2	3.7 ± 1.3	2.9 ± 0.9	3.5 ± 1.4
skin toughness (1 = very tender; 7 = very tough)	4.4 ± 1.0	4.4 ± 1.3	4.1 ± 1.0	4.1 ± 1.2
flesh juiciness (1 = dry; 7 = very juicy)	3.9 ± 1.2	3.8 ± 1.1	3.8 ± 1.0	3.6 ± 1.1
overall juiciness (1 = dry; 7 = very juicy)	5.0 ± 1.1	5.1 ± 1.0	5.0 ± 1.1	4.9 ± 1.2
sourness (1 = slightly sour; 7 = very sour)	3.9 ± 1.3	4.0 ± 1.3	3.5 ± 1.3	3.6 ± 1.4
sweetness (1 = slightly sweet; 7 = very sweet)	3.3 ± 1.4	3.5 ± 1.5	3.3 ± 1.4	3.3 ± 1.1
characteristic tomato flavor (1 = absent; 7 = intense)	4.1 ± 1.2	4.3 ± 1.0	4.0 ± 1.2	3.8 ± 1.2
off-odor (1 = absent; 7 = intense)	1.8 ± 1.6	2.0 ± 1.6	1.8 ± 1.5	1.9 ± 1.4
off-flavor (1 = absent; 7 = intense)	1.5 ± 0.9	1.5 ± 0.9	1.5 ± 1.0	1.9 ± 1.3
overall quality (1 = very poor; 7 = excellent)	4.3 ± 1.2	4.3 ± 1.0	4.0 ± 1.2	3.8 ± 1.2

Yorker tomatoes increased in yellowness.

No significant difference was found between the a/b ratios of the control and sludge-grown tomatoes, showing that the tomatoes were at similar stages of maturity when the other measurements were made. This is advantageous to the data analysis, since variations in ripeness would be a strong confounding factor in the measurements of the other quality characteristics.

As with the results of the HCDM, there was no significant difference in the taste panel evaluation of skin color for the sludge-grown vs. that for the control tomatoes. Similarly, no difference in flesh color was found.

Texture. The sludge treatment significantly decreased the firmness of the pericarp wall tissue ($p < 0.05$), radial wall tissue ($p < 0.1$), and core tissue ($p < 0.01$). The firmness of tomato flesh is strongly influenced by the ability of the plant to adequately produce pectic substances and other compounds that contribute to flesh firmness (Kader and Morris, 1976). Flesh firmness is also related to growth conditions, with warmer, more moist conditions leading to the production of softer fruits (Shafshak and Winsor, 1964). Furthermore, the mineral status of the soil can affect the calcium level of tomatoes, and firm tomatoes have been associated with the accumulation of more calcium in the fleshy portion of the fruit (Hamson, 1952), possibly due to the production of a calcium pectate gel in the tissue (Dennison, 1955). Sewage sludge application to soil can interfere with the synthesis capabilities of plants (Hinesly et al., 1976), may increase the moisture level of the soil (EPA, 1975; Epstein et al., 1976), and can interfere with mineral accumulation and/or translocation by plants (Lepp, 1981). No increase in concentration of calcium in bermuda grass (*Cynodon dactylon L.*) was found when it was grown on sludge-amended soils (King and Morris, 1972; Mays et al., 1973).

Similarly, the taste panel rated the sludge-grown tomatoes as significantly less firm ($p < 0.001$) than the control tomatoes. There was also a significant ($p < 0.05$) sludge × variety interaction. The New Yorker tomatoes decreased more in firmness than the Heinz 1350 tomatoes did when grown on sludge-amended soil.

No significant difference was found between the skin toughness values of the control and sludge-grown tomatoes when measured by using the Instron instrument. However,

Table II. Summary of Analysis of Variance Results

dependent variable	significance level
physiochemical	
weight	0.001
volume	0.001
height	0.01
diameter	0.0001
L color	NS
a color	NS
b color	NS
a/*b* ratio	NS
pericarp wall firmness	0.05
radial wall firmness	0.1
core firmness	0.01
skin toughness	NS
percentage of locular material	NS
moisture concentration--whole tomatoes	NS
moisture concentration—locular material	NS
moisture concentration—combined flesh and skin	NS
soluble solids	NS
pH	NS
titratable acidity	0.01
soluble solid/titratable acidity ratio	0.05
reduced ascorbic acid—whole tomatoes	NS
reduced ascorbic acid—locular material	NS
reduced ascorbic acid—combined flesh and skin	0.05
sensory	
skin color	NS
flesh color	NS
flesh firmness	0.001
skin toughness	0.01
flesh juiciness	NS
overall juiciness	NS
sourness	0.01
sweetness	NS
characteristic tomato flavor	0.05
off-odor	NS
off-flavor	NS
overall quality	0.01

[a] NS = no significant difference.

the taste panel rated the skins of the sludge-grown tomatoes as significantly ($p < 0.01$) more tender than those of the control tomatoes. This variation in results may be attributable to the different sample presentations of the two methods.

In this study, juiciness was measured in terms of percentage of locular material and moisture concentration. The percentage of locular material values were not significantly different for the control and sludge-grown tomatoes. However, a significant sludge × variety interaction ($p < 0.05$) was found. The New Yorker tomatoes tended to have an increased percentage of locular material when grown in sludge-treated soil, while the Heinz 1350 tomatoes had less. No significant dfference was found between the percentage of moisture in the control vs. the sludge-grown tomatoes for the whole tomatoes, locular material, or combined flesh and skin tissues. Similarly, no significant difference was found between the taste panel ratings of flesh juiciness or overall juiciness for the control and sludge-grown tomatoes.

Flavor and Odor. Physiochemical measurements were used to measure the concentration of compounds that strongly contribute to tomato flavor, while sensory evaluations were used to measure specific odor and flavor notes. The sludge treatment did not significantly affect the soluble solid concentrations of the tomatoes, but there was a significant ($p < 0.05$) sludge × variety interaction. The Heinz 1350 tomatoes tended to decrease in soluble solid concentration with the sludge treatment, and the New Yorker tomatoes tended to increase. Hinesly et al. (1976) reported that carbohydrate production was relatively low in stunted plants growing on plots amended with high levels of sewage sludge. However, it is also known that fruits exposed to sunlight tend to have higher soluble solid concentrations than shade fruits (Dennison, 1955). It is possible that the sludge-grown tomatoes, especially those on the New Yorker plants, were exposed to more sunlight, due to the less luxuriant growth of the plants. As with the soluble solids data, no significant difference was found between the sweetness ratings of the control and sludge-grown tomatoes.

There was no significant difference between the pH values of the sludge-grown and control tomatoes, but the sludge-grown tomatoes had significantly ($p < 0.01$) lower titratable acidity values than the control tomatoes. Decreased tomato acidity has been associated with higher moisture levels in the soil (Walkof and Hyde, 1963), and sludge application may increase the moisture content of the soil (Epstein et al., 1976). Furthermore, the concentration of citric and malic acid are increased by high levels of potassium in the soil (Davies, 1964), and potassium deficiency may result in a lower acid content in tomatoes (Bradley, 1962). The titratable acidity results seen here may have resulted from the lower potassium content of the sludge (fertilizer equivalent 0.1%) vs. that of the manure (fertilizer equivalent 2.9%). The sludge-grown tomatoes had higher ($p < 0.05$) soluble solids/titratable acidity ratios than the control tomatoes, reflecting their lower titratable acidity levels.

The taste panel rated the sludge-grown tomatoes significantly less sour ($p < 0.01$) than the control tomatoes. These results are supported by the titratable acidity data, which indicated decreased acidity in the sludge-grown tomatoes. McIntyre et al. (1977) grew crops on land fertilized with wastewater sewage sludge and reported that tomatoes harvested from the sludge-grown plants tasted less acidic.

The control tomatoes were rated significantly higher ($p < 0.05$) in characteristic tomato flavor than the sludge-grown tomatoes were. Also, a significant ($p < 0.1$) sludge × variety interaction was found. The Heinz 1350 tomatoes were decreased more than the New Yorker variety in characteristic tomato flavor when grown in sludge-amended soil. The presence of characteristic tomato flavor depends on the levels of volatile compounds and the balance of sugars, organic acids, and other chemical components of the fruit. In this study, titratable acidity was decreased in the sludge-grown tomatoes, but the pH level and soluble solids concentration did not significantly change.

The control and sludge-grown tomatoes were rated similarly in off-odor and off-flavor. The overall low scores for all treatment groups indicate that the taste panel considered any off-odor or -flavor to be absent or faint. There was a significant sludge × variety interaction ($p < 0.1$) for off-flavor. The New Yorker tomatoes were rated similarly from the control and sludge-amended plots, but the Heinz 1350 tomatoes increased in off-flavor when grown in the sludge-amended plot.

Ascorbic Acid. There was no significant difference in the reduced ascorbic acid concentration of the sludge-grown vs. the control group for the whole tomatoes or the locular material. However, the reduced ascorbic acid concentration of the combined flesh and skin tissues of the

Table III. Cadmium Concentration in Tomatoes and Growth Media Materials

sample	cadmium, ppm, dry wt control	sludge grown
tomato (Heinz 1350)	0.27	1.38
tomato (New Yorker)	0.44	1.26
sludge	81.0	
manure	0.6	
soil	1.3	

sludge-grown tomatoes was significantly higher than that of the control tomatoes ($p < 0.05$). Lee et al. (1980) found that sludge-grown vegetables were higher in ascorbic acid than control vegetables. It is recognized that tomatoes that are exposed to more sunlight tend to be higher in ascorbic acid (Beeson and Matrone, 1976). Furthermore, McCollum (1946) found that in unshaded tomato fruits, the outer flesh is highest in ascorbic acid and the locular material is lowest, but in shaded fruits the locular material is higher in ascorbic acid. It is likely that the sludge-grown tomatoes were exposed to more sunlight, due to the less luxuriant foliage of the plants, and this probably accounts for the difference in ascorbic acid between the combined flesh and skin tissues of the control and sludge-grown tomatoes.

Cadmium. The cadmium concentrations in ppm, dry weight, are listed in Table III. The sludge-grown tomatoes were notably higher in cadmium concentration. Since the tomatoes contained over 90% moisture (Table I), these concentrations of cadmium would be low on a fresh weight basis. There is no established federal tolerance for cadmium in foods.

Overall Quality. The sludge-grown tomatoes were rated significantly lower in overall quality than the control tomatoes ($p < 0.01$).

The plants grown on sludge-amended soil did not appear to grow as well as the control plants and were considerably smaller. The mean weights of the tomato plants (stems and foliage) per treatment group ($n = 27$) were 1025 g for the control New Yorker, 541 g for the sludge-grown New Yorker (52.8% by weight of the control plants), 2078 g for the control Heinz 1350, and 1752 g for the sludge-grown Heinz 1350 (84.3% by weight of the control plants).

Further research is necessary before sludge can be recommended for use in agriculture. The composition of sludge may vary considerably depending on the spectrum of industries served and their changing rates of production and periodic relocations. The availability of heavy metals in soil for crop uptake will vary with soil type, pH, organic matter, and clay content as well as weather conditions and crop species. The potential for groundwater pollution by synthetic organics (Tomson et al., 1981) or pathogens (Moore et al., 1981) in sludge, direct hand to mouth contamination by children frequenting such sludge-treated areas (De Crosta, 1981), or possible later contamination of subsequently grown high cadmium absorbing crops such as leafy vegetables as land uses change with time are serious limitations to its use on agricultural land. Furthermore, it has recently been shown that earthworms in municipal sludge amended soil can absorb high concentrations of cadmium (Wade et al., 1982) that could be toxic to birds.

Registry No. L-Ascorbic acid, 50-81-7; cadmium, 7440-43-9.

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