Quality of Potatoes Grown in Soils Amended with Sewage Sludge

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The effect of sludge-amended soil on total, nonprotein, and protein nitrogen content and the ascorbic acid and phenolic content as well as enzymatic darkening of potatoes was investigated in a 2-year indicative study. In both years the cortex tissue of potatoes grown on sludge-amended soil was higher in total and protein nitrogen than the controls. In the pith tissues, however, the trend was opposite of that found in the cortex. In the first year of the study potatoes grown on sludge-amended soil were slightly higher in ascorbic acid than the controls, but in the second year the trend was reversed. No significant trends were observed for phenols and enzymatic darkening in potatoes grown on sludge-amended soil.

Vesiland (1980) estimated that approximately 10^7 dry metric tons of municipal sludge will be produced annually in the United States by 1990. Due to the organic matter and plant nutrient content in sludge, research is presently under way to study its potential use as a fertilizer and soil conditioner in agriculture (Boyd et al., 1982).

Much work has been reported on the absorption of heavy metals such as Cd, Cu, Ni, Pb, Zn by plants when grown on municipal sludge amended soils, and these have been reviewed by Sommers (1980). In contrast, little has been reported on the use of municipal sewage sludges in agriculture and their effect on crop quality including nutrient content.

Potatoes provide practically all the essential dietary factors including a high-quality protein, minerals, and essential vitamins (Woodward and Tally, 1953), but these vary with variety, storage conditions, growing conditions, soil composition, and type of fertilization. Muthuswamy et al. (1977) reported that application of industrial and mineral wastes to soil in India significantly increased the crude protein content of potatoes. Application of zinc sulfate at a rate of 112 kg/ha was found to increase the protein nitrogen of potatoes (Mondy and Chandra, 1981). The effect of municipal sewage on nitrogeneous constituents of potatoes has not been studied, and it is important that this factor be considered.

Potatoes grown on sludge-amended soil relative to controls were shown to contain higher amounts of ascorbic acid, riboflavin, thiamin, and niacin on the dry weight basis, but no significant differences in flavor were observed (Lee et al., 1980). Application of zinc sulfate at a rate of 112 kg/ha was found to increase the ascorbic acid content of potatoes (Chandra, 1981), and fertilization with manganese also has been found to increase ascorbic acid content of tomatoes (Hester, 1941).

Relatively little is known concerning the effect of sludge fertilization on the chemical composition of potato tubers, especially phenols. The phenolic content of tubers was found to be positively correlated with tuber astringency and bitterness (Mondy et al., 1971), as well as enzymatic discoloration (Mondy et al., 1967). The principal phenolic compound in potatoes is chlorogenic acid, which is concentrated in the cortex region of the tuber (Mondy et al., 1971) and is affected by mineral fertilization. Nitrogen fertilization increased tuber discoloration over that of control tubers (Mondy et al., 1979), and zinc fertilization decreased tuber discoloration (Mondy and Chandra, 1981).

The objectives of this indicative, short-term study were to determine the effects of heavy applications of a metal contaminated municipal sewage sludge on the nitrogenous constituents, ascorbic acid, total phenols, and enzymatic discoloration of potatoes.

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MATERIALS AND METHODS

The Katahdin potatoes were grown in Binghamton, NY, on a Mardin channery silt loam (coarse, loamy, mixed, mesic Typic Fragiocrept). The application site was established in 1975 as part of commercial sewage sludge disposal operation. The sludge was derived from treatment of municipal effluents discharged by about 100 industries as well as the domestic wastes from a metropolitan area. The average composition of the anaerobically digested sewage sludge was estimated to be as follows: total solids 4%, Kjeldahl nitrogen 5.5%, ammonia nitrogen 2.5%, phosphorus 2.0%, Cd 130 mg/kg, Cu 1050 mg/kg, Ni 540 mg/kg, Pb 45 mg/kg, and Zn 3500 mg/kg on a dry weight basis. No lime or chemicals were added during the treatment process. During the 5 years of use, the disposal site received sewage sludge at the rate of 100–120 dry kg/ha annually, which is considered as an excessively high rate of application. Sewage sludge was applied by spray irrigation and by soil injection to a depth of 15 cm by a special all-terrain vehicle (Ag-Gator) with a delivery capacity of 45 000 L. The treated soil was later disked to a depth of 20 cm. No further sludge applications were made after 1979. Field corn was grown on the site in 1980. In 1981 (year 1) and 1982 (year 2) growing seasons, potatoes (*Solanum tuberosum* L., cv. Katahdin) were grown on this site in a completely random design. The pH for year 1 (mean ± SD) was 5.3 ± 0.1 and 5.1 ± 0.1 for year 2. Cation exchange capacity (CEC) was 24.6 ± 2.4. Katahdin potatoes from the same seed source were also grown on a control site that had not been sludge amended but had received the recommended amount of N-P-K (1-2-1) fertilizer each year. In both years of the study potatoes were harvested 17 weeks following planting and were stored at 5 °C until analyzed.

Samples of sludge-amended soil were taken at each growing season before potatoes were planted. Elemental analyses of the sludge-amended soil are presented in Table I. These were performed by the Soil Testing Laboratory of the Department of Agronomy at Cornell University (Greweling and Peech, 1965).

Potato tubers were washed, dried, and stored at 5 °C in the dark for 6 months prior to analysis. Potatoes of comparable size were selected in order to limit variations resulting from size differences. Tubers were cut longitudinally from bud to stem end in order to include both apical (bud) and basal (stem) portions, and slices were subsequently separated into cortex and pith sections. Cortex tissue (including the periderm) from four tubers was used in the total phenol analysis since this is the area highest in phenolic content. Fresh cortex and pith tissue from 10 tubers each from the control as well as the treated

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Table I. Mineral Composition of Sewage Sludge Amended Soil[a]

element	concentration year 1	concentration year 2
	mt/ha[b]	
P	99.8 ± 11.2	90.4 ± 13.6
K	299.0 ± 28.2	232.2 ± 11.0
Mg	302.0 ± 29.9	198.1 ± 23.21
Ca	3416.0 ± 233.0	2772.0 ± 183.0
Mn	722.0 ± 174.0	662.7 ± 75.3
Fe	23.4 ± 2.91	62.4 ± 6.6
Al	42.0 ± 3.1	66.5 ± 5.5
Zn	494.0 ± 115	299.7 ± 32.7
	μg/g of Dry Weight[c]	
Cu[d]	192.2 ± 21.8	161.8 ± 14.1
Cd	35.1 ± 4.7	31.5 ± 2.6
Zn	692.6 ± 83.1	640.0 ± 64.5
B[e]	2.2 ± 0.3	2.1 ± 0.3

[a] Mean ± standard deviation. [b] NaOAc/HOAc soluble (available). [c] Acid soluble by 8 N HNO_3 digestion (total). [d] Acid soluble by 0.1 N HCl digestion (available). [e] Water soluble (available).

were frozen, lyophized in a Stokes freeze-dryer, ground in a Wiley mill through a 40-mesh screen, and stored under nitrogen until analyzed. Four determinations were made on each of the control potatoes as well as those that were grown on sludge-amended soil.

Determination of Total Nitrogen. Total nitrogen was determined on freeze-dried potato powder according to the micro-Kjeldahl method described in AOAC (1975).

Determination of Nonprotein Nitrogen. The method of Desborough and Weiser (1974) modified by Klein et al. (1980) using trichloroacetic acid precipitation was used for nonprotein nitrogen determination.

Determination of Protein Nitrogen and Protein Content. Protein nitrogen content was determined by substracting nonprotein nitrogen from total nitrogen. Percent protein was calculated by multiplying protein nitrogen content with micro-Kjeldahl conversion factor of 7.5 for potato protein as indicated by Desborough and Weiser (1974).

Ascorbic Acid Determination. L-Ascorbic acid was determined on potato tissue by using the 2,6-dichloroindophenol method of Horwitz (1970).

Determination of Phenols. The total phenolic content was determined colorimetrically by using tannic acid as the standard (Mondy et al., 1966).

Determination of Enzymatic Discoloration. Color measurments were made by using the Hunter color difference meter (Mondy et al., 1967).

Statistical Analyses. A completely random design was employed, and statistical significance of the data was determined by using 2 × 2 or 2 × 2 × 2 analysis of variance with protected LSD test described by Steel and Torrie (1980).

RESULTS AND DISCUSSION

Total Nitrogen. The total nitrogen content of cortex and pith tissues of potatoes is reported in Table II. In both years the total nitrogen of cortex tissues of potatoes grown on sludge-amended soil was significantly ($p < 0.05$) higher and the pith significantly lower than that of the controls (Figure 1; Table II). In the control potatoes the pith was significantly higher ($p < 0.05$) in total nitrogen than the cortex tissue. However, this trend was not observed in potatoes grown in sludge-amended soil.

Nonprotein Nitrogen. The nonprotein nitrogen of cortex and pith tissues of potatoes is given in Table II. In the first year, the nonprotein nitrogen content of cortex tissues of potatoes grown on sludge-amended soil was significantly ($p < 0.05$) higher than that of controls and both control and treated cortex tissues had higher nonprotein content than pith tissues, but this trend was not observed in the second year (Figure 2).

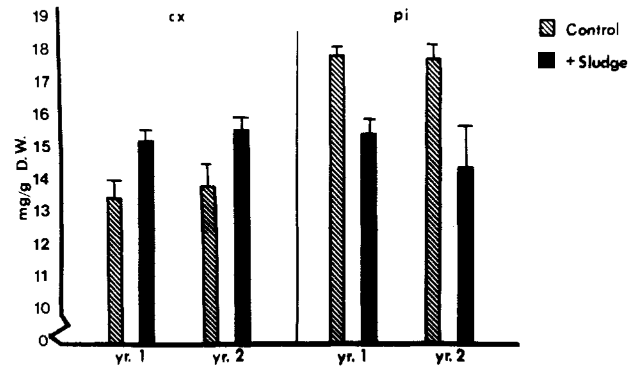

Figure 1. Effect of sludge-amended soil on total nitrogen content (dry weight basis) of potatoes.

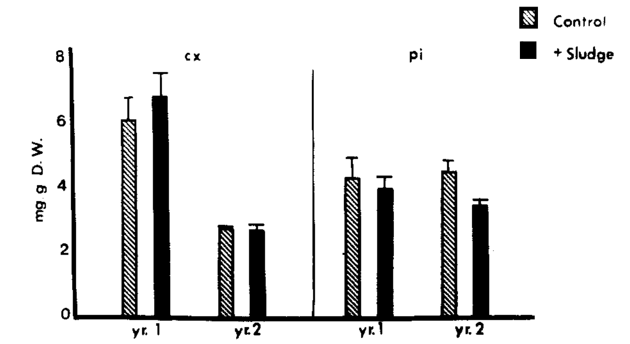

Figure 2. Effect of sludge-amended soil on nonprotein nitrogen content (dry weight basis) of potatoes.

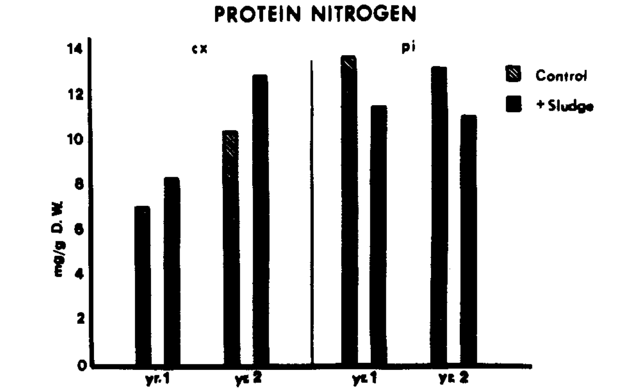

Figure 3. Comparison of protein nitrogen content (dry weight basis) of potatoes grown in sludge-amended soil.

Protein Nitrogen. Protein nitrogen was higher in the cortex tissue and lower in pith tissues of potatoes grown on sludge-amended soil than in the controls (Figure 3; Table II). A similar trend was observed in the protein content (Table II).

Ascorbic Acid. The ascorbic acid content of potatoes is presented in Table III. For the ascorbic acid content, treatment and year were significant ($p < 0.05$). In the second year, both cortex and pith of potatoes grown on sludge-amended soil was significantly ($p < 0.05$) low in ascorbic acid content than the controls (Figure 4; Table III). The ascorbic acid content of tubers in year 2 was significantly ($p < 0.05$) higher than that of year 1 (Figure 4). The reason for this is unknown. Sunlight is known as

Table II. Nitrogenous Constituents of Cortex and Pith Tissues of Potatoes

treatment	mean[a] control	mean[a] +sludge	range control	range +sludge
	mg/g on a Dry Weight Basis			
total nitrogen				
year 1				
Cx	13.54 ± 0.47	15.32 ± 0.30	12.97–14.01	14.98–15.77
Pi	17.92 ± 0.26	15.53 ± 0.44	17.68–18.15	15.11–15.94
year 2				
Cx	13.88 ± 0.64	15.63 ± 0.40	13.12–14.51	15.08–15.95
Pi	17.77 ± 0.41	14.41 ± 0.59	17.40–18.34	13.75–15.07
nonprotein nitrogen				
year 1				
Cx	6.19 ± 0.77	6.96 ± 0.70	5.30–6.95	6.24–7.89
Pi	4.30 ± 0.64	4.08 ± 0.36	3.72–4.98	3.72–4.45
year 2				
Cx	2.75 ± 0.08	2.72 ± 0.05	2.66–2.84	2.67–2.79
Pi	4.47 ± 0.35	3.31 ± 0.05	4.09–4.79	3.28–3.39
protein nitrogen				
year 1				
Cx	7.35	8.36		
Pi	13.62	11.45		
year 2				
Cx	11.13	12.91		
Pi	13.30	11.10		
	% on a Dry Weight Basis			
protein content				
year 1				
Cx	5.51	6.27		
Pi	10.20	8.59		
year 2				
Cx	8.35	9.68		
Pi	9.98	8.33		

[a] Mean ± standard deviation.

Table III. Ascorbic Acid Content of Cortex and Pith Tissues of Potatoes

treatment	mg/100 on a fresh weight basis: mean[a] control	mean[a] +sludge	range control	range +sludge
year 1				
Cx	13.11 ± 0.53	14.45 ± 1.10	12.62–13.84	12.99–15.62
Pi	13.45 ± 2.14	14.47 ± 0.67	11.25–16.29	13.59–15.13
year 2				
Cx	26.69 ± 4.19	21.11 ± 1.79	20.52–29.70	18.90–22.79
Pi	24.96 ± 3.66	18.94 ± 2.14	20.30–28.90	17.66–22.14

[a] Mean ± standard deviation.

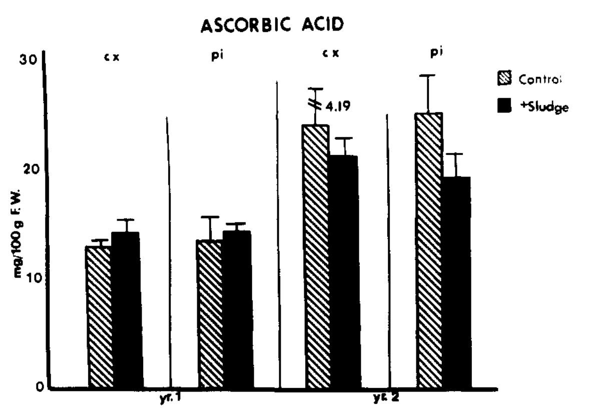

Figure 4. Comparison of ascorbic acid content (fresh weight basis) of potatoes grown in sludge-amended soil.

Table IV. Enzymatic Discoloration and Phenolic Content of Potatoes

treatment	mean[a] control	mean[a] +sludge	range control	range +sludge
	Enzymatic Discoloration: Color (Rd)[b]			
year 1	21.4 ± 0.5	22.9 ± 3.8	20.8–22.0	19.1–26.3
year 2	19.9 ± 0.3	18.9 ± 0.4	19.6–20.1	18.5–19.4
	Phenolic Content mg/100 g on a Fresh Weight Basis			
year 1	80.16 ± 2.59	73.63 ± 11.81	77.59–83.76	63.22–85.85
year 2	81.60 ± 1.16	90.89 ± 7.10	80.20–83.03	80.56–96.78

[a] Mean ± standard deviation. [b] Reflectance is expressed as Rd and the Rd values decrease as blackening increases.

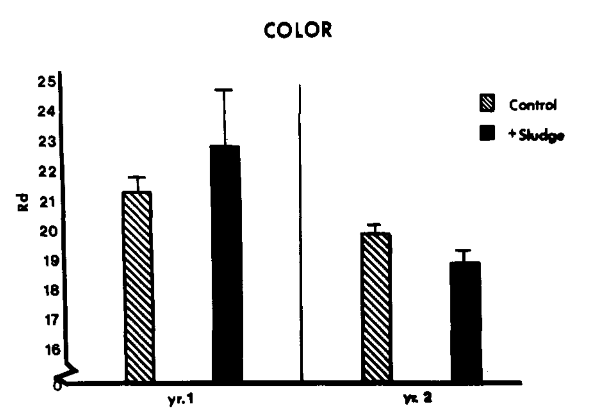

Figure 5. Effect of sludge-amended soil on enzymatic darkening of potatoes.

a major factor affecting synthesis of ascorbic acid (Brown, 1954).

Enzymatic Darkening and Phenols. The enzymatic discoloration of cortex tissues of potatoes is reported in Table IV. In both years the enzymatic darkening of tubers grown on sludge-amended soil was not significantly different from that of controls (Figure 5), but a wide variation in enzymatic darkening of sludge-grown potatoes occurred.

The phenolic content of cortex tissues of potatoes is reported in Table IV. In both years the phenolic content of potatoes grown on sludge-amended soil was not significantly different from that of controls (Figure 6), but

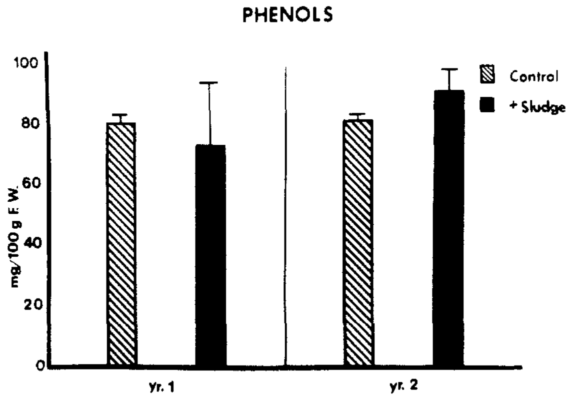

Figure 6. Effect of sludge-amended soil on phenolic content (fresh weight basis) of potatoes.

there was a wide range in phenolic content of sludge-grown potatoes. A high positive correlation between darkening and the phenolic content of tubers has been reported (Mondy et al., 1967). The wide variation of enzymatic discoloration and phenolic content may have been due to the wide variation in trace minerals in the soil and/or to the mineral interactions. Sludge-amended soil had high concentrations of phytotoxic minerals, which may have caused stress to the plants.

CONCLUSION

In both years of the study the cortex tissue of potatoes grown on sludge-amended soil was significantly ($p < 0.05$) higher in total and protein nitrogen than the controls. However, the opposite trend was observed for pith tissue. No significant differences in ascorbic acid content were observed in the first year of the study, but in the second year both cortex and pith from potatoes grown in sludge-amended soil were significantly ($p < 0.05$) lower in ascorbic acid content than the controls. Phenolic content and darkening did not show a significant trend with sludge-amended soil.

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Registry No. N_2, 7727-37-9; ascorbic acid, 50-81-7.

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Novel Volatiles in Pineapple Fruit and Their Sensory Properties

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Nineteen additional, mainly in trace amounts, occurring volatiles of pineapple fruit—including four nonterpenoid hydrocarbons and a number of carboxylic esters—have been isolated under enzyme inhibition, enriched by liquid–liquid extraction, fractionated on silica gel, and identified by gas chromatography and coupled GC–MS. Among them, 1-(*E*,*Z*)-3,5-undecatriene and 1-(*E*,*Z*,*Z*)-3,5,8-undecatetraene may contribute to the typical flavor of pineapple. They combine a fragrant odor with extremely low odor detection thresholds. The corresponding *E*,*E* and *E*,*E*,*Z* isomers are much less odorous (factors of 10^6 and 10^4, respectively). Disintegration of the fruit tissue without enzyme inhibition causes a rapid decrease of all undecaenes.

The distinct and pleasant flavor of pineapple fruit has been the subject of a number of studies, resulting in the identification of more than 100 components (van Straten, 1977). More recently, 4-methoxy-2,5-dimethyl-2(*H*)-furan-3-one (Pickenhagen et al., 1981), 2-propenyl hexanoate (Nitz and Drawert, 1982), and a number of sesquiterpene hydrocarbons (Berger et al., 1983) have been found to be genuine components of pineapple flavor.

Nevertheless, the manufacture of commercial pineapple formulations is difficult (Broderick, 1975), and satisfying results are only obtained by addition of various (nonpi-

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