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Experimental plots near Castroville were irrigated with three water types, fertilized at four nitrogen rates, and cultivated with six crops over five years. Photo shows artichoke plots at the right and lettuce at the left. In infrared photo of the same area on the cover, visible differences are attributable to different fertilizer rates. No other differences were noted in any of the crops tested.

Reclaimed water for irrigation of vegetables eaten raw

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A five-year study revealed no public health risk associated with irrigation of raw-eaten vegetable crops with reclaimed domestic wastewater.

Treated municipal wastewater has long been used for agricultural irrigation in many parts of the world with varying degrees of environmental safeguards and protection of public health. (See "Using reclaimed municipal wastewater for irrigation" by Takashi Asano and G. Stuart Pettygrove, *California Agriculture*, March-April 1987.) In California, State Department of Health Services regulations strictly control wastewater reuse for spray irrigation of unprocessed food crops, and make reuse for vegetable irrigation economically impractical. Special conditions have arisen in northern Monterey County, however, that make such an undertaking possible: severe water shortage, seawater intrusion into the coastal aquifers, and construction of a new 30-million-gallon-per-day regional wastewater treatment plant in the midst of the most severely affected farming area.

When the concept of reclamation was first proposed, local public health officials and vegetable growers were wary and demanded that a long-term field study be conducted before reclaimed water was put into widespread use. As a result, the Monterey Wastewater Reclamation Study for Agriculture (MWRSA) was created. MWRSA was a field study of the feasibility of using tertiary-treated municipal wastewater to irrigate food crops that are eaten raw, as well as artichokes, a principal crop of the Castroville area. Tertiary treatment removes practically all solids and organic matter from wastewater.

The experiment

The field trial site, on a farm in Castroville, included 3 acres of experimental plots and 25 acres of demonstration fields.

The experimental plots consisted of 96 subplots irrigated with one of three water types, fertilized at four nitrogen rates, and cultivated with six crops over five years. The three water types compared were (1) filtered secondary-treated wastewater (referred to here as "filtered effluent"); (2) coagulated, flocculated, settled, and filtered secondary effluent ("Title-22 water," conforming strictly to the highest treatment process steps required in the California Administrative Code, Title 22, Division 4, for direct reuse to irrigate food crops eaten raw [nonprocessed food crops]); and (3) local well water as a control. The four fertilizer rates compared were zero, one-third, two-thirds, and the full nitrogen fertilizer rate commonly used in the area. Each combination of water type and fertilizer rate was replicated four times in the experimental plots. The purpose was to generate reliable statistical data on the separate effects of the water types and fertilizer rates on the various crops and the soil. Varying fertilizer rates allowed assessment of the nutrient value of the reclaimed water.

The experimental plots were the most prominent component of MWRSA. From these plots, arranged in a split-plot design, we obtained quantitative, statistically analyzable data to test the hypothesis that "both filtered effluent and Title-22 water are safe and acceptable for irrigation of food crops that are eaten raw."

Six crops common in northern Monterey County were grown over the five-year period. One-half of the field was continuously planted with artichokes, and the other half was planted with a succession of different vegetables: celery, broccoli, head lettuce, several varieties of leaf lettuce, and cauliflower.

During and after each growing season, samples of plant tissues, plant residues, soils (from depths of 1, 3, and 6 feet), and irrigation and runoff waters were collected and analyzed for viruses, bacteria, pathogens, metals, and a host of other chemical and physical properties. The results were then subjected to statistical testing — analysis of variance (ANOVA) — to separate the effects of the various water types and fertilizer rates from random variations due to chance.

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The Castroville sewage treatment plant was modified and expanded for this experiment. Tertiary treatment unit was added to remove solids and organic matter from the wastewater. Effluent from these units was stored in redwood tanks at right and piped to nearby experimental plots.

The existing Castroville secondary treatment plant was extensively modified and expanded to provide the two tertiary streams of reclaimed water to the experimental and demonstration plots. Before modification, the plant provided conventional activated sludge treatment. (Plant flows averaged 400,000 gallons a day.) Two small tertiary process flowstreams were added following the secondary treatment processes. One process stream, the "filtered-effluent" flowstream, consisted of direct filtration followed by chlorine disinfection and dechlorination and had an average flow of 235,000 gallons per day. The other, highly treated, Title-22 process stream, consisting of chemical coagulation, flocculation, settling, filtration, chlorine disinfection, and dechlorination, averaged flows of 15,000 gallons per day.

Because of particular interest in virus survival characteristics, MWRSA included an extensive virology element: (1) development and evaluation of methods for the recovery of animal viruses from irrigation waters and from irrigated plants and soils; (2) determination of characteristics of virus survival on plants and soils; (3) on-site monitoring of irrigation waters, plants, and soils; and (4) extensively repeated virus seeding to determine treatment plant effectiveness in inactivating viruses. The developmental studies and the seeding experiments were conducted using vaccine-strain poliovirus.

Fifteen soil chemical properties were measured on all soils sampled from the experimental plots: pH, electrical conductivity, calcium, magnesium, sodium, potassium, carbonate, bicarbonate, total Kjeldahl nitrogen (TKN), nitrate, ammonia, phosphorus, chloride, sulfate, and boron. In addition, the sodium adsorption ratio (SAR) and adjusted SAR were calculated on the soil saturation extracts. Nine heavy metals were analyzed on all soil samples at three depths.

Results

Five years of field data were collected and analyzed. Table 1 lists chemical properties of irrigation waters. Results of the study upheld the hypothesis that there are no significant differences among crops irrigated with the two types of tertiary effluents and well water.

No viruses were detected in any of the tertiary effluent samples. These samples averaged more than 800 gallons in volume each, and 68 samples were taken from each of the two effluents during the five years of the study. Total and fecal coliform counts in the reclaimed waters were consistently higher than levels in well water because of regrowth following dechlorination, mainly during storage in redwood tanks. These differences, however, were generally not reflected in significant differences in the coliform counts in the soil or plant tissue samples. To determine the effects of dechlorination on regrowth, we discontinued dechlorination in the third year with no ill effects on produce quality or yield.

Heavy metal content in all of the irrigation waters was low, in many cases below detection levels. Because no heavy metals were being detected in any of the water samples, we refined analytical techniques during the third year to improve detection levels. Even with these refinements, concentrations of cadmium, zinc, iron, manganese, copper, nickel, cobalt, chromium, and lead in all three water types were generally close to or below the lower detection limit. For all three water types, median heavy metal concentrations were well below irrigation water quality maximums for continuous use on all soils. The average heavy metal content in reclaimed irrigation waters even met California safe drinking water standards.

The reclaimed waters used for irrigation contained considerably higher levels of some chemicals, including nutrients, than did the well water. These higher levels are believed to have caused the consistently greater sodium and chloride levels in the soils of subplots irrigated with reclaimed water. The higher sodium concentration in the effluents was reflected in generally higher sodium adsorption ratios (SAR). Values for SAR and adjusted SAR were closely related at all three soil depths, with coefficients of correlation ranging from .834 to .927.

Irrigation waters that are relatively high in sodium and low in total salt content may lower soil permeability by causing clay swelling and dispersion. Figure 1 shows the salinity and SAR boundary that divides irrigation waters into those creating poor soil permeability and those producing favorable soil conditions. The stippled band rising from lower left to upper right of the graph summarizes the judgment of J.D. Oster and J.D. Rhoades ("Water Management for Salinity and Sodicity Control" in *Irrigation with Reclaimed Municipal Wastewater — A Guidance Manual*, 1985, G. S. Pettygrove and T. Asano [editors], Lewis Publishers, Inc., Chelsea, Michigan) based on the results of decades of research by a number of soil and plant scientists. The band on the graph is derived from this study, and the authors state that it is equally applicable to SAR or adjusted SAR values. The ill effects of the higher SAR were more than amply compensated for by correspondingly higher salinities, as measured by total dissolved solids. These effects were more pronounced at the 1-foot soil depth than in the deeper soils.

Samples of each crop harvested, in this case cauliflower, were boxed and placed in cold storage for up to four weeks to evaluate quality and shelf life. Produce grown with reclaimed water was equal in these characteristics to produce grown with well water.

Soil properties affected by fertilizer rate included concentrations of nutrients and of several heavy metals (zinc, cadmium, and nickel). No trends with time were observed for any of the elements over the five-year period.

Surface-soil sampling for microbiological content included analysis for total and fecal coliform. No significant difference in coliform levels attributable to water type was observed. Any samples with fecal coliform counts above the detection limit were tested for presence of the pathogens *Salmonella* and *Shigella*, and none were found. All soils were also analyzed for parasites — *Ascaris lumbricoides, Entamoeba histolytica*, and miscellaneous parasites — and none were positive.

As previously noted, monthly sampling of tertiary treatment plant effluents did not detect any virus during the five years. When plants in the field were seeded with vaccine-strain poliovirus, an obvious decrease with time occurred in the average number of viruses recovered from the plants exposed to local conditions. Virus decay appears to be log linear with time. Results indicate that the average T99 value (the number of days for a 99 percent, or two orders of magnitude, reduction in poliovirus on plants in the test plots at site D) for artichokes was 5.4 days, and the T99 values for romaine and butter lettuce were 5.9 and 7.8 days, respectively.

TABLE 1. Chemical properties of irrigation waters, August 19, 1980 to June 13, 1985

	Well water		Title-22 water		Filtered effluent	
Parameter	Range	Median	Range	Median	Range	Median
	mg/L, unless otherwise noted					
pH*	6.9-8.1	7.8	6.6-8.0	7.2	6.8-7.9	7.3
Electrical conductivity†	400-1344	700	517-2,452	1,256	484-2,650	1,400
Calcium	18-71	48	17-61.1	52	21-66.8	53
Magnesium	12.6-36	18.8	16.2-40	20.9	13.2-57	22
Sodium	29.5-75.3	60	77.5-415	166	82.5-526	192
Potassium	1.6-5.2	2.8	5.4-26.3	15.2	13-31.2	18
Carbonate, as $CaCO_3$	0.0-0.0	0.0	0.0-0.0	0.0	0.0-0.0	0.0
Bicarbonate, as $CaCO_3$	136-316	167	56.1-248	159	129-337	199.5
Hardness, as $CaCO_3$	154-246	2,025	187-416	217.5	171-435	226.5
Nitrate as N	0.085-0.64	0.44	0.18-61.55	8.0	0.08-20.6	6.5
Ammonia as N	**-1.04	**	0.02-30.8	1.2	0.02-32.7	4.3
Total phosphorus	**-0.6	0.02	0.2-6.11	2.7	3.8-14.6	8.0
Chloride	52.2-140	104.4	145.7-841	221.1	145.7-620	249.5
Sulfate	6.4-55	16.1	30-256	107	55-216.7	84.8
Boron	0.01-9	0.08	0.01-0.81	0.36	0.11-0.9	0.4
Total dissolved solids	244-570	413	643-1,547	778	611-1621	842
Biochemical oxygen demand	0.6-33	1.35	0.7-102	13.9	**-315	19
Adjusted SAR‡	1.5-4.2	3.1	3.1-18.7	8.0	3.9-24.5	9.9
MBAS§	**-**	**	0.095-0.25	0.136	0.05-0.585	0.15

* Standard pH units
† Micromhos/centimeter
‡ Sodium adsorption ratio, no unit
§ Methylene-blue-active substance
** Chemical concentration below detection limit

Detection limits are as follows:
Ammonia = 0.02 mg/L
Phosphorus = 0.01 mg/L
Boron = 0.02 mg/L
Biochemical oxygen demand = 1.0 mg/L
MBAS = 0.05 mg/L

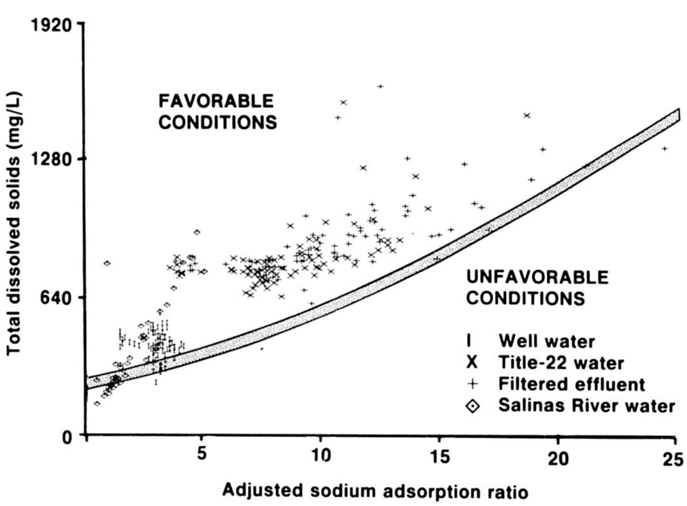

Fig. 1. Soil permeability problems normally expected from higher sodium (adjusted SAR) in the effluents were offset by correspondingly higher salinities (total dissolved solids).

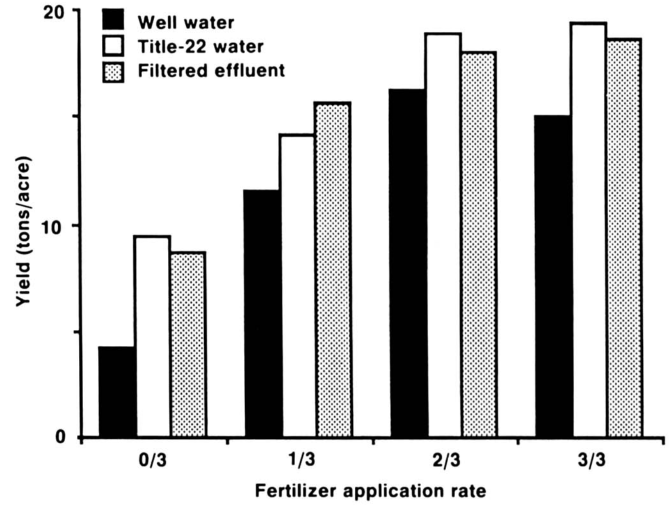

Fig. 2. Crops such as lettuce produced significantly higher yields when irrigated with reclaimed waters, probably because of the higher nutrient content of these waters.

As with the soil samples, we found that in many instances the fertilizer application rate had a much greater effect on plant tissue properties than did the type of irrigation water used (table 2). Higher fertilizer rates produced higher tissue levels of nutrients and of some metals, such as cadmium, zinc, and manganese. None of these differences were of any nutritional or toxicological significance. There were no consistent significant differences in levels of metals in tissues attributable to the type of water used.

We also measured total and fecal coliform and heavy metal levels on plants in the neighboring fields. No relationships between any of these levels and distance from the project site were evident.

Statistically significant yield differences due to water type were observed in the lettuce, celery, cauliflower, and broccoli crops. These crops produced significantly higher yields when they were irrigated with the reclaimed waters (see example, fig. 2). These differences probably resulted from the higher nutrient value of the reclaimed waters, which produced a higher nutrient concentration in the associated plant tissues.

For assessment of crop quality, samples of each crop harvested were boxed and placed in cold storage warehouses for varying periods of up to four weeks after harvest. The produce was examined every week during the storage period for signs of pithiness, flaccidity, black heart, outside tissue breakdown, discolorations, decay, and other signs of spoilage. In general, all of the produce was of excellent quality and showed no unexpected deterioration over time. Quality and shelf life of all produce grown with the two reclaimed waters equaled that of produce grown with well water.

TABLE 2. Average concentrations of heavy metals in edible vegetable tissues, Monterey Wastewater Reclamation Study for Agriculture, 1980 to 1985

		Water type			Fertilizer rate*			
Heavy metal	Plant	Well water	Title-22	Filtered effluent	0/3	1/3	2/3	3/3
		mg/kg						
Cadmium	Artichokes	1.08	1.12	1.12	0.94	1.12	1.20	1.17
(Cd)	Vegetables	2.11	2.08	2.19	2.09	2.07	2.24	2.10
Zinc	Artichokes	31.40	33.00	27.90	33.00	30.70	30.10	30.80
(Zn)	Vegetables	20.10	26.50	28.10	24.80	27.30	28.20	29.90
Iron	Artichokes	67.10	66.60	65.80	65.30	65.40	68.80	66.60
(Fe)	Vegetables	217.00	197.00	193.00	219.00	175.00	232.00	184.00
Manganese	Artichokes	22.90	21.40	21.40	19.00	21.10	23.50	24.00
(Mn)	Vegetables	43.30	44.50	44.60	37.00	42.50	47.80	49.20
Copper	Artichokes	4.74	4.33	4.29	5.33	4.31	4.08	4.13
(Cu)	Vegetables	4.47	4.54	4.42	4.31	4.43	4.67	4.50
Nickel	Artichokes	6.59	5.58	4.79	5.53	4.75	5.48	6.84
(Ni)	Vegetables	9.42	8.72	8.57	9.05	9.40	10.10	9.28
Cobalt	Artichokes	1.85	1.69	1.72	1.78	1.75	1.75	1.75
(Co)	Vegetables	2.24	2.33	2.28	2.25	2.26	2.20	2.41
Chromium	Artichokes	1.91	1.97	1.85	1.84	1.80	1.96	2.02
(Cr)	Vegetables	2.56	2.56	2.38	2.46	2.34	2.55	2.66
Lead	Artichokes	3.40	3.16	3.16	3.00	3.32	3.38	3.27
(Pb)	Vegetables	5.12	4.26	4.67	4.71	5.07	4.47	4.48

NOTE: Concentrations for water types are averaged across fertilizer rates, concentrations for fertilizer rates are averaged across water types.

* The average full nitrogen application rates for each crop were 361 lb N/acre for artichokes, 229 lb N/acre for broccoli; 321 lb N/acre for celery, 186 lb N/acre for cauliflower, and 146 lb N/acre for lettuce. These figures do not include the nitrogen in the irrigation water.

Conclusions

There was no significant difference in the growth or quality of food crops irrigated with domestic wastewater reclaimed either with the presently accepted wastewater treatment method (Title-22) or by the direct filtration method (filtered effluent). Nor was there a difference between these reclaimed wastewaters and the well water used in the study.

From the data collected during the five-year study, there appears to be no significant public health risk associated with the irrigation of raw-eaten vegetable crops with waters reclaimed by either process. No soil or groundwater degradation was observed. Conventional farming practices have thus far proved adequate in growing crops with reclaimed wastewater.

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