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CITRUS IRRIGATION WITH RECLAIMED MUNICIPAL WASTEWATER

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Abstract. **More than 7,000 acres of citrus in western Orange and eastern Lake Counties have been irrigated with highly treated reclaimed municipal wastewater since January, 1987. Thirty observation and sampling sites were established for soil water monitoring, tree appearance rating and leaf, fruit, and soil samplings. Trees at 9 of the 30 sampling sites were in groves irrigated with well water and were used as controls. Groves irrigated with reclaimed wastewater had higher soil water content than control groves. High soil water content adversely influenced the juice quality by reducing both the soluble solids and acid. Trees irrigated with reclaimed wastewater had a better appearance than trees irrigated with well water. Higher leaf and soil N, P, and Na levels were found in groves irrigated with reclaimed wastewater.**

The City of Orlando and Orange County wastewater treatment plants historically have discharged their effluent into Shingle Creek, a tributary of Lake Tohopekaliga. Faced with the need to expand wastewater treatment volume and a state requirement to eliminate discharge of treated effluent to surface waters, both the City and the County entered a negotiated settlement with the Florida Department of Environmental Regulation (FDER) and the United States Environmental Protection Agency (EPA) to cease effluent discharge into Shingle Creek by March, 1988. To facilitate this, Orange County and the City of Orlando jointly developed an innovative water reclamation program.

The Water Conserv II/Southwest Orange County Water Reclamation Project involves the use of highly treated wastewater (reclaimed water) for citrus irrigation and groundwater recharge through rapid infiltration basins (RIBS). It is one of the largest water reuse projects in the United States and the first reuse program permitted in Florida that involves irrigation of crops intended for human consumption. The program, which became fully operational in January, 1987, currently supplies about 25 million gallons per day (mgd) of reclaimed municipal wastewater to irrigate more than 7,000 acres of citrus. The program is designed to provide up to 50 mgd for irrigation of 15,000 acres of citrus.

Citrus groves in western Orange and eastern Lake Counties were selected for the Conserv II project because of their high demand for irrigation water and soil types which have high permeability. This area is a primary aquifer recharging area. Use of reclaimed wastewater for irrigation, in lieu of previous surface water discharges, benefits the urban sector by reducing competition from the agricultural demand for potable water and by increasing available groundwater supplies through supplementing natural recharge of the aquifer.

The agricultural sector benefits from the project in the following ways:

1. The project provides citrus growers with a long-term source of water that will increase (not decrease) with urban growth.
2. The water is provided to growers free of charge at pressures adequate for operation of under-tree irrigation systems (40 lb. per square inch minimum).
3. Growers who would have obtained water from deep wells can save well construction and energy costs of pumping water. It is estimated that growers could save as much as $100 per acre per year in irrigation pumping cost.

Due to the size of the project and the intended use of reclaimed wastewater for irrigation of a crop that is consumed by people, the Florida Department of Health and Rehabilitative Services (HRS) had extensive input in establishing safe water quality guidelines. The HRS was primarily concerned about removal of bacteriological and virological pathogens at the treatment plants prior to delivery to the growers.

In addition, the application of treated wastewater on land is regulated by Florida Department of Environmental Regulations (FDER) which is mainly concerned that wastewater meets minimum standards to minimize ground water-pollution (8).

The objectives of this paper are to present the concept of Water Conserv II and to evaluate tree and soil responses to the reclaimed wastewater in 1987 and 1988.

Materials and Methods

To evaluate the effects of reclaimed municipal wastewater on citrus, 30 observation stations were established in the Conserv II citrus groves covering about 4,000 acres. These groves are under 6 different commercial management programs and fruit companies. Soils in the area are deep well-drained sands, mostly classified as Chandler fine sand (hyperthermic, uncoated Typic Quartzipsamments), with a depth to clay pan of more than 9 ft at all stations except one where sandy-clay mixture was found at a 7.5 ft depth.

'Valencia' and 'Hamlin' oranges (*Citrus sinensis* (L.) Osbeck, Swingle) on rough lemon (*Citrus jambhiri* Lush.) and Carrizo citrange (*Poncirus trifoliata* (L.) Raf. × *C. sinensis*) rootstocks were the principal cultivars with the exception of some young 'Washington' navel orange trees in one of the groves. Six stations were located in blocks of 3- to 5-yr-old trees and 15 stations were in mature blocks. Nine of the 30 stations were designated as controls; they were located in blocks where well water was used for irrigation.

Soil water content was measured to a depth of 66 inches (168 cm) at biweekly intervals throughout the year with a neutron probe (CPN Corp. Model 503DR Hydroprobe) and at the 0 to 6 inch (0 to 15 cm) depth gravimetrically. Reclaimed water samples were collected when soil water content was measured and analyzed for macro- and micro-

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nutrients. Leaf, soil and fruit samples were collected annually from 20 trees at each station. Spring flush leaves from nonfruiting twigs were sampled in August of each year and analyzed for macro (N, P, K, Ca, and Mg) and micro elements (Na, Mn, Cu, Zn, and Fe). Soil samples were collected annually at 6-inch increments to a depth of 66 inches (168 cm) and analyzed for pH, N, P, K, Ca, Mg, and Na. Fruit samples were collected just prior to fruit harvest to measure juice quality. The same 20 trees at each station were evaluated visually for leaf color, canopy appearance, and fruit crop every 3 months.

Twenty trees in 2 young tree blocks irrigated with reclaimed wastewater were measured in 1987 and again in 1989 to observe tree growth. Tree height and width (north-south and east-west directions) were measured and canopy surface was calculated using a modified formula for a parabola (2). A young 'Valencia' irrigated with well water was used as control.

Data were not analyzed statistically because this is a survey type of study. Means and standard deviations (SD) were calculated where applicable.

Results and Discussion

Composition of reclaimed municipal wastewater. Characteristics and chemical composition of reclaimed municipal wastewater are summarized in Table 1. Only major and minor nutrients that are known to be important to citrus are listed in Table 1. A complete listing of all elements known to occur in this reclaimed water has been published elsewhere (8). This reclaimed water was highly treated having relatively low biological oxygen demand (BOD) and mineral nutrient contents. The average concentration for most elements over a 2-yr period was considerably lower than the maximum allowable limits except for sodium (Na) and chloride (Cl). The Na concentration in water was approaching the maximum allowable limit. The average concentration of the Cl was higher than that of Na but levels fluctuated within less than 70% of the allowable limits, while Na levels were close to 90% of allowable limits (8).

Soil water content level. Monthly soil water content levels for both the Conserv II and control stations are plotted in Fig. 1 and 2. Rainfall data were obtained from U.S. Weather Bureau records in Clermont, Florida (9). Soil water content data to a depth of 66 inches (168 cm) were expressed as acre-inches. Monthly fluctuations in soil water content followed rainfall distribution both in 1987 and 1988. In general, growers in the project followed sound irrigation practices. In 1987, soil water content in Conserv II groves was higher than in the control groves while in 1988, soil water content in both Conserv II and control groves was similar. This was caused by a decrease in water applied to the Conserv II groves and an increase in the

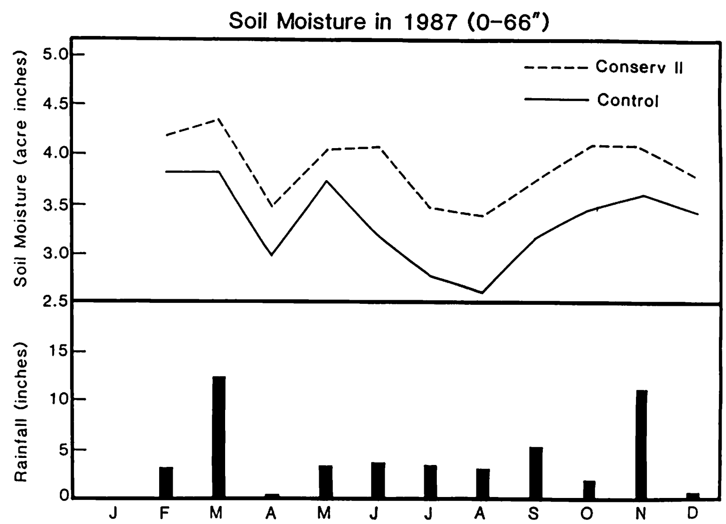

Fig. 1. Soil water content and rainfall distribution in 1987.

Table 1. Composition of reclaimed municipal wastewater (1987 and 1988). (Average of 24 monthly samples)

Characteristics	Max conc limits	Avg conc mean ± SD	Range
pH	6. – 8.4	7.02 ± 0.12	6.68 – 7.72
BOD	30	2.69 ± 0.42	1.9 – 3.5
COD	120	24.33 ± 14.42	10.0 – 60.0
ECw (μmhos/cm)	1100	668.29 ± 84.35	495 – 878
TSS (%)	5	3.18 ± 0.78	1.9 – 5.2
Bicarbonate (%)	200	97.25 ± 22.66	64 – 174
Elements	mg/l	mg/l	mg/l
Boron	1.0	0.18 ± 0.06	0.08 – 0.32
Calcium	200	39.00 ± 5.87	22 – 48
Chloride	120	79.08 ± 10.46	40 – 90
Copper	0.20	0.017 ± 0.013	0.005 – 0.070
Iron	5.0	0.09 ± 0.04	0.02 – 0.16
Magnesium	25.0	8.96 ± 1.34	5.2 – 10.9
Manganese	0.20	0.015 ± 0.008	0.002 – 0.036
Nitrogen	30	10.09 ± 2.90	5.30 – 18.30
Nitrate		8.15 ± 1.98	4.02 – 12.00
Phosphorous	10	5.43 ± 1.37	3.40 – 8.84
Potassium	30	11.47 ± 1.93	8.50 – 14.60
Sodium	70	62.83 ± 6.26	50 – 77
Sulfates	100	43.65 ± 15.83	7.9 – 66.8
Zinc	1.0	0.067 ± 0.015	0.046 – 0.096

Source: Metcalf & Eddy Services, Inc. and City of Orlando.

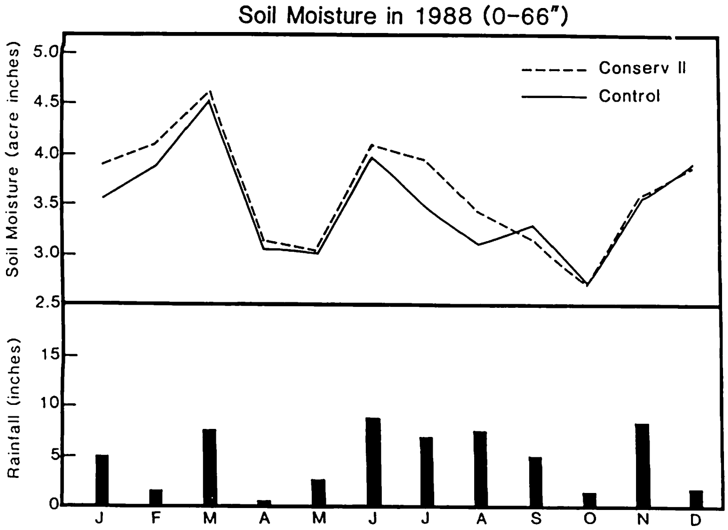

Fig. 2. Soil water content and rainfall distribution in 1988.

control groves. Changes in irrigation practices were influenced by the effects of water on fruit production and quality. Higher soil water content was maintained in the young bearing tree blocks where soil moisture measurements showed values above field capacity for most of 1987 and 1988.

Leaf analysis. Leaf samples collected from 1986 to 1989 indicated that both trees irrigated with reclaimed wastewater and well water were adequately fertilized (Table 2). The 1986 leaf samples were collected prior to the introduction of reclaimed wastewater and most elements were either in the optimum or the high range of the leaf analysis standard (5).

Since 1987, trees receiving reclaimed wastewater had higher leaf N, P, Na, Fe, and lower Mn and Zn contents than trees on well water program (Table 2). No consistent trends were observed for leaf K, Ca, Mg, and Cu contents. The high leaf N and P contents found in the reclaimed wastewater groves were substantiated by the higher soil N

Table 2. Mineral composition of leaf samples from Conserv II and control groves.

Element	Year	Control mean ± SD[z]	Conserv II mean ± SD[z]
Nitrogen (%)	1986	2.99 ± 0.19	
	1987	3.00 ± 0.12	3.02 ± 0.14
	1988	2.87 ± 0.13	2.95 ± 0.19
	1989	2.82 ± 0.07	2.90 ± 0.20
Phosphorous (%)	1986	0.145 ± 0.017	
	1987	0.128 ± 0.015	0.144 ± 0.016
	1988	0.132 ± 0.008	0.136 ± 0.012
	1989	0.132 ± 0.011	0.138 ± 0.010
Potassium (%)	1986	1.38 ± 0.24	
	1987	1.55 ± 0.25	1.51 ± 0.26
	1988	1.23 ± 0.21	1.41 ± 0.30
	1989	1.37 ± 0.23	1.39 ± 0.19
Calcium (%)	1986	3.29 ± 0.54	
	1987	3.12 ± 0.41	3.14 ± 0.43
	1988	3.81 ± 0.56	3.53 ± 0.43
	1989	3.24 ± 0.54	3.29 ± 0.43
Magnesium (%)	1986	0.400 ± 0.075	
	1987	0.365 ± 0.065	0.395 ± 0.075
	1988	0.413 ± 0.091	0.391 ± 0.080
	1989	0.356 ± 0.063	0.369 ± 0.066
Sodium (%)	1986	0.05 ± 0.02	
	1987	0.04 ± 0.02	0.09 ± 0.07
	1988	0.04 ± 0.02	0.07 ± 0.05
	1989	0.04 ± 0.01	0.11 ± 0.08
Manganese (ppm)	1986	18 ± 23	
	1987	45 ± 25	27 ± 21
	1988	43 ± 19	25 ± 16
	1989	34 ± 12	24 ± 12
Zinc (ppm)	1986	26 ± 18	
	1987	47 ± 26	30 ± 18
	1988	77 ± 31	47 ± 27
	1989	22 ± 5	21 ± 6
Copper (ppm)	1986	12 ± 8	
	1987	14 ± 8	15 ± 6
	1988	19 ± 8	18 ± 9
	1989	21 ± 8	21 ± 8
Iron (ppm)	1986	85 ± 14	
	1987	54 ± 18	68 ± 16
	1988	76 ± 13	82 ± 14
	1989	65 ± 11	78 ± 17

[z]SD: Standard deviation.

Number of samples:	1986	Control and Conserve II: 28	
	1987	Control: 7	Conserv II 21
	1988	Control: 9	Conserv II 19
	1989	Control: 9	Conserv II 19

All 1986 samples were pre-Conserv II samples.

and P contents found in the 1988 data (Table 3). The non-consistent trend in leaf K and Ca contents could also be explained by the similar soil K and Ca concentrations in the 1988 data. More data are needed to establish a firm trend for Mg.

Although leaf Na content from trees irrigated with reclaimed wastewater was twice as high as trees on well water, Na content of both groups was well within the optimum standard value for citrus (1). Previous investigation using citrus processing wastewater indicated that leaf Na content will stabilize with time after the initial rise (3, 4).

The average concentration of micronutrients present in the reclaimed wastewater was very low ranging from 0.01 to 0.18 mg/l (Table 1). The differences in leaf Cu, Mn and Zn contents found between groves irrigated with reclaimed wastewater and well water could be attributed to grower's practice of nutritional and fungicidal sprays. Iron is not a recommended component of nutritional or fungicidal sprays in citrus (5). The higher leaf Fe content found in groves irrigated with reclaimed wastewater could have resulted from Fe present in the reclaimed wastewater.

Soil nutrient status. Soil samples were collected annually and the data are summarized in Table 3. Both the surface soil, 0 to 6 inch (0 to 15 cm) and the soil profile 0 to 66 inch depth (0 to 168 cm) were analyzed for N, P, K, Ca, Mg, Na, and pH. All 1986 samples were collected prior to the introduction of reclaimed water.

Normally, soil samples are collected from the 0 to 6 inch (0 to 15 cm) depth only. While the surface soil did not show any consistent trends due to reclaimed water, accumulation of nutrient elements became more apparent when the soil profile was examined. Higher nitrogen and P were found in the soil profile of the reclaimed water groves in 1988 when compared to the well water groves. No differences were observed in the extractable *soil K, Ca,* Mg, and Na of reclaimed water and control groves; however, sodium increased with time in both. Reasons for the increase in the control groves are not clear and should be further investigated. It is known that some of the potassium chloride used in citrus fertilization contains Na, but it is not known to what extent it contributes toward the rise of Na in the soil of the control groves.

Table 3. Soil pH and soil nutrient status of well and reclaimed water groves.

Element	Year	0 to 6 inches Control	0 to 6 inches Conserv II	0 to 66 inches Control	0 to 66 inches Conserv II
pH	1986	7.13	7.22	5.82	5.73
	1987	6.72	7.11	5.36	6.18
	1988	6.71	6.76	5.72	5.89
		pounds per acre			
Nitrogen	1986	948	917	2368	2104
	1987	1014	825	2405	2170
	1988	826	919	2480	2836
Phosphorus	1986	127	135	628	578
	1987	125	137	591	542
	1988	92	137	406	621
Potassium	1986	38	32	200	185
	1987	43	50	217	259
	1988	69	61	407	407
Calcium	1986	798	933	1888	1947
	1987	857	893	2049	2330
	1988	851	695	2071	2085
		pounds per acre			
Magnesium	1986	77	76	227	275
	1987	100	99	240	323
	1988	102	87	298	318
Sodium	1986	38	35	262	278
	1987	54	36	377	338
	1988	61	54	422	485

1986 Control: 6 samples Conserv II: 13 samples
1987 7 samples 23 samples
1988 9 samples 21 samples
All 1986 samples were pre-Conserv II samples.

Fruit quality and fruit production. Fruit from trees irrigated with reclaimed water had lower soluble solids and acid contents than fruit from control trees (Table 4). The difference was especially apparent in 1987 when fruit from the reclaimed water groves was about 0.75 lb. lower in soluble solids per box than that from the control groves. Such effects of irrigation on juice quality are well-documented (6, 7). In 1987, the soil water content was considerably higher in the reclaimed water groves than the control groves (Fig. 1) resulting in lower soluble solids. In 1988, soil water content in the reclaimed water groves was only slightly higher than the control groves (Fig. 2) and differences in soluble solids were not detected.

The relationship between soil water content and soluble solids can best be illustrated in Table 5 where a wide range of soil moisture was maintained. In young bearing 'Hamlin' orange groves where soil water content was maintained above field capacity for most of 1988, soluble solids dropped dramatically when compared to mature bearing trees where a lower soil water content was maintained. Data in Table 5 also indicated that the frequency of attainment of soil moisture levels above field capacity influenced soluble solids in addition to the average soil water content throughout the year.

While no attempt was made to collect fruit production data from the 7,000 plus acres, growers have reported increases in fruit production from 10 to 30% over years prior to receiving water from the Conserv II project. A small number of trees from 2 stations adjacent to each other was selected for fruit production estimations. These 2 stations have same age trees of the same scion and rootstock ('Hamlin'/rough lemon) and are under the same management.

Table 4. Effects of reclaimed water on juice quality of 'Hamlin' and 'Valencia' oranges.

Measurement	Treatment	Hamlin 1987	Hamlin 1988	Valencia 1987	Valencia 1988
Juice (%)	Conserv II	57.24	57.63	59.27	60.32
	Control	60.10	55.92	59.41	57.34
Sol. solids (%)	Conserv II	10.92	11.54	11.02	12.15
	Control	11.97	11.73	12.28	13.10
Acid (%)	Conserv II	0.80	0.80	0.79	0.86
	Control	0.88	0.84	0.90	0.89
SS/Acid ratio	Conserv II	13.62	14.44	13.86	14.00
	Control	13.60	14.00	13.67	14.71
Solids (lb./box)	Conserv II	5.66	5.97	5.82	6.59
	Control	6.47	5.89	6.56	6.77

Number of samples:					
Hamlin	Conserv II	1987	5	1988	8
	Control	1987	1	1988	5
Valencia	Conserv II	1987	4	1988	4
	Control	1987	4	1988	4

Table 5. Relationship between soil water content and soluble solids of 'Hamlin' and 'Valencia' oranges (1988).

Cultivar	Treatments	Number stations	Soil moisture[z] Average	Above FC	Soluble solids
			inch	%	lb./box
Hamlin	Control	5	3.58	23	5.89
	Conserv II	8	3.49	18	5.97
	Young trees	4	4.32	60	5.22
Valencia	Control	4	3.43	24	6.77
	Conserv II	4	3.23	26	6.59

[z]Average soil water content per acre represents 0 to 66 inch depth. Percent (measurement) above field capacity (FC) is based on 22 measurements. Field capacity 0 to 66 inch depth = 4.24 inches.

Table 6. Effects of reclaimed water on fruit production and fruit size of 'Hamlin' oranges (1988).

Measurements	Conserv II	Control
Fruit diam (cm)	6.81	6.49
Fruit wt (g)	187	174
Fruit/tree (No.)	1434	1254
Production (box/tree)	6.56	5.34
Increase (%)	23	

The only difference was that one side was irrigated with reclaimed water and the other was irrigated with well water. Data collected from these 2 stations on soil moisture, leaf, soil and fruit analyses were comparable to data reported in Tables 1 to 4. Fruit size and weight were measured from fruit samples collected. Number of fruit per tree was counted and fruit production was calculated (Table 6). Trees on reclaimed water had larger, heavier fruit and more fruit than the control trees. Fruit production was 23% higher from trees on reclaimed water than those irrigated with well water, an observation in agreement with grower reports.

Tree growth. Tree height and width measurements made in 1987 and 1989 in the 'Hamlin' and the 'Washington' navel blocks showed tremendous growth in 2 years (Table 7). Canopy growth for the 2 varieties were 225% and 443%, respectively, when compared to 174% for 'Valencia' on the well water program. Differences in tree growth due to varietal characteristics should be considered. Nevertheless, the rate of canopy growth for the 2 blocks on reclaimed water program is higher than typical young tree groves in the area.

Observations and data collected in 1987, 1988, and 1989 indicated that the use of reclaimed water for citrus irrigation was a horticulturally sound practice. Reclaimed water used in the Conserv II program is a highly treated wastewater and relatively low in mineral elements. There are indications that reclaimed water is supplying N, P, and other nutrients to the trees but not enough data are available to quantify the nutrient levels supplied. Further investigation is therefore justified.

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Table 7. Effects of reclaimed and well water on young tree growth.[z]

Treatment	Variety[z]	Date	Height	Width[y]	Canopy surface	Growth
			ft	ft	ft²	%
Reclaimed water	Hamlin	5-21-87	4.8	7.3	72	
		6-28-89	10.3	10.9	234	225
	Navel	5-21-87	3.5	6.9	49	
		6-28-89	10.9	11.8	266	443
Well water	Valencia	5-21-87	4.8	4.1	42	
		7-28-89	7.5	7.3	115	174

[z]'Hamlin' and Navel trees were approximately 3-yr-old in May, 1987 and the 'Valencia' trees were about 2-yr-old.
[y]Width is the average of north-south and east-west measurements.