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FINAL REPORT

Microsprinkler Irrigation of Grapefruit in the Flatwoods
Using Reclaimed Wastewater

Submitted to the St. Johns River Water Management District

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EXECUTIVE SUMMARY

Citrus is economically the most important crop in Florida. Citrus trees also are a major user of irrigation with more than 34% of available agricultural water being used for citrus irrigation in 1992. Rapid expansion of Florida's urban sectors has also placed great demands on water supplies as well as increasing wastewater production. Reclaimed wastewater has been applied to citrus groves since 1986 at the Conserv II project near Orlando. However, the soil composition, drainage patterns and tree characteristics differ from those found in the flatwoods growing districts. Therefore, in 1989 a joint project was initiated between St. Johns River Water Management District, Indian River County, and the University of Florida to study the effects of reclaimed wastewater on growth and development, yields, fruit quality, and soil nutrient levels and movement in flatwoods-type soils.

The study was conducted on a 20-acre site adjacent to the Vero Beach municipal wastewater treatment facility using 25-year-old 'Redblush' and 'Marsh' grapefruit trees on sour orange or rough lemon rootstocks, respectively. A parallel young tree study was conducted using 'Redblush' on 'Swingle' citrumelo rootstock for the first 3 years after planting. Secondarily-treated wastewater was applied using 360° Maxijet® microsprinklers at 15 gal. per hour and two emitters per tree. The entire within tree row surface area was covered by the irrigation; no irrigation was applied between rows to the tops of the beds. Treatments for mature trees consisted of reclaimed wastewater applied at 0.9, 1.2, or 1.5 in. per week and canal water applied based on soil water deficits of one-third Jan. to June and two-thirds July to Dec. as determined by the neutron probe. Reclaimed wastewater was applied at 0.75, 1.00, or 1.25 in. per week in the young tree study. Reclaimed wastewater was applied two or three times per week at 4 hours per application depending on rate used. Soil water content was maintained above field capacity during most of the year for all reclaimed wastewater treatments but fluctuated between one- and two-thirds field capacity for the canal water treatments. Amount of water applied per year for the mature site averaged 2165.9, 2866.9, and 3526.4 x 1000 gals for the three reclaimed wastewater treatments, repectively, and 671.5 x 1000 gals for the canal water treatments.

Trees receiving reclaimed wastewater were more vigorous and generally had higher yields than those receiving canal water for all 3 years of the study. Yields averaged 352 lbs per tree for the canal water treatment and 518.5, 536.8, and 475.9 lbs per tree for the 0.9, 1.2, and 1.5 in reclaimed wastewater treatments, respectively. Reclaimed wastewater treatments improved fruit size and number over those in the control treatment. Yields and tree vigor were greater for the 0.9 and 1.2 in treatments versus the 1.5 in treatment, suggesting that the highest rate may be detrimental in these soil types and growing conditions.

Effects of reclaimed wastewater on fruit quality varied seasonally depending on amount of rainfall. In some years total soluble solids (TSS) and titratable acidity (TA) decreased due to dilution by the high rates of irrigation in the reclaimed wastewater treatments, while in other years there was no effect. However, generally TA was decreased more often than TSS, thus reducing TSS:TA ratio which may lead to earlier maturity. Fruit and juice weight generally increased with use of reclaimed wastewater compared with fruit from control treatments.

There were no consistent effects of using reclaimed wastewater on tree nutrition with nitrogen, phosphorus, potassium, magnesium, calcium, and sodium levels usually falling in acceptable ranges, again with some yearly variations. Leaf boron levels increased over control values with application of reclaimed wastewater, but no toxic effects were observed. Most importantly, however, application of these levels of reclaimed wastewater substituted totally (high rate) or partially (low and mod. rates) for fertilization. Therefore, use of low to moderate rates of reclaimed wastewater increased yields and tree vigor while reducing fertilizer costs. The frequent applications of low levels of nutrients also may reduce groundwater pollution and nutrient run-off from the grove.

Irrigation with reclaimed wastewater over the three years of the study posed no health threat due to presence of heavy metals, bacteria or enteric viruses. Heavy metals were consistently present in less than trace amounts as expected based on water analysis. Similarly, fecal coliform levels were within state standards and no enteric viruses were found at the efflux side of the treatment facility or on the fruit.

The primary adverse effect of using reclaimed wastewater for citrus irrigation on the flatwoods was increased weed growth. The high levels of water and nutrients in reclaimed wastewater greatly increased weed growth, reduced effectiveness of soluble residual herbicides, and increased the need for spot herbicide sprays. Therefore, weed management will be a significant and costly problem when using reclaimed wastewater for irrigation.

Reclaimed wastewater also had no significant effect on growth and development of reset trees. Growth rates were similar though variable for all treatments. Some sodium and boron accumulation occurred with reclaimed wastewater treatments, but no toxic levels were noted. With young trees, reclaimed wastewater does not provide sufficient nutrients to maintain an adequate growth rate; therefore supplemental fertilization is necessary. As with mature trees, weed management is a significant problem associated with use of reclaimed wastewater in young or reset groves.

Redox potential measurements can be used qualitatively to indicate whether a soil is aerobic or anaerobic. Oxygen depletion occurs when the redox potential is in the range of 250 to 300 mV. At the 18 in.-depth, the soil profile remained aerobic during most of the year except after periods of heavy rainfall. At the 30 in.-depth, the soil was anaerobic during much of the year. Reclaimed wastewater had no consistent effect on soil redox potential. In the 'Redblush' grove, reclaimed wastewater application affected redox potential in a positive manner, i.e., values were higher in the reclaimed wastewater treatments than the standard treatment, suggesting that the water remained oxygenated as it moved through the soil.

Water samples were taken monthly at a depth of 39 in. and also in the ditches between beds. None of the water quality parameters, except possibly phosphorus, indicated any adverse effect of the reclaimed wastewater application at any rate. The treatment which received the standard management practices for groves in this area with regard to fertilization and also received canal water for irrigation instead of reclaimed wastewater, often had significantly higher nutrient concentrations compared to the reclaimed wastewater treatments. Soluble reactive phosphorus (SRP) was greater in the reclaimed wastewater treatments than the standard treatment and tended to increase with reclaimed wastewater irrigation rate. The increasing SRP concentration with reclaimed wastewater application suggests that phosphorus accumulation potentially could become a problem with continued application. However, the relatively low concentrations suggest that it would take many years to accumulate to problematic concentrations. Concentrations of toxic metals were low for all treatments with no indication of potential problems.

Nutrient concentrations in ditch water samples were also low, except for phosphorus. A continued increase in phosphorus concentrations in subsequent years may eventually be problematic.

Soil was sampled at depths of 0-6, 6-18, and 18-30 in. at 3-month intervals in the 'Redblush' and 'Marsh' blocks. Other than phosphorus, there were no adverse effects of reclaimed wastewater on soil nutrient and metal concentrations. Phosphorus did accumulate in the soil and this was reflected in shallow ground water and drainage water phosphorus concentrations. Phosphorus accumulation would only produce a water quality problem and would not adversely affect soil properties or tree health. If a water quality problem develops with phosphorus, it could be resolved by directing drainage from the grove through a constructed or natural wetland.

The potential advantages in water and fertilizer savings far outweigh any risks resulting from the use of reclaimed wastewater for irrigation of mature or young (1 to 3 years old) grapefruit trees. Moreover, any health risks from enteric viruses or heavy metals are extremely low. Some adjustments in weed control programs, however, will be necessary. These findings apply only to properly designed and drained sites. Where drainage was poor, tree growth and yields were adversely affected by the use of reclaimed wastewater. Consequently, use of 0.9 to 1.2 in. per wk in two to three applications has several potential benefits to citrus growers in the Indian River area on the soil series tested (Wabasso fine sand) and with proper drainage.

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INTRODUCTION

In Florida, 34% of agriculturally available water is used to irrigate citrus trees (Smajstrala et al., 1992). Competition for limited water resources is increasing from urban, industrial and agricultural interests. This competition is especially acute in the coastal areas of Florida where salt water intrusion is often a problem due to excessive demand on the ground water supply. In addition, urban growth in the coastal areas of Florida has increased the need for efficient and environmentally safe disposal of municipal reclaimed wastewater. Currently, about one-half of all citrus is grown in flatwoods areas of Florida (Fla. Dept. of Agr. and Consumer Serv., 1992). The use of reclaimed wastewater for irrigation of citrus is potentially beneficial to both urban and agricultural interests. Reclaimed wastewater could provide an economical means of irrigating, decrease pollution of surface waters, and provide ground water recharge.

The use of reclaimed wastewater for irrigation of citrus trees has other potential advantages. Reclaimed wastewater contains many essential nutrients for plant growth and its application may reduce fertilizer application rates (Neilsen et al., 1989). In addition, recycling of nutrients in reclaimed wastewater and reduction in fertilizer use may prevent surface and/or ground water contamination (Sanderson, 1986). Potential disadvantages of using reclaimed wastewater include accumulation of phytotoxic levels of heavy metals (Omran et al., 1988) or salts (Basiouny, 1982) and concern over the health risk associated with viruses and bacteria in the water (Zekri and Koo, 1993).

The use of reclaimed wastewater in mature groves may have some potential benefits in the management of resets. Reset trees must compete with mature trees for available water and nutrients. In addition, reset trees have a limited root zone with which to extract available water and nutrients (Jackson, 1981). About 85% of the roots are located in the top 10 inches of soil volume one year after planting (Marler and Davies, 1990). Growers predominantly use microsprinkler irrigation for resets (Taylor et al., 1989) because they realize a net return 1-to-2 years earlier when using microirrigation for newly planted citrus trees compared with conventional irrigation methods (Smajstrla, 1993). Therefore, the frequent irrigation associated with use of reclaimed wastewater may be beneficial for reset trees in a mature grove.

Fertilization of resets is costly because rates must be adjusted to ensure that trees receive the correct amount of material (Jackson, 1981). Currently, 62% of resets are fertilized with standard granular fertilizer (Taylor and Ferguson, 1993). Reclaimed wastewater at high rates can supply from two-thirds to all of the yearly N requirement for mature citrus trees, but supplies $\leq$10% of the yearly N requirement for resets due to their limited rootzone. Maurer and Davies (1993) observed that newly planted citrus trees receiving reclaimed wastewater alone exhibited N deficiency.

Use of reclaimed wastewater has the potential to affect soil and water quality as well as citrus tree characteristics. Application of high amounts of water and nutrients may affect the composition of the soil and quality of the water exiting the grove. Moreover, soil oxygen levels could be decreased especially in the shallow flatwoods soils present in the Indian River area. There was also concern that the reclaimed wastewater would move laterally from the grove into surface waters.

The objective of this experiment was to evaluate the effects of irrigation with reclaimed wastewater on the growth and development, fruit quality and yield of mature and growth of newly planted 'Redblush' grapefruit trees on flatwoods type soils. In addition, the effects of reclaimed wastewater on percent soil oxygen, nutrient levels, and nutrient movement from the grove site throughout the year were also studied. The overall goal of this study was to determine whether citrus growers can safely and economically use reclaimed wastewater for citrus irrigation on flatwoods-type soils on the east coast of Florida.

MATURE TREE STUDIES

In Florida, 34% of agriculturally available water is used to irrigate citrus trees (Smajstrala et al., 1992). Competition for limited water resources is increasing from urban, industrial and agricultural interests. This competition is especially acute in the coastal areas of Florida where salt water intrusion is often a problem due to excessive demand on the ground water supply. In addition, urban growth in the coastal areas of Florida has increased the need for efficient and environmentally safe disposal of municipal reclaimed wastewater. Currently, about one-half of all citrus is grown in flatwoods areas of Florida (Fla. Dept. of Agr. and Consumer Serv., 1992). The use of reclaimed wastewater for irrigation of citrus is potentially beneficial to both urban and agricultural interests. Reclaimed wastewater could provide an economical means of irrigating, decrease pollution of surface waters, and provide ground water recharge.

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Reclaimed wastewater has been used for irrigation of citrus on the deep sandy soils of the ridge area of Florida (Zekri and Koo, 1993). No in-depth studies have been conducted, however, on the east coast flatwoods where soil types and drainage patterns vary considerably due to the presence of hard pans and a high water table.

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MATERIALS AND METHODS

The experimental site consisted of a 20-acre (8.1 ha) block of 25-year old 'Redblush' grapefruit trees (*Citrus paradisi* Macf.) on sour orange (*Citrus aurantium* L.) rootstock. The study was conducted from 1 Oct. 1990 to 12 Dec. 1993. The site was located adjacent to the Indian River County municipal wastewater treatment facility located near Vero Beach, Fla. Trees were planted on double beds 60 ft (18.3 m) wide and 575 ft (177 m) in length. The crest of the bed was about 3 ft (0.9 m) above the bottom of the water furrows. Trees were spaced 30 ft (9.15 m) between and 20 ft (6.1 m) within rows (29 trees per row). The soil type was predominantly a Wabasso fine sand (sandy, siliceous, hyperthermic Alfic Haplaquods) with areas of Chobee loamy fine sand (fine-loamy, siliceous, hyperthermic Typic Argiaquolls) and EauGallie fine sand (sandy, siliceous, hyperthermic Alfic Haplaquods) occurring in portions of the block. The soil had a volumetric field capacity of 9.95%, a permanent wilting point of 2.48%, and a mean bulk density of 1.61 gcm^{-3}.

Four treatments were arranged in a completely randomized design with each double bed representing a replicate, with four replicates per treatment. Irrigation treatments were arranged in this manner to assure statistical validity and because it was impractical to irrigate an area smaller than an entire bed. Treatments consisted of a control (canal water) irrigated based on soil moisture depletion of one-third from Jan. to June and two-thirds from July to Dec. (Koo, 1963) and reclaimed wastewater (secondary treated municipal wastewater) applied at low (0.9 in. per wk, 23.1 mm), moderate (1.2 in. per wk, 30.7 mm) and high (1.5 in. per wk, 38.6 mm) rates (Tables 1-4). Amount of water actually applied to each treatment varied by <7% of the expected levels. This error margin is extremely low considering the size of the irrigated area and the large number of irrigations applied. Trees were irrigated using 15 gal per hour (56.8 liter per hour), 360° Maxijet® microsprinklers (two per tree) located within the tree row. The wetting pattern was 11.8 ft (3.5 m) in diameter at 15 psi pressure. However, the actual wetted diameter after lateral movement of the water was 16 ft (4.8 m). The arrangement of the microsprinklers overlapped sufficiently to provide coverage of the entire grove floor within the tree rows. The drive middle between rows was not irrigated. Reclaimed wastewater was applied for 4-hour intervals 2 or 3 days per week during each year depending on irrigation rate, with the exception of times when the water furrows were being cleaned to improve drainage from 25 Nov. to 16 Dec. 1991 (Table 5).

All treatments received about 145 lb N per acre per yr (130 kg N per ha per yr). The control treatment was fertilized two times per year (one-half on 15 Feb. 1990, one-half on 15 Aug. 1990) using a 12N-2P-16K analysis granular fertilizer. Because reclaimed wastewater contains N, P, K and other nutrients, N rates were adjusted for these treatments to standardize nutrient levels among treatments as much as possible for such a large area. Fertilizer was applied in Feb. or Mar. at 53 (24 kg) and 31 (14 kg) lb N per acre per yr for the low and moderate-reclaimed wastewater treatments, respectively. The remaining N was provided in the reclaimed wastewater. The high-reclaimed wastewater treatment received no granular fertilizer and received from 107 (48 kg) to 129 (59 kg) lb N per acre per yr from the reclaimed wastewater alone depending on the season.

Soil water was monitored with a Troxler 4300 neutron probe (Troxler, Raleigh, N.C.) once a week for the reclaimed wastewater treatments and twice a week for the control treatment. One aluminum access tube was placed at the drip-line about half-way down in the tree row of each bed in 1990 to 1992. In 1993, additional tubes were placed at the east and west ends of the control beds because of variations in soil water content along the bed. Soil water content in the control treatment was then determined by taking the average of the three lowest readings from the 12 tubes. These tubes were selected so that trees would be irrigated based on the driest soil conditions. This would ensure that the control trees would not be under water stress. Neutron probe readings were taken at a depth of 9 in. (23 cm) from the crest of the bed because most of the roots were located in this region and the water table fluctuated between a 12 to 18 in. (30 to 45 cm) depth.

Table 1. Total water applied via irrigation to 'Redblush' grapefruit trees at Vero Beach, Fla., 1990-93.[z]

Treatment	1990-91[y]	1992	1993	Total
	(gal x 1000)			
Canal water	726.1	713.4	574.9	2014.4
Reclaimed wastewater				
Low - 0.9 in./wk	2503.7	2021.1	1972.9	6497.7
Mod. - 1.2 in./wk	3166.7	2797.0	2637.0	8600.7
High - 1.5 in./wk	3922.4	3403.1	3253.7	10579.2

[z]Water was applied to a 0.21 acre area within each tree row.
[y]Irrigation was discontinued from 25 Nov. to 16 Dec. 1991 to clean and repair the water furrows. Includes water applied for the final quarter of 1990.

Table 2. Total water applied via irrigation by quarter to 'Redblush' grapefruit trees at Vero Beach, Fla., 1990-91.[z]

Treatment	Oct.-Dec.	Jan.-Mar.	Apr.-June	July-Sept.	Oct.-Dec.[y]	Total
	(gal x 1000)					
Canal water	72.2	80.5	137.2	0	436.3	726.1
Reclaimed wastewater						
Low - 0.9 in./wk	525.1	564.9	502.3	488.6	422.8	2503.7
Mod. - 1.2 in./wk	606.4	716.5	619.3	660.2	564.4	3166.6
High - 1.5 in./wk	796.4	937.6	792.3	746.5	701.0	3922.4

[z]Water was applied to a 0.21 acre area within each tree row.
[y]Irrigation was discontinued from 25 Nov. to 16 Dec. 1991 to clean and repair the water furrows.

Table 3. Total water applied via irrigation by quarter to 'Redblush' grapefruit trees at Vero Beach, Fla., 1992[z].

Treatment	Jan.-Mar.	Apr.-June	July-Sept.	Oct.-Dec.	Total
			(gal x 1000)		
Canal water	191.9	521.5	0	0	713.4
Reclaimed wastewater					
Low - 0.9 in./wk	494.1	550.8	540.4	435.9	2021.1
Mod. - 1.2 in./wk	630.3	732.0	844.2	590.6	2797.1
High - 1.5 in./wk	788.9	787.2	1039.6	787.5	3403.1

[z]Water was applied to a 0.21 acre area within each tree row.

Table 4. Total water applied via irrigation by quarter to 'Redblush' grapefruit trees at Vero Beach, Fla., 1993[z].

Treatment	Jan.-Mar.	Apr.-June	July-Sept.	Oct.-Dec.	Total
			(gal x 1000)		
Canal water	23.0	258.3	3790.7	29.0	574.9
Reclaimed wastewater					
Low - 0.9 in./wk	463.7	576.3	517.8	414.9	1972.9
Mod. - 1.2 in./wk	621.8	758.1	703.1	554.3	2637.3
High - 1.5 in./wk	745.4	940.7	876.6	691.0	3253.7

[z]Water was applied to a 0.21 acre area within each tree row.

Table 5. Four- and 5-day schedules for reclaimed wastewater irrigation for 'Redblush' grapefruit trees, Vero Beach, Fla., 1990-1993[z].

Five-day irrigation schedule.					
Treatment	Mon.	Tue.	Wed.	Thur.	Fri.
			(in/day)		
Low - 0.9 in./wk	0.3			0.6	
Mod. - 1.2 in./wk		0.6			0.6
High - 1.5 in./wk	0.6		0.6		0.3
Four-day irrigation schedule.					
Treatment	Mon.	Tue.	Wed.	Thur.	Fri.
			(in/day)		
Low - 0.9 in./wk			0.9		
Mod. - 1.2 in./wk		0.9		0.3	
High - 1.5 in./wk	0.9			0.6	

[z]Reclaimed wastewater was applied two or three times per wk for 2 to 4 hours per application.

Growth and Development

Tree vigor was rated visually before initiating irrigation treatments in 1989 and in each subsequent year. The grove had been irrigated using flooding, but was converted to microsprinkler irrigation in fall of 1989. Visual evaluations were made on 17 Nov. 1989, 13 Dec. 1990, 11 May 1991, 14 Sept. 1992, and 23 Dec. 1993. Twelve trees per bed were randomly selected as subsamples. Trees were rated from 1 (poorly growing, unhealthy) to 8 (vigorously growing, healthy). In addition, trunk diameter measurements were taken about 1 ft (30 cm) above ground level each year from 1990-93 in December.

Fruit growth was measured by randomly selecting and tagging eight fruit per tree (two fruit from each quadrant) from four trees per bed and measuring the fruit equatorial diameter each month. Measurements began on 13 Mar. 1990, 18 Apr. 1991, 14 May 1992, and 11 June 1993 after the initial fruit drop period. Dates varied seasonally due to differences in bloom date. Full bloom occurred in Feb. 1990, March 1991, mid-March 1992 and mid-April 1993. Fruit growth was measured monthly until harvest, which also varied seasonally.

Leaf Tissue Analysis

Leaves for mineral nutrition tissue analysis were collected in Aug. 1990 and 1991 and Sept. 1992 and 1993. In 1990 and 1991, 100 mature spring flush leaves from non-fruiting branches were selected from the 12 sample trees in each bed and from four beds per treatment. In 1992 and 1993, five leaves from four sample trees were collected with three samples per bed and four beds per treatment. This sampling technique was used to determine the amount of tree-to-tree variation within a bed. Leaves were then washed in detergent (Dreft; Proctor and Gamble, Cincinnati), rinsed once with running tap water and four times in deionized water, dried at 158°F (70°C) for 48 hours and ground to pass through an ≈ 0.5 mm (40 mesh) screen. Total Kjeldahl N was determined by the micro Kjeldahl procedure (Wolf, 1982) using a rapid flow analyzer (Alpkem Corp., Clackamas, Ore). Leaf P, K, Ca, Mg, Na, B, Cu, Fe, Mn, and Zn were determined by ashing a 0.5 g sample in a muffle furnace at 1022°F (550°C) for 8 hours using quartz crucibles. The ash was then brought to a volume of 50 ml with 1N HCl and filtered. Samples were than analyzed by the Analytical Research Laboratory, Univ. of Florida, Gainesville on an Inductively Coupled Argon Plasma Spectrometer (Thermo Jarrell Ash Corp., Boston, MA).

Fruit Quality

Fruit weight, juice weight, peel thickness, total soluble solids (TSS), titratable acidity (TA), and TSS:TA ratio were measured monthly beginning in Aug., Sept. or Oct. in 1991, 1992, and 1993, respectively. TSS is an estimate of the sugar content of the juice and TA an estimate of the citric acid content. This starting date varied yearly based on date of bloom. Fruit samples consisted of 10 fruit per tree (Wardowski et al., 1979) from three trees per bed and four beds per treatment. Fruit were sectioned equatorially so that peel thickness could be measured with a hand caliper and the juice extracted by hand with a Sunkist motor driven extractor. TSS was determined with a temperature compensating refractometer and TA by titration of a 25 ml aliquot of juice using 0.3125N NaOH to an end-point with phenolphthalein as an indicator (Wardowski et al., 1979).

Levels of Cd, Pb, and Ni were determined by taking 7 mm core samples from the peel of 10 fruit per tree from three trees per bed and four beds per treatment on 15 Oct. 1991 and 6 Jan. 1993. The samples were then dried at 158°F (70°C) for 48 hours and then processed as described previously for leaf tissue.

Yield

Yield was determined from 1991 to 1994 by counting the number of bins harvested per bed and dividing the total by the number of healthy, productive trees per bed. Yields were then averaged for four beds (replicates) per treatment. In March 1992, a severe storm caused a large number of fruit to drop prior to harvest of some of the trees. An estimate of fruit drop was made by counting fruit under sample trees in each bed. Fruit drop averaged 20 to 25% of total yield. In addition, each bed was evaluated yearly for missing or severely diseased trees. The healthy tree count per bed was then revised prior to harvest.

Water Quality Analysis

Water quality was monitored monthly for both the canal water and reclaimed wastewater irrigation sites by collecting samples at the water input source to the irrigation system (Table 6). Three water samples from each source were collected and analyzed for pH, electrical conductivity (EC), NO_3^-, NH_4^+, PO_4^-, K, Ca, Mg, Zn, Cu, Cd, Ni, Pb, Na, and B. The pH was determined using a pH meter (Orion Research Inc. model 520A Boston, MA) and EC with a conductance meter (YSI model 35 YellowSprings, OH). Nitrate-N was determined on the rapid flow analyzer (Alpkem Corp. Clackamas, OR). Ammonium-N and PO_4^- were determined on an AutoAnalyzer II (Technicon Instruments Corp. Tarrytown, NY). All other nutrients were analyzed by the Analytical Research Laboratory, Univ. of Florida, Gainesville on an Inductively Coupled Argon Plasma Spectrometer (Thermo Jarrell Ash Corp., Boston, MA).

Analysis of influent and effluent water for enteroviruses was made quarterly. Samples consisted of three 1-liter influent samples collected at the inlet value where the wastewater entered the treatment facility and three 387-liter effluent samples collected at the efflux valve. Analysis during 1990-91 was conducted by the State of Florida, Dept. of Health and Rehabilitative Services (HRS). Subsequent analysis was performed by Dr. S. Farrah at the Dept. of Microbiology and Cell Sciences, Univ. of Florida, Gainesville. Procedures used for analysis of enterovirus levels were modified from those described in the USEPA Manual of Methods for Virology. (Cincinnati, OH).

In addition, eight fruit from both the high-reclaimed wastewater and control treatments were harvested in 17 Mar. 1992 and 18 Feb. 1993 and analyzed for the presence of enteroviruses (Farrah, unpublished). Briefly, the following procedure was used. One grapefruit was placed in a sterile beaker with 200 ml of 0.05% beef extract at pH 9. After mixing for 5 min, the solution was removed and concentrated by adjustment to pH 3.5 and addition of 0.005 M ferric chloride to enhance flocculation. Samples were centrifuged at 14,000xg for 10 min. The floc was

Table 6. Average chemical analysis of reclaimed wastewater and canal water from Vero Beach, Fla[z].

Characteristic	Reclaimed wastewater	Canal water
	Mean ± SD	
pH	7.07 ± 0.10	7.46 ± 0.16
Electrical conductivity	764.6 ± 72.4	1058.0 ± 211.1
Element	(ppm)	
Ammonium nitrogen (NH^{+4}-N)	0.32 ± 0.41	0.17 ± 0.16
Cadmium (Cd)	ND	ND
Calcium (Ca)	44.08 ± 23.88	103.24 ± 23.49
Copper (Cu)	0.003 ± 0.007	0.009 ± 0.011
Lead (Pb)	0.001 ± 0.005	0.002 ± 0.006
Magnesium (Mg)	13.64 ± 3.64	27.63 ± 6.28
Nickel (Ni)	ND	ND
Nitrate nitrogen (NO^{-3}-N)	5.61 ± 2.20	0.48 ± 0.52
Phosphorus (P)	3.88 ± 1.24	0.13 ± 0.08
Potassium (K)	16.68 ± 2.31	8.32± 2.78
Sodium (Na)	136.47 ± 13.68	129.27 ± 25.30
Zinc (Zn)	0.048 ± 0.021	0.031 ± 0.021

[z]Values represent the mean of three samples per month collected from Oct. 1992 to Nov. 1993.
ND=None detected or below detectable limits.

suspended in 10 ml of 0.15M sodium phosphate and again centrifuged. The supernatant was adjusted to pH 7 and assayed as described previously (Farrah, unpublished). Seeded studies with poliovirus added to the surface of the grapefruit showed that 58% of the added virus could be recovered in the final sample. Therefore, these techniques gave an accurate representation of the presence of enteroviruses on grapefruit.

Weed Intensity

Weed intensity within the tree rows was determined monthly by visual evaluation beginning in Jan. 1992. Ratings ranged from 0 (no weed growth) to 5 (≥50% of ground surface covered with weeds). All beds had bahia grass between rows; the grass was mowed as necessary. Pest, weed, and disease control treatments were applied by Arapaho Groves, Inc. as currently recommended for groves receiving standard irrigation in the Vero Beach area. No adjustments in herbicide or pest control practices were made initially for the reclaimed wastewater treatments. However, after observing the influence of wastewater application on weed growth some changes in herbicide practices were made including the use of less soluble materials such as Solicam® and more frequent spot applications with glyphosphate.

Weather Data

Weather data were collected using a Campbell Scientific, Inc. remote weather station (Logan, UT). Solar and quantum radiation (average and maximum), temperature, relative humidity (average, maximum, and minimum) and rainfall data were collected weekly. These data, in particular rainfall, were used to help separate environmental factors from treatment effects (Appendix).

Statistical Analysis

Experiments were analyzed using the Statistical Analysis System general linear model procedure and analysis of variance. Visual ratings and trunk diameter values were analyzed using analysis of covariance to standardize differences in initial tree measurements. Repeated measure analyses were used in analyzing fruit growth, fruit quality and weed intensity. Regression analysis and contrasts were used to determine trends in the data and to separate means where appropriate.

Results and Discussion

Tree Growth

Trees receiving moderate levels of reclaimed wastewater were in general more vigorous than those receiving the other treatments (Table 7). In 1992, all reclaimed wastewater treated trees were significantly more vigorous than trees receiving canal water. Trunk diameter also was similar in 1990, 1991 and 1992 for all treatments; however; in 1993 trees receiving low- and moderate-

Table 7. Reclaimed wastewater and canal water effects on vegetative growth and development of 'Redblush' grapefruit trees at Vero Beach, Fla., 1989-93.

Treatment	Visual rating[z]				
	28 Nov. 1989	13 Dec. 1990	16 May 1991	14 Sept. 1992	23 Dec. 1993
Canal water (CW)	5.1[x] (4.9)	5.1 (4.9)	5.2 (5.1)	5.3 (5.2)	5.5 (5.3)
Reclaimed wastewater					
Low - 0.9 in./wk	5.1 (5.0)	5.1 (5.2)	5.3 (5.4)	5.6 (5.7)	5.7 (5.9)
Mod. - 1.2 in./wk	5.1 (5.3)	5.5 (5.7)	5.8 (5.9)	6.1 (6.2)	6.4 (6.5)
High - 1.5 in./wk	5.1 (5.3)	5.3 (5.6)	5.4 (5.7)	5.7 (5.9)	5.6 (5.9)
Significance					
Treatment	NS	***	***	***	***
Contrast					
CW vs. Low				*	
CW vs. Mod.		***	***	***	***
CW vs. High				**	
Low vs. Mod.		***	***	***	***
Low vs. High					
Mod. vs. High			***	**	***

[z]Visual rating ranged from 1 (a poorly growing, unhealthy) to 8 (a healthy, vigorous) tree.
[x]Numbers in parentheses are actual means. Other numbers represent adjusted means from analysis of covariance. Each number represents the mean of 12 samples per bed with four replicates per treatment.
NS,*,**,***=Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

reclaimed wastewater treatments had significantly greater trunk diameters than those receiving the canal water or high wastewater treatment (Table 8). Visual ratings and trunk diameter measurements suggest that trees receiving reclaimed wastewater at high rates may have been over-irrigated, although soil in the treated area was rarely anaerobic based on soil redox potential measurements. Soil water content data (Appendix), however, for the high-reclaimed wastewater treatment were consistently higher than for the other treatments. In addition, soil water content in the low- and moderate-reclaimed wastewater treatments was typically higher than that for the areas receiving canal water. Trees receiving canal water also had reduced growth compared to those in the low and moderate-reclaimed wastewater treatments, which in this instance was more likely due to water stress rather than excess water. Therefore, the low and moderate levels of reclaimed wastewater produced the most favorable soil moisture levels for tree growth at this location. Yields steadily increased yearly for the reclaimed wastewater trees but varied only slightly for the trees receiving canal water.

Leaf Nutrient Concentrations

Macronutrients. Leaf tissue N was similar for all treatments in 1990 and 1991 (Tables 9 and 10); however, in 1990 the leaf N was in the optimum range (2.5-2.7%), whereas in 1991 leaf N was in the deficient range (<2.2%). These deficient N levels were attributable to the higher than normal rainfall (Appendix), which caused leaching of fertilizer from the root-zone. Additionally, the wet soil conditions prevented a second fertilizer application. In 1992 and 1993, leaf N concentrations for trees receiving canal water were slightly but significantly higher than for the reclaimed wastewater treatments (Tables 11 and 12). In 1993, leaf N concentration was greater for trees receiving the moderate- and high-reclaimed wastewater treatments than for those receiving the low levels. The differences in leaf N levels, however, were small and are probably not significant from a practical standpoint. In addition, lower than optimum leaf N concentrations may be desirable for the production of fresh market grapefruit in the Indian River area. The fact that leaf N levels differed only slightly with treatment is potentially significant considering the greatly different levels of fertilizer applied. Frequent application of nutrients in itself may also be beneficial in maintaining leaf N at steady levels.

Leaf P concentrations were similar for all treatments in 1990, 1991 and 1992 (Tables 9-11). In 1990 and 1992 leaf P concentrations were in the optimum range (0.12-0.16%); in 1991, leaf P was in the low range (0.09-0.11%), again due to excessive rainfall. Even though there were statistically significant differences in leaf P among treatments in 1993, levels were within the optimum range (Table 12). Phosphorus levels were moderately low in the reclaimed wastewater and low levels were also applied in the fertilizer due to P accumulation in the soil in the mature grove.

Leaf K concentrations were similar for all treatments in 1990, 1991 and 1992 (Tables 9-11). In 1990 and 1991, leaf K was in the low range (0.7-1.1%), but increased to the optimum range (1.2-1.7%) in 1992. Leaf K concentration was significantly higher for all reclaimed wastewater treatments than for the canal water treatment in 1993 (Table 12). Possibly K accumulated in this year versus others due to lower rainfall (Appendix), because K readily leaches from the soil.

Table 8. Reclaimed wastewater and canal water effects on trunk diameter of 'Redblush' grapefruit tress at Vero Beach, Fla., 1990-93.

Treatment	Trunk diameter (in)[z]			
	Nov. 1990	Sept. 1991	Sept. 1992	Nov. 1993
Canal water	8.8[x] (8.1)	8.9 (8.3)	9.0 (8.4)	9.1 (8.6)
Reclaimed wastewater				
Low - 0.9 in./wk	8.8 (8.7)	9.0 (8.9)	9.1 (9.0)	9.3 (9.3)
Mod. - 1.2 in./wk	8.8 (9.0)	8.9 (9.1)	9.0 (9.3)	9.3 (9.5)
High - 1.5 in./wk	8.8 (9.2)	8.9 (9.4)	8.9 (9.5)	9.1 (9.6)
Significance				
Treatment	NS	NS	NS	*
Contrast				
CW vs. Low				*
CW vs. Mod.				*
Low vs. High				*
Mod. vs. High				*

[z]Trunk diameter measurements were taken approximately 8 in. above ground level.
[y]Numbers in parentheses are actual means. Other numbers represent adjusted means from the analysis of covariance. Each number represents the mean of 12 samples per bed with four replicates per treatment.
NS,*,**,***=Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 9. Reclaimed wastewater and canal water effects on leaf nutrient concentrations of 'Redblush' grapefruit trees in Vero Beach, Fla., 1990[z].

Treatment	N	P	K	Ca	Mg	Na	B	Cu	Fe	Mn	Zn
	(% dry wt)					(ppm dry wt)					
Canal water	2.6	0.13	0.7	5.3	0.44	970	--[y]	121	51	16	20
Reclaimed wastewater											
Low - 0.9 in./wk	2.6	0.12	0.7	5.1	0.45	918	--[y]	135	48	16	21
Mod. - 1.2 in./wk	2.6	0.12	0.8	5.0	0.44	888	--[y]	135	48	17	23
High - 1.5 in./wk	2.6	0.13	0.8	5.1	0.44	980	--[y]	111	49	14	21
Significance											
Treatment	NS	NS	NS	NS	NS	NS		NS	NS	NS	NS

[z]Each number represents the mean of 100 leaves per bed from four beds/treatment. Leaf samples were taken from fully expanded spring flush leaves on non-fruiting branches in Aug., 1990.
[y]Missing data.
NS=Not significant.

Table 10. Reclaimed wastewater and canal water effects on leaf nutrient concentrations of 'Redblush' grapefruit trees in Vero Beach, Fla. 1991[z].

Treatment	N	P	K	Ca	Mg	Na	B	Cu	Fe	Mn	Zn
			(% dry wt)					(ppm dry wt)			
Canal water	1.8	0.09	0.7	5.4	0.49	675	100	121	57	13	19
Reclaimed wastewater											
Low - 0.9 in./wk	1.8	0.09	0.8	5.3	0.48	760	115	147	56	13	20
Mod. - 1.2 in./wk	1.8	0.09	0.7	5.3	0.47	730	132	154	59	15	21
High - 1.5 in./wk	1.8	0.09	0.8	5.4	0.45	793	102	178	61	11	25
Significance											
Treatment	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z]Each number represents the mean of 100 leaves per bed from four beds per treatment. Leaf samples were taken from fully expanded spring flush leaves on non-fruiting branches in Aug., 1991.

Table 11. Reclaimed wastewater and canal water effects on leaf nutrient concentrations of 'Redblush' grapefruit trees in Vero Beach, Fla., 1992[z].

Treatment	N	P	K	Ca	Mg	Na	B	Cu	Fe	Mn	Zn
	(% dry wt)					(ppm dry wt)					
Canal water (CW)	2.5	0.14	1.1	4.2	0.46	1284	103	292	91	20	37
Reclaimed wastewater											
Low - 0.9 in./wk	2.4	0.14	1.0	4.8	0.50	1129	158	465	126	19	38
Mod. - 1.2 in./wk	2.4	0.14	1.0	5.2	0.50	830	179	590	114	21	36
High - 1.5 in./wk	2.3	0.14	1.2	4.3	0.47	1110	152	432	103	18	34
Significance											
Treatment	*	NS	NS	*	NS	NS	***	**	NS	NS	NS
Contrast[y]											
CW vs. Low	*						**	**			
CW vs. Mod.	**			**			***	***			
CW vs. High	**						**	*			
Low vs. Mod.								*			
Mod. vs. High				**				*			

[z]Each number represents the mean of five leaves per tree from 12 trees per bed and four beds per treatment. Leaf samples were taken from fully expanded spring flush leaves on non-fruiting branches in Aug., 1992.
[y]Only significant contrasts are presented.
NS,*,**,***=Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 12. Reclaimed wastewater and canal water effects on leaf nutrient concentrations of 'Redblush' grapefruit trees in Vero Beach, Fla., 1993[z].

Treatment	N	P	K	Ca	Mg	Na	B	Cu	Fe	Mn	Zn
	(% dry wt)					(ppm dry wt)					
Canal water (CW)	2.5	0.13	1.0	4.7	0.50	1027	64	226	51	14	27
Reclaimed wastewater											
Low - 0.9 in./wk	2.3	0.12	1.2	4.5	0.45	1126	139	279	51	14	28
Mod. - 1.2 in./wk	2.4	0.12	1.2	4.2	0.41	1188	161	274	50	11	28
High - 1.5 in./wk	2.4	0.14	1.3	4.2	0.39	1203	149	229	49	11	28
Significance											
Treatment	***	***	***	*	***	NS	***	NS	NS	***	NS
Contrast											
CW vs. Low	***	*	**		*		***				
CW vs. Mod.	*		***	**	***		***			**	
CW vs. High	**		***	**	***		***			***	
Low vs. Mod.	*				*		***			**	
Low vs. High		***			**					***	
Mod. vs. High		**					*				

[z]Each number represents the mean of five leaves per tree from 12 trees per bed and four beds per treatment. Leaf samples were taken from fully expanded spring flush leaves on non-fruiting branches in Aug., 1993.

NS,*,**,***=Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Leaf Ca concentrations were similar for all treatments in 1990 and 1991 (Tables 9-10). All leaf Ca concentrations were in the high range (5.0-6.9%). In 1992, leaf Ca levels in trees receiving the moderate levels of reclaimed wastewater were significantly higher than for those receiving the canal water or high reclaimed wastewater treatment. Leaf Ca concentrations were in the optimum range (3.0-4.9%) (Table 11). In 1993, trees receiving canal water and moderate reclaimed wastewater were significantly higher in leaf Ca than those receiving moderate and high-reclaimed wastewater (Table 12); however, all levels were within the optimum range.

Leaf Mg concentrations were similar for all treatments in 1990, 1991 and 1992 (Tables 9-11), with all concentrations within the optimum range (0.30-0.49%). In 1993, trees receiving canal water had significantly higher leaf Mg levels than those receiving reclaimed wastewater, with the low-reclaimed wastewater treatment having significantly higher Mg levels than the moderate and high-reclaimed wastewater treatments. Although, there were statistical differences among treatments, all leaf Mg levels were within the optimum range.

Leaf Na concentrations were similar for all treatments in all 4 years. Leaf Na levels were lowest in 1991 (Tables 9-12) due to leaching of Na beyond the root zone by excessive rainfall (Appendix). Sodium concentrations in the leaves did not reach toxic levels throughout the study.

Micronutrients. Leaf B concentrations were not analyzed in 1990 (Table 9), but in 1991 all treatments produced similar leaf B concentrations (Table 10), which were in the low end of the high range (101-200 ppm). In 1992, trees irrigated with reclaimed wastewater showed a 50% increase in leaf B over the canal water treatments (Table 11), but with all treatments, leaf B levels were in the high range. In 1993, trees receiving reclaimed wastewater had twice the concentration of leaf B of those receiving canal water (Table 12). Irrigation at the moderate rate increased leaf B concentrations more than at the other two rates. Leaf B levels for the reclaimed wastewater treatments were within the high range. Reclaimed wastewater contained four times more B than the canal water which accounted for increased leaf B concentrations. Nevertheless, leaf B concentrations were below toxic levels (<250 ppm) for citrus trees and no adverse effects on tree growth or yields were observed. Increased leaf B due to reclaimed wastewater treatment are consistent with previous results for citrus on the ridge for the Conserv II project (Zekri and Koo, 1993).

Leaf Cu concentrations were also similar for all treatments (Tables 9-12), but varied greatly from year-to-year due to the addition of Cu containing fungicide sprays applied for melanose and greasy spot control. Similarly, leaf Fe concentrations were similar for all treatments for all 4 years (Tables 9-12). In 1990, 1991, and 1993 leaf Fe concentrations were in the low range (36-59 ppm); in 1992, they were in the optimum range (60-120 ppm). Leaf Mn concentrations were similar for all treatments in 1990, 1991, and 1992 (Tables 9-11). Levels were in the deficient range (< 17 ppm) in 1990 and 1991, and the low range (18-24 ppm) in 1992. In 1993, trees receiving canal water and low-reclaimed wastewater had significantly higher leaf Mn than those in the other treatments (Table 12), but all leaf Mn concentrations were in the deficient range. Leaf Zn concentrations were similar for all treatments in each year with levels in the low range (18-24 ppm) in 1990 and 1991 (Tables 9 and 10) and in the optimum range (25-100 ppm) in 1992 and 1993 (Tables 11 and 12).

With the exception of leaf B, micronutrient levels were not significantly affected by reclaimed wastewater application as expected based on micronutrient levels in the wastewater. Growers should monitor B levels, however, especially if they add additional B in fertilizer. Citrus trees are sensitive to excessive or deficient B levels.

Fruit Growth

Fruit growth patterns were similar in 1990, 1991, and 1992 for all treatments and followed a typical sigmoid growth pattern for citrus fruit (Figs. 1 and 2). In contrast, in 1993 trees receiving reclaimed wastewater had significantly larger fruit than those receiving canal water (Fig. 2B). The lack of difference in fruit growth in 1991 may have been attributed to above normal rainfall during the summer which negated any irrigation effects (Appendix).

Fruit weight for trees receiving reclaimed wastewater treatments was significantly greater than for those receiving canal water in 1991-92 (Fig. 3A). Fruit weight of trees receiving canal water was significantly less than other treatments from Aug. to Nov. but was similar from Dec. to Feb. In 1992-93, fruit weight was significantly greater for reclaimed wastewater treatments compared to the canal water treatment (Fig. 4A) as in 1991-92. Fruit weight for the reclaimed wastewater treatments was significantly greater than the canal water treatment for Oct. to Nov.; fruit weight was similar from Dec. to Feb. In 1993-94, fruit weight for the reclaimed wastewater treatments was significantly greater than for those in the canal water treatment (Fig. 5A).

Juice weight exhibited a similar trend to fruit weight. Fruit from trees receiving reclaimed wastewater had significantly higher juice weight than from trees receiving canal water in all three seasons (Figs. 3B, 4B, 5B). In 1991-92, the juice weight decreased for trees receiving canal water until Dec., but the juice weight was similar for all treatments by Jan. to Feb. In 1992-93, fruit from trees receiving canal water had a significantly lower juice weight in Nov. to Dec.; however, the juice weight was similar for all other months. The juice weight of trees receiving reclaimed wastewater was significantly greater for the entire season in 1993-94.

Peel thickness was similar for all treatments in each of the three years (Figs. 3C, 4C, 5C) even though juice and fruit weight differed for some treatments. This similarity in peel thickness may have been due to similar leaf K levels in most seasons for all treatments. Potassium has a significant regulatory effect on peel thickness in citrus.

Fruit TSS and TA

TSS was significantly lower for trees receiving moderate levels of reclaimed wastewater compared to the other treatments in 1991-92 (Fig. 6A). However, from Dec. until harvest all treatments had similar fruit TSS. In 1992-93, fruit had similar TSS for all treatments (Fig. 7A). In 1993-94, fruit from the moderate-reclaimed wastewater treatment were significantly lower in TSS compared to fruit receiving canal water (Fig. 8A). The variable effects of high irrigation levels on TSS are consistent with results obtained in other studies for Conserv II (Zekri and Koo, 1993).

TA levels were similar for all treatments in 1991-92 (Fig. 6B) and 1993-94 (Fig. 8B), but in 1992-93 TA of trees receiving the canal water was significantly higher than for those receiving the reclaimed wastewater treatments (Fig. 7B). In contrast, fruit TA was consistently lower for trees receiving reclaimed wastewater than well-water in the Conserv II project (Zekri and Koo, 1993). Differences in soil water holding capacity and rainfall patterns and amounts between the two study areas may account for such differences. Rainfall effects in particular may overshadow the effects of irrigation on fruit TA.

Fruit TSS:TA ratio was similar for all treatments in 1991-92 (Fig. 7C). In 1992-93, fruit from the low and moderate-reclaimed wastewater treatments had a significantly higher TSS:TA ratio than those from the canal water treatment (Fig. 8C). This difference occurred from Dec. until harvest and was due to the decrease in fruit TA. In 1993-94, fruit TSS:TA ratio was again similar for all treatments (Fig. 9C).

In summary, reclaimed wastewater irrigation had variable effects on fruit TSS, TA and TSS:TA. However, high rates of reclaimed wastewater may actually be beneficial. Even though reclaimed wastewater treatments at times diluted fruit TSS and TA, the fruit TSS:TA ratios were higher for reclaimed wastewater than the canal water treatment in some years as in 1992-93 (Fig. 8). Thus, fruit attained minimum maturity standards about 2 to 3 weeks earlier for reclaimed wastewater compared to canal water treatments. Attainment of earlier ratio without decreasing TSS would be advantageous for growers selling grapefruit to the early season market.

Heavy Metals in Fruit

No accumulation of Cd, Ni, or Pb occurred in the fruit in 1992 or 1993 (data not shown). This finding is not surprising since the reclaimed wastewater had only trace amounts of heavy metals which is typical of non-industrial wastewater. Therefore, use of wastewater of this quality poses no threat to citrus trees or consumers from heavy metal accumulation.

Yields

Fruit from the 1990-91 season were harvested in Oct. 1990 and again in June 1991. A moderate freeze of Dec. 1989 had caused two distinct blooms to occur, one in Jan. 1990 and a second in Mar. to Apr. 1990. Prior to implementation of the irrigation treatments in 1990-91 yields were statistically similar for all beds averaging 431 lb per tree (196 kg) (Table 13). However, trees receiving treatment with canal water had numerically lower yields than the other trees. Thus, subsequent yields were analyzed by covariate analyses to adjust for this difference. The 1991-92 crop was harvested in Mar. 1992. Trees receiving low- and moderate-reclaimed wastewater treatments produced significantly higher yields than trees receiving canal water. Yield for the high reclaimed wastewater trees was also greater than for canal water trees ($P \leq 0.14$), but was similar to the low- and moderate-reclaimed wastewater treatments (Table 13). Harvest of the 1992-93 crop began in early Mar. 1993. On 13 Mar. 1993 a severe wind storm caused an estimated loss of 90 lb per tree for some of the trees. This estimate was added to the yield to adjust for these losses. Yield for the low, moderate and high-reclaimed wastewater treatments was significantly greater than for the trees receiving canal water at $P \leq 0.05$, 0.11 and 0.10, respectively (Table 13). The 1993-94 crop was harvested 15-18 Apr. 1994. Again, yields in all reclaimed wastewater treatments were similar and greater than those for the canal water treatment.

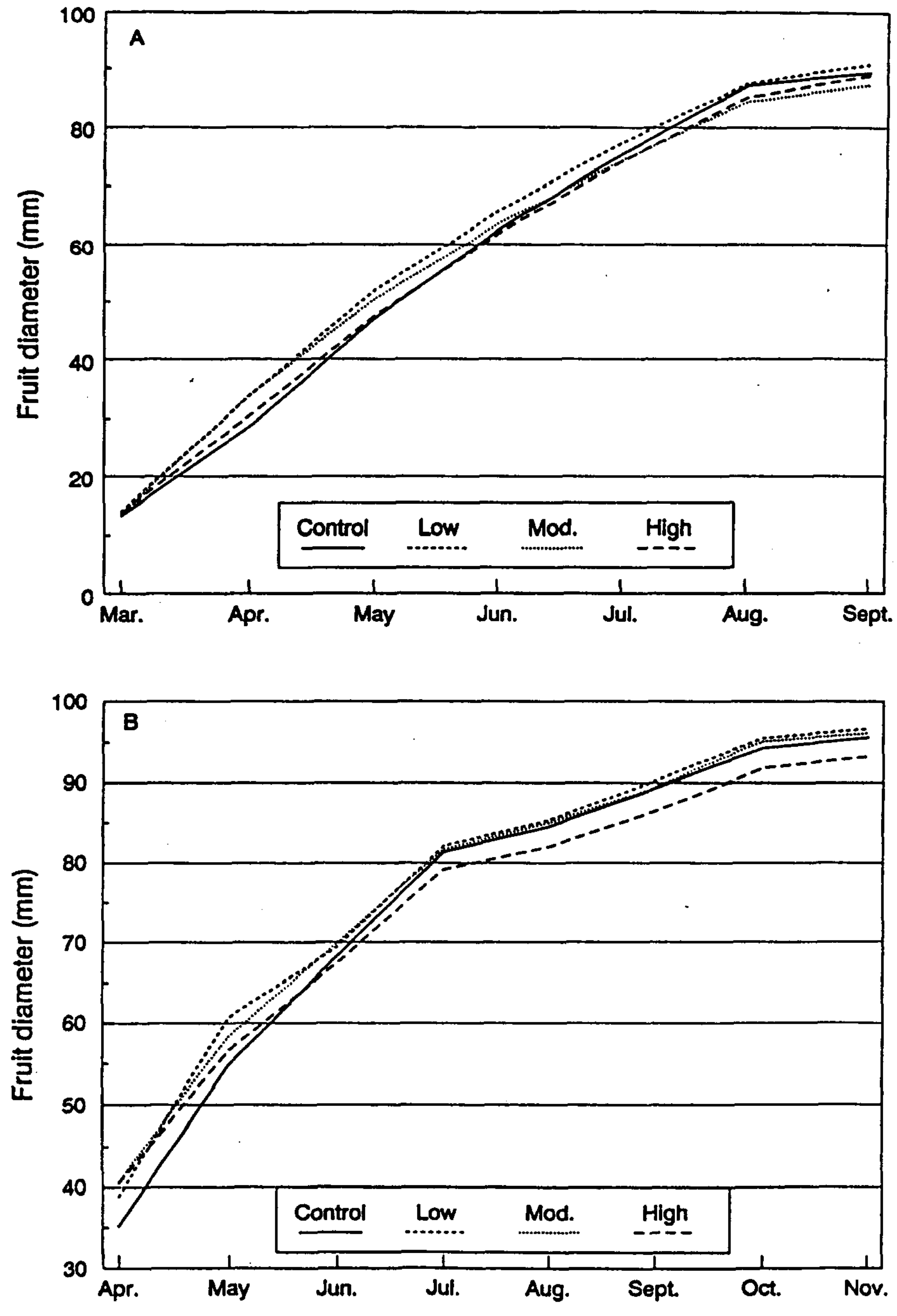

Fig. 1. Reclaimed wastewater and canal water (control) effects on fruit growth of 'Redblush' grapefruit at Vero Beach, Fla., 1990 and 1991. (A) 1990 and (B) 1991. Note: control=canal water; low=0.9, mod.=1.2, high=1.5 in./wk.

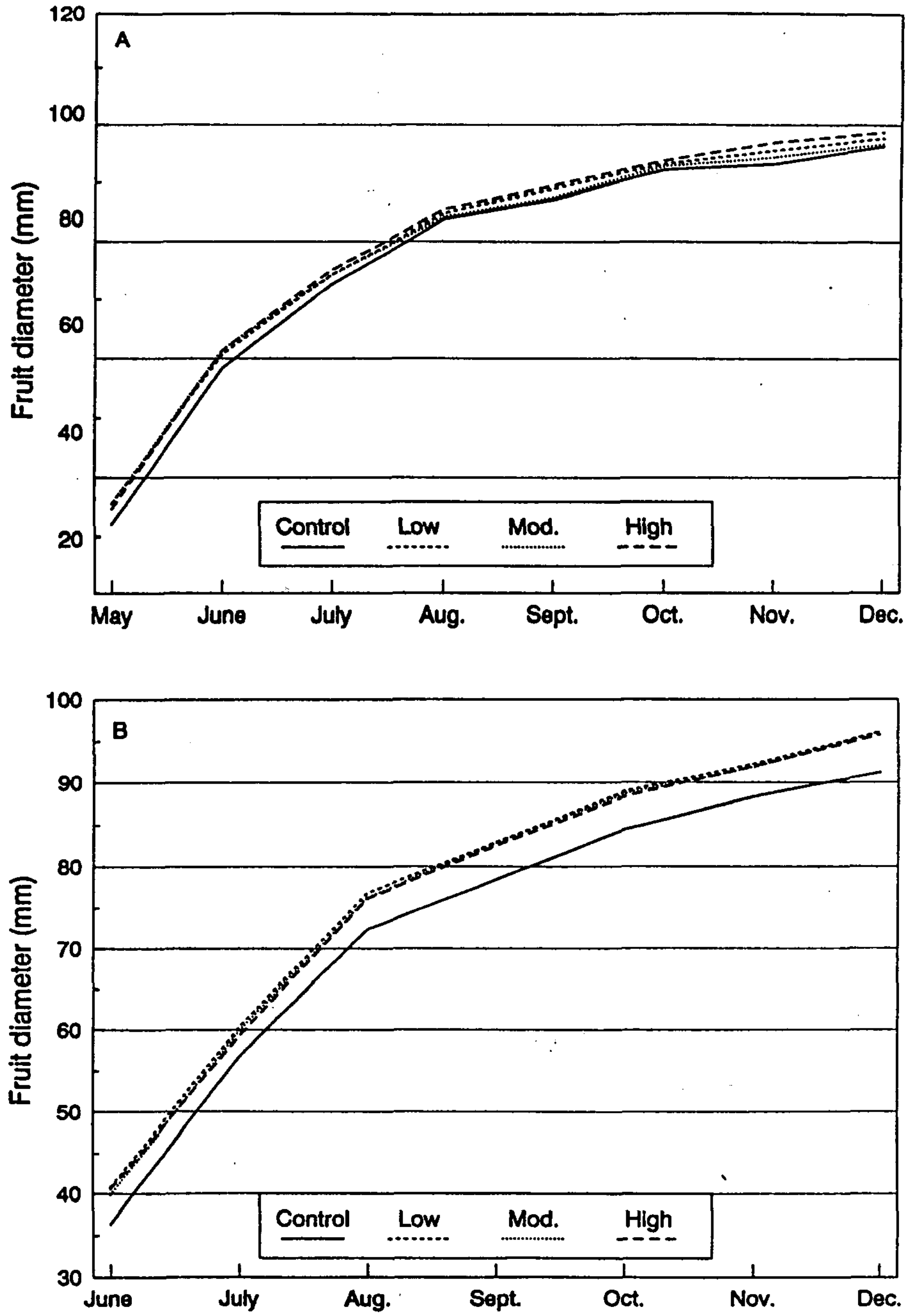

Fig. 2. Reclaimed wastewater and canal water (control) effects on fruit growth of 'Redblush' grapefruit at Vero Beach, Fla., 1992 and 1993. (A) 1992 and (B) 1993. Note: control=canal water; low=0.9, mod.=1.2, high=1.5 in/wk.

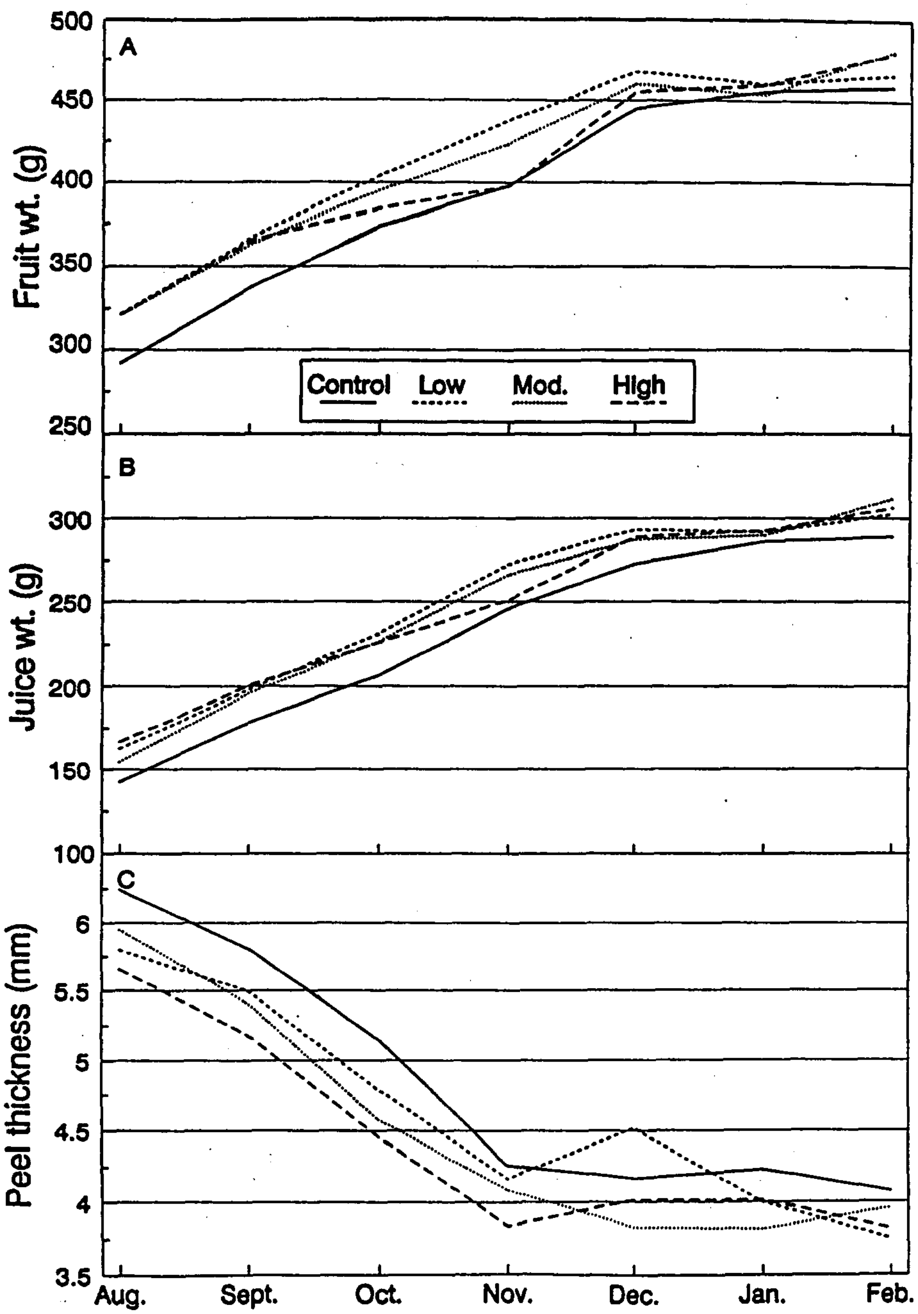

Fig. 3. Reclaimed wastewater and canal water (control) effects on fruit and juice weight and peel thickness of 'Redblush' grapefruit at Vero Beach, Fla., 1991-92. (A) Fruit weight, (B) juice weight, and (C) fruit peel thickness. Note: control=canal water; low=0.9, mod.=1.2, high=1.5 in./wk.

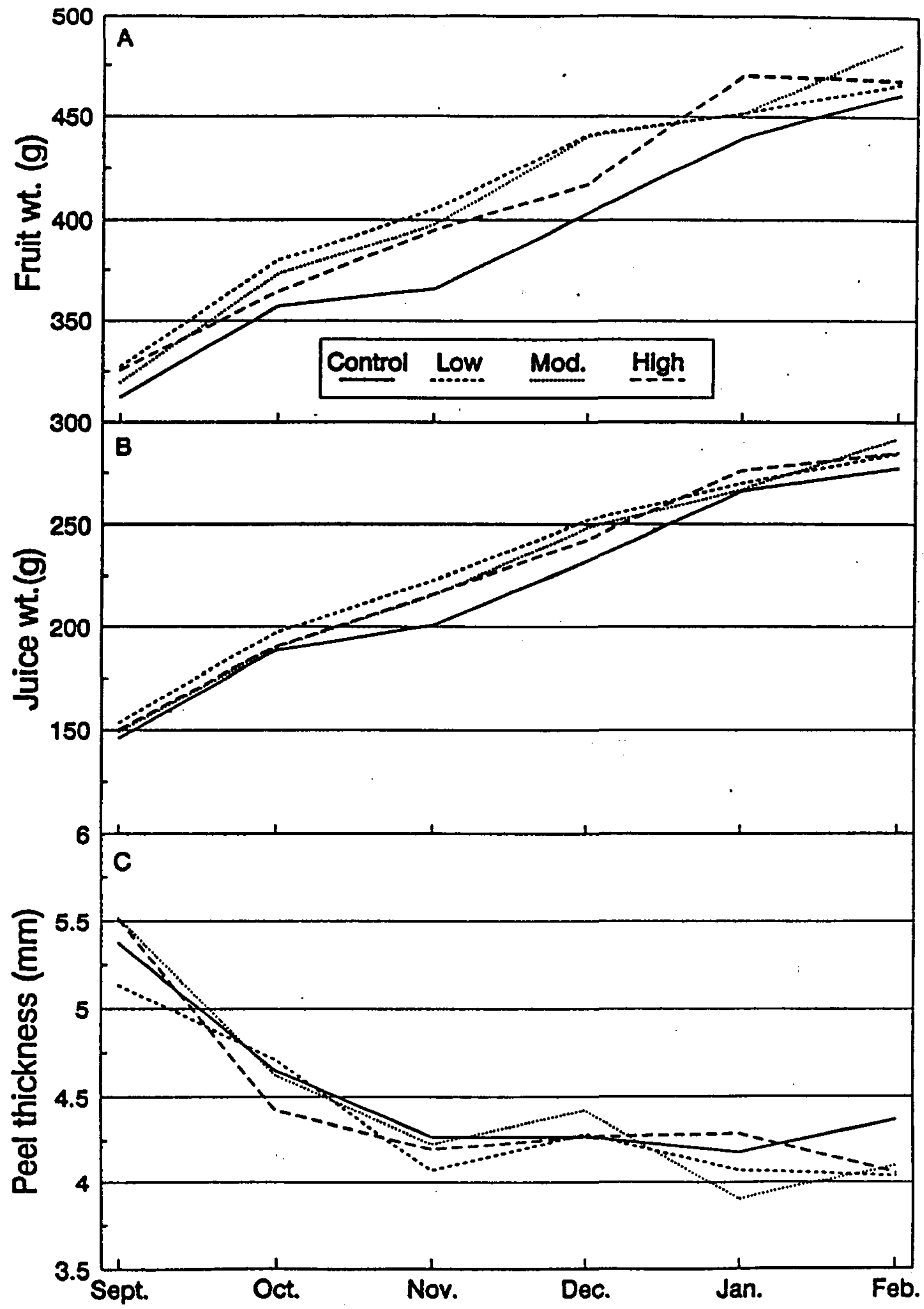

Fig. 4. Reclaimed wastewater and canal water effects on fruit and juice weight and peel thickness of 'Redblush' grapefruit at Vero Beach, Fla., 1992-93. (A) Fruit weight, (B) fruit juice weight, and (C) fruit peel thickness. Note: control=canal water; low 0.9, mod.=1.2, high=1.5 in/wk.

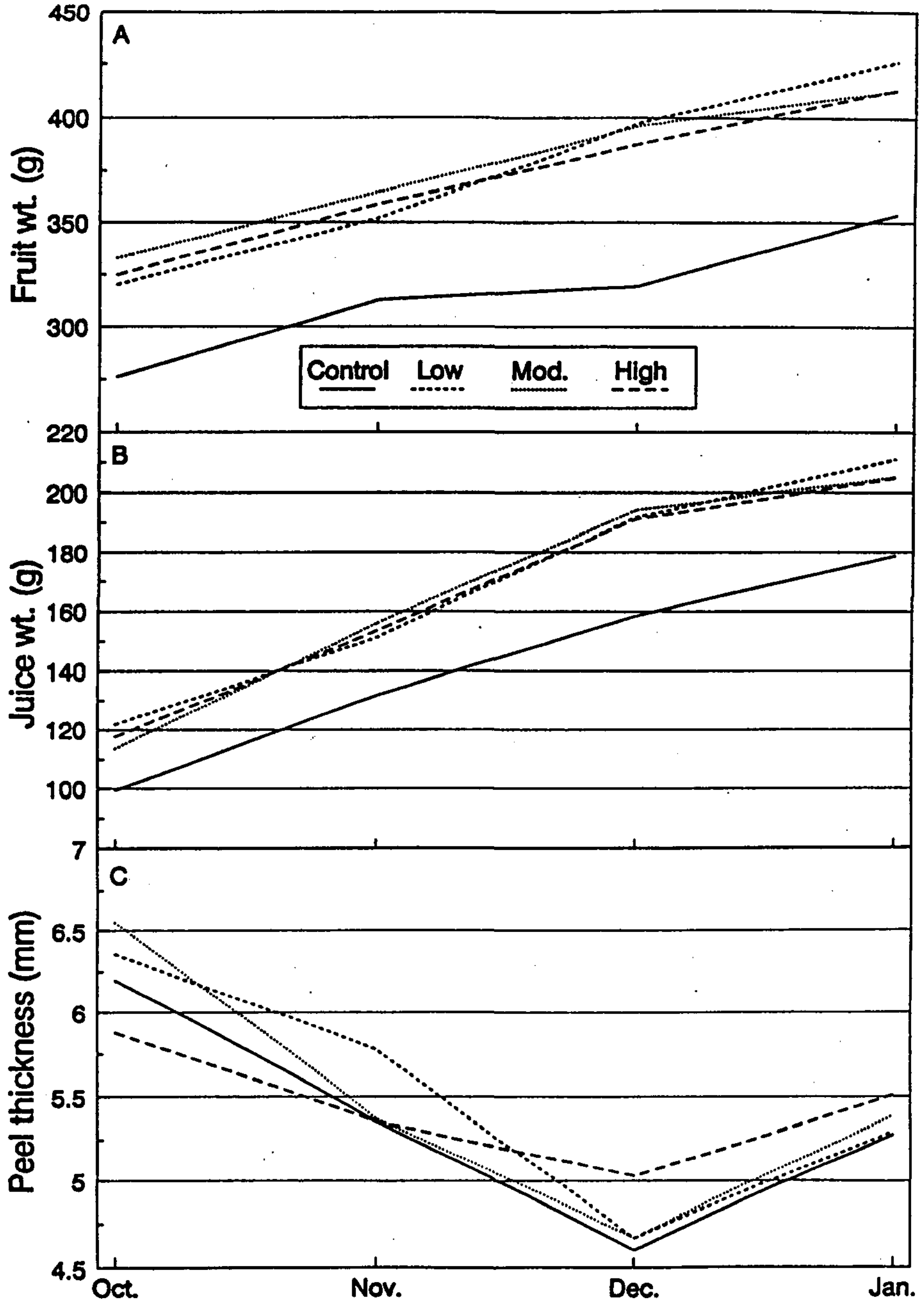

Fig. 5. Reclaimed wastewater and canal water (control) effects on fruit and juice weight and peel thickness of 'Redblush' grapefruit at Vero Beach, Fla., 1993-94. (A) Fruit weight , (B) fruit juice weight, and (C) fruit peel thickness. Note: control=canal water; low=0.9, mod.=1.2, high=1.5 in./wk.

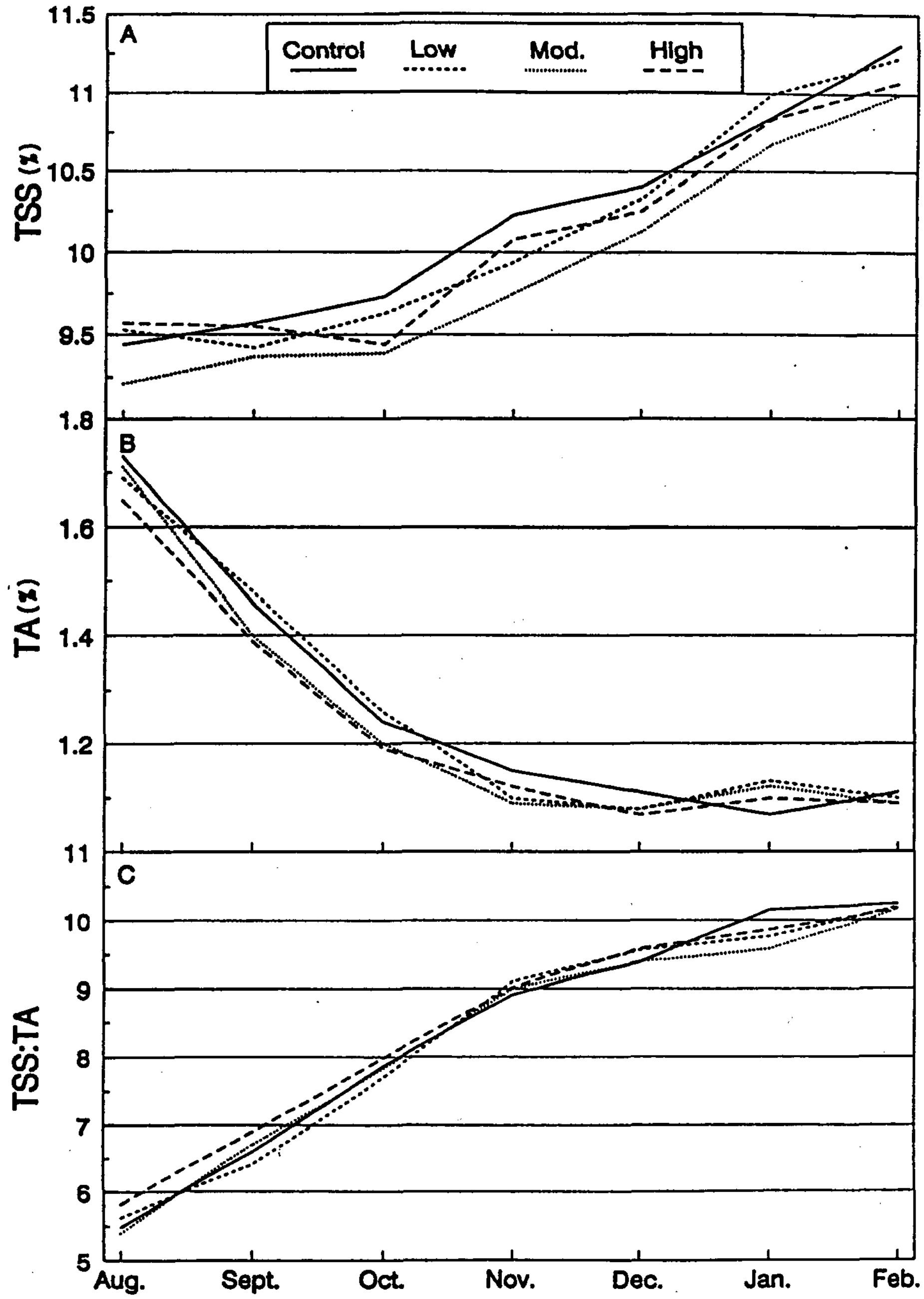

Fig. 6. Reclaimed wastewater and canal water effects on (A) fruit total soluble solids (TSS), (B) titratable acidity (TA), and (C) TSS:TA ratio of 'Redblush' grapefruit at Vero Beach, Fla., 1991-92. Note: control=canal water; low=0.9, mod.=1.2, high=1.5 in./wk.

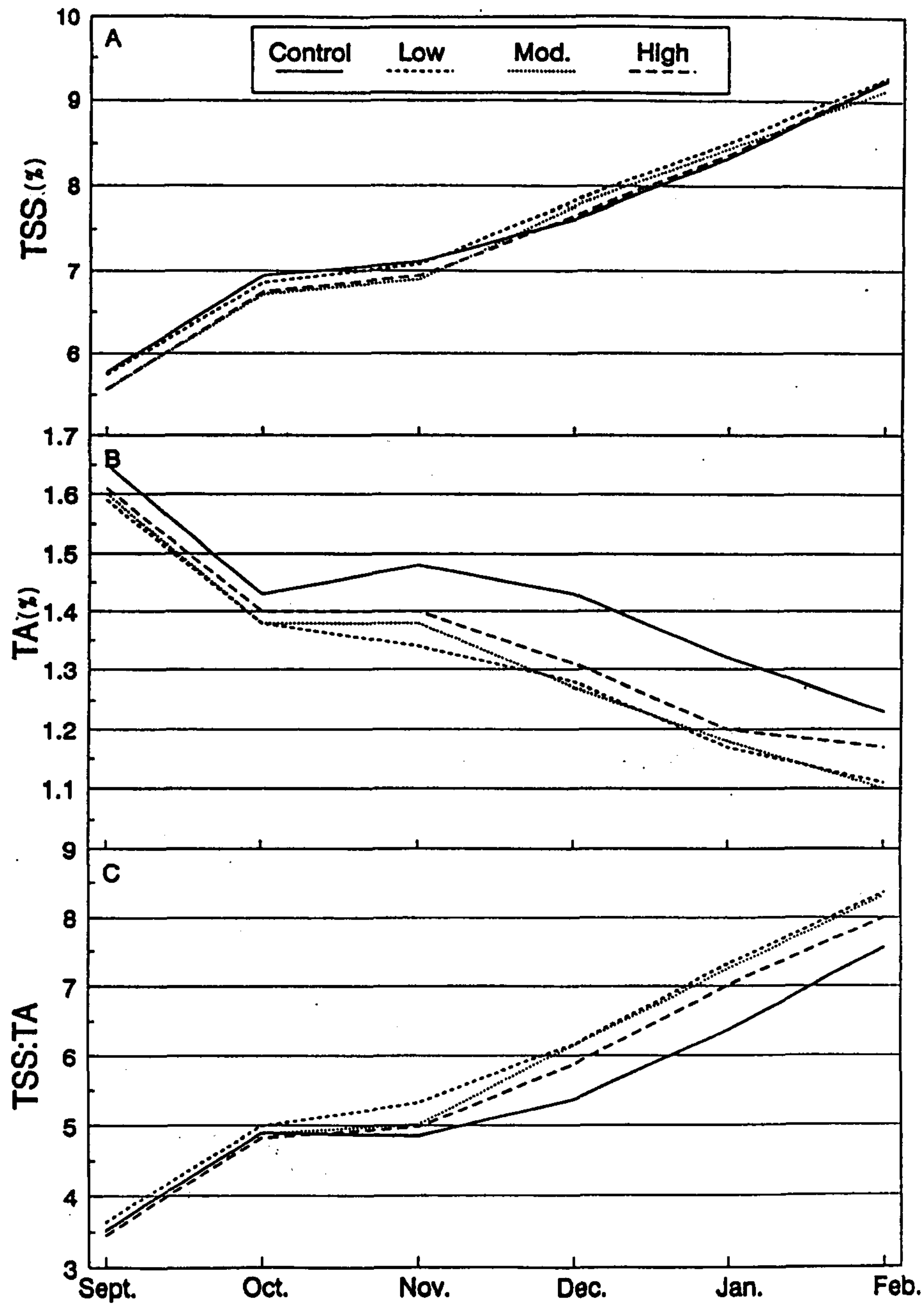

Fig. 7. Reclaimed wastewater and canal water effects on fruit (A) total soluble solids (TSS), (B) titratable acidity (TA), and (C) TSS:TA ratio of 'Redblush' grapefruit at Vero Beach, Fla., 1992-93. Note: control=canal water; low=0.9, mod.=1.2, high=1.5 in./wk.

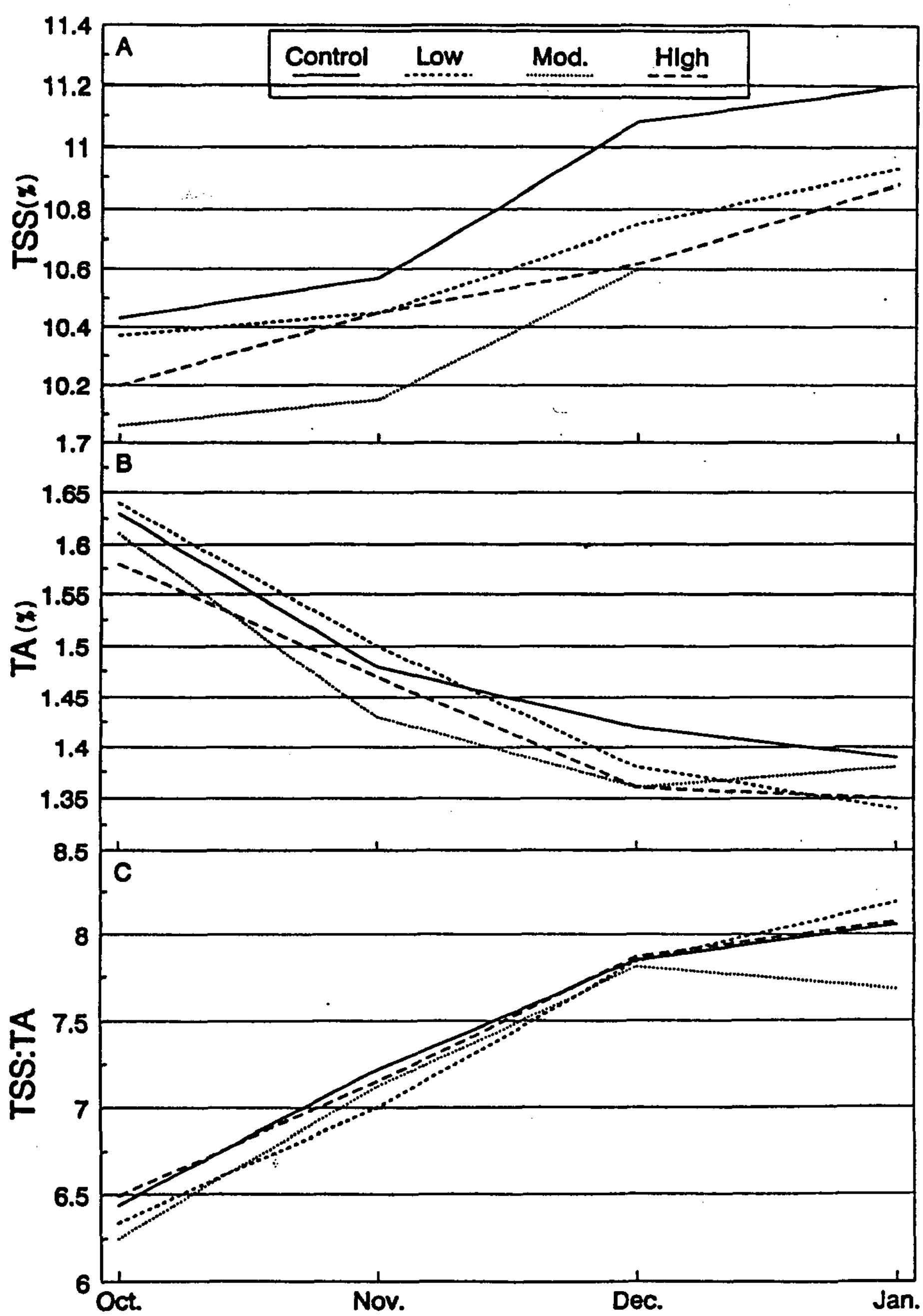

Fig. 8. Reclaimed wastewater and canal water effects on fruit (A) total soluble solids (TSS), (B) titratable acidity (TA) and (C) TSS:TA ratio of 'Redblush' grapefruit at Vero Beach, Fla., 1993-94. Note: control=canal water; low=0.9, mod.=1.2, high=1.5 in./wk.

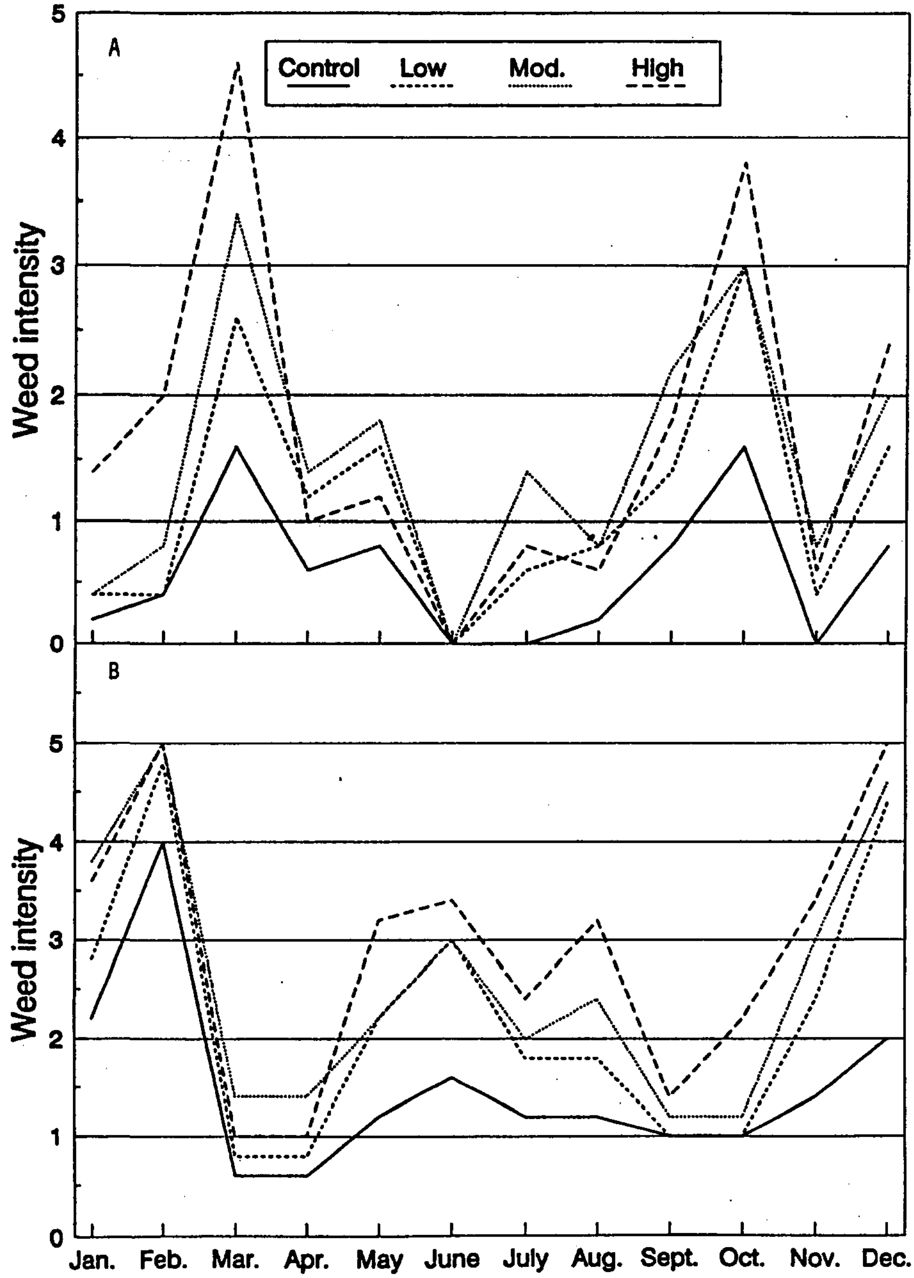

Fig. 9. Reclaimed wastewater and canal water (control) effects on weed growth in the tree row for 'Redblush' grapefruit at Vero Beach, Fla., (A) 1992 and (B) 1993. Rating was based on a scale of 0 (no weed growth) to 5 (>50% weed growth) for four beds/treatment. Note: control=canal water, low=0.9, mod.=1.2, high=1.5 in./wk.

It is well documented that irrigation during the critical period from bloom through fruit set is important for increasing yield. The increased yield in this study observed from the use of reclaimed wastewater is similar to that found for citrus on the ridge in the Conserv II project (Zekri and Koo, 1993). Nevertheless, the data also suggest that application rates of 1.5 in. per wk or more may decrease yields for the soil types used in this study. These data also suggest that the one-third to two-thirds soil moisture depletion scheme used for irrigation may not be sufficient for mature trees on shallow, flatwoods soils. This is evidenced by the fluctuations in soil water content (SWC) in the control versus reclaimed wastewater treatments (Appendix). In addition, SWC varied greatly within a bed and certainly within a grove. Therefore, the basis for scheduling irrigation in bedded groves may need to be revised.

Enteric Viruses

An important concern related to the use of reclaimed wastewater is the potential health hazards posed by bacteria and viruses in the water. The water used in this project received secondary treatment and had less than minimum levels of fecal coliform bacteria (data not shown). Reclaimed wastewater analysis for enteroviruses averaged 195.5 plaque-forming units (PFU) per liter for the influent, but <0.003 PFU per liter for the effluent which was used for irrigation (Table 14). Influent levels varied greatly depending on the season, but levels in the effluent were consistently low. Furthermore, fruit from trees treated with high rates of reclaimed wastewater in the laboratory also had <0.003 PFU per liter on the peel. Similar findings were made by the Florida State Dept. of Health in 1989 (unpublished). Citrus fruit dipped directly into untreated wastewater had no enteric viruses in the fruit or on the peel following washing with standard packinghouse procedures. Moreover, the reclaimed wastewater in this study was applied under tree to the soil and not directly to the fruit surfaces. Therefore, any risk to workers or consumers associated with use of reclaimed wastewater is extremely small.

Weed Growth

Weed intensity in 1992-93 varied seasonally and with herbicide treatments. Decreases in weed intensity were associated with herbicide applications in Mar., May, and Oct. 1992 and Mar. and Sept. 1993. Weed growth was nearly always greater for beds receiving reclaimed wastewater than canal water (Fig. 9). Weed intensity was greatest in areas where trees had been removed or resets planted, however, weed growth was greater even under trees with full canopies. Increased weed growth is a problem associated with use of reclaimed wastewater for irrigation. Application of high amounts of reclaimed wastewater provides abundant water and nutrients. In addition, the heavy applications of reclaimed wastewater may leach herbicides from the soil. Weed growth, especially, around microsprinklers also interferes with distribution patterns and ground coverage. Zekri and Koo (1993) also observed increased weed growth with use of reclaimed wastewater in the ridge area of Florida. Consequently, growers opting to use reclaimed wastewater for citrus irrigation must alter current weed control practices by using less water soluble herbicides and additional spot sprays. These factors will increase production costs.

Table 13. Reclaimed wastewater and canal water effects on yield of 'Redblush' grapefruit trees at Vero Beach, Fla., 1990-94.

Treatment	Yield (lbs per tree)			
	1990-91	1991-92	1992-93	1993-94
Canal water (CW)	431.2[z]	341.0	477.4	290.4
	(396.0)	(323.4)	(457.6)	(275.0)
Reclaimed wastewater				
Low - 0.9 in./wk	431.2 (431.2)	457.6 (457.6)	655.6 (655.6)	442.2 (442.2)
Mod. - 1.2 in./wk	431.2 (466.4)	457.6 (486.2)	620.4 (638.0)	466.4 (486.2)
High - 1.5 in./wk	431.2 (413.6)	422.4 (413.6)	620.4 (611.6)	407.0 (402.6)
Significance				
Treatment		0.03	0.1	0.06
Contrast				
CW vs. Low		0.05	0.05	0.04
CW vs. Mod.		0.05	0.11	0.03
CW vs. High		0.14	0.1	0.11
Low vs. Mod.		NS	NS	NS
Low vs. High		NS	NS	NS
Mod. vs. High		NS	NS	NS

[z]Numbers in parentheses are actual means. Other numbers represent adjusted means from analysis of covariance. Numbers represent the means of 58 trees per bed and four beds per treatment. NS=Nonsignificant.

Table 14. Influent and effluent water analyses of enterovirus levels at Vero Beach, Fla. 1990-93.

Sample date	Influent[z]	Effluent[z]
	PFU per liter[y]	
Nov. 19, 1990[x]	79.2	< 0.003
Feb. 12, 1991[x]	1.6	< 0.003
Apr. 29, 1991[x]	0.7	< 0.003
Sept. 11, 1991	380.0	< 0.003
Dec. 9, 1991	28.7	< 0.003
Mar. 17, 1992	21.3	< 0.003
June 11, 1992	166.7	< 0.003
Sept. 1, 1992	466.7	< 0.003
Jan. 11, 1993	188.3	< 0.003
Mar. 25, 1993	62.5	< 0.003
June 10, 1993	325.0	< 0.003
Sept. 23, 1993	625.0	< 0.003
Mean	195.5 ± 290	< 0.003

[z]Numbers represent the mean of three 1-liter samples taken from the influent and three 387-liter samples from the effluent.
[y]PFU per liter = plaque-forming units per liter.
[x]Analyses were conducted by the Florida Department of Health and Rehabilitative Services. All other analyses were done be Dr. S. Farrah, Department of Microbiology and Cell Science, University of Florida.

YOUNG TREE STUDIES

The use of reclaimed wastewater in mature groves may have some potential benefits in the management of resets. Reset trees must compete with mature trees for available water and nutrients. In addition, reset trees have a limited root zone with which to extract available water and nutrients (Jackson, 1981). About 85% of the roots are located in the top 10 inches of soil volume one year after planting (Marler and Davies, 1990). Growers predominantly use microsprinkler irrigation for resets (Taylor et al., 1989) because they realize a net return 1-to-2 years earlier when using microirrigation for newly planted citrus trees compared with conventional irrigation methods (Smajstrla, 1993). Therefore, the frequent irrigation associated with use of reclaimed wastewater may be beneficial for reset trees in a mature grove.

Fertilization of resets is costly because rates must be adjusted to ensure that trees receive the correct amount of material (Jackson, 1981). Currently, 62% of resets are fertilized with standard granular fertilizer (Taylor and Ferguson, 1993). Reclaimed wastewater at high rates can supply from two-thirds to all of the yearly N requirement for mature citrus trees, but supplies ≤10% of the yearly N requirement for resets due to their limited rootzone. Maurer and Davies (1993) observed that newly planted citrus trees receiving reclaimed wastewater alone exhibited N deficiency.

The objective of these experiments was to determine the effects of various rates of reclaimed wastewater on growth and development of reset trees in a mature grapefruit grove.

MATERIALS AND METHODS

Two experiments were designed to evaluate the growth and development of reset 'Marsh' grapefruit trees at various rates of reclaimed wastewater and canal water on a flatwoods type soil as described in the previous section. Plantings were located adjacent to the Indian River County municipal wastewater treatment facility at Vero Beach, Fla. within a grove of 25-year-old 'Marsh' grapefruit trees. This block was located directly north of the 'Redblush' block used in mature tree studies in the previous section. One hundred containerized 'Marsh' grapefruit trees (*Citrus paradisi* Macf.) on 'Swingle' citrumelo (*Citrus paradisi* Macf. x *Poncirus trifoliata* [L.] Raf.) rootstock ca. 1 year in the nursery (Becker Citrus Nursery, Ft. Pierce, Fla.) were planted on 21 Nov. 1990 (Expt. 1). A second experiment using one hundred containerized 'Marsh' grapefruit trees on sour orange (*Citrus aurantium* L.) rootstock ca. 1.5 years in the nursery (Becker Citrus Nursery, Ft. Pierce, Fla.) was begun on 2 Mar. 1993 (Expt. 2). Treatments were arranged as a completely randomized design consisting of five trees (samples) per bed with five beds (replicates) per treatment. Trees were planted to replace dead or missing trees within a mature grove on double beds (60 ft [18.3 m] wide x 575 ft [177 m] long) with trees spaced 30 ft (9.15 m) between rows and 25 ft (7.6 m) within the row. Trees were wrapped with R-11 fiberglass tree wraps to prevent sprouting and herbicide damage.

Treatments in 1991 and 1992 consisted of a control (canal water) irrigated based on soil moisture depletion of one-third from Jan. to June and two-thirds from July to Dec. as currently recommended for mature citrus trees. However, in 1993 irrigation was applied at one-third soil moisture depletion the entire year as recommended for young trees (Marler and Davies, 1990). Reclaimed wastewater was applied at low (0.75 in. per wk, 19 mm), moderate (1.0 in. per wk, 25.4 mm) and high (1.25 in. per wk, 32 mm) rates (Tables 15-18). Trees were irrigated with 15 gal/h (58 liter per hour) 360° Maxijet® mircosprinklers using one emitter per tree. Water was applied on a 2- or 3-day schedule as outlined in Table 19.

Trees in Expt. 1 received 0.5 (227 g), 0.75 (340 g) and 1.0 (454 g) lb N per tree per yr in 1991, 1992 and 1993, respectively, which was applied in five to six equal applications per year within the tree drip-line as currently recommended (Koo et al., 1984). Trees in Expt. 2 received 0.5 lb (227 g) N per tree per yr in 1993. Trees in both experiments received granular fertilizer formulated as 8N (4% ammonium 4% nitrate)-2P-8K-2Mg.

Tree vigor was rated visually at the end of each year from 1 (poorly growing, unhealthy) to 5 (vigorous, healthy). Tree height and trunk diameter were measured at planting and at the end of each season. Trunk diameter was measured at a height of about 1 ft (30 cm) above ground level.

Leaf tissue samples were taken in Aug. or Sept. from fully expanded spring flush leaves by collecting four leaves from each tree per bed (20 leaves per bed from each of five beds per treatment). Nutrient concentration was determined as described for mature trees.

Soil water content was monitored with a Troxler 4300 neutron probe once a week for the reclaimed wastewater treatments and twice a week for the control treatment. One aluminum access tube was placed at the drip-line within the tree row in about the middle of each bed. Neutron probe readings were taken at a depth of 9 in. (23.8 cm) to avoid reading soil water levels of the water table. Water quality was monitored monthly from both the canal water and reclaimed wastewater treatments as described previously (Table 6).

Weed intensity ratings were made subjectively for each bed within the tree row and ranged from 0 (no weeds) to 5 (>50% weed cover). An area around each reset was maintained weed free to prevent competition and obstruction of the microsprinkler. All beds had between row bahia grass ground cover which was mowed as necessary. In addition, pest, weed and disease control were conducted as currently recommended for groves receiving standard irrigation. No adjustments in herbicide or pest control practices were made for the reclaimed wastewater treatments.

Experiments were analyzed as a completely randomized design. The Statistical Analysis System general linear model procedure was used to perform analysis of variance. Analysis of covariance was used for visual ratings, tree height, and trunk diameter measurements. Contrasts were used to determine trends in the data and to separate means.

RESULTS AND DISCUSSION

Tree Growth and Development

Visual ratings of tree vigor, tree height and trunk diameter measurements were similar for all treatments in 1991, 1992 and 1993 for Expt. 1 (Tables 20-21). Likewise, visual ratings and trunk diameter measurements were similar for all treatments in 1993 for Expt. 2 (Table 22).

Table 15. Total water applied via irrigation to 'Marsh' reset grapefruit trees at Vero Beach, Fla., 1990-93.[z]

Treatment	1990-91[y]	1992	1993	Total
		(gal x 1000)		
Canal water	745.5	817.0	1322.1	2884.6
Reclaimed wastewater				
Low - 0.75 in./wk	2570.7	2075.2	2025.7	6671.6
Mod. - 1.00 in./wk	3251.4	2871.9	2707.8	8831.1
High - 1.25 in./wk	4027.3	3628.0	3340.8	10996.1

[z]Water was applied to a 0.21 acre area within each row.
[y]Includes water applied in the final quarter of 1990.

Table 16. Total water applied by quarter via irrigation to 'Marsh' grapefruit trees at Vero Beach, Fla., 1990-91.

Treatment[y]	Oct.-Dec.	Jan.-Mar.	Apr.-June	July-Sept.	Oct.-Dec.[y]	Total
			(gal x 1000)			
Canal water	74.1	82.7	140.8	0	447.9	745.5
Reclaimed wastewater						
Low - 0.75 in./wk	539.1	580.0	515.7	501.7	434.2	2570.7
Mod. - 1.00 in./wk	622.6	735.6	635.8	677.8	579.5	3251.4
High - 1.25 in./wk	817.7	909.8	813.5	766.4	719.8	4027.3

[z]Irrigation was discontinued from 25 Nov. to 16 Dec., 1991 to repair double beds and clean furrows.
[y]Water was applied to a 0.21 acre area within each tree row for each treatment.

Table 17. Total water applied by quarter via irrigation to 'Marsh' grapefruit trees at Vero Beach, Fla., 1992[z].

Treatment	Jan.-Mar.	Apr.-June	July-Sept.	Oct.-Dec.	Total
			(gal x 1000)		
Canal water	197.1	535.5	0	84.4	817.0
Reclaimed wastewater					
Low - 0.75 in./wk	507.3	565.5	554.8	447.6	2075.2
Mod. - 1.00 in./wk	647.2	751.6	866.7	606.4	2871.9
High - 1.25 in./wk	810.0	942.1	1067.4	808.5	3628.0

[z]Water was applied to a 0.21 acre area within each tree row for each treatment.

Table 18. Total water applied by quarter via irrigation to 'Marsh' grapefruit trees at Vero Beach, Fla., 1993[z].

Treatment	Jan.-Mar.	Apr.-June	July-Sept.	Oct.-Dec.	Total
			(gal x 1000)		
Canal water	124.1	426.9	447.3	323.8	1322.1
Reclaimed wastewater					
Low - 0.75 in./wk	476.1	591.9	531.7	426.0	2025.7
Mod. - 1.00 in./wk	638.5	778.3	721.9	569.1	2707.8
High - 1.25 in./wk	765.3	965.9	900.0	709.5	3340.8

[z]Water was applied to a 0.21 acre area within each tree row for each treatment.

Table 19. Four- and 5-day schedules and amounts of reclaimed wastewater irrigation for 'Marsh' grapefruit trees, Vero Beach, Fla., 1990-93[z].

Five-day irrigation schedule.

Treatment	Mon.	Tue.	Wed.	Thur.	Fri.
			(in/day)		
Low - 0.75 in./wk	0.25			0.5	
Mod. - 1.00 in./wk		0.5			0.5
High - 1.25 in./wk	0.5		0..50		0.5

Four-day irrigation schedule.

Treatment	Mon.	Tue.	Wed.	Thur.	Fri.
			(in/day)		
Low - 0.75 in./wk			0.75		
Mod. - 1.00 in./wk		0.75		0.25	
High - 1.25 in./wk	0.75			0.75	

[z]Reclaimed wastewater was applied two or three times per wk for 2-4 hours per application.

Table 20. Reclaimed wastewater and canal water effects on tree height of reset 'Marsh' grapefruit trees planted Nov. 1990 at Vero Beach, Fla., 1990-93 (Expt. 1).

Treatment	Tree height (in)			
	21 Nov. 1990	5 Sept. 1991	15 Sept. 1993	2 Dec. 1993
Canal water	20.1[z] (20.4)	37.3 (37.0)	56.5 (56.0)	96.8 (96.7)
Reclaimed wastewater				
Low - 0.75 in./wk	20.8 (20.6)	35.6 (35.5)	58.6 (58.3)	93.7 (93.6)
Mod. - 1.00 in./wk	20.8 (21.4)	35.8 (36.1)	59.0 (59.6)	96.1 (96.3)
High - 1.25 in./wk	20.8 (21.1)	33.8 (33.9)	61.8 (62.0)	100.4 (100.5)
Significance				
Treatment	NS	NS	NS	NS

[z]Numbers in parentheses are actual means. Other numbers represent adjusted means from the analysis of covariance. Each number represents the mean of five trees per bed and five beds per treatment.

NS=Nonsignificant.

Table 21. Reclaimed wastewater and canal water effects on trunk diameter of reset 'Marsh' grapefruit trees planted Nov. 1990 at Vero Beach, Fla., 1990-93 (Expt. 1).

Treatment	Trunk diameter (in)[z]			
	21 Nov. 1990	5 Sept. 1991	15 Sept. 1992	2 Dec. 1993
Canal water	0.19[y] (0.18)	0.60 (0.60)	1.43 (1.43)	2.76 (2.76)
Reclaimed wastewater				
Low - 0.75 in./wk	0.19 (0.19)	0.57 (0.57)	1.39 (1.39)	2.65 (2.64)
Mod. - 1.00 in./wk	0.19 (0.18)	0.59 (0.58)	1.33 (1.22)	2.65 (2.65)
High - 1.25 in./wk	0.19 (0.20)	0.55 (0.55)	1.36 (1.36)	2.64 (2 .66)
Significance				
Treatment	NS	NS	NS	NS

[z]Trunk diameter measurements were taken approximately 8 in. above ground level.
[y]Numbers in parentheses are actual means. Other numbers represent adjusted means from the analysis of covariance. Each number represents the mean of five trees per bed and five beds per treatment.
NS=Nonsignificant.

Table 22. Reclaimed wastewater and canal water effects on trunk diameter and tree height of reset 'Marsh' grapefruit trees planted June 1993 at Vero Beach, Fla., 1993 (Expt. 2).[z]

Treatment	Trunk diameter (in)[y]		Tree height (in)	
	2 Mar. 1993	2 Dec. 1993	2 Mar. 1993	2 Dec. 1993
Canal water	0.32	0.67	2.28	3.64
Reclaimed wastewater				
Low - 0.75 in./wk	0.31	0.64	2.23	3.47
Mod. - 1.00 in./wk	0.34	0.64	2.29	3.83
High - 1.25 in./wk	0.33	0.71	2.28	4.06
Significance				
Treatment	NS	NS	NS	*
Contrast[x]				
Low vs. High				**

[z]Number represents the mean of five trees per bed and five beds per treatment.
[y]Trunk diameter measurements were taken approximately 8 in. above ground level.
[x] Only significant contrasts are presented.
NS,*,**,***= Nonsignificant or significance at $P \leq 0.05$, 0.01, or 0.001, respectively.

However, heights of trees receiving the low-reclaimed wastewater treatment were significantly lower than those receiving the high rate. In 1990 high levels of melanose on leaves and poor weed control for Expt. 1 damaged many of the young trees and caused significant differences in size and vigor. The coefficient of variability ranged from 15 to 23. For Expt. 2 in 1993, citrus leaf miners severely reduced canopy size and growth of the summer flush which could partially account for lack of differences related to treatment. There were no consistent trends related to treatments in either study. Thus, use of reclaimed wastewater for irrigation of resets had no effect on growth as long as sufficient fertilizer was provided and that sites were maintained weed free.

Leaf Tissue Analysis

Leaf tissue N concentrations were similar and in the high range (2.8-3.0%) for all treatments in 1991 (Table 23). In 1992, leaf N was significantly higher for trees receiving canal water than the reclaimed wastewater treatments. All leaf N levels were within the optimum range (2.5-2.7%) (Table 24). Similarly, in 1993 leaves from trees in the low- and high-reclaimed wastewater treatments had significantly lower N than those of the canal water trees, but levels were still within the optimum range (Table 25). The high levels of N found in leaf tissue are not unusual and are similar to those found for young 'Hamlin' orange trees in Florida (Willis et al., 1990).

Leaf K was significantly higher for trees receiving reclaimed wastewater treatments (1.7-1.9%) compared to those receiving canal water in 1991 (Table 23). Conversely, in 1992 all treatments produced similar leaf K levels which were in the low range (0.9-1.1%) (Table 24). In 1993, trees receiving the reclaimed wastewater treatments again had significantly higher leaf K (1.9-2.0%) compared to those receiving canal water (1.7%) (Table 25). The increase in leaf K for trees receiving reclaimed wastewater probably occurred because of high K levels in the water. Differences in K levels had no effect on tree appearance or growth. Leaf Ca was significantly higher for trees receiving canal water than those receiving reclaimed wastewater treatments in 1991 (Table 23), with all treatments in the low range (1.5-2.9%). Leaf Ca concentration was similar and in the high range for all treatments in 1992 (5.0-6.9%) (Table 24). In 1993, leaf Ca levels were all similar and in the optimum range (3.0-4.9%). Although the reclaimed wastewater treatments received larger amounts of water than the canal water treatment, canal water had about three times the level of Ca, thus accounting for the differences. Elevated Ca levels had no effect on leaf appearance or tree growth.

There was concern that relatively high levels of Na and B in the reclaimed wastewaster would adversely affect growth and development of young trees. Leaf Na concentrations were significantly higher in 1991 for trees receiving reclaimed wastewater than those receiving canal water (Table 23). The increase in leaf Na for the reclaimed wastewater trees is likely due to the high volume of water applied since Na levels in the water were similar. However, in 1992-93 leaf Na concentrations were similar for all treatments (Tables 24 and 25). Leaf Na concentrations for all three years were below toxic levels of 2500 ppm and thus were not of concern.

Reclaimed wastewater treated trees had significantly higher leaf B levels than trees receiving canal water in 1991 (Table 23). All levels were within the optimum range (36-100 ppm). In 1992, all treatments again had similar leaf B levels which were in the high range (101-200 ppm)

Table 23. Reclaimed wastewater and canal water effects on leaf nutrient concentrations of reset 'Marsh' grapefruit trees planted Nov. 1990 at Vero Beach, Fla., 1991[z].

Treatment	N	P	K	Ca	Mg	Na	B	Cu	Fe	Mn	Zn
	(% dry wt)					(ppm)					
Canal water (CW)	2.9	0.20	1.5	2.9	0.51	226	55	53	48	12	22
Reclaimed wastewater											
Low - 0.75 in./wk	3.0	0.23	1.7	2.4	0.48	986	79	30	47	11	23
Mod. - 1.00 in./wk	3.0	0.19	1.8	2.4	0.48	1060	78	43	51	10	22
High - 1.25 in./wk	3.0	0.21	1.9	2.4	0.48	1096	78	26	40	7	21
Significance											
Treatment	NS	NS	**	**	NS	***	***	NS	NS	*	NS
Contrast[y]											
CW vs. Low			*	**		***	***				
CW vs. Mod.			**	**		***	***				
CW vs. High			***	**		***	***			**	
Low vs. High										**	

[z]Each number represents the mean of five leaves per tree from four trees per bed and five beds per treatment. Leaf samples were taken from fully expanded spring flush leaves on non-fruiting branches in Aug. 1991.
[y]Only significant contrasts are presented.
NS,*,**,***=Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 24. Reclaimed wastewater and canal water effects on leaf nutrient concentrations of reset 'Marsh' grapefruit trees planted Nov. 1990 at Vero Beach, Fla., 1992[z].

Treatment	N	P	K	Ca	Mg	Na	B	Cu	Fe	Mn	Zn
	(% dry wt)					(ppm)					
Canal water (CW)	3.0	0.20	0.9	5.2	0.45	886	130	743	233	18	28
Reclaimed wastewater											
Low - 0.75 in./wk	2.8	0.18	1.0	5.0	0.49	884	109	904	259	20	30
Mod. - 1.00 in./wk	2.8	0.24	0.9	5.2	0.46	956	110	1109	228	20	29
High - 1.25 in./wk	2.7	0.19	1.1	5.0	0.46	934	121	1253	294	19	31
Significance											
Treatment	*	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Contrast[y]											
CW vs. Low	*										
CW vs. Mod.	*										
CW vs. High	**										

[z]Each number represents the mean of five leaves per tree from four trees per bed and five beds per treatment. Leaf samples were taken from fully expanded spring flush leaves on non-fruiting branches in Aug. 1992.
[y]Only significant contrasts are presented.
NS,*,**,***=Nonsignificant of significance at $P \leq 0.05$, 0.01, or 0.001, respectively.

Table 25. Reclaimed wastewater and canal water effects on leaf nutrient concentrations of reset 'Marsh' grapefruit trees planted Nov. 1990 at Vero Beach, Fla., 1993[z].

Treatment	N	P	K	Ca	Mg	Na	B	Cu	Fe	Mn	Zn
	(% dry wt)					(ppm)					
Canal water (CW)	3.0	0.14	1.7	3.4	0.39	1056	89	220	42	14	22
Reclaimed wastewater											
Low - 0.75 in./wk	2.7	0.14	1.9	3.4	0.39	1274	177	235	44	14	23
Mod. - 1.00 in./wk	2.9	0.15	2.0	3.2	0.38	1206	181	251	48	13	24
High - 1.25 in./wk	2.6	0.14	2.0	3.4	0.37	1254	182	241	44	9	24
Significance											
Treatment	*	NS	**	NS	NS	NS	***	NS	NS	NS	NS
Contrast[y]											
CW vs. Low	*		*				***				
CW vs. Mod.			**				***				
CW vs. High	**		***				***				
Mod. vs. High	*										

[z]Each number represents the mean of five leaves per tree from four trees per bed and five beds per treatment. Leaf samples were taken from fully expanded spring flush leaves on non-fruiting branches in Sept. 1993.
[y]Only significant contrasts are presented.
NS,*,**,***=Nonsignificant or significance at $P \leq 0.05$, 0.01, or 0.001, respectively.

(Table 24). In 1993 again trees receiving reclaimed wastewater had leaf B concentrations significantly higher (high range) than the canal water trees (optimum range) (Table 25). The increase in leaf B for trees receiving the reclaimed wastewater treatments is attributed the high volume of water and the high levels of B in the reclaimed wastewater.

Leaf P, Mg, Cu, Fe, Mn, and Zn concentrations were similar for all treatments in all three years (Tables 23-25). Leaf P was in the high range (0.17-0.29%) in 1991 and 1992 and decreased to the optimum range (0.12-0.16%) in 1993. All treatments had similar leaf Mg concentrations for all three years. Although the canal water had twice the level of Mg of the reclaimed wastewater, all trees received the same level of Mg from granular fertilization. Leaf Cu and Fe levels varied from year-to-year and were extremely high in 1992 resulting from yearly Cu sprays for melanose control. Leaf Mn and Zn concentrations were not significantly different due to their low levels in both water sources.

In Expt. 2, which represents only a single year's data, all treatments produced leaf tissue N concentrations in the excess range (≥3.0%) (Table 26). Leaf nutrient concentrations were also similar for P, K, Mg, Cu, Fe, Mn, and Zn. Leaf Ca levels for trees receiving canal water were again significantly higher than those receiving reclaimed wastewater. Leaf Na was also significantly higher for trees receiving the low-reclaimed wastewater than the other treatments. All treatments produced >2500 ppm (excess) levels in the leaves, however, no toxicity symptoms were observed possibly due to differences in rootstocks used in Expts. 1 and 2. Trees receiving reclaimed wastewater had leaf B concentrations significantly higher than trees receiving canal water. In addition, trees receiving high levels of reclaimed wastewater had significantly higher leaf B levels than the other reclaimed wastewater treatments. High levels of Na and B caused no adverse effects on tree growth or leaf appearance.

Weed Growth

Weed intensity was greater in beds receiving the reclaimed wastewater treatments than for those receiving the canal water in 1992 and 1993 (Fig. 10). Weed growth varied seasonally in 1992 and 1993. Winter annuals were prevalent in Jan. to Feb. but decreased following herbicide treatments in March. In May 1992 a second herbicide treatment was applied. Weed levels again increased from June to Sept. Following application of glyphosate in Oct. weed levels decreased, but winter annuals again increased until Feb. Weed growth increased from Apr. to Aug. until beds were herbicided in Sept. Weed growth again increased from Oct. to Jan. Weed growth tended to increase with increased reclaimed wastewater application as observed in the mature tree block.

Increases in growth of annual and perennial weeds is a potential drawback to the use of high rates of reclaimed wastewater. Changes in weed management practices may be required when using high rates of reclaimed wastewater. Using less water soluble herbicides or increased herbicide frequency could significantly increase weed management costs.

Reclaimed wastewater irrigation of resets under mature tree management systems had no effect on tree growth. Nevertheless, resets should be fertilized on a regular young tree program because insufficient nutrients are available in the reclaimed wastewater to support adequate growth. Weed pressures from the use of reclaimed wastewater may require changes in herbicide programs and increase production costs.

Table 26. Reclaimed wastewater and canal water effects on leaf nutrient concentrations of reset 'Marsh' grapefruit trees planted June 1993 at Vero Beach, Fla., 1993[z].

Treatment	N	P	K	Ca	Mg	Na	B	Cu	Fe	Mn	Zn
	(% dry wt)					(ppm)					
Canal water (CW)	3.0	0.15	1.9	2.6	0.51	2702	66	558	60	24	26
Reclaimed wastewater											
Low - 0.75 in./wk	3.2	0.17	2.1	2.1	0.49	4946	151	884	76	23	30
Mod. - 1.00 in./wk	3.2	0.17	2.3	2.1	0.48	3612	155	652	60	20	24
High - 1.25 in./wk	3.1	0.16	2.2	2.2	0.49	4114	184	858	59	16	25
Significance											
Treatment	NS	NS	NS	*	NS	*	***	NS	NS	NS	NS
Contrast[y]											
CW vs. Low				**		**	***				
CW vs. Mod.				**			***				
CW vs. High				*			***				
Low vs. High							*				
Mod. vs. High							*				

[z]Each number represents the mean of five leaves per tree from four trees per bed and five beds per treatment. Leaf samples were taken from fully expanded spring flush leaves on non-fruiting branches in Sept. 1993.
[y]Only significant contrasts are presented.
NS,*,**,***=Nonsignificant or significance at P≤0.05, 0.01, or 0.001, respectively.

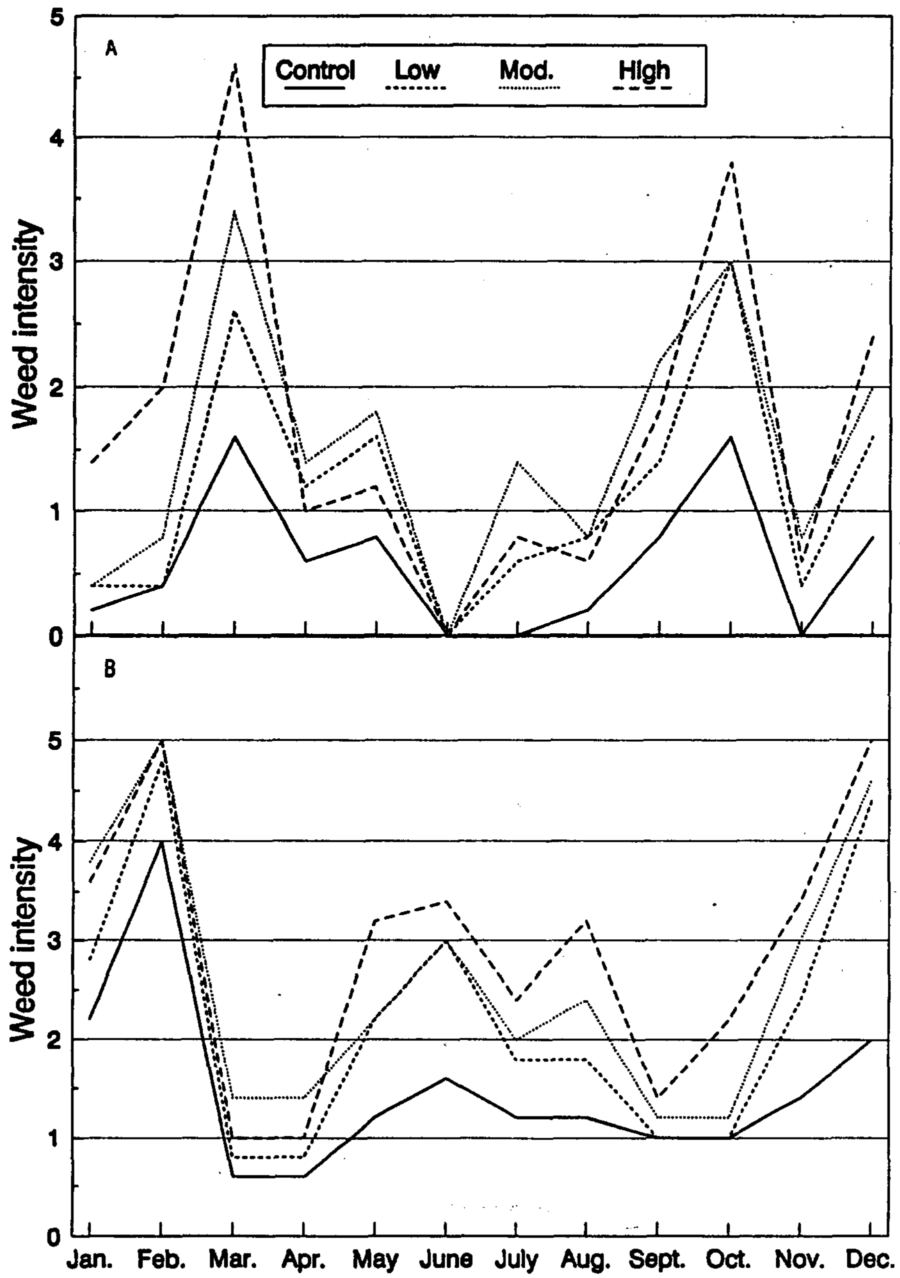

Fig. 10. Reclaimed wastewater and canal water effects on weed growth in the row for 'Marsh' grapefruit at Vero Beach, Fla. (A) 1992 and (B) 1993. Note: control=canal water, reclaimed wastewater at low=0.7, mod.=1.00, and high=1.25 in./wk.

SOIL STUDIES

Use of reclaimed wastewater has the potential to affect soil and water quality as well as citrus tree characteristics. Application of high amounts of water and nutrients may affect the composition of the soil and water exiting the grove. Moreover, soil oxygen levels could be decreased especially in the shallow flatwoods soils present in the Indian River area. There was also concern that the reclaimed wastewater would move laterally from the grove into surface waters.

The objectives of this part of the study were to monitor nutrient levels in the soil and soil solution over time and to determine if application of high amounts of reclaimed wastewater would produce anaerobic soil conditions. Levels of potentially hazardous elements such as Na, B and heavy metals in the soil and water exiting the site were also monitored.

MATERIALS AND METHODS

Soil Redox Measurements

Redox potential measurements can be used qualitatively to indicate whether a soil is aerobic or anaerobic. Soil redox measurements were taken at depths of 18 (45 cm) and 30 in. (75 cm). Electrodes were constructed of platinum (Pt) wire and placed at the appropriate depths by inserting a steel probe into the soil to provide a channel for electrode insertion. Measurements were made by connecting a calomel electrode and the Pt electrode to a millivolt meter. After the meter stabilized, usually within 5 min, a measurement was recorded. Measurements were made at monthly intervals in both the 'Redblush' (mature trees) and 'Marsh' (young trees) blocks.

Well-Water Sampling

Water samples were taken from wells on a monthly basis. Wells consisted of 2 in. (5 cm) I.D. polyvinyl chloride (PVC) pipe with a 1 ft (30 cm) well screen at the bottom and were drilled approximately 39 in (1 m) deep (immediately above the hardpan layer) at a distance of 39 in. from a microsprinkler. Deeper wells placed within and immediately below the hardpan were consistently dry during the first two sampling periods. At the same time, it was observed that considerable lateral movement of water was occurring above the hardpan and was entering the drainage ditch between each tree bed. To avoid this occurrence, water samples were taken directly from the ditch, in place of deeper well samples, to obtain an indication of runoff water quality. Ditch water samples were taken at the drainage end of each ditch.

The procedure for obtaining water samples consisted of first pumping the wells dry, waiting approximately 2 hours, and then pumping a water sample from the well using a vacuum pump and glass sampling equipment. Water samples were placed on ice and transported back to Gainesville on the same day as sampling. Samples were then placed under refrigeration at 39°F (4°C) until analyzed. Holding times recommended by EPA were followed. Water samples were analyzed for pH, electrical conductivity (EC), ammonium and nitrate nitrogen, orthophosphate, Ca, Mg, K, Na, Cu, Zn, Cd, Ni, and Pb using EPA recommended analytical procedures.

Soil Sampling

Soil samples were taken prior to and during application of reclaimed wastewater from all treatments at depths of 0-6 in. (0-15 cm), 6-18 in. (15-45 cm), and 18-30 in. (45-75 cm), respectively. Samples were taken using a stainless steel probe, placed in plastic bags and then placed on ice for transport to the laboratory in Gainesville where they were refrigerated at 39°F (4°C) until analyzed. Ammonium and nitrate were determined after extraction with 1 N KCl. Soil pH was measured in a 2:1 water:soil suspension. Other nutrients and metals were extracted with Mehlich I extractant.

RESULTS AND DISCUSSION

Soil Redox Potential

Oxygen depletion occurs when the redox potential is in the range of 250 to 300 mV. At the 18-in. (45-cm) depth, the soil profile remained aerobic during most of the year except after periods of heavy rainfall (Table 27). The redox potentials for the high reclaimed wastewater application rate were lower than those for the control treatment, although soils remained aerobic during most of the year. At the 30-in. depth, the soil was anaerobic during much of the year. Reclaimed wastewater had no consistent effect on soil redox potential. In the 'Redblush' block, reclaimed wastewater application affected redox potential in a positive manner, i.e., values were higher in the reclaimed wastewater treatment areas than in the control treatment. This is likely due to a greater quantity of aerated water moving through the reclaimed wastewater treatments than in the control treatment.

These results point out the need for good drainage in groves receiving water quantities above normal rates. The poorer drainage in the 'Redblush' block could adversely affect tree health over prolonged wet periods. However, in the tree root zone (above 18-in. depth), adequate drainage did not appear to be a significant problem.

Shallow Well Water and Drainage (Ditch) Water

Results are presented separately for the two blocks because the general tree health appeared to be better in the 'Redblush' block. Averages for the 1992 and 1993 sampling periods are presented in Tables 28-31. Samples obtained during 1991 were affected by the well installation procedure and it took several samplings for the soil, and thus the water samples, to stabilize. Therefore, the data for 1991 are not included in this report. Ditch samples could not be separated by treatment due to the fact that each ditch received drainage water from two different treatments. Effluent and canal water samples were also taken on a monthly basis and the averages are presented in the appropriate tables.

Overall, results from the two years were similar and the discussion will cover both years together. None of the water quality parameters, except possibly P, indicated any adverse effects from the reclaimed wastewater application. The treatment area that received the standard

Table 27. Soil redox potential yearly averages at Vero Beach, Fla. for 1992 and 1993.

Year	Block	Reclaimed wastewater application rate (in./wk)[z]			
		Control[y]	0.9 (0.75)	1.2 (1.0)	1.5 (1.25)
			18-in. depth		
1992	Redblush	361ab[y]	326b	390a	276c
	Marsh	486a	406b	489a	419b
1993	Redblush	309ab	298ab	351a	285b
	Marsh	429a	336c	398ab	387b
			30-in. depth		
1992	Redblush	-5c	139b	234a	180ab
	Marsh	300b	314ab	367a	187b
1993	Redblush	65c	171ab	198a	140b
	Marsh	263b	298ab	328a	197b

[z]Values in parentheses indicate amount applied to the 'Marsh' block. Other values represent amount applied to the 'Redblush' block.
[y]Letters in rows represent separation by the Wallers-Duncan test, $P \leq 0.05$.

Table 28. Mean shallow well water characteristics at Vero Beach, Fla. in 1992.

Water source	pH	EC (mmhos)	SRP	NO_3-N (ppm)	NH_4-N
RCW[z]	7.03	714	1.79	3.6	0.25
Canal[z]	7.49	1286	0.03	0.5	0.49
			'Redblush'		
Canal	6.38	1222	0.16	1.8	3.77
RCW (0.9 in.)	6.54	821	0.53	1.2	0.77
RCW (1.2 in.)	6.61	756	1.19	0.5	0.62
RCW9 (1.5 in.)	6.47	881	0.48	0.9	1.80
Ditch	7.49	775	1.48	1.1	0.48
			'Marsh'		
Canal	6.30	785	0.40	12.5	1.67
RCW (0.75 in.)	5.27	507	0.42	0.4	0.31
RCW (1.00 in.)	7.00	628	0.29	1.0	0.15
RCW (1.25 in.)	6.53	548	0.60	0.5	0.16
Ditch	7.35	657	0.88	1.3	0.89

[z]RCW=reclaimed wastewater sampled directly from the ditch. Canal=water sampled directly from the canal. All other samples were taken within the planting.

Note: EC=electrical conductivity, SRP=soluble reactive phosphorus, RCW=reclaimed wastewater.

Table 29. Mean shallow water nutrient and metal concentrations at Vero Beach, Fla. in 1992.

Water source	Ca	Mg	K	Zn	Cu	Na	Cd	Pb	Ni
				(ppm)					
RCW[z]	69.93	17.47	12.50	0.08	0	130.33	0	0	0
Canal[z]	75.55	20.40	10.70	0.05	0	137.00	0	0	0
				'Redblush'					
Canal	110.93	33.18	14.87	0.05	0	131.72	0	0	0
RCW (0.9 in.)	58.42	17.89	10.13	0.07	0.01	116.84	0	0	0
RCW (1.2 in.)	70.03	15.92	10.10	0.05	0.02	98.89	0	0	0
RCW (1.5 in.)	72.97	16.15	13.94	0.16	0	118.01	0	0	0
Ditch	14.06	11.04	0.07	0.03	123.06	0	0	0	0
				'Marsh'					
Canal	59.57	25.95	24.57	0.16	0.03	80.56	0	0	0
RCW (0.75 in.)	20.22	9.20	13.72	0.17	0.01	79.38	0	0	0
RCW (1.00 in.)	40.48	13.82	14.28	0.09	0.01	94.18	0	0	0
RCW (1.25 in.)	28.76	10.39	14.24	0.07	0.02	86.36	0	0	0
Ditch	39.77	13.14	10.28	0.10	0.05	100.33	0	0	0

[z]RCW=reclaimed wastewater sampled directly from the ditch. Canal=water sampled directly from the canal. All other samples were taken within the planting.
Note: EC=electrical conductivity, SRP=soluble reactive phosphorus, RCW=reclaimed wastewater.

Table 30. Mean shallow well water characteristics at Vero Beach, Fla. in 1993.

Water source	pH	EC (mmhos)	SRP	NO_3-N (ppm)	NH_4-N
RCW[z]	6.95	756	4.49	8.1	0.24
Canal[z]	7.50	1034	0.07	0.1	0.12
			'Redblush'		
Canal	6.10	891	0.16	0.2	3.87
RCW (0.9 in.)	6.48	712	0.44	0.2	0.18
RCW (1.2 in.)	6.50	677	1.02	0.2	0.05
RCW (1.5 in.)	6.16	684	0.31	0.05	1.29
Ditch	7.17	914	1.90	0.04	0.16
			'Marsh'		
Canal	6.09	449	0.20	1.81	0.16
RCW (0.75 in.)	4.80	458	0.02	0.1	0.33
RCW (1.00 in.)	6.78	530	0.32	1.9	0
RCW (1.25 in.)	6.37	4.03	0.67	0.5	0.09
Ditch	6.62	738	2.08	0.05	2.70

[z]RCW=reclaimed wastewater sampled directly from the ditch. Canal=water sampled directly from the canal. All other samples were taken within the planting.

Note: EC=electrical conductivity, SRP=soluble reactive phosphorus, RCW=reclaimed wastewater.

Table 31. Mean shallow water nutrient and metal concentrations at Vero Beach, Fla. in 1993.

Water source	Ca	Mg	K	Zn	Cu	Na	Cd	Pb	Ni	B	Mn
					(ppm)						
RCW[z]	42.45	13.29	22.22	0.04	0	137.03	0	0	0	0.42	0.01
Canal[z]	104.92	28.07	8.17	0.03	0.01	128.80	0	0	0	0.11	0
					'Redblush'						
Canal	32.32	25.09	0.08	0.01	119.62	0	0	0.02	0.11	0.03	
RCW (0.9 in.)	64.36	20.51	14.48	0.06	0.01	120.68	0	0.01	0	0.28	0.02
RCW (1.2 in.)	81.07	15.60	29.24	0.20	0.01	110.26	0	0	0	0.30	0.01
RCW (1.5 in.)	71.42	14.91	18.75	0.15	0.01	110.84	0	0	0	0.28	0.01
Ditch	55.98	18.35	14.48	0.05	0.05	138.86	0	0	0	0.33	0
					'Marsh'						
Canal	53.52	24.31	18.36	0.07	0.02	92.65	0	0	0	0.12	0.02
RCW (0.75 in.)	22.17	10.59	14.64	0.09	0.02	74.26	0	0	0	0.16	0.01
RCW (1.00 in.)	38.73	13.43	10.95	0.03	0.01	94.16	0	0	0	0.32	0.03
RCW (1.25 in.)	25.85	9.00	12.48	0.05	0.02	84.93	0	0	0	0.24	0
Ditch	54.77	18.54	23.64	0.14	0.06	124.77	0	0.01	0	0.24	0

[z]RCW=reclaimed wastewater sampled directly from the ditch. Canal=water sampled directly from the canal. All other samples were taken within the planting.

Note: EC=electrical conductivity, SRP=soluble reactive phosphorus, RCW=reclaimed wastewater.

management practices for fertilizing groves in this area and that received canal water for irrigation instead of reclaimed wastewater often had significantly higher nutrient concentrations compared to the reclaimed wastewater treatment areas. This appears to be due to the application of fertilizer only twice per year and also application of less irrigation water. Application of fertilizer at this rate resulted in relatively high amounts of nutrients being available in the soil at these two times. In contrast, the reclaimed wastewater treatment areas had nutrients applied in small quantities over many applications.

Water pH ranged between 5 and 7 for both years in all treatments. There were no consistent trends among any of the treatments. Water pH in this range will not adversely effect ground or drainage water quality. Electrical conductivity (EC) was significantly higher for the canal water treatment compared to the reclaimed wastewater treatments. This is primarily a reflection of the differences in EC between the canal water and the reclaimed wastewater. Soluble reactive phosphorus (SRP) was greater in the reclaimed wastewater treatments than in the canal water treatment and tended to increase with reclaimed wastewater irrigation rate. However, values showed a tendency to decrease in the third year compared to the second year. This decrease likely reflects the fertilization history prior to the beginning of the study. The increasing SRP concentration with reclaimed wastewater application suggests that P accumulation potentially could become a problem with continued application. The relatively low concentrations suggest that it would take many years to accumulate to problematic concentrations.

Nitrate and ammonium concentrations were significantly higher in the canal water treatment than in the reclaimed wastewater treatments. As indicated above, this is likely due to two applications of fertilizer yearly in the standard treatment compared to many small applications of nutrients in the reclaimed wastewater. None of the concentrations, except the canal water treatment during 1992, produced nitrate concentrations above the public health limit of 10 mg per L nitrate-N.

Concentrations of Ca, Mg, K, and Na were not affected by reclaimed wastewater application. Boron concentrations were higher in the effluent than the canal water and this is reflected in the respective treatments. However, the boron concentrations observed should not cause a water quality or a tree toxicity problem.

Concentrations of toxic metals were low for all treatments with no indication of potential problems. Concentrations of Zn and Cu likely reflect the application of these elements in fertilizers and pesticides rather than reclaimed wastewater. Cadmium, Pb, and Ni concentrations were often below detectable limits.

Nutrient concentrations in ditch water samples were also low, except for P. Phosphorus concentration averages ranged from 1 to 2 mg per liter during the two-year monitoring period. Although these concentrations are not extremely high, a continued increase in P concentrations in subsequent years may eventually be problematic. Since the ditches represent drainage water from two beds, i.e., two treatments, the effects of reclaimed wastewater application rate cannot be evaluated with these data.

Soil Nutrient and Metal Concentrations

The soil was sampled at three-month intervals in the 'Redblush' and 'Marsh' blocks. Data are presented for the last four quarters of the study because they represent the potential accumulation effects of the reclaimed wastewater and also do not appear to be affected by the previous fertilization history of the two groves. Soil pH, water content, and ammonium, nitrate, and phosphate concentrations are presented in Tables 32-39. Reclaimed wastewater and the application rate had no effect on soil pH. Soil pH was relatively high for all treatments and increased during the last four quarters an average of 0.9, 0.6, and 0.5 pH units over all treatments for the three soil depths sampled in the 'Redblush' block. In the 'Marsh' block, pH increased approximately 0.4 pH unit over the same time period at the soil depths sampled.

Soil water content in the 'Redblush' block reflected poorer drainage conditions with considerably higher values than in the 'Marsh' block. The medium and high reclaimed wastewater application rates also had higher water contents in the surface layer of the 'Redblush' block compared to the control and low application rate. In the 'Marsh' block, there was no effect of reclaimed wastewater application rate, but the reclaimed wastewater treatments always had higher water contents than in the control.

Soil ammonium and nitrate concentrations remained relatively stable throughout the study period in both blocks. Concentrations were less than 5 μg per gm across all treatments with no significant effect of reclaimed wastewater application rates. This was expected since fertilizer application rates were adjusted to account for N in the reclaimed wastewater. Phosphorus concentrations in the soil increased over the last four quarters but there was no consistent effect of reclaimed wastewater application rate on P concentrations. All concentrations in the surface layer at the end of the study were in the high range of soil test values indicating that no additional P would be needed.

Additional nutrient (Ca, Mg, K, and Na) and metal (Zn, Cu, Cd, Ni, and Pb) concentrations are given in Tables 40-47. Calcium, Mg, and K concentrations in the soil did not show any effects of reclaimed wastewater or the application rates in either block. Sodium concentrations were higher in the reclaimed wastewater treatment areas with no effect of application rate. Sodium is readily leached through the soil and the slightly higher concentrations in the reclaimed wastewater treatment areas reflect the higher concentrations in the reclaimed wastewater compared to the canal water used in the control.

All metal concentrations in the reclaimed wastewater were extremely low and this was reflected in the soil metal concentrations. Zinc and Cu concentrations in the soil reflect the influence of fertilizer and pesticide applications. Lead concentrations were higher than Cd and Ni, but all concentrations were low and well below toxic concentrations. There also was no accumulation of metals with time.

Other than P, there was no adverse effects of reclaimed wastewater on soil nutrient and metal concentrations. Phosphorus did accumulate in the soil and this was reflected in shallow ground water and drainage water P concentrations. The accumulation rate is relatively slow, and if a problem develops, it could take 10-15 years to become a significant problem. Phosphorus accumulation would only produce a water quality problem and would not adversely affect soil properties or tree health. If a water quality problem develops with P, it could be resolved by directing drainage from the grove through a constructed or natural wetland.

Table 32. Soil pH, water content, and extractable N and P concentrations in the 'Redblush' block at Vero Beach, Fla. on 10 Oct. 1992.

Depth (in.)		pH	SWC (%)	NH_4-N (ppm)	NO_3-N (ppm)	DAP (ppm)
				Canal water		
6	Mean	7.37	8.86	1.32	4.79	69.39
	SD	0.32	6.98	0.59	2.57	46.51
18	Mean	6.92	13.43	1.57	3.12	16.28
	SD	0.33	5.84	0.83	0.33	11.20
30	Mean	6.84	18.25	1.99	2.81	18.46
	SD	0.40	2.93	0.46	0.63	17.87
				0.9 in. reclaimed wastewater/wk		
6	Mean	7.41	9.84	0.98	3.18	87.94
	SD	0.60	3.33	0.34	0.96	33.39
18	Mean	7.52	13.21	0.80	3.60	21.56
	SD	0.37	3.39	0.45	1.46	14.43
30	Mean	7.39	18.75	0.80	3.91	14.26
	SD	0.08	2.13	0.24	2.23	7.02
				1.2 in. reclaimed wastewater/wk		
6	Mean	6.89	12.94	1.15	2.90	43.46
	SD	0.81	3.12	0.37	0.82	43.69
18	Mean	6.48	18.78	0.69	4.37	17.21
	SD	0.71	1.83	0.12	2.13	5.22
30	Mean	6.72	21.27	0.68	3.43	20.35
	SD	0.37	1.83	0.24	1.32	12.80
				1.5 in. reclaimed wastewater/wk		
6	Mean	7.36	11.91	1.25	5.50	102.18
	SD	0.68	5.38	0.42	4.26	32.98

Table 32 - Continued

Depth (in.)		pH	SWC (%)	NH_4-N (ppm)	NO_3-N (ppm)	DAP (ppm)
18	Mean	7.34	12.16	0.70	3.06	43.55
	SD	1.08	5.13	0.22	0.81	24.72
30	Mean	7.13	16.85	0.65	3.36	24.12
	SD	0.60	2.64	0.29	1.40	13.12

Note: SWC=soil water content, DAP=double acid extractable phosphorus.

Table 33. Soil pH, water content, and extractable N and P concentrations in the 'Marsh' block at Vero Beach, Fla. on 10 Oct. 1992.

Depth (in.)		pH	SWC (%)	NH_4-N (ppm)	NO_3-N (ppm)	DAP (ppm)
			Canal water			
6	Mean	7.36	5.35	1.47	3.05	111.47
	SD	0.57	1.70	0.87	0.67	59.20
18	Mean	7.13	10.34	0.72	2.52	17.94
	SD	0.41	4.16	0.28	0.19	18.31
30	Mean	7.13	16.30	1.05	2.69	10.89
	SD	0.35	2.46	0.37	0.60	13.10
			0.75 in. reclaimed wastewater/wk			
6	Mean	7.72	7.25	1.07	2.92	88.42
	SD	0.20	0.62	0.35	0.55	13.50
18	Mean	7.52	13.11	0.73	2.76	24.04
	SD	0.38	1.66	0.26	0.96	11.87
30	Mean	7.08	18.06	0.93	2.72	7.90
	SD	0.54	1.90	0.23	0.72	9.73
			1.00 in. reclaimed wastewater/wk			
6	Mean	7.65	8.18	1.44	3.63	122.59
	SD	0.23	0.66	0.42	0.48	48.91
18	Mean	7.63	12.22	1.15	3.01	33.34
	SD	0.65	1.86	0.46	0.52	12.65
30	Mean	7.23	18.81	1.02	3.01	21.81
	SD	0.54	2.97	0.37	0.74	7.87
			1.25 in. reclaimed wastewater/wk			
6	Mean	7.90	7.76	0.86	2.49	58.36
	SD	0.30	2.36	0.17	0.37	36.45

Table 33 - Continued

Depth (in.)		pH	SWC (%)	NH_4-N (ppm)	NO_3-N (ppm)	DAP (ppm)
18	Mean	7.75	12.76	0.78	2.85	22.99
	SD	0.06	2.78	0.13	0.39	19.78
30	Mean	7.55	17.28	0.85	2.73	19.37
	SD	0.26	2.45	0.28	0.65	31.49

Note: SWC=soil water content, DAP=double acid extractable phosphorus.

Table 34. Soil pH, water content, and extractable N and P concentrations in the 'Redblush' block at Vero Beach, Fla. on 21 Jan. 1993.

Depth (in.)		pH	SWC (%)	NH_4-N (ppm)	NO_3-N (ppm)	DAP (ppm)
			Canal water			
6	Mean	7.82	6.46	2.09	2.50	122.10
	SD	0.17	2.82	0.42	1.45	22.15
18	Mean	7.38	9.78	2.64	0.44	20.50
	SD	0.67	4.25	0.76	0.88	16.58
30	Mean	7.72	15.17	1.11	0.62	8.53
	SD	0.77	5.07	0.62	1.08	9.38
			0.9 in. reclaimed wastewater/wk			
6	Mean	7.97	15.17	2.39	4.77	146.20
	SD	0.15	8.79	0.89	3.88	8.47
18	Mean	7.58	12.24	3.02	0	9.90
	SD	0.65	3.76	1.35	0	9.13
30	Mean	7.50	16.19	2.72	0.52	12.30
	SD	0.57	3.85	1.48	1.04	8.58
			1.2 in. reclaimed wastewater/wk			
6	Mean	8.01	8.95	1.73	4.24	268.80
	SD	0.19	3.34	0.69	3.12	27.58
18	Mean	7.64	11.39	2.57	0.49	27.50
	SD	1.16	5.09	1.74	0.98	12.81
30	Mean	7.45	15.76	3.80	0	19.40
	SD	1.06	1.71	2.20	0	10.90
			1.5 in. reclaimed wastewater/wk			
6	Mean	7.66	15.78	2.40	4.25	164.00
	SD	0.33	5.41	0.73	1.41	73.26

Table 34 - Continued

Depth (in.)		pH	SWC (%)	NH_4-N (ppm)	NO_3-N (ppm)	DAP (ppm)
18	Mean	7.77	17.14	3.63	2.30	16.40
	SD	0.72	5.78	2.05	2.13	13.98
30	Mean	7.90	17.36	4.20	0	5.30
	SD	0.48	3.10	3.85	0	6.51

Note: SWC=soil water content, DAP=double acid extractable phosphorus.

Table 35. Soil pH, water content, and extractable N and P concentrations in the 'Marsh' block at Vero Beach, Fla. on 21 Jan. 1993.

Depth (in.)		pH	SWC (%)	NH_4-N (ppm)	NO_3-N (ppm)	DAP (ppm)
			Canal water			
6	Mean	7.59	3.58	1.53	2.05	84.16
	SD	0.45	1.79	0.56	3.67	54.89
18	Mean	7.46	5.41	1.40	0.70	11.92
	SD	0.38	1.07	0.55	0.96	5.20
30	Mean	7.07	13.70	1.55	0	35.84
	SD	0.59	3.88	0.70	0	41.99
			0.75 in. reclaimed wastewater/wk			
6	Mean	7.91	8.98	3.98	2.61	101.60
	SD	0.30	0.93	3.96	2.03	28.07
18	Mean	7.67	7.441	1.42	0.37	18.40
	SD	0.62	0.92	0.26	0.82	17.18
30	Mean	7.15	15.77	1.31	0	21.52
	SD	0.50	2.18	0.32	0	38.20
			1.00 in. reclaimed wastewater/wk			
6	Mean	8.14	5.56	1.88	1.76	141.36
	SD	0.22	1.53	0.28	2.41	90.20
18	Mean	7.80	5.53	1.19	0.35	11.04
	SD	0.20	1.40	0.19	0.78	7.28
30	Mean	7.40	14.08	1.08	0	8.32
	SD	0.22	1.15	0.12	0	3.86
			1.25 in. reclaimed wastewater/wk			
6	Mean	8.12	6.68	2.48	2.54	116.96
	SD	0.12	2.56	0.69	1.99	50.32

Table 35 - Continued

Depth (in.)		pH	SWC (%)	NH_4-N (ppm)	NO_3-N (ppm)	DAP (ppm)
18	Mean	7.65	8.13	1.29	0	11.52
	SD	0.27	1.22	0.39	0	9.11
30	Mean	7.52	16.27	1.60	0	10.00
	SD	0.27	2.90	0.29	0	9.17

Note: SWC=soil water content, DAP=double acid extractable phosphorus.

Table 36. Soil pH, water content, and extractable N and P concentrations in the 'Redblush' block at Vero Beach, Fla. on 18 May 1993.

Depth (in.)		pH	SWC (%)	NH_4-N (ppm)	NO_3-N (ppm)	DAP (ppm)
			Canal water			
6	Mean	7.62	7.13	0	3.16	81.40
	SD	0.14	2.43	0	2.68	68.42
18	Mean	7.39	16.58	0	1.70	20.40
	SD	0.29	4.52	0	2.28	10.41
30	Mean	7.18	18.05	0	0	18.90
	SD	0.67	2.47	0	0	10.91
			0.9 in. reclaimed wastewater/wk			
6	Mean	7.47	9.82	0	5.38	121.60
	SD	0.34	5.73	0	1.33	107.65
18	Mean	6.97	10.46	0	0.95	17.40
	SD	0.90	4.20	0	1.10	7.04
30	Mean	6.79	12.28	0	0	5.50
	SD	1.55	8.60	0	0	4.63
			1.2 in. reclaimed wastewater/wk			
6	Mean	7.33	10.57	3.97	4.77	45.30
	SD	0.12	3.18	4.03	2.44	30.55
18	Mean	7.44	11.14	0	6.29	13.70
	SD	0.29	4.99	0	10.05	9.79
30	Mean	7.10	26.82	0	0	4.20
	SD	0.22	22.36	0	0	2.86
			1.5 in. reclaimed wastewater/wk			
6	Mean	7.72	16.77	0	5.90	109.90
	SD	0.06	2.55	0	1.67	82.60

Table 36 - Continued

Depth (in.)		pH	SWC (%)	NH_4-N (ppm)	NO_3-N (ppm)	DAP (ppm)
18	Mean	7.77	14.38	0	2.74	29.70
	SD	0.38	3.51	0	1.53	8.61
30	Mean	6.96	23.66	2.96	1.35	8.90
	SD	1.07	11.74	5.92	2.71	8.08

Note: SWC=soil water content, DAP=double acid extractable phosphorus.

Table 37. Soil pH, water content, and extractable N and P concentrations in the 'Marsh' block at Vero Beach, Fla. on 18 May 1993.

Depth (in.)		pH	SWC (%)	NH_4-N (ppm)	NO_3-N (ppm)	DAP (ppm)
				Canal water		
6	Mean	7.26	6.44	0	2.33	67.68
	SD	0.56	1.99	0	1.18	26.36
18	Mean	7.05	8.86	0	0	11.76
	SD	0.72	2.71	0	0	12.59
30	Mean	6.78	13.05	0	0	16.72
	SD	0.79	4.25	0	0	21.37
				0.75 in. reclaimed wastewater/wk		
6	Mean	7.39	6.58	0	2.15	101.28
	SD	0.23	0.85	0	2.25	118.78
18	Mean	7.39	11.11	0	1.39	18.40
	SD	0.21	3.78	0	2.19	12.69
30	Mean	6.82	16.33	0	5.70	29.20
	SD	0.64	6.06	0	6.14	22.93
				1.00 in. reclaimed wastewater/wk		
6	Mean	7.74	7.87	0	3.14	123.52
	SD	0.10	2.12	0	2.15	45.59
18	Mean	7.51	6.82	0	0.73	16.56
	SD	0.32	2.09	0	1.00	8.40
30	Mean	7.22	12.90	0	0	25.92
	SD	0.32	2.40	0	0	14.51
				1.25 in. reclaimed wastewater/wk		
6	Mean	7.82	6.85	0	1.28	166.40
	SD	0.22	0.84	0	2.00	70.22

Table 37 - Continued

Depth (in.)		pH	SWC (%)	NH_4-N (ppm)	NO_3-N (ppm)	DAP (ppm)
18	Mean	7.49	8.05	0	1.32	9.52
	SD	0.23	2.76	0	2.09	4.84
30	Mean	7.10	18.04	0	1.53	8.00
	SD	0.43	4.47	0	2.43	5.40

Note: SWC=soil water content, DAP=double acid extractable phosphorus.

Table 38. Soil pH, water content, and extractable N and P concentrations in the 'Redblush' block at Vero Beach, Fla. on 22 Sept. 1993.

Depth (in.)		pH	SWC (%)	NH_4-N (ppm)	NO_3-N (ppm)	DAP (ppm)
			Canal water			
6	Mean	7.90	8.67	0.97	7.47	132.60
	SD	0.75	4.65	1.12	5.88	45.86
18	Mean	7.57	10.84	0	7.60	41.80
	SD	1.06	4.33	0	5.48	23.61
30	Mean	7.30	16.07	1.02	7.07	21.10
	SD	0.80	1.46	1.18	8.19	17.84
			0.9 in. reclaimed wastewater/wk			
6	Mean	8.29	12.82	1.00	2.93	103.00
	SD	0.34	4.30	1.16	2.29	20.87
18	Mean	7.96	10.85	0	0.90	25.60
	SD	0.31	5.92	0	1.04	14.94
30	Mean	7.76	15.91	1.29	2.31	12.60
	SD	0.35	2.28	2.59	2.15	8.19
			1.2 in. reclaimed wastewater/wk			
6	Mean	8.23	13.10	3.49	4.72	139.90
	SD	0.21	5.07	4.46	3.81	52.48
18	Mean	7.75	12.37	1.61	9.90	34.20
	SD	0.75	4.96	2.19	15.41	7.88
30	Mean	7.93	15.60	0	2.29	8.10
	SD	0.54	1.87	0	2.14	5.29
			1.5 in. reclaimed wastewater/wk			
6	Mean	8.19	18.26	0.50	2.92	117.80
	SD	0.29	4.93	1.00	1.76	56.61

Table 38 - Continued

Depth (in.)		pH	SWC (%)	NH_4-N (ppm)	NO_3-N (ppm)	DAP (ppm)
18	Mean	7.56	16.40	1.51	1.55	42.80
	SD	0.86	3.79	1.01	1.03	16.72
30	Mean	7.19	17.73	5.97	0.51	14.30
	SD	0.84	4.21	8.65	1.02	8.36

Note: SWC=soil water content, DAP=double acid extractable phosphorus.

Table 39. Soil pH, water content, and extractable N and P concentrations in the 'Marsh' block at Vero Beach, Fla. on 22 Sept. 1993.

Depth (in.)		pH	SWC (%)	NH_4-N (ppm)	NO_3-N (ppm)	DAP (ppm)
			Canal water			
6	Mean	7.82	4.08	1.05	3.35	121.52
	SD	0.16	1.90	0.96	3.44	32.90
18	Mean	7.84	4.32	1.04	2.47	15.84
	SD	0.08	1.71	0.95	3.66	8.66
30	Mean	7.69	10.97	0.78	0.74	10.80
	SD	0.19	3.19	1.06	1.02	5.85
			0.75 in. reclaimed wastewater/wk			
6	Mean	7.99	7.34	1.08	1.65	134.00
	SD	0.43	1.49	0.99	1.90	44.29
18	Mean	8.00	7.49	1.45	1.10	29.28
	SD	0.14	1.33	0.81	1.00	20.37
30	Mean	7.52	14.67	1.60	0.39	16.08
	SD	0.42	1.45	0.89	0.88	13.55
			1.00 in. reclaimed wastewater/wk			
6	Mean	7.92	7.76	0.72	2.91	164.24
	SD	0.38	1.16	0.99	1.47	58.43
18	Mean	7.93	6.41	1.43	0.72	18.72
	SD	0.07	0.47	0.80	0.98	4.99
30	Mean	7.78	10.92	0.37	0.37	26.72
	SD	0.07	3.40	0.82	0.82	23.01
			1.25 in. reclaimed wastewater/wk			
6	Mean	8.21	9.25	0.37	2.22	117.84
	SD	0.17	1.46	0.82	2.30	39.36

Table 39 - Continued

Depth (in.)		pH	SWC (%)	NH_4-N (ppm)	NO_3-N (ppm)	DAP (ppm)
18	Mean	8.03	8.156	1.83	0.93	17.84
	SD	0.13	1.22	0.03	2.08	12.06
30	Mean	7.78	14.29	1.18	3.40	5.68
	SD	0.12	3.10	1.08	2.35	6.94

Note: SWC=soil water content, DAP=double acid extractable phosphorus.

Table 40. Soil nutrient and metal concentrations of samples taken from the 'Redblush' block at Vero Beach, Fla. on 10 Oct. 1992.

Depth (in.)		Ca	Mg	K	P	Zn (ppm)	Cu	Na	Cd	Pb	Ni
						Canal water					
6	Mean	1240.00	346.50	48.70	75.30	15.28	20.93	8.50	0.13	0.86	0.18
	SD	1003.61	351.76	59.84	50.70	9.14	11.86	4.57	0.09	0.42	0.08
18	Mean	193.20	38.30	20.30	16.00	1.92	4.03	5.20	0.02	0.26	0.10
	SD	54.45	12.88	24.74	12.39	1.26	2.03	2.71	0.02	0.12	0.02
30	Mean	194.40	37.70	9.50	19.00	2.18	4.32	7.60	0.02	0.34	4.18
	SD	89.08	18.99	2.36	19.74	1.48	2.17	3.91	0.02	0.20	4.49
						0.9 in. reclaimed wastewater/wk					
6	Mean	1740.00	440.90	26.60	94.20	18.54	23.26	60.40	0.19	0.85	0.26
	SD	497.40	168.89	17.31	40.91	10.89	19.43	33.00	0.09	0.34	0.02
18	Mean	661.50	118.90	22.17	24.00	1.48	3.11	61.40	0.03	0.26	0.11
	SD	324.34	40.90	19.14	12.76	0.50	1.56	30.66	0.02	0.10	0.04
30	Mean	390.10	74.50	19.90	14.00	1.06	2.23	52.10	0.02	0.22	0.61
	SD	228.91	54.31	23.10	9.47	1.09	2.08	18.84	0.02	0.10	0.93
						1.2 in. reclaimed wastewater/wk					
6	Mean	1081.00	216.30	67.10	43.20	8.63	17.75	75.50	0.11	0.70	0.15

Table 40 - Continued

Depth (in.)		Ca	Mg	K	P	Zn	Cu	Na	Cd	Pb	Ni
						(ppm)					
	SD	315.36	95.14	84.47	44.69	5.09	9.21	87.36	0.07	0.16	0.07
18	Mean	1427.00	130.20	39.40	27.90	3.40	7.09	69.30	0.05	0.59	0.37
	SD	1646.74	27.56	48.72	15.81	2.68	5.27	44.20	0.02	0.31	0.45
30	Mean	865.90	128.10	20.40	23.90	2.87	4.27	58.80	0.06	0.50	1.12
	SD	623.22	53.93	5.15	13.55	1.49	1.86	17.19	0.02	0.10	1.41
						1.5 in. reclaimed wastewater/wk					
6	Mean	1575.00	343.00	46.20	108.80	25.15	29.06	72.20	0.22	0.86	0.31
	SD	558.10	150.75	34.33	31.93	16.04	25.44	72.33	0.11	0.43	0.06
18	Mean	484.30	112.20	25.50	40.80	2.44	3.64	63.10	0.05	0.32	0.15
	SD	107.68	44.95	17.87	22.69	0.64	1.75	55.31	0.02	0.06	0.04
30	Mean	787.30	103.40	84.80	26.20	1.16	1.69	54.90	0.04	0.79	2.05
	SD	766.42	37.57	122.80	13.31	0.21	0.56	29.32	0	0.76	1.95

Table 41. Soil nutrient and metal concentrations of samples taken from the 'Marsh' block at Vero Beach, Fla. on 10 Oct. 1992.

Depth (in.)		Ca	Mg	K	P	Zn	Cu	Na	Cd	Pb	Ni
		(ppm)									
		Canal water									
6	Mean	1439.20	329.36	13.52	114.64	34.37	38.84	9.28	0.22	1.84	0.17
	SD	1017.00	312.45	7.53	63.77	21.37	16.54	3.99	0.16	0.64	0.12
18	Mean	261.12	44.16	10.80	18.00	4.90	9.38	3.52	0.02	0.41	0.05
	SD	196.54	36.37	11.43	19.17	3.86	6.29	1.45	0.04	0.49	0.05
30	Mean	155.68	29.92	14.80	11.44	2.61	4.81	6.00	0.01	0.27	0.62
	SD	136.39	27.07	14.71	14.74	2.38	4.17	3.68	0.02	0.36	1.22
		0.75 in. reclaimed wastewater/wk									
6	Mean	1100.00	230.24	20.00	93.20	25.38	29.50	25.92	0.14	1.86	0.14
	SD	217.57	71.17	4.03	15.89	5.60	10.20	5.62	0.05	0.54	0.02
18	Mean	293.76	45.92	15.68	23.92	2.87	6.06	26.64	0.01	0.24	0.04
	SD	190.36	25.95	11.39	13.47	1.06	3.33	12.70	0.02	0.17	0.03
30	Mean	111.44	18.48	34.24	7.04	0.93	1.49	21.84	0	0.06	0.03
	SD	148.69	22.86	63.82	9.03	0.51	0.77	4.674	0	0.09	0.04
		1.0 in. reclaimed wastewater/wk									
6	Mean	1334.40	292.80	31.04	126.56	22.28	29.76	27.92	0.18	1.80	0.15

Table 41 - Continued

Depth (in.)		Ca	Mg	K	P	Zn (ppm)	Cu	Na	Cd	Pb	Ni
	SD	443.50	146.15	21.89	53.33	8.22	13.45	11.76	0.09	0.40	0.05
18	Mean	410.16	51.36	26.16	33.52	2.06	5.31	21.76	0.04	0.42	0.07
	SD	119.71	10.30	26.28	11.78	0.77	1.50	4.14	0.03	0.14	0.02
30	Mean	188.48	26.64	76.16	22.48	1.89	3.86	17.28	0.02	0.29	0.05
	SD	42.77	7.64	121.51	7.81	1.08	1.56	3.89	0.04	0.22	0.05
						1.5 in. reclaimed wastewater/wk					
6	Mean	834.40	150.64	18.96	60.16	11.20	17.85	24.32	0.10	1.44	0.06
	SD	505.70	82.69	8.16	39.07	6.22	9.09	22.77	0.06	0.74	0.04
18	Mean	439.52	63.92	16.64	31.68	4.26	7.57	19.12	0.04	0.70	0.05
	SD	436.87	58.43	11.46	33.37	3.02	4.24	9.61	0.07	0.79	0.02
30	Mean	171.52	24.24	16.88	18.56	1.25	3.13	23.76	0.01	0.13	0.06
	SD	147.51	14.75	11.79	29.08	0.48	1.67	5.25	0.02	0.16	0.02

Table 42. Soil nutrient and metal concentrations of samples taken from the 'Redblush' block at Vero Beach, Fla. on 21 Jan. 1993.

Depth (in.)		Ca	Mg	K	Zn	Cu (ppm)	Na	Cd	Pb	Ni
						Canal water				
6	Mean	1129.00	176.90	24.30	19.40	38.65	35.50	0.16	1.64	0.18
	SD	358.54	93.17	14.32	7.18	21.75	4.53	0.06	0.53	0.05
18	Mean	341.70	52.80	12.50	1.40	3.31	27.80	0.02	0.22	0.10
	SD	173.75	21.80	13.08	0.28	1.09	6.11	0.02	0.12	0.10
30	Mean	162.00	38.80	2.00	0.27	0.67	36.80	0.01	0.20	0.75
	SD	204.92	55.46	1.06	0.12	0.12	27.07	0.02	0.17	0.40
					0.9 in. reclaimed wastewater/wk					
6	Mean	977.87	201.10	15.70	31.14	36.46	26.40	0.23	1.97	0.17
	SD	659.00	25.57	5.61	8.72	14.57	11.76	0.04	0.43	0.02
18	Mean	274.50	41.30	2.90	1.98	5.22	21.40	0.01	0.19	0.05
	SD	187.25	25.17	1.83	0.50	2.91	11.90	0.02	0.09	0.02
30	Mean	193.50	30.00	5.20	0.95	2.19	19.90	0.01	0.23	0.60
	SD	175.19	22.58	2.79	0.39	1.05	15.82	0.02	0.06	0.40
					1.2 in. reclaimed wastewater/wk					
6	Mean	2105.00	352.70	27.80	42.35	45.37	46.00	0.39	2.76	0.24

Table 42 - Continued

Depth (in.)		Ca	Mg	K	Zn	Cu	Na	Cd	Pb	Ni
					(ppm)					
	SD	460.69	80.27	9.89	10.29	16.01	6.97	0.12	0.77	0.03
18	Mean	305.00	46.00	9.70	1.09	3.57	25.10	0	0.27	0.07
	SD	118.22	21.69	5.86	0.52	2.24	10.10	0	0.04	0.04
30	Mean	94.70	14.40	4.20	0.64	1.25	24.50	0	0.21	0.31
	SD	11.81	4.04	2.41	0.39	1.00	6.069	0	0.04	0.35
					1.5 in. reclaimed wastewater/wk					
6	Mean	1445.00	249.00	17.30	21.20	38.79	26.10	0.19	1.68	0.15
	SD	627.95	169.90	6.44	8.78	20.23	12.48	0.06	0.64	0.02
18	Mean	281.30	41.10	11.60	1.85	5.33	20.00	0.01	0.26	0.08
	SD	96.43	9.37	5.40	1.03	4.45	3.59	0.02	0.10	0.06
30	Mean	56.50	9.60	2.00	0.42	0.80	13.10	0	0.09	0.50
	SD	27.49	3.35	1.35	0.26	0.20	2.60	0	0.06	0.58

Table 43. Soil nutrient and metal concentrations of samples taken from the 'Marsh' block at Vero Beach, Fla. on 21 Jan. 1993.

Depth (in.)		Ca	Mg	K	Zn	Cu	Na	Cd	Pb	Ni
		(ppm)								
		Canal water								
6	Mean	995.20	186.32	28.32	15.63	22.56	32.00	0.15	1.05	0.15
	SD	377.11	79.82	22.25	10.92	13.28	24.75	0.11	0.91	0.08
18	Mean	319.28	51.76	13.60	0.45	20.8	26.72	0	0.22	0.21
	SD	228.33	27.68	11.31	0.14	1.63	23.14	0	0.05	0.36
30	Mean	555.12	68.56	16.00	5.78	7.97	29.84	0.08	0.30	0.74
	SD	736.14	78.67	18.67	8.58	10.03	27.28	0.11	0.22	1.11
		0.75 in. reclaimed wastewater/wk								
6	Mean	1052.00	147.28	18.40	24.01	43.37	28.32	0.22	1.26	0.15
	SD	404.64	34.95	13.89	12.19	27.98	19.15	0.08	0.56	0.08
18	Mean	349.04	45.36	10.80	1.63	3.62	21.44	0.01	0.29	0.09
	SD	297.11	25.75	9.29	1.69	1.93	13.32	0.02	0.17	0.09
30	Mean	346.24	29.36	7.92	0.48	0.87	31.52	0.02	0.29	0.46
	SD	294.43	30.83	7.580	0.36	0.56	12.94	0.02	0.24	0.40
		1.0 in. reclaimed wastewater/wk								
6	Mean	1528.56	265.92	22.08	28.06	29.77	21.04	0.26	1.32	0.18

Table 43 - Continued

Depth (in.)		Ca	Mg	K	Zn	Cu	Na	Cd	Pb	Ni
					(ppm)					
	SD	1006.27	172.24	10.97	18.76	19.64	15.47	0.16	1.02	0.09
18	Mean	245.60	53.60	12.08	0.50	1.48	23.04	0	0.18	0.05
	SD	224.38	60.14	13.16	0.25	0.84	20.23	0	0.07	0.03
30	Mean	372.00	54.08	12.56	0.66	1.36	29.28	0.01	0.22	0.57
	SD	396.98	44.18	10.18	0.45	1.26	18.05	0.02	0.07	0.70
					1.25 in. reclaimed wastewater/wk					
6	Mean	1547.20	260.72	26.56	29.74	61.41	53.36	0.26	1.21	0.21
	SD	824.38	164.42	12.39	11.84	30.34	32.79	0.13	0.36	0.07
18	Mean	909.60	84.40	11.68	1.31	3.40	44.88	0.01	0.34	0.46
	SD	1309.14	48.83	11.29	1.28	2.91	32.43	0.02	0.18	0.55
30	Mean	437.20	33.04	5.20	1.94	4.98	25.12	0.01	0.30	1.83
	SD	607.35	16.35	3.10	2.25	5.93	12.69	0.02	0.27	1.48

Table 44. Soil nutrient and metal concentrations of samples taken from the 'Redblush' block at Vero Beach, Fla. on 18 May 1993.

Depth (in.)		Ca	Mg	K	Zn	Cu	Na	Cd	Pb	Ni
		(ppm)								
		Canal water								
6	Mean	1547.00	287.30	34.00	17.30	19.18	25.00	0.10	0.80	0.10
	SD	1017.31	249.63	7.915	17.31	11.21	13.74	0.20	0.33	0.20
18	Mean	711.40	99.50	15.00	2.03	3.12	24.20	0	0.40	0
	SD	341.46	45.43	4.511	1.56	2.56	20.20	0	0	0
30	Mean	1335.50	90.10	21.30	1.49	2.84	33.60	0	0.40	0
	SD	2177.87	98.52	22.60	0.80	2.24	37.82	0	0	0
		0.9 in. reclaimed wastewater/wk								
6	Mean	1516.60	301.30	31.00	29.36	32.69	66.70	0.20	0.90	0.20
	SD	1191.48	281.13	32.19	29.61	35.18	62.88	0.23	0.60	0.23
18	Mean	397.40	78.00	22.10	1.32	1.87	52.20	0	0.40	0
	SD	183.17	31.76	19.16	0.64	1.08	24.35	0	0	0
30	Mean	207.30	33.80	16.50	0.85	0.61	37.40	0	0.20	0
	SD	266.54	35.13	18.61	0.04	0.47	19.09	0	0.23	0
		1.2 in. reclaimed wastewater/wk								
6	Mean	596.60	95.00	23.30	7.97	9.49	40.90	0	0.50	0.10

Table 44 - Continued

Depth (in.)		Ca	Mg	K	Zn	Cu	Na	Cd	Pb	Ni
					(ppm)					
	SD	224.02	43.58	14.83	5.73	3.74	21.38	0	0.20	0.20
18	Mean	1650.90	81.80	18.50	0.80	1.16	41.30	0	0.70	0
	SD	2771.20	74.16	15.18	0.90	0.86	33.27	0	0.60	0
30	Mean	785.50	75.10	19.70	0.74	0.79	43.30	0	0.20	0
	SD	1447.14	125.24	31.68	0.58	1.08	60.05	0	0.23	0
					1.5 in. reclaimed wastewater/wk					
6	Mean	1665.00	213.70	42.70	31.44	23.06	66.50	0.10	0.90	0.30
	SD	1024.22	120.14	23.05	26.58	18.19	21.13	0.20	0.50	0.20
18	Mean	776.50	100.60	24.00	1.37	1.45	47.70	0	0.40	0.10
	SD	576.26	66.81	8.03	0.66	0.70	17.59	0	0	0.20
30	Mean	244.70	28.00	9.70	0.52	0.27	25.10	0	0.40	0
	SD	263.61	21.62	5.66	0.34	0.16	12.12	0	0.33	0

Table 45. Soil nutrient and metal concentrations of samples taken from the 'Marsh' block at Vero Beach, Fla. on 18 May 1993.

Depth (in.)		Ca	Mg	K	Zn	Cu	Na	Cd	Pb	Ni
		(ppm)								
		Canal water								
6	Mean	972.08	97.84	12.80	16.84	27.77	16.88	0	1.60	0.08
	SD	564.33	44.48	2.62	10.90	11.12	5.09	0	0.75	0.18
18	Mean	220.96	37.28	5.84	3.69	6.51	11.44	0	0.56	0
	SD	105.09	22.20	1.64	3.17	3.83	5.02	0	0.36	0
30	Mean	240.80	28.88	4.25	3.00	5.27	12.00	0	0.64	0.08
	SD	331.32	28.22	1.66	4.90	8.46	4.20	0	0.61	0.18
		0.75 in. reclaimed wastewater/wk								
6	Mean	1371.44	153.04	15.36	23.90	21.50	30.64	0.08	1.44	0.16
	SD	1409.56	170.87	10.31	18.64	13.62	13.30	0.18	0.88	0.22
18	Mean	298.00	38.72	7.04	3.54	5.85	15.84	0	0.48	0.08
	SD	225.27	26.84	4.75	2.23	2.92	9.64	0	0.18	0.18
30	Mean	372.08	46.32	9.20	3.00	4.58	35.20	0	0.72	0.08
	SD	210.64	27.18	4.96	3.40	5.07	29.40	0	0.33	0.18
		1.00 in. reclaimed wastewater/wk								
6	Mean	1322.40	204.40	22.72	22.46	27.26	40.32	0.24	1.60	0.24

Table 45 - Continued

Depth (in.)		Ca	Mg	K	Zn	Cu	Na	Cd	Pb	Ni
		(ppm)								
	SD	622.24	115.18	6.74	12.65	15.33	10.15	0.22	0.75	0.22
18	Mean	269.12	35.84	11.60	1.35	4.07	21.20	0	0.40	0
	SD	119.80	20.12	6.80	0.58	1.79	9.403	0	0	0
30	Mean	137.36	23.68	7.84	0.42	1.28	25.44	0	0.48	0
	SD	68.94	13.55	5.75	0.14	0.61	14.02	0	0.18	0
		1.25 in. reclaimed wastewater/wk								
6	Mean	1677.60	288.16	20.56	26.50	32.76	35.60	0.24	2.40	0.32
	SD	703.73	125.81	5.75	7.30	9.12	8.68	0.22	0.75	0.18
18	Mean	216.56	23.04	7.04	2.51	5.46	15.12	0	0.40	0.40
	SD	84.92	7.11	3.77	1.08	0.26	4.05	0	0	0.89
30	Mean	171.60	29.92	6.16	0.90	1.45	18.88	0	0.56	0.16
	SD	159.05	37.56	6.68	0.37	0.69	20.23	0	0.36	0.22

Table 46. Soil nutrient and metal concentrations of samples taken from the 'Redblush' at Vero Beach, Fla. on 22 Sept. 1993.

Depth (in.)		Ca	Mg	K	Zn	Cu	Na	Cd	Pb	Ni	B
						(ppm)					
						Canal water					
6	Mean	1388.00	250.30	37.30	29.00	23.95	36.00	0.30	0.70	0.30	0.70
	SD	385.36	93.58	15.62	5.25	6.91	12.37	0.11	0.16	0.02	0.19
18	Mean	642.00	125.50	36.00	5.94	8.92	39.30	0.07	0.22	0.14	0.37
	SD	267.84	52.45	24.69	2.80	3.22	10.50	0.05	0.08	0.05	0.14
30	Mean	344.40	79.80	22.20	1.16	1.49	35.90	0.02	0.25	0.16	0.27
	SD	252.03	62.65	15.90	0.59	0.64	24.46	0.02	0.34	0.03	0.15
						0.9 in. reclaimed wastewater/wk					
6	Mean	1514.00	310.40	34.10	22.66	31.17	66.40	0.23	0.74	0.34	1.00
	SD	398.70	121.77	17.64	6.44	13.36	33.52	0.04	0.42	0.13	0.22
18	Mean	525.00	81.40	21.70	1.74	3.08	42.60	0.02	0.10	0.18	0.33
	SD	235.82	41.18	15.97	0.90	2.46	26.55	0.02	0.07	0.07	0.13
30	Mean	368.30	45.70	14.90	1.22	1.78	37.50	0.01	0.11	0.17	0.26
	SD	313 .30	31.18	13.62	0.79	1.61	14.47	0.02	0.08	0.06	0.19
						1.2 in. reclaimed wastewater/wk					
6	Mean	2066.00	244.50	28.90	46.00	58.00	78.00	0.28	0.94	0.52	1.40

Table 46 - Continued

Depth (in.)		Ca	Mg	K	Zn	Cu	Na	Cd	Pb	Ni	B
						(ppm)					
	SD	1231.00	57.92	5.66	21.62	10.41	48.45	0.07	0.12	0.40	0.63
18	Mean	1241.80	84.70	16.90	4.56	9.29	60.20	0.04	0.26	0.30	0.50
	SD	1314.60	35.01	12.43	3.51	6.10	24.59	0	0.07	0.33	0.23
30	Mean	894.70	43.70	12.80	1.13	1.83	43.00	0.01	0.12	0.24	0.40
	SD	1411.11	44.99	12.55	0.46	1.40	20.47	0.02	0.13	0.19	0.51
						1.5 in. reclaimed wastewater/wk					
6	Mean	1628.00	353.20	39.60	21.29	19.84	73.20	0.26	0.63	0.36	1.03
	SD	686.09	177.05	28.24	5.11	10.90	33.67	0.10	0.17	0.12	0.36
18	Mean	622.60	141.70	29.80	3.16	4.44	90.60	0.05	0.31	0.37	0.59
	SD	286.56	93.73	21.47	4.25	6.62	49.34	0.02	0.20	0.39	0.26
30	Mean	304.48	64.20	19.40	1.07	1.24	54.70	0.02	0.19	0.14	0.31
	SD	230.76	52.19	15.10	0.43	0.46	16.01	0.02	0.23	0.04	0.21

Table 47. Soil nutrient and metal concentrations of samples taken in the 'Marsh' block at Vero Beach, Fla. on 22 Sept. 1993.

Depth (in.)		Ca	Mg	K	Zn	Cu (ppm)	Na	Cd	Pb	Ni	B
6	Mean	1613.60	230.80	11.12	23.50	38.17	16.08	0.15	1.72	0.18	0.52
	SD	531.12	55.98	3.04	7.59	12.07	2.93	0.04	0.71	0.02	0.05
18	Mean	300.64	44.08	7.44	2.58	8.21	10.88	0.02	0.19	0.25	0.14
	SD	162.44	22.77	4.05	1.77	3.93	7.24	0.02	0.22	0.31	0.06
30	Mean	128.96	19.68	5.52	1.91	4.53	12.48	0	0.14	0.18	0.09
	SD	20.89	4.27	2.37	0.97	1.58	7.89	0	0.05	0.17	0.02
6	Mean	1200.00	214.88	15.60	23.72	43.73	35.76	0.18	1.80	0.26	0.66
	SD	264.30	63.96	4.43	7.66	13.27	6.80	0.05	0.73	0.05	0.10
18	Mean	393.44	46.00	10.56	2.71	7.90	26.48	0.03	0.22	0.14	0.26
	SD	147.79	8.70	6.38	1.26	3.94	6.33	0.02	0.14	0.05	0.06
30	Mean	166.56	22.80	8.40	0.91	1.94	28.40	0.01	0.10	0.15	0.20
	SD	108.91	16.14	7.26	0.26	0.65	8.31	0.02	0.10	0.08	0.14
6	Mean	1692.80	255.20	20.64	30.08	40.98	40.16	0.18	1.47	0.22	0.84
	SD	676.22	103.31	7.60	13.91	19.26	13.78	0.05	0.61	0.05	0.24
18	Mean	309.36	40.40	9.84	2.54	5.36	21.84	0.01	0.16	0.22	0.21
	SD	115.81	14.80	4.41	1.41	2.60	9.95	0.02	0.16	0.30	0.07

Table 47 - Continued

Depth (in.)		Ca	Mg	K	Zn	Cu (ppm)	Na	Cd	Pb	Ni	B
30	Mean	273.52	37.92	8.56	1.88	4.49	25.76	0	0.17	0.10	0.19
	SD	209.49	23.71	4.40	4.55	4.26	8.44	0	0.16	0.02	0.10
6	Mean	1152.00	206.96	30.16	25.40	39.40	37.28	0.16	1.50	0.19	0.65
	SD	529.98	93.11	28.82	12.02	15.04	12.03	0.06	0.58	0.03	0.25
18	Mean	270.16	36.56	7.60	3.49	8.92	22.48	0.02	0.19	0.15	0.20
	SD	117.09	14.14	2.73	2.21	4.54	3.59	0.02	0.24	0.08	0.07
30	Mean	65.84	10.88	5.12	0.69	1.55	26.64	0	0.01	0.09	0.08
	SD	20.57	1.58	2.22	0.30	0.71	5.34	0	0.02	0.02	0.03

CONCLUSIONS

Mature grapefruit trees receiving reclaimed wastewater tended to be more vigorous and produced higher yields than those receiving canal water based on soil water depletion levels. More importantly, fertilizer rates could be lowered significantly without reduction in yields when irrigating with reclaimed wastewater at the rates used in this study. In fact, soil nitrate and ammonium levels were actually greater in the canal water compared with the reclaimed wastewater treatments.

Irrigation of mature 'Redblush' grapefruit trees using reclaimed wastewater on flatwoods soils caused no deleterious effects when adequate drainage was provided. Nevertheless, yields and vigor were reduced significantly in areas where drainage was poor. This reduction occurred in low spots within a bed and in the southwest area of the grove where drainage was impeded. Furthermore, tree growth and development and yields were not affected by accumulation of Na, Cl, or B. Soil P levels increased over time and could potentially cause future problems. Irrigation with reclaimed wastewater over the three years of the study posed no health threat due to presence of heavy metals, bacteria or viruses. Heavy metals were consistently present in less than trace amounts as expected based on water analysis. Similarly, fecal coliform levels were within state standards and no enteric viruses were found at the efflux side of the treatment facility or on the fruit. Thus, the risk to workers or consumers was extremely small.

Fruit growth and quality from trees receiving reclaimed wastewater varied from year-to-year with no clear trends apparent. However, changes in fruit quality were generally favorable with the use of reclaimed wastewater, that is, TSS was unaffected and TA was reduced. Increased weed growth from use of reclaimed wastewater is a major concern and may require changes in weed management practices such as the use of herbicides with low water solubility. Increased costs for weed management should be compensated for by reductions in fertilizer use and increased yields.

Reclaimed wastewater also had no significant effect on growth and development of reset grapefruit trees. Some Na and B accumulated in leaves, but no toxicity occurred. Reclaimed wastewater does not supply sufficient nutrients for young tree growth; therefore, supplemental fertilization is necessary. Increased weed growth is also a major problem associated with use of reclaimed wastewater for young trees.

The results obtained in this study are applicable to the soil types tested. Although a hardpan was present at about 39 in., the upper sandy layer had a very high percolation rate and drained rapidly. In areas of the grove where drainage was impeded due to weed buildup or clogging of drain pipes, trees became stunted and unproductive. Moreover, irrigation rates should not exceed 1.2 in. per wk and irrigation frequency should not exceed two to three times per wk to decrease the possibility of causing anaerobic conditions. It is important to choose groves that are well-designed without low spots in order to facilitate maximum drainage. Under these conditions, reclaimed wastewater has the potential to increase yields while saving on fertilizer and irrigation costs. Consequently, use of 0.9 to 1.2 in. per wk in two to three applications has several potential benefits to citrus growers in the Indian River area on the soil series tested (Wabasso fine sand) and with proper drainage.

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APPENDIX

Weather and Soil Moisture Data

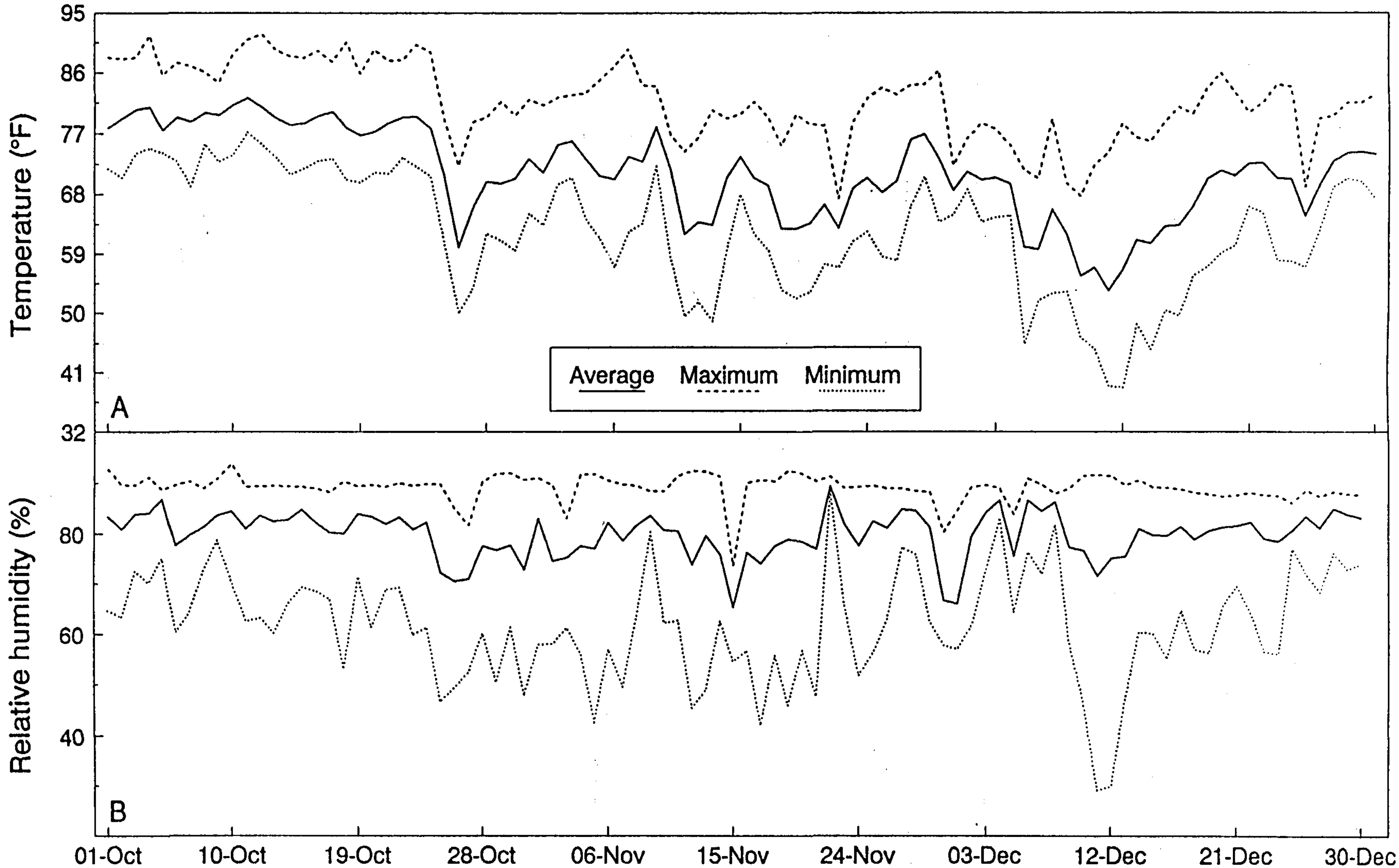

Fig. A1. (A) Average, maximum, and minimum daily temperatures, and (B) average, maximum, and minimum relative humidity for quarter 4, 1990 Vero Beach, Fla.

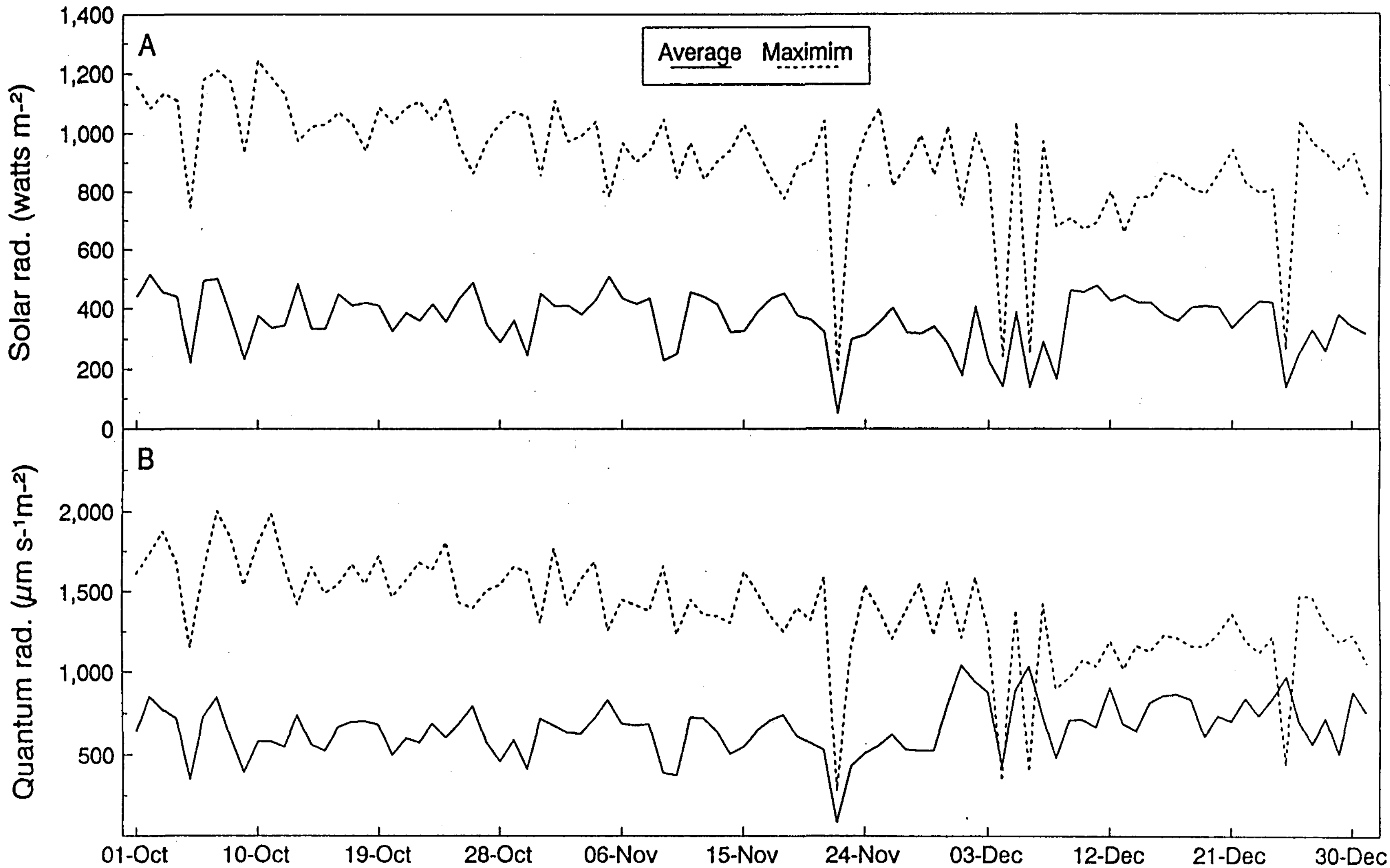

Fig. A2. (A) Average and maximum daily solar radiation, and (B) average and maximum daily quantum radiation for quarter 4, 1990 Vero Beach, Fla.

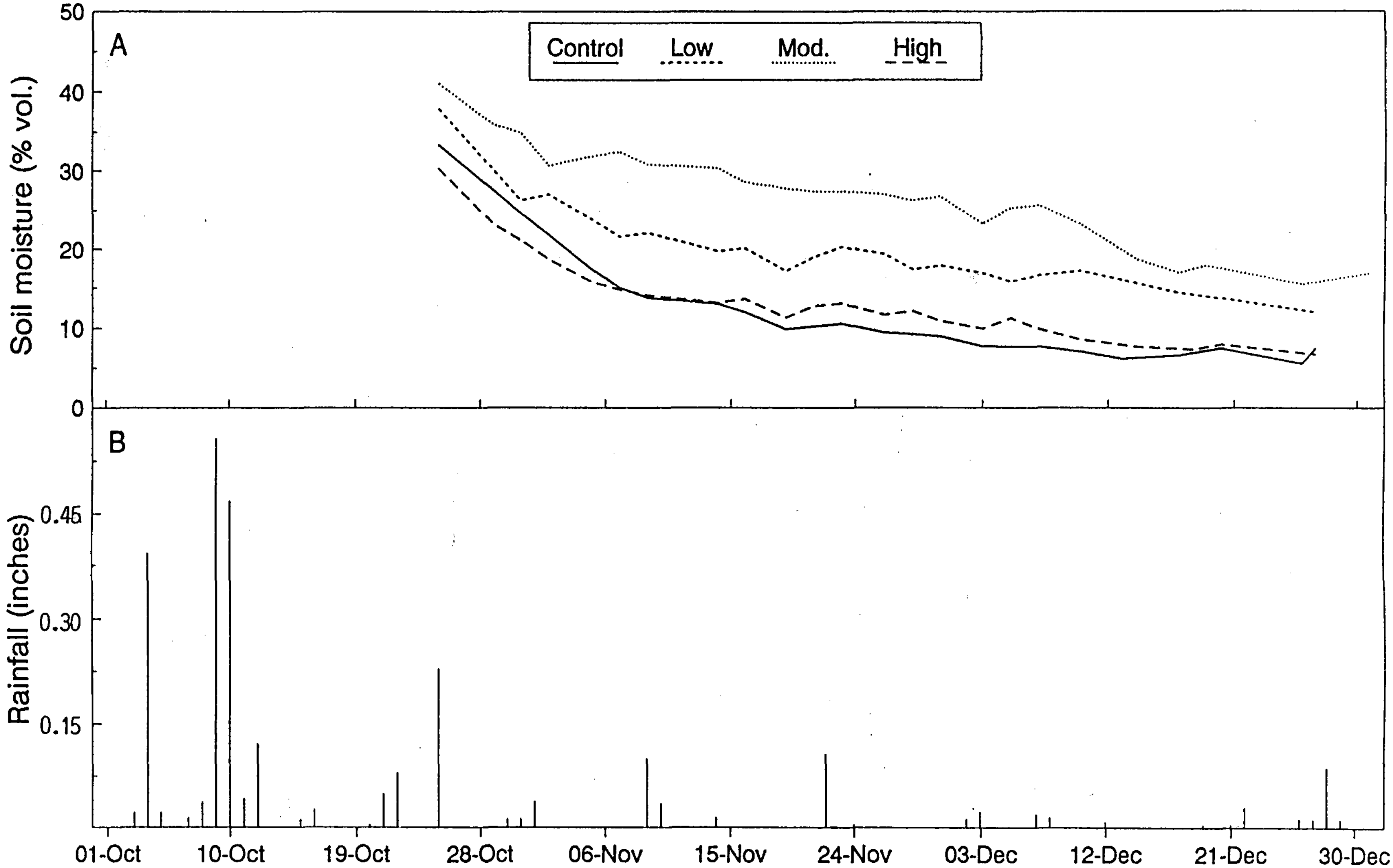

Fig. A3. (A) Mean soil moisture, and (B) daily rainfall for quarter 4, 1990, Vero Beach, Fla. (Control = canal water, low = 0.9 in/wk, mod. = 1.2 in/wk, and high = 1.5 in/wk.)

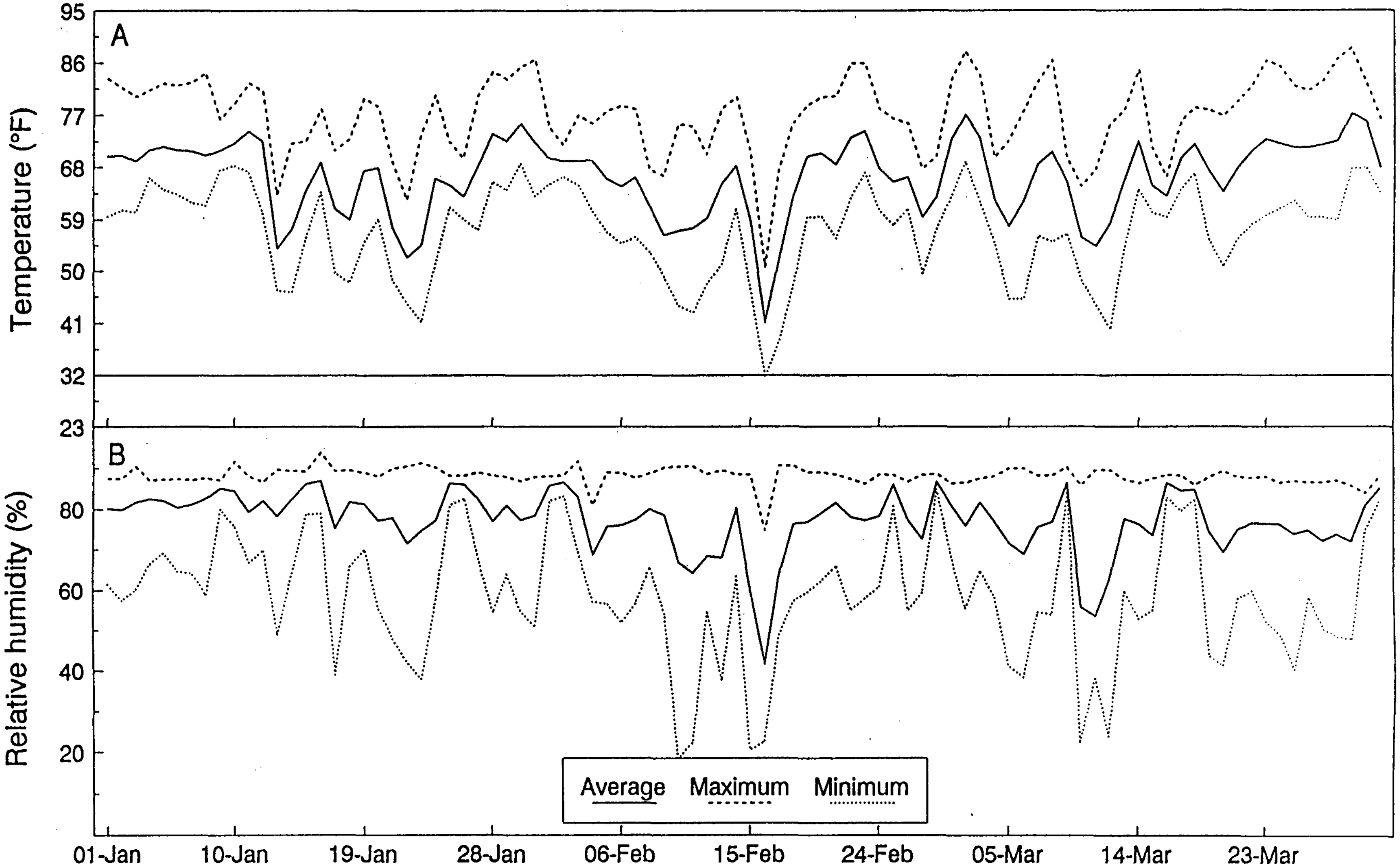

Fig. A4. (A) Average, maximum, and minimum daily temperatures, and (B) average, maximum, and minimum relative humidity for quarter 1, 1991 Vero Beach, Fla.

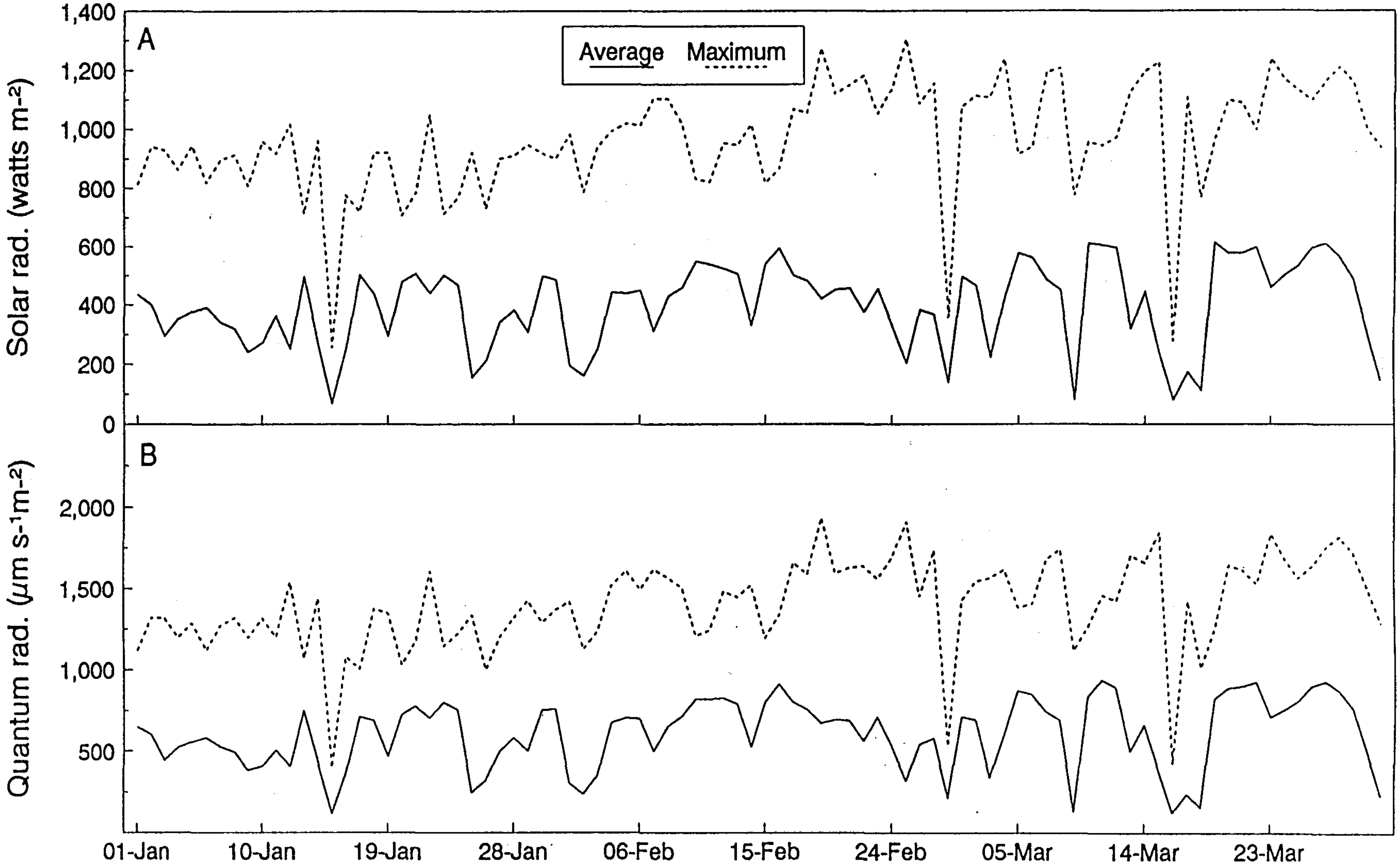

Fig. A5. (A) Average and maximum daily solar radiation, and (B) average and maximum daily quantum radiation for quarter 1, 1991 Vero Beach, Fla.

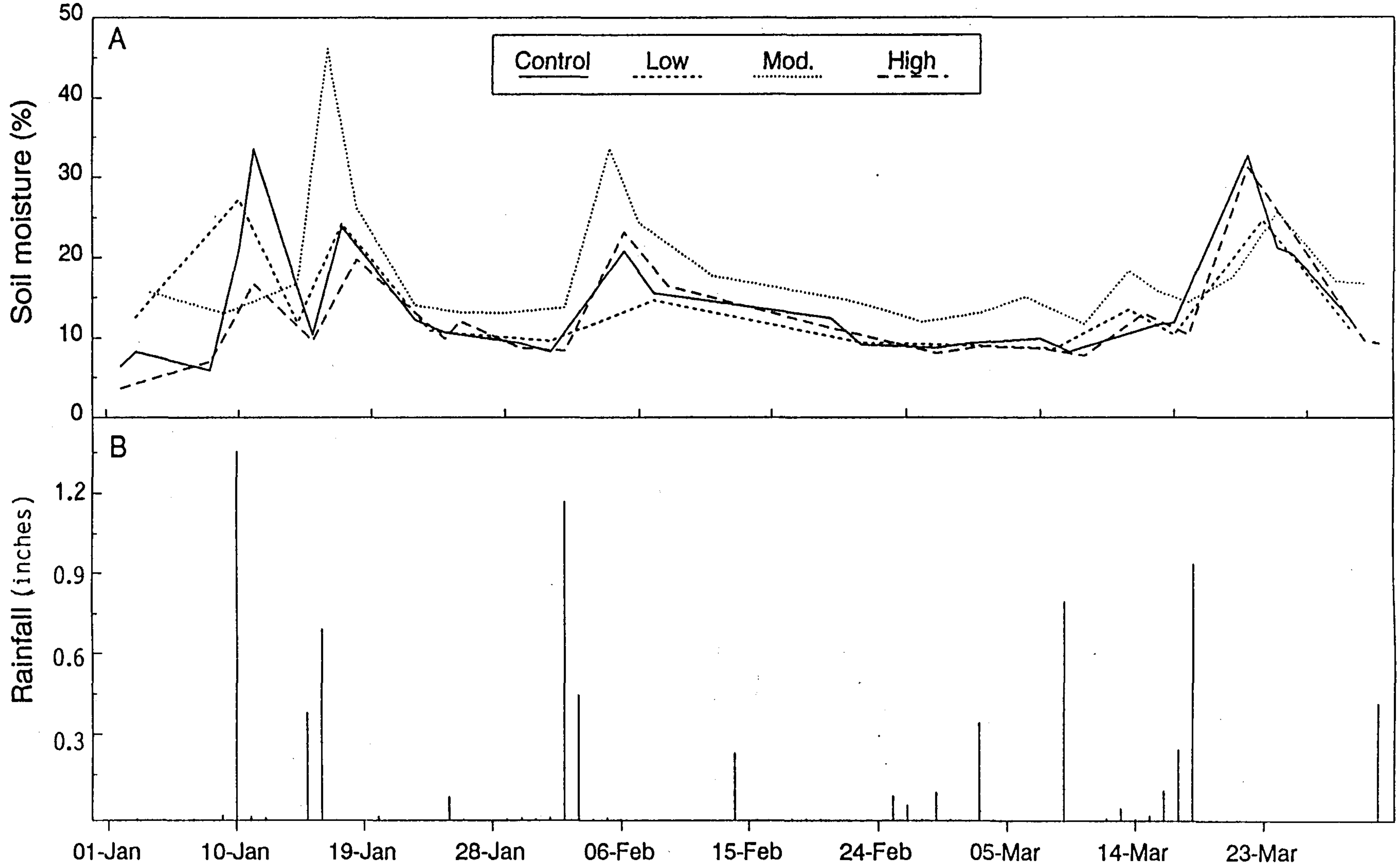

Fig. A6. (A) Mean soil moisture, and (B) daily rainfall for quarter 1, 1991, Vero Beach, Fla. (Control = canal water, low = 0.9 in/wk, mod. = 1.2 in/wk, and high = 1.5 in/wk.)

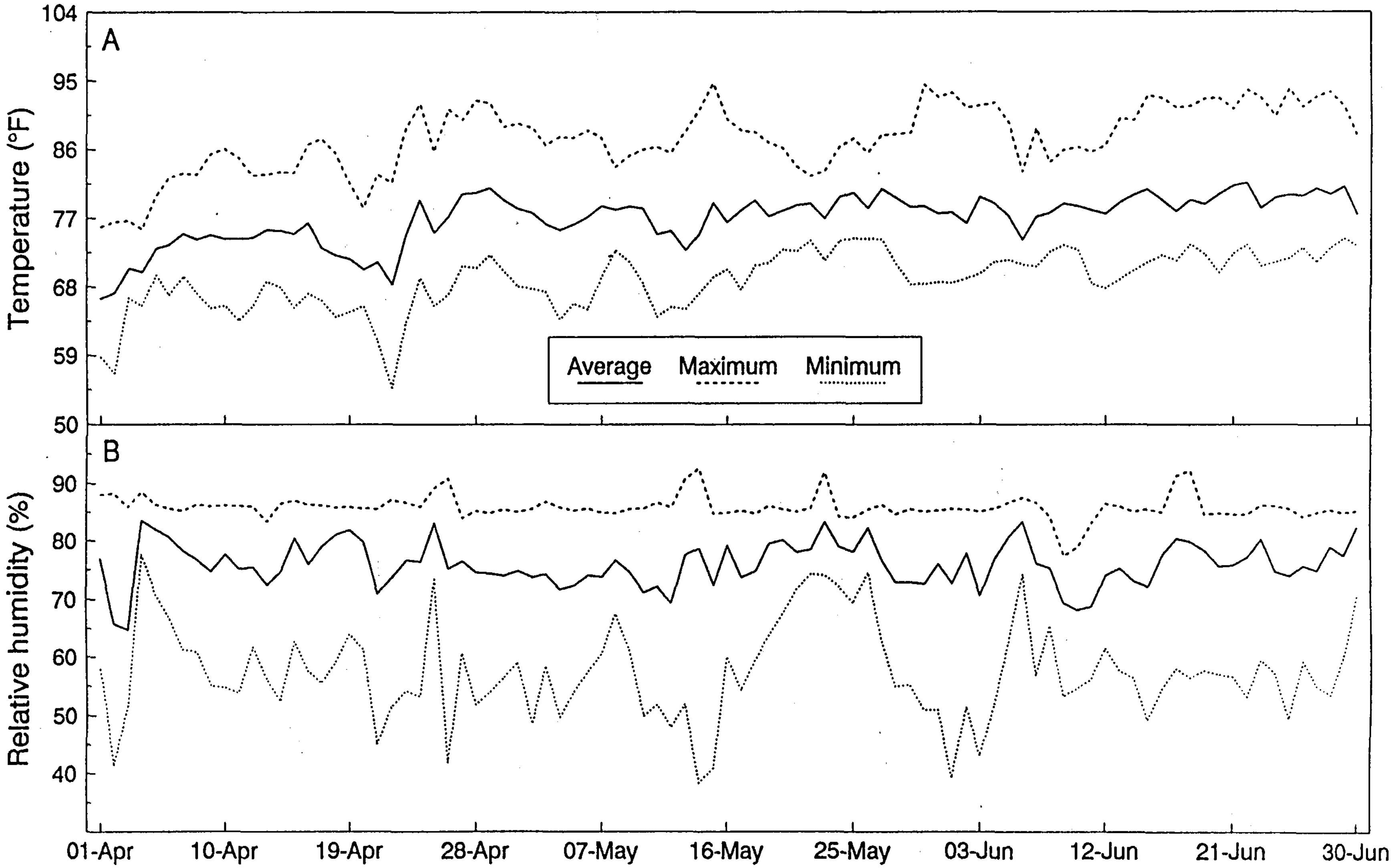

Fig. A7. (A) Average, maximum, and minimum daily temperatures, and (B) average, maximum, and minimum relative humidity for quarter 2, 1991 Vero Beach, Fla.

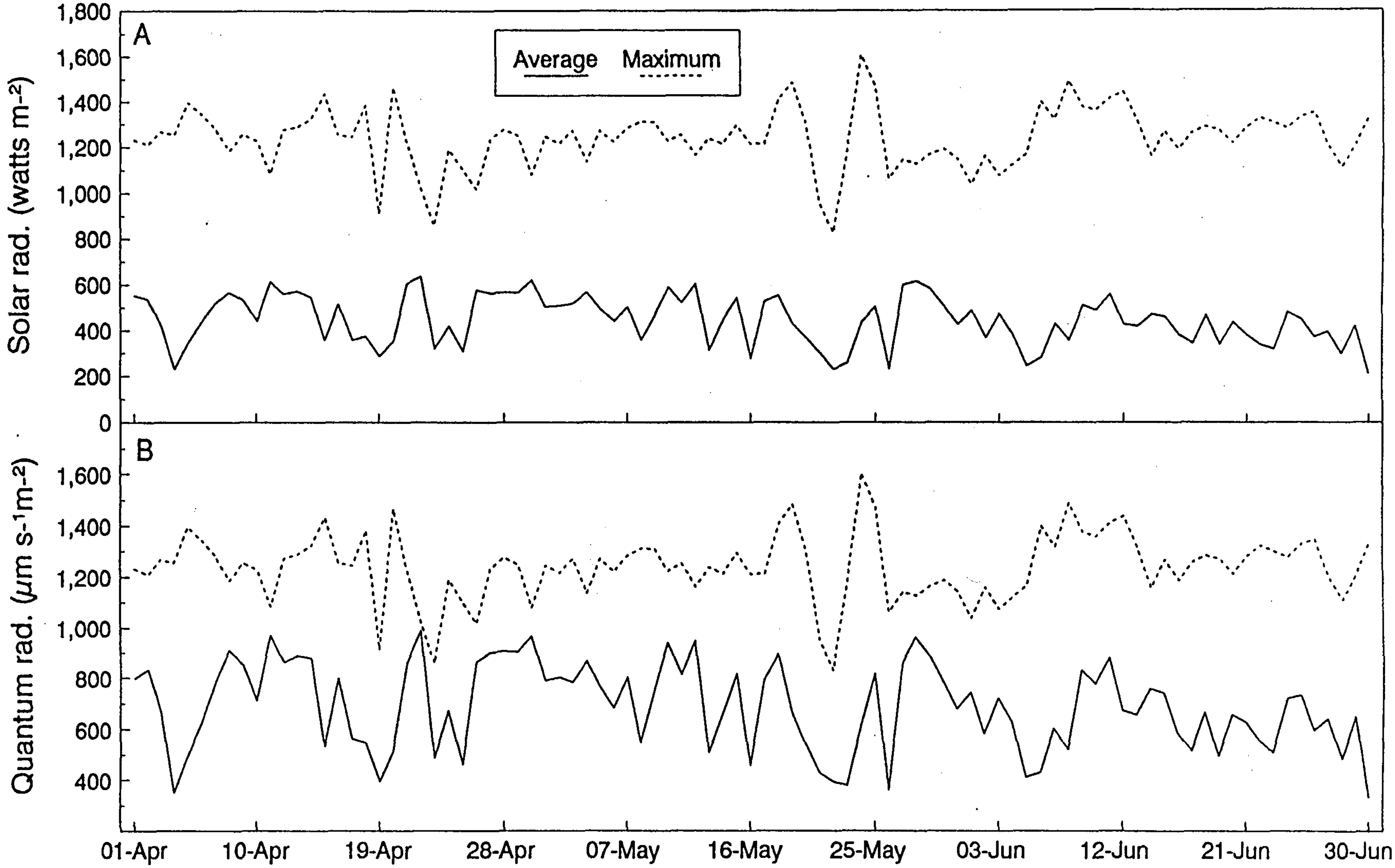

Fig. A8. (A) Average and maximum daily solar radiation, and (B) average and maximum daily quantum radiation for quarter 2, 1991 Vero Beach, Fla.

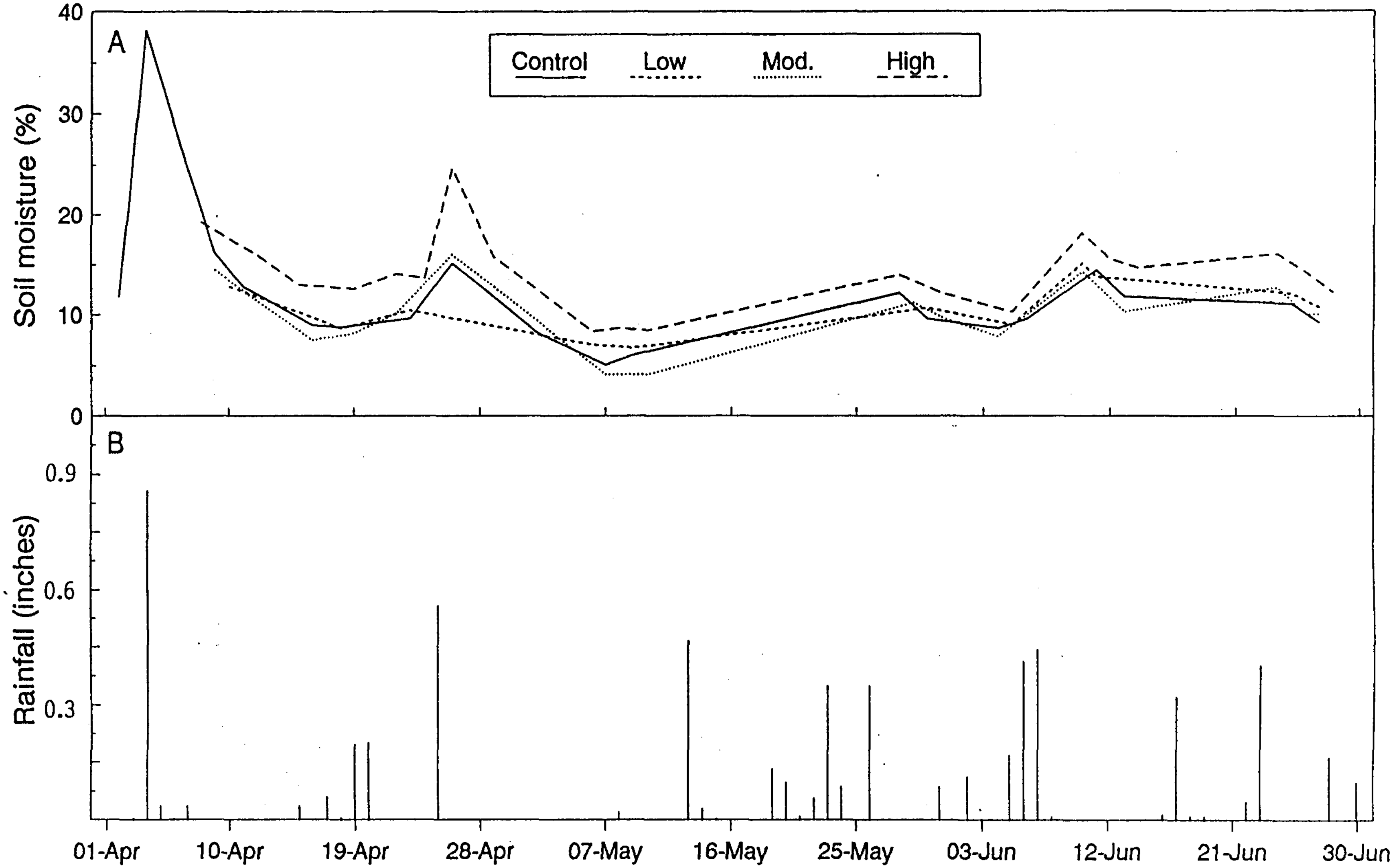

Fig. A9. (A) Mean soil moisture, and (B) daily rainfall for quarter 2, 1990, Vero Beach, Fla. (Control = canal water, low = 0.9 in/wk, mod. = 1.2 in/wk, and high = 1.5 in/wk.)

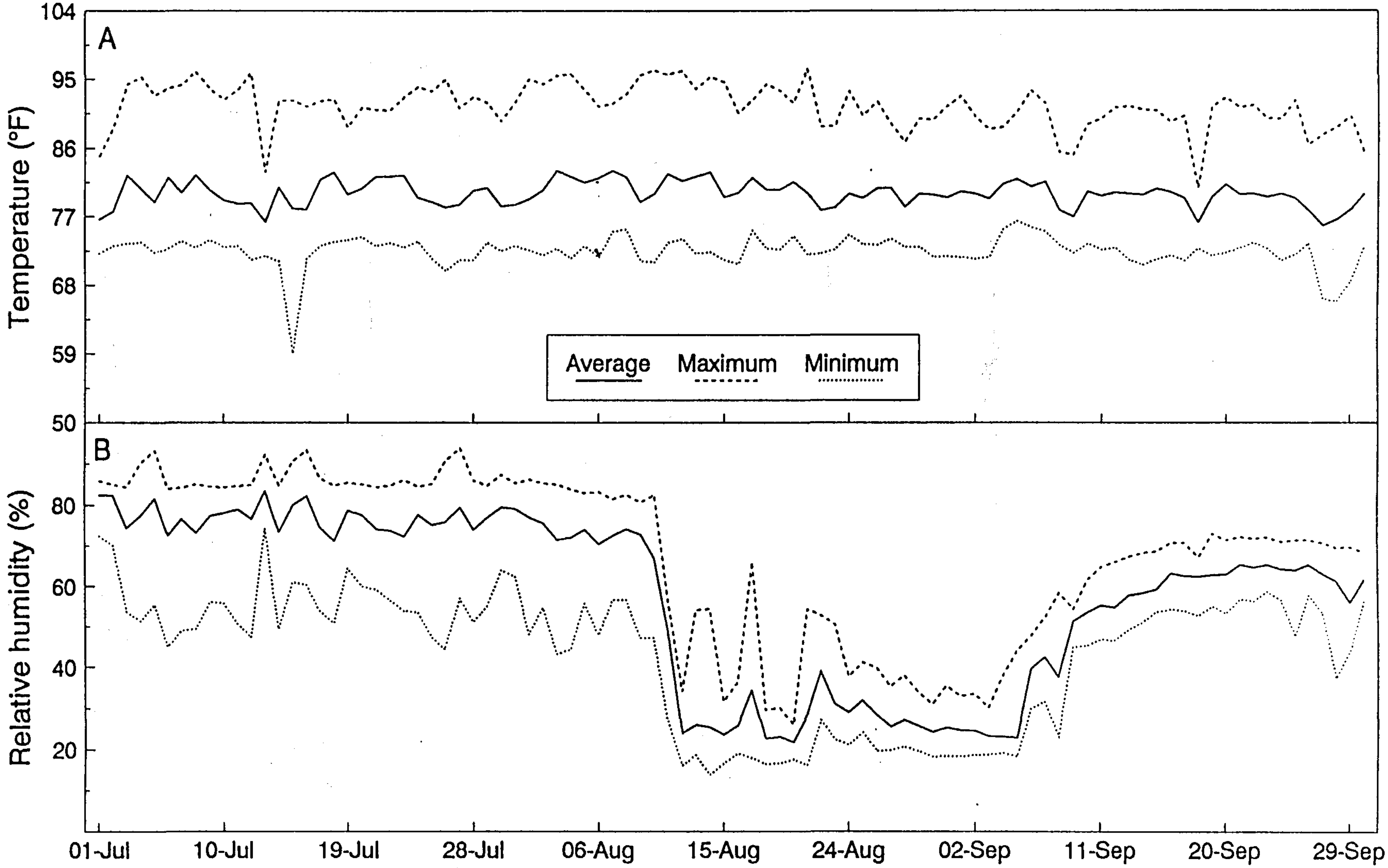

Fig. A10. (A) Average, maximum, and minimum daily temperatures, and (B) average, maximum, and minimum relative humidity for quarter 3, 1991 Vero Beach, Fla.

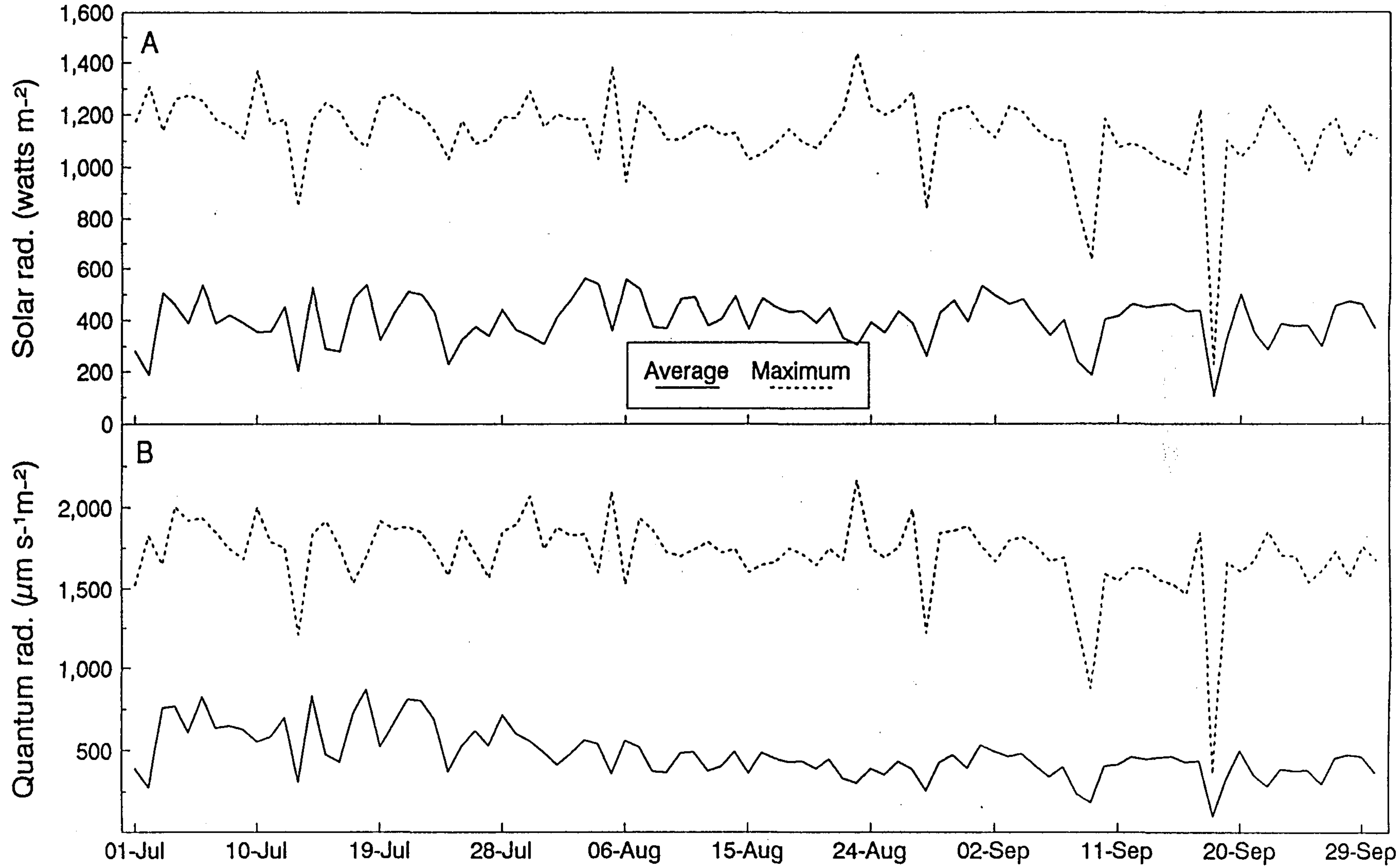

Fig. A11. (A) Average and maximum daily solar radiation, and (B) average and maximum daily quantum radiation for quarter 3, 1991 Vero Beach, Fla.

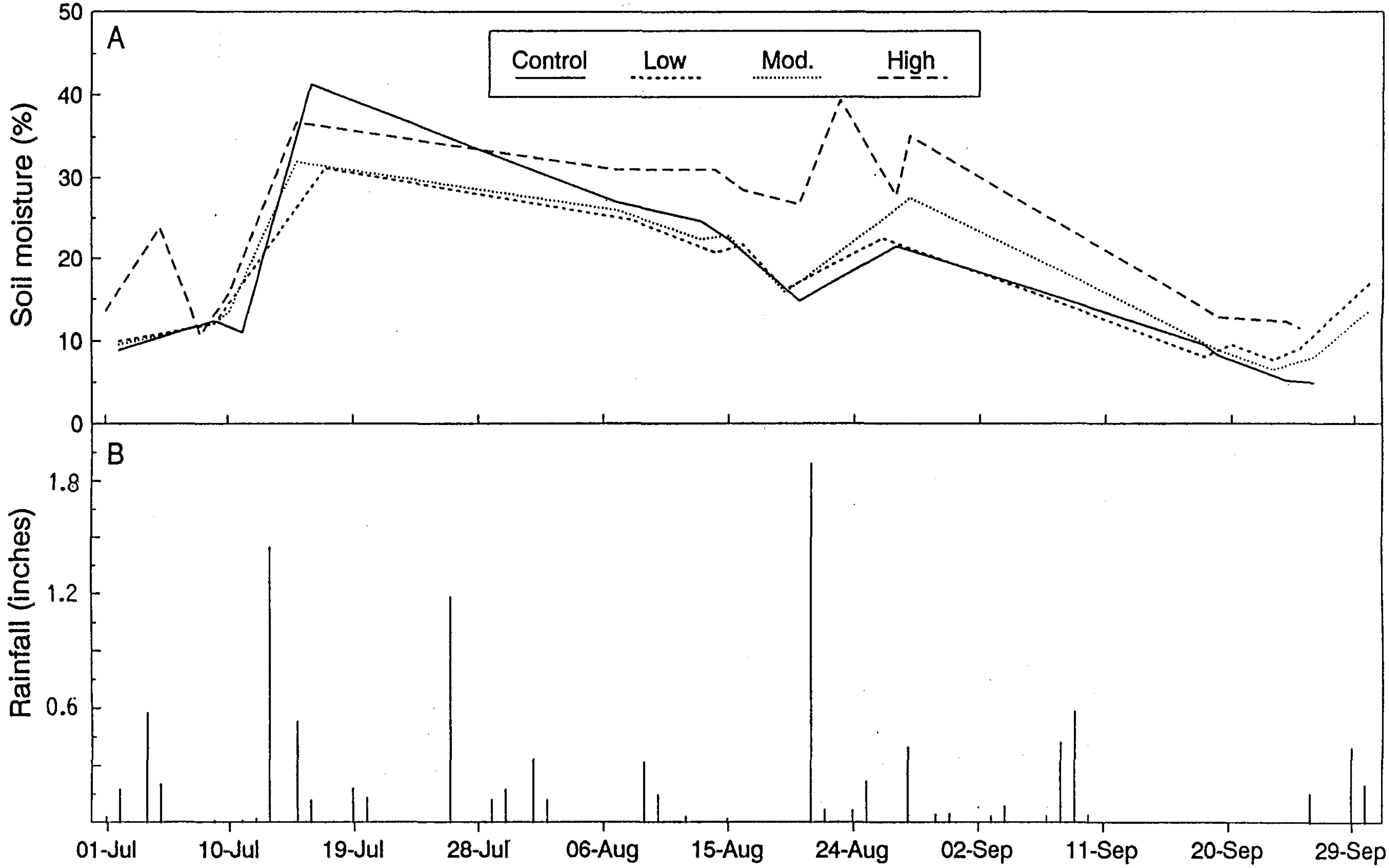

Fig. A12. (A) Mean soil moisture, and (B) daily rainfall for quarter 3, 1991, Vero Beach, Fla. (Control = canal water, low = 0.9 in/wk, mod. = 1.2 in/wk, and high = 1.5 in/wk.)

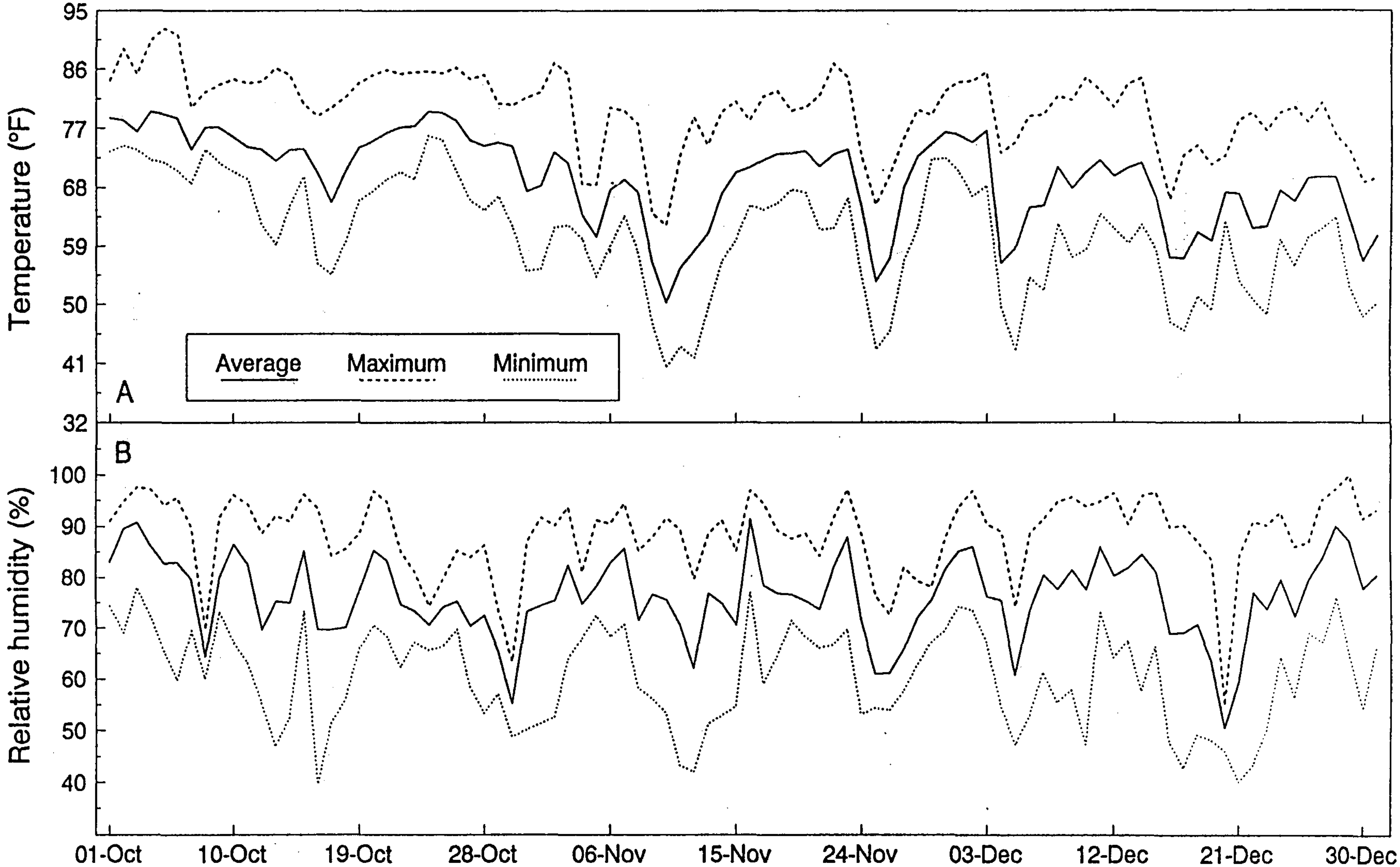

Fig. A13. (A) Average, maximum, and minimum daily temperatures, and (B) average, maximum, and minimum relative humidity for quarter 4, 1991 Vero Beach, Fla.

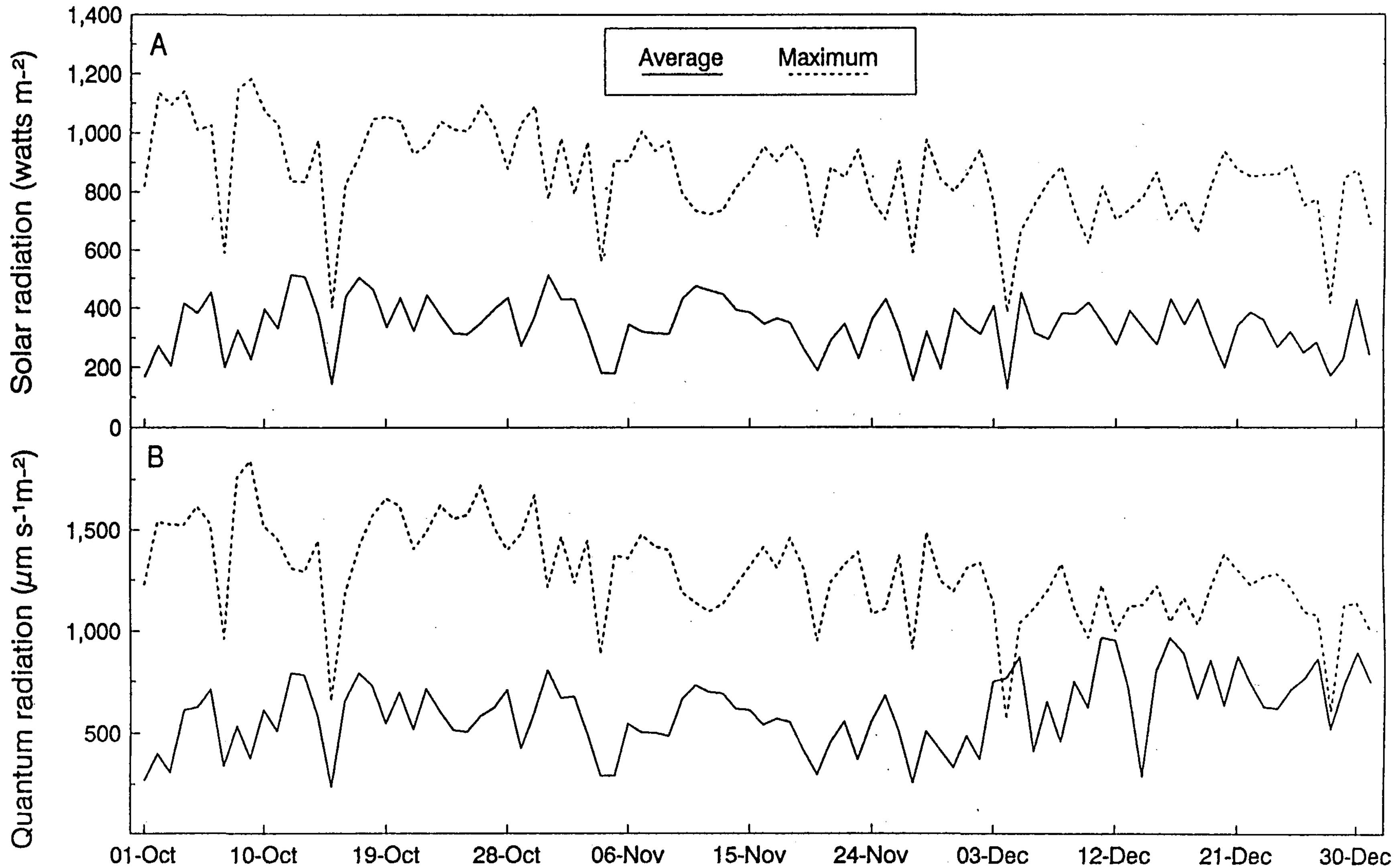

Fig. A14. (A) Average and maximum daily solar radiation, and (B) average and maximum daily quantum radiation for quarter 4, 1991 Vero Beach, Fla.

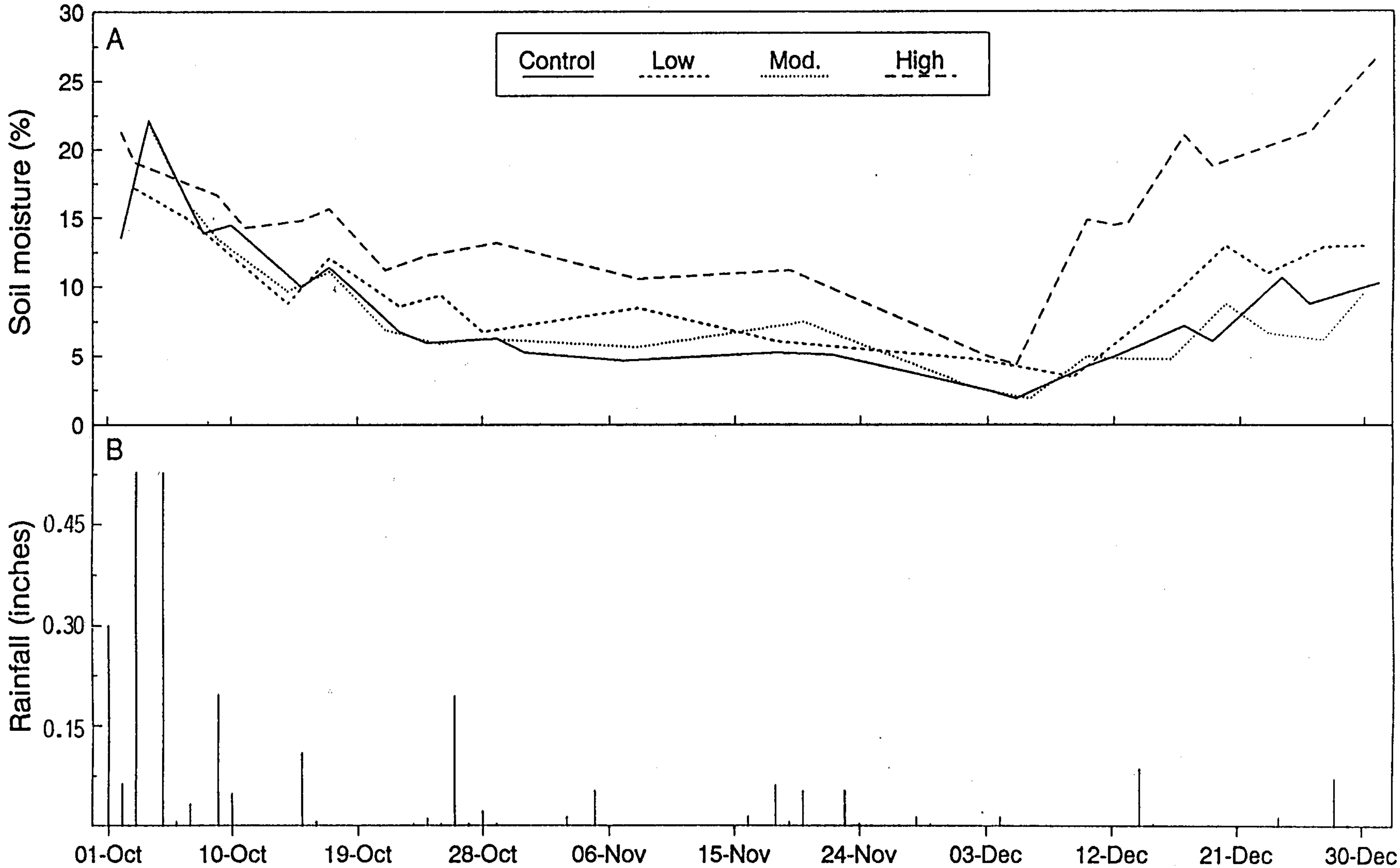

Fig. A15. (A) Mean soil moisture, and (B) daily rainfall for quarter 4, 1991, Vero Beach, Fla. (Control = canal water, low = 0.9 in/wk, mod. = 1.2 in/wk, and high = 1.5 in/wk.)

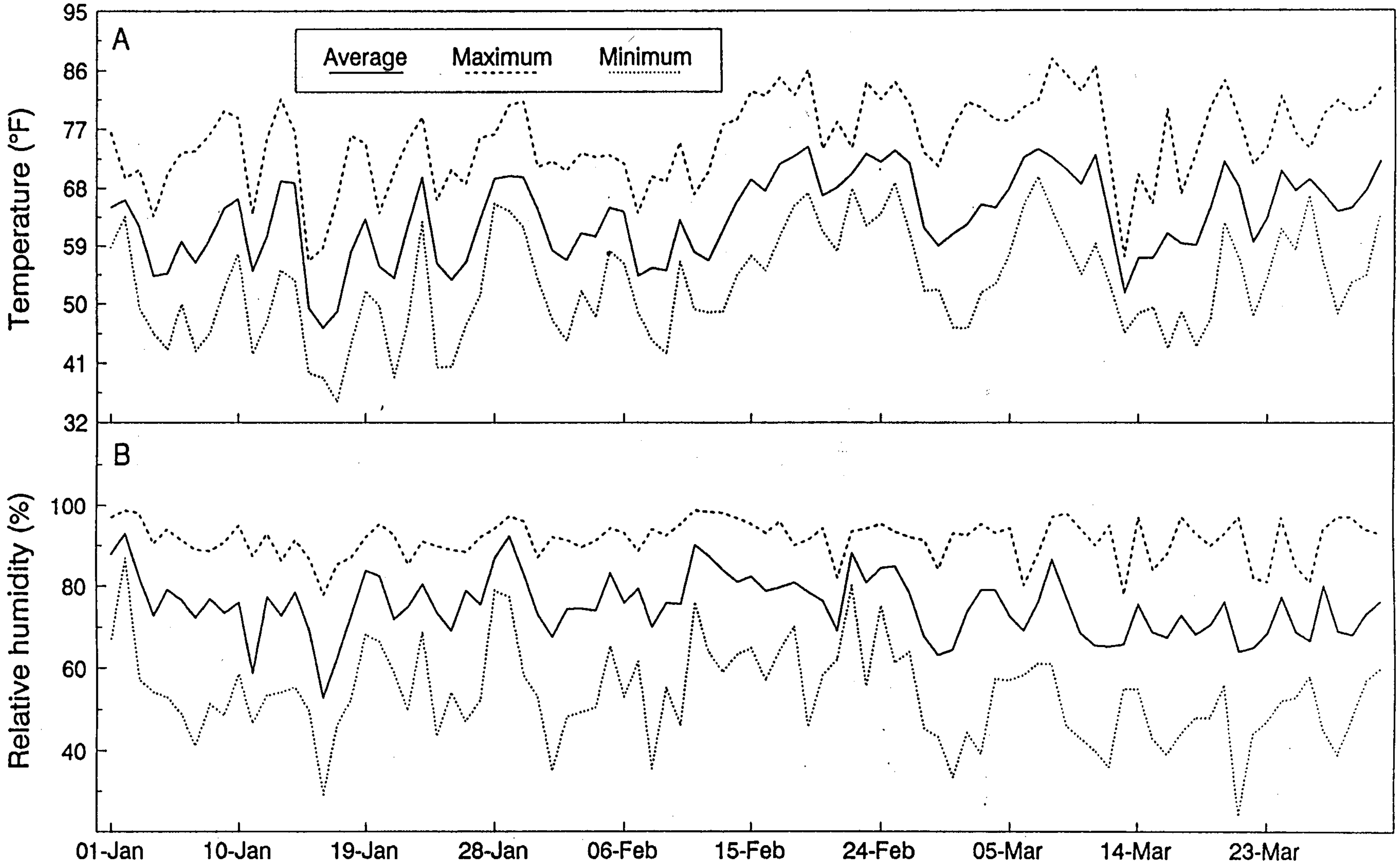

Fig. A16. (A) Average, maximum, and minimum daily temperatures, and (B) average, maximum, and minimum relative humidity for quarter 1, 1992 Vero Beach, Fla.

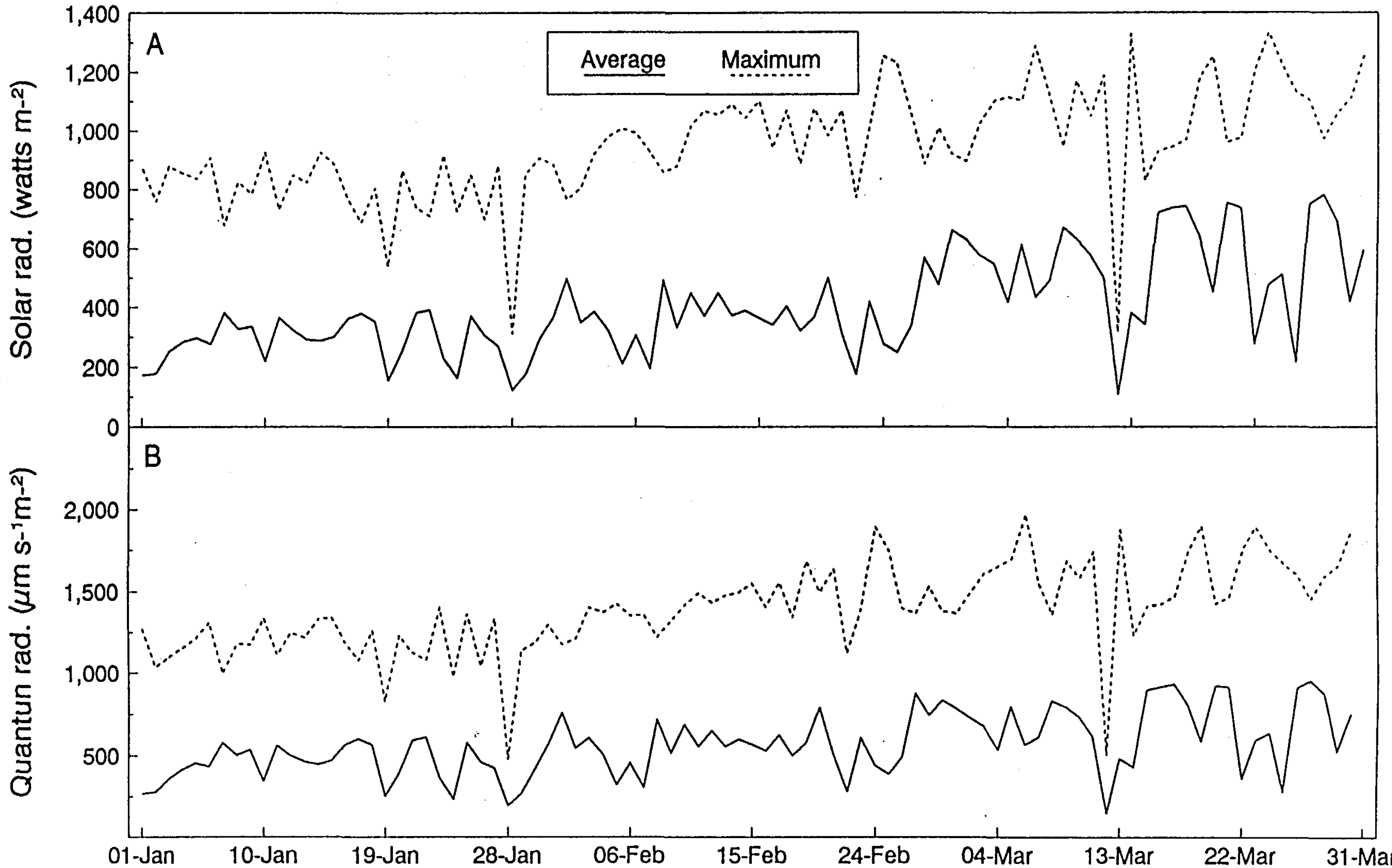

Fig. A17. (A) Average and maximum daily solar radiation, and (B) average and maximum daily quantum radiation for quarter 1, 1992 Vero Beach, Fla.

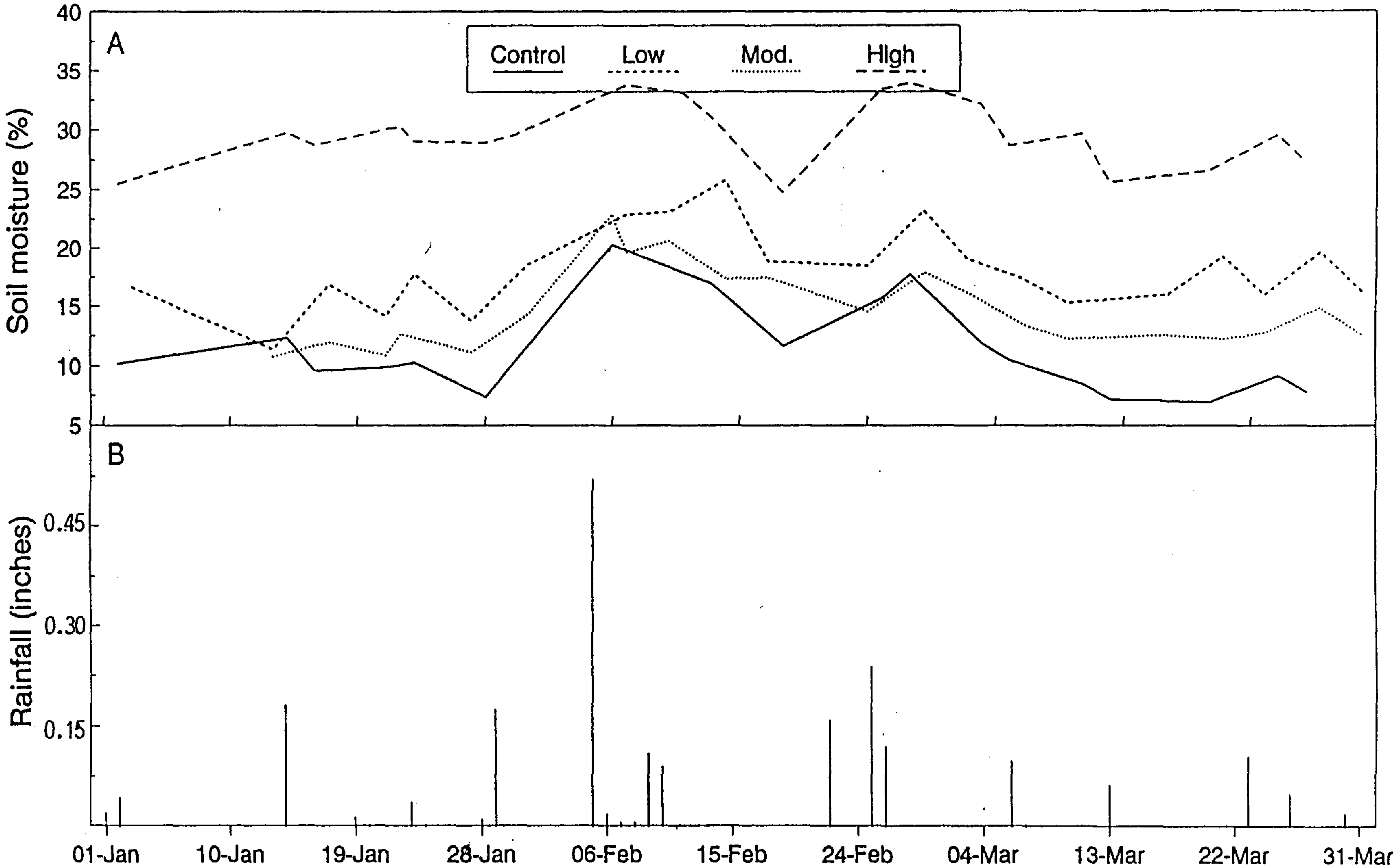

Fig. A18. (A) Mean soil moisture, and (B) daily rainfall for quarter 1, 1992, Vero Beach, Fla. (Control = canal water, low = 0.9 in/wk, mod. = 1.2 in/wk, and high = 1.5 in/wk.)

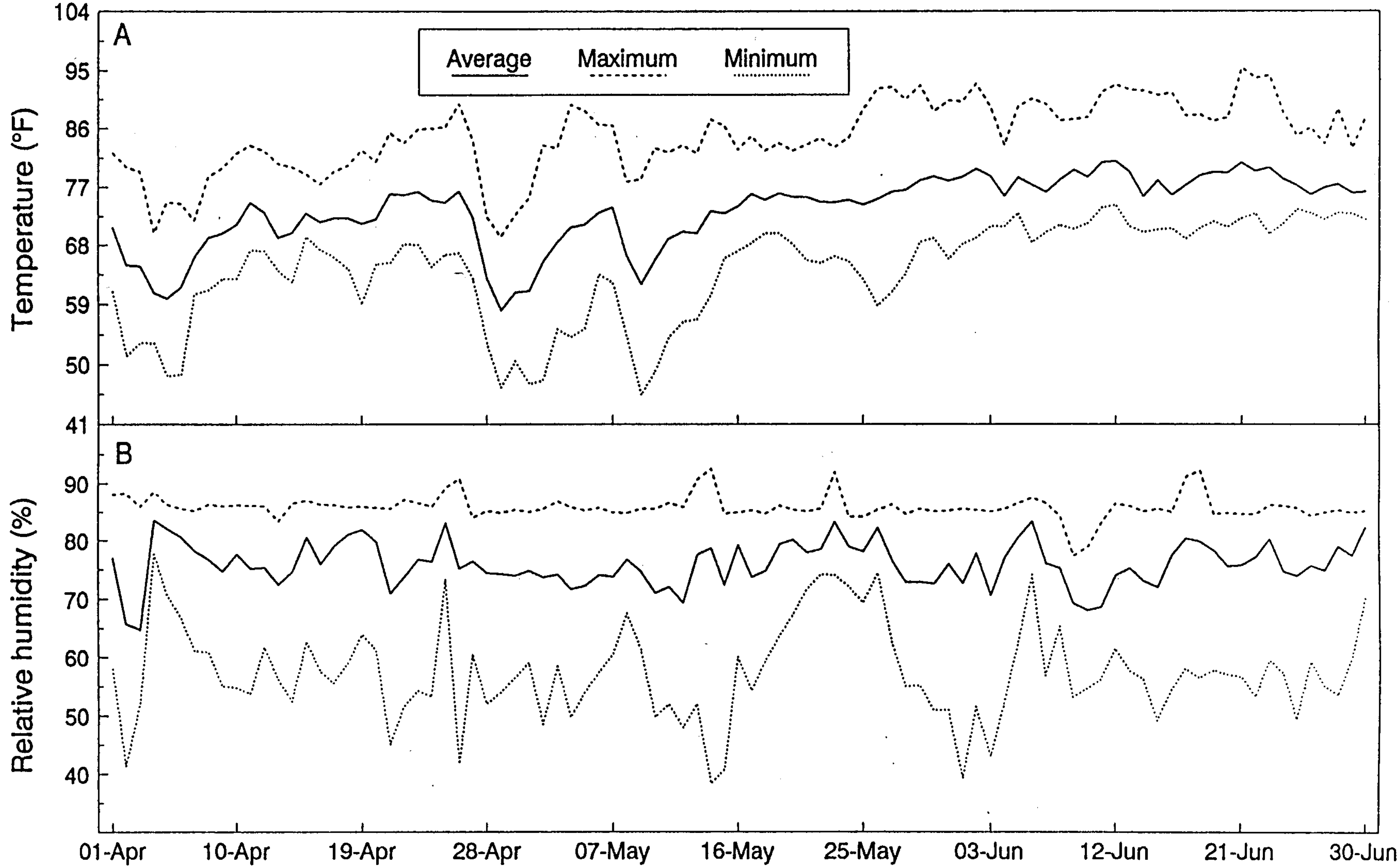

Fig. A19. (A) Average, maximum, and minimum daily temperatures, and (B) average, maximum, and minimum relative humidity for quarter 2, 1992 Vero Beach, Fla.

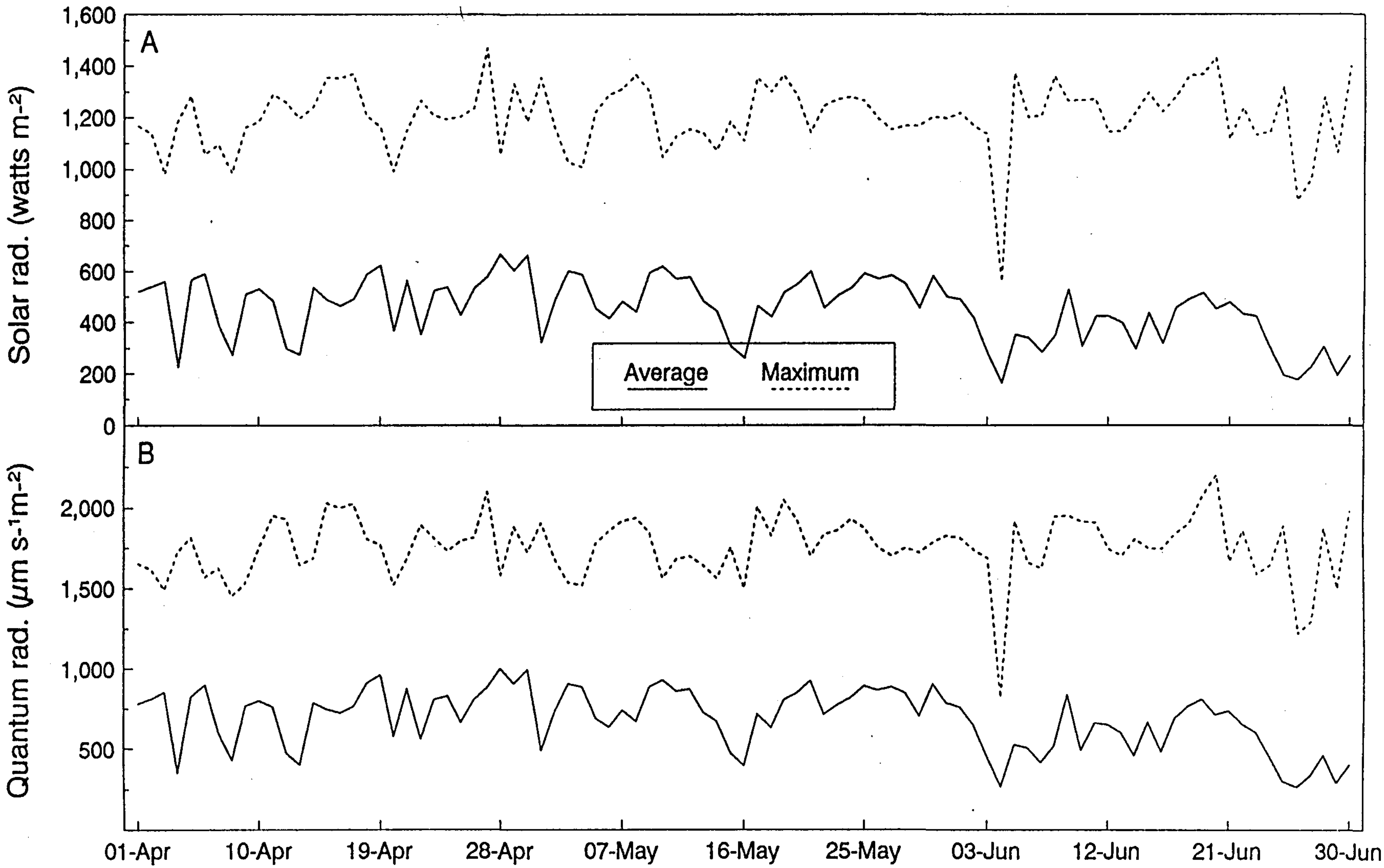

Fig. A20. (A) Average and maximum daily solar radiation, and (B) average and maximum daily quantum radiation for quarter 2, 1992 Vero Beach, Fla.

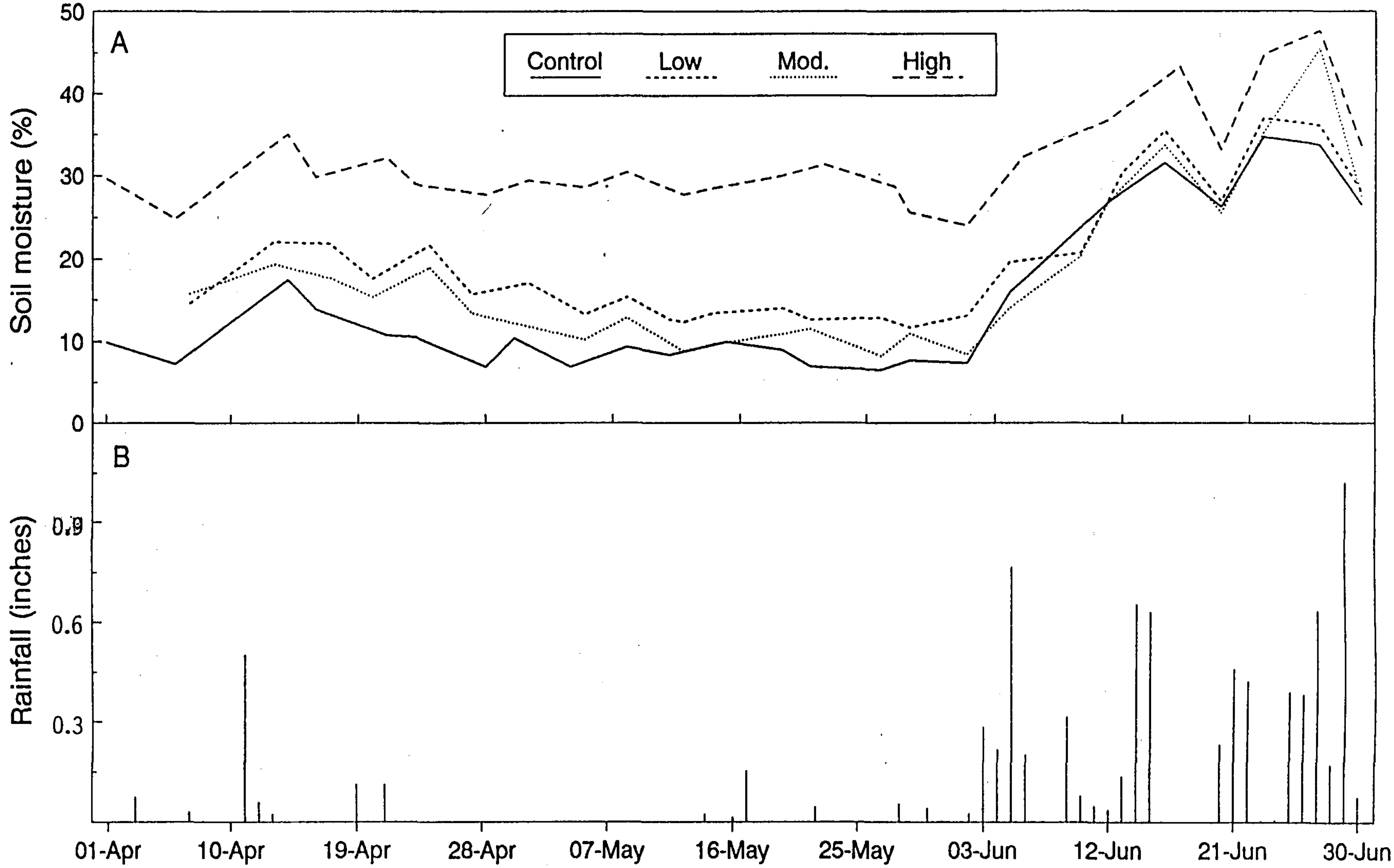

Fig. A21. (A) Mean soil moisture, and (B) daily rainfall for quarter 2, 1992, Vero Beach, Fla. (Control = canal water, low = 0.9 in/wk, mod. = 1.2 in/wk, and high = 1.5 in/wk.)

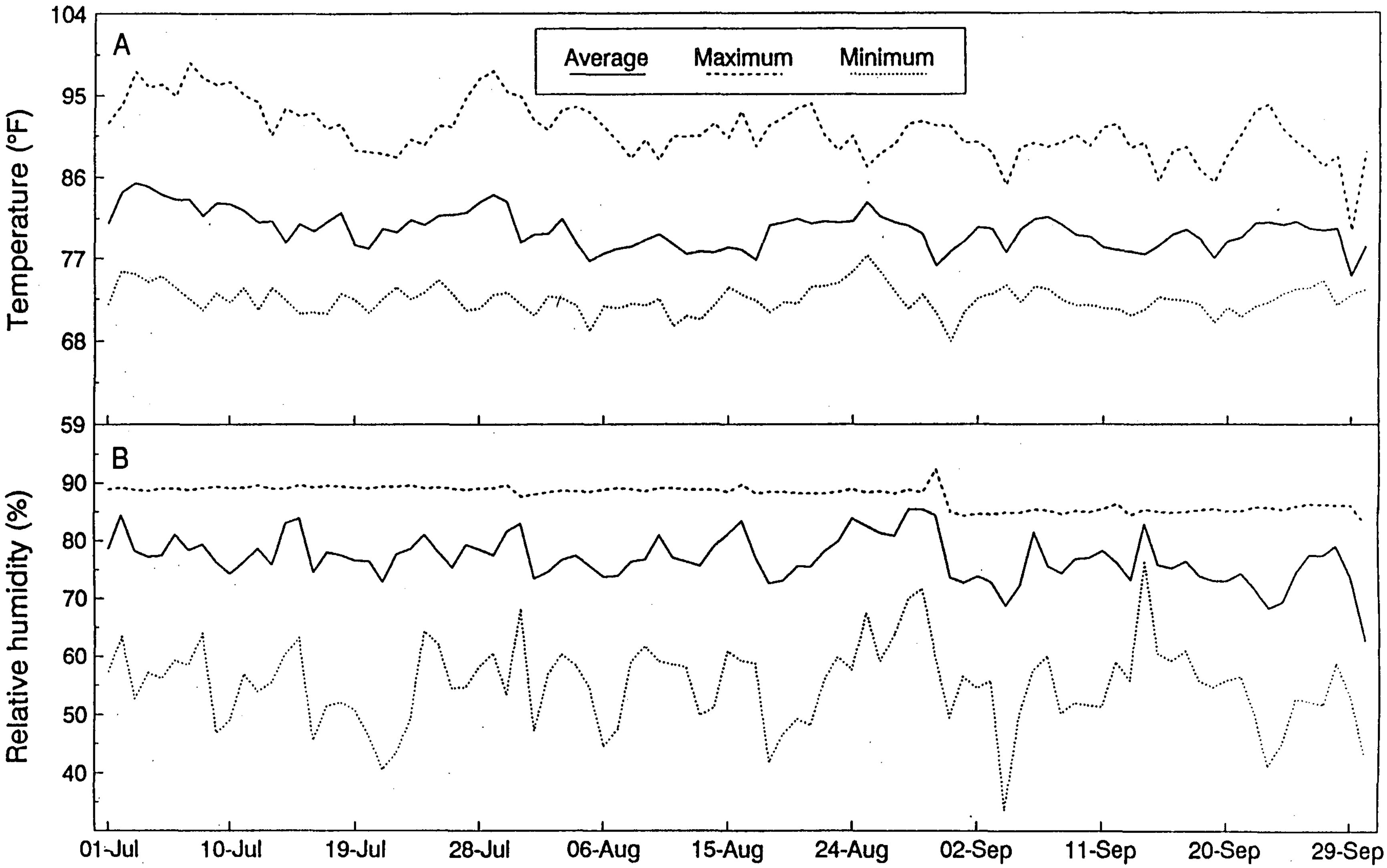

Fig. A22. (A) Average, maximum, and minimum daily temperatures, and (B) average, maximum, and minimum relative humidity for quarter 3, 1992 Vero Beach, Fla.

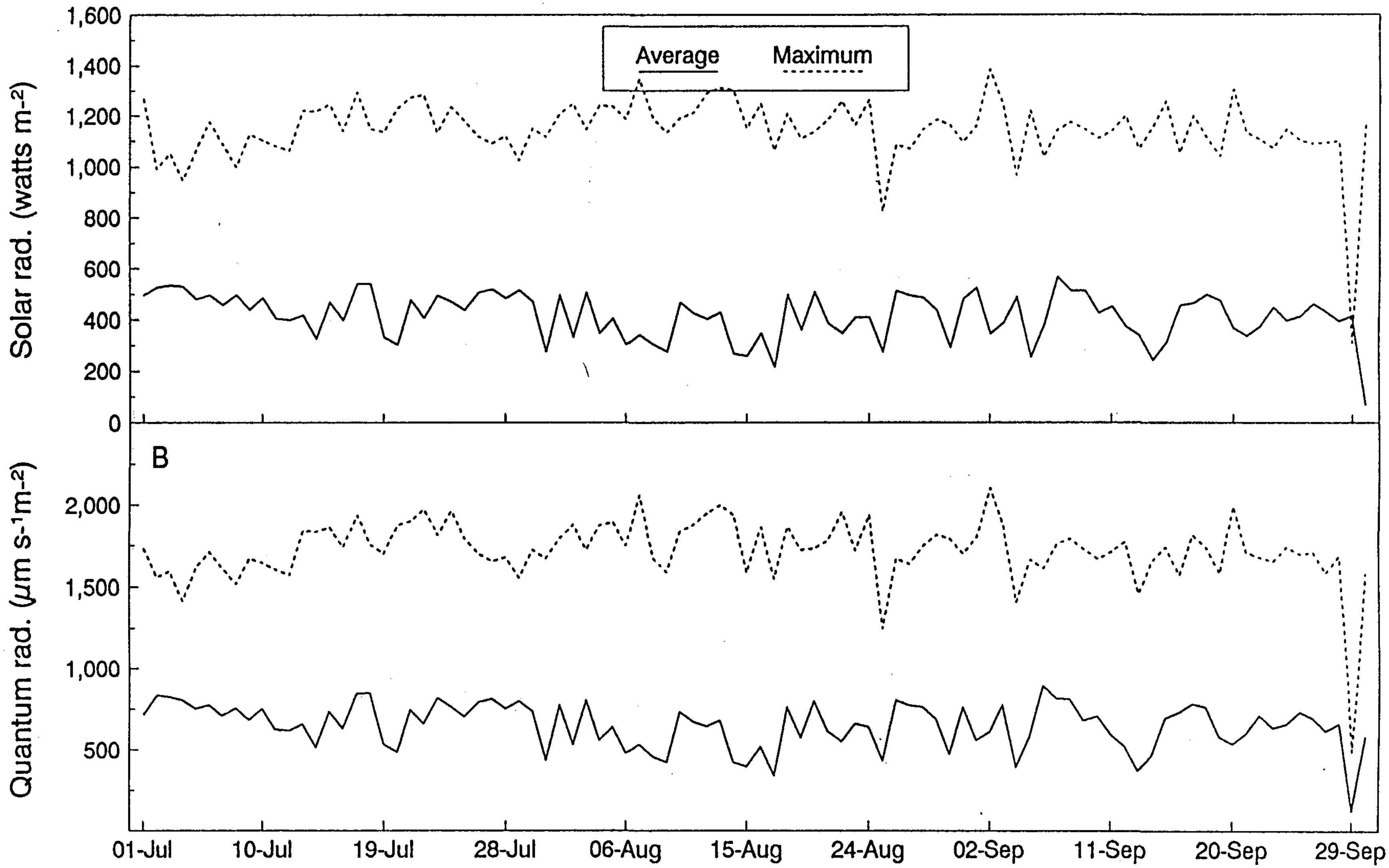

Fig. A23. (A) Average and maximum daily solar radiation, and (B) average and maximum daily quantum radiation for quarter 3, 1992 Vero Beach, Fla.

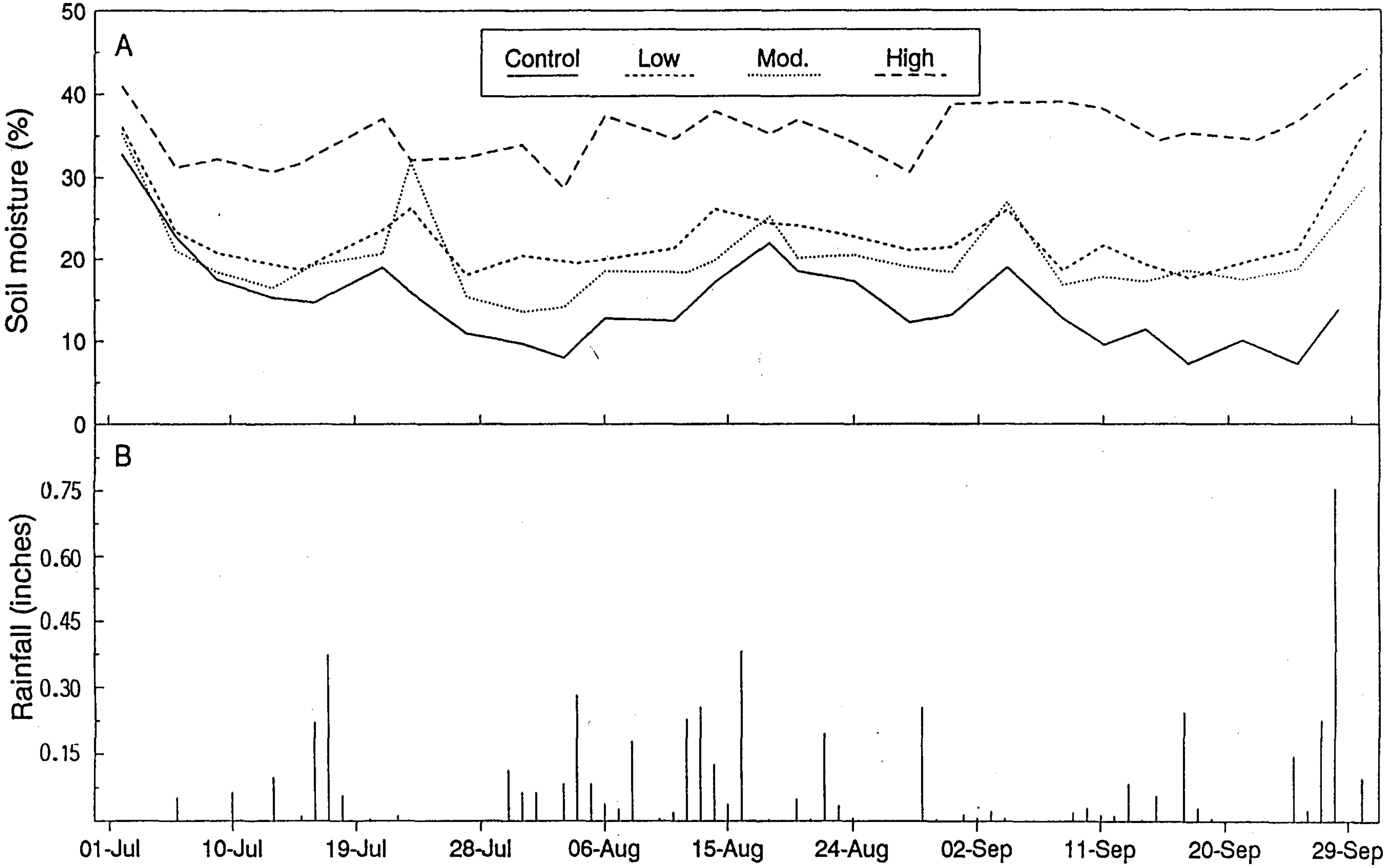

Fig. A24. (A) Mean soil moisture, and (B) daily rainfall for quarter 3, 1992, Vero Beach, Fla. (Control = canal water, low = 0.9 in/wk, mod. = 1.2 in/wk, and high = 1.5 in/wk.)

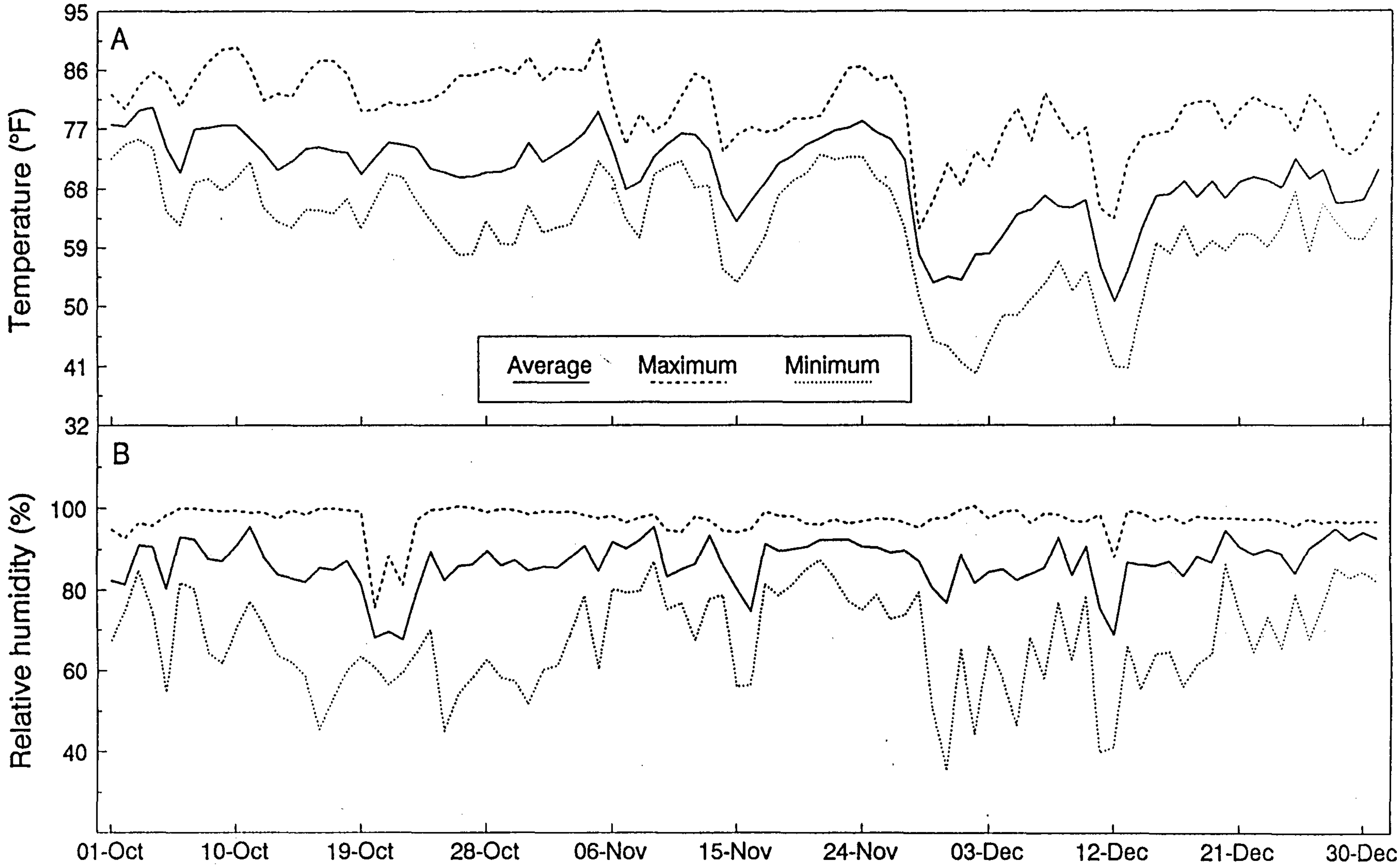

Fig. A25. (A) Average, maximum, and minimum daily temperatures, and (B) average, maximum, and minimum relative humidity for quarter 4, 1992 Vero Beach, Fla.

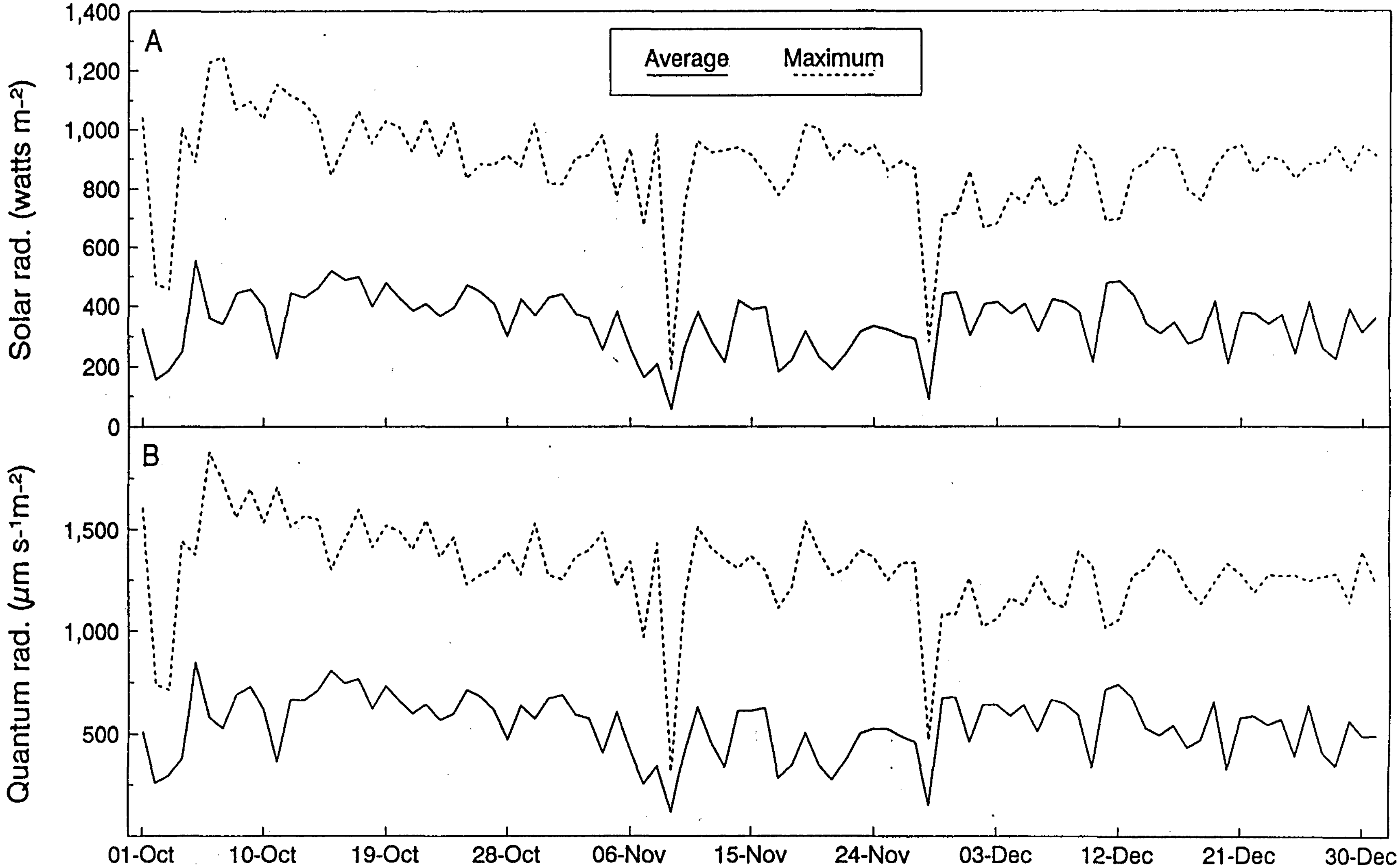

Fig. A26. (A) Average and maximum daily solar radiation, and (B) average and maximum daily quantum radiation for quarter 4, 1992 Vero Beach, Fla.

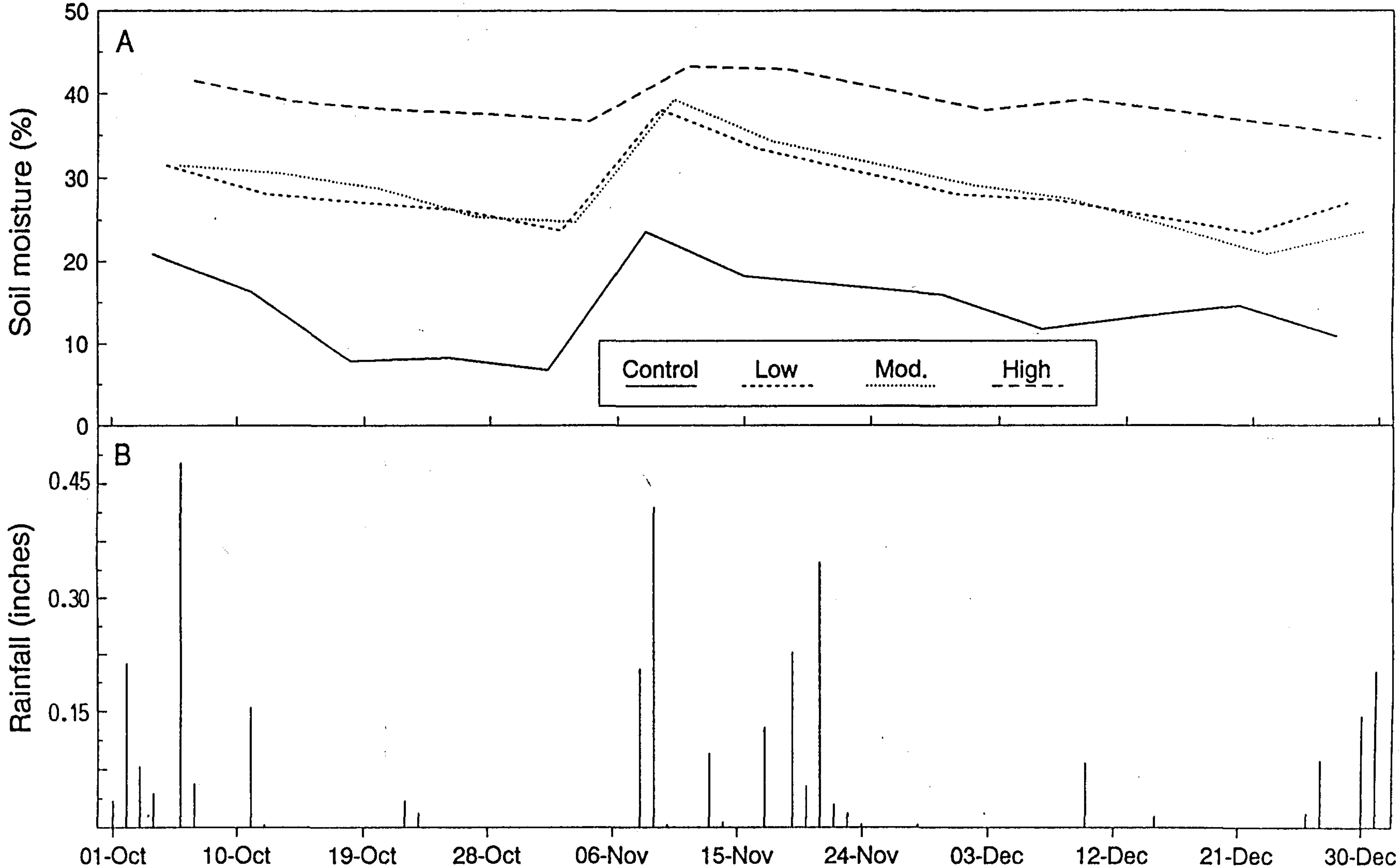

Fig. A27. (A) Mean soil moisture, and (B) daily rainfall for quarter 4, 1992, Vero Beach, Fla. (Control = canal water, low = 0.9 in/wk, mod. = 1.2 in/wk, and high = 1.5 in/wk.)

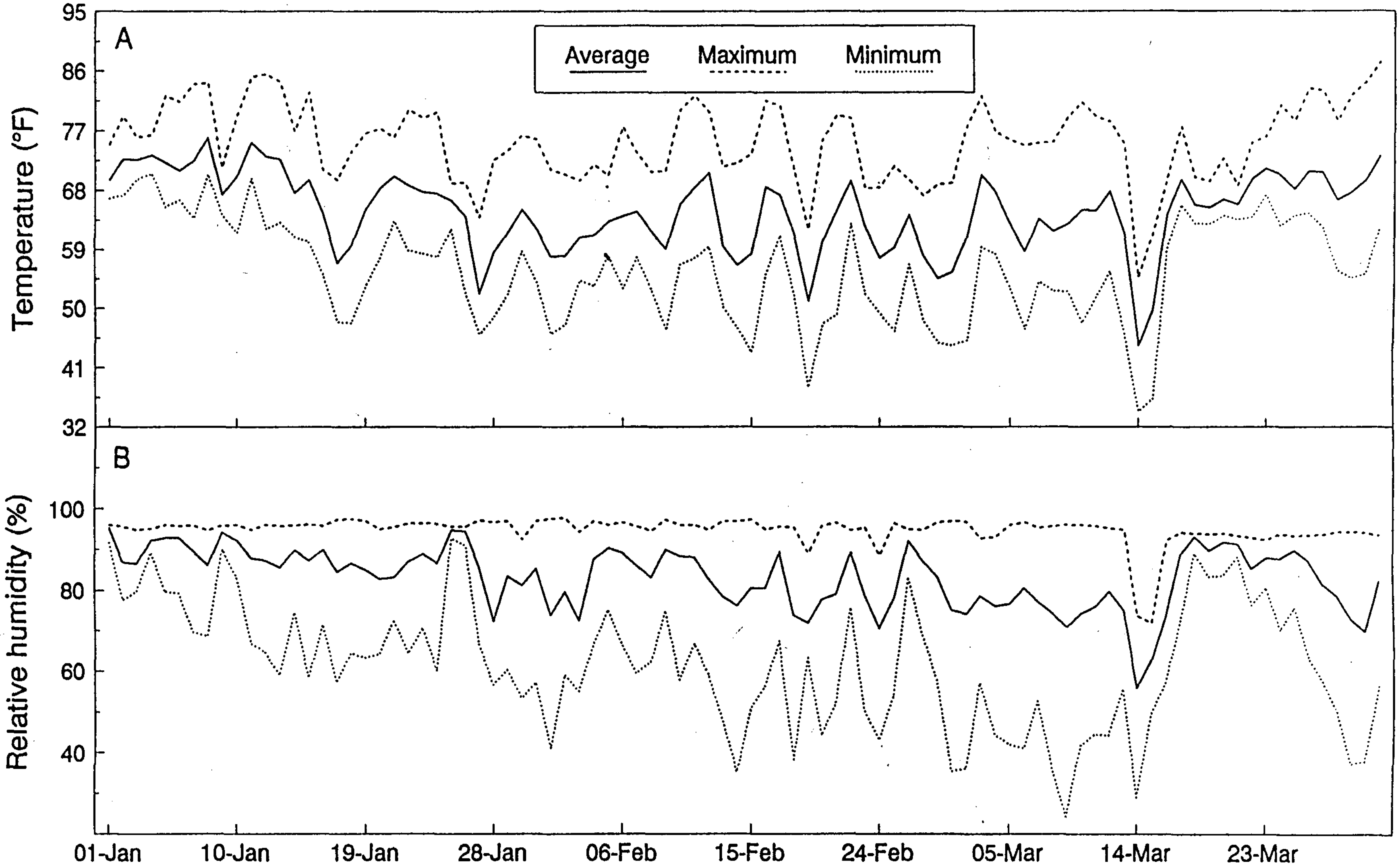

Fig. A28. (A) Average, maximum, and minimum daily temperatures, and (B) average, maximum, and minimum relative humidity for quarter 1, 1993 Vero Beach, Fla.

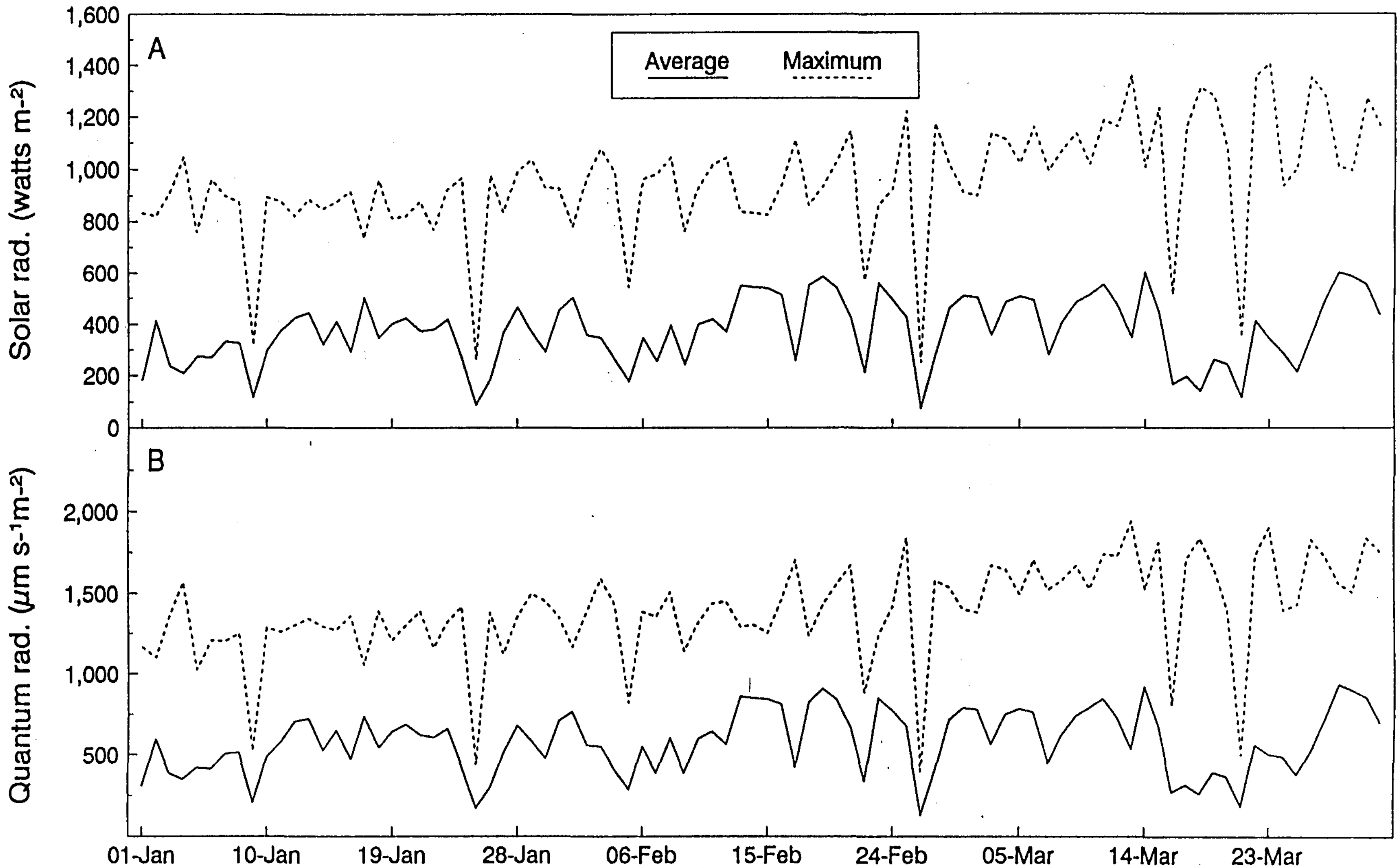

Fig. A29. (A) Average and maximum daily solar radiation, and (B) average and maximum daily quantum radiation for quarter 1, 1993 Vero Beach, Fla.

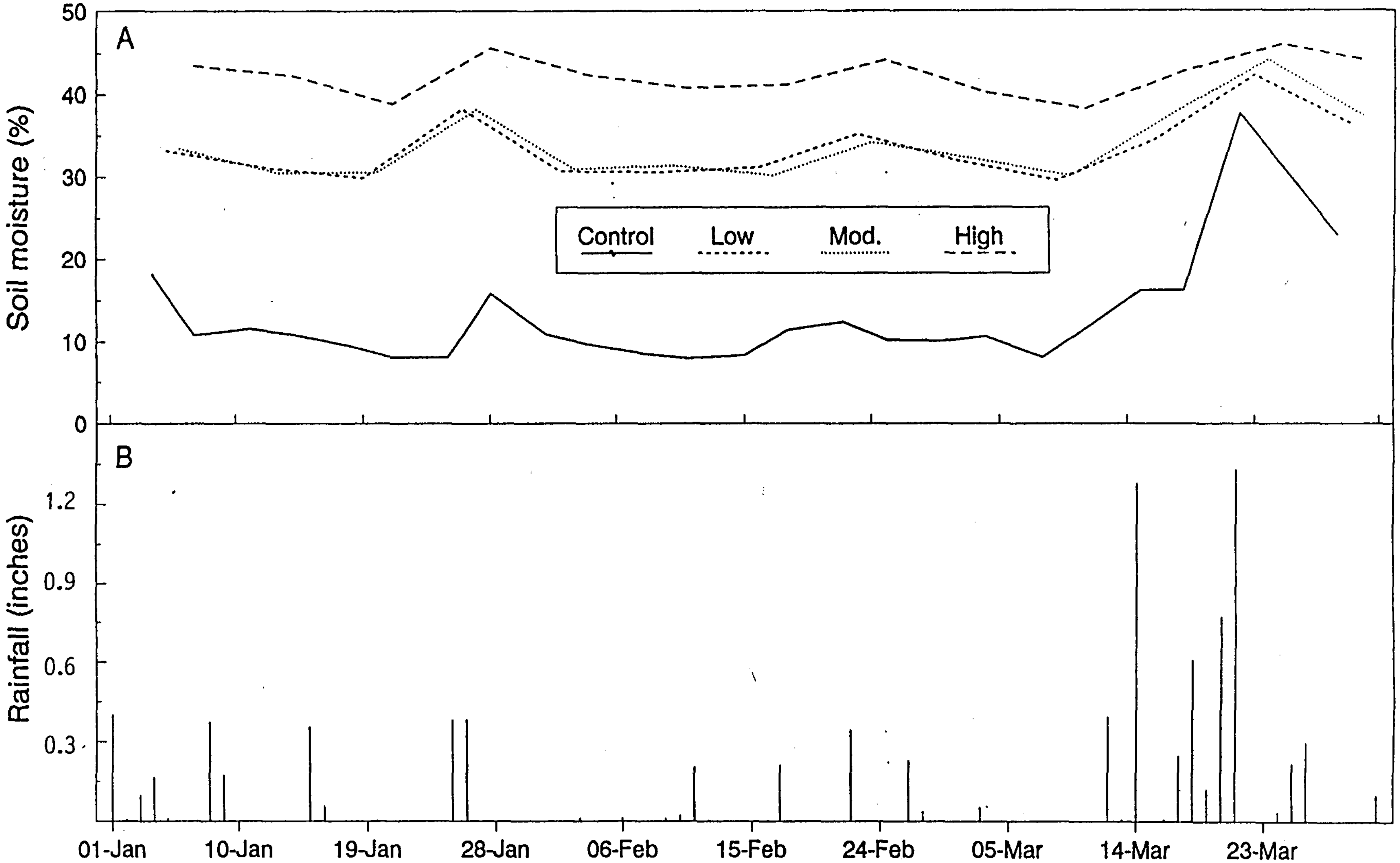

Fig. A30. (A) Mean soil moisture, and (B) daily rainfall for quarter 1, 1993, Vero Beach, Fla. (Control = canal water, low = 0.9 in/wk, mod. = 1.2 in/wk, and high = 1.5 in/wk.)

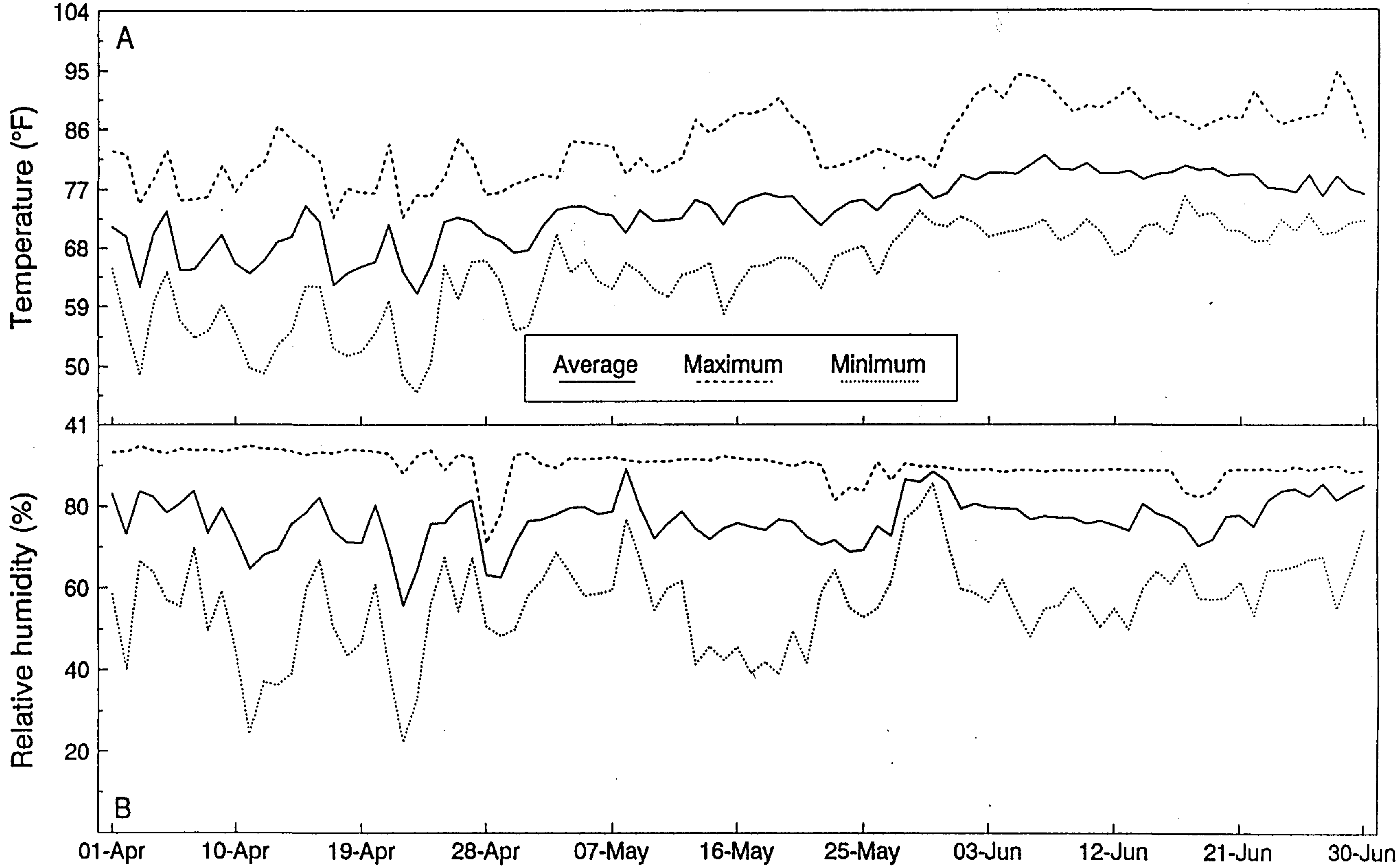

Fig. A31. (A) Average, maximum, and minimum daily temperatures, and (B) average, maximum, and minimum relative humidity for quarter 2, 1993 Vero Beach, Fla.

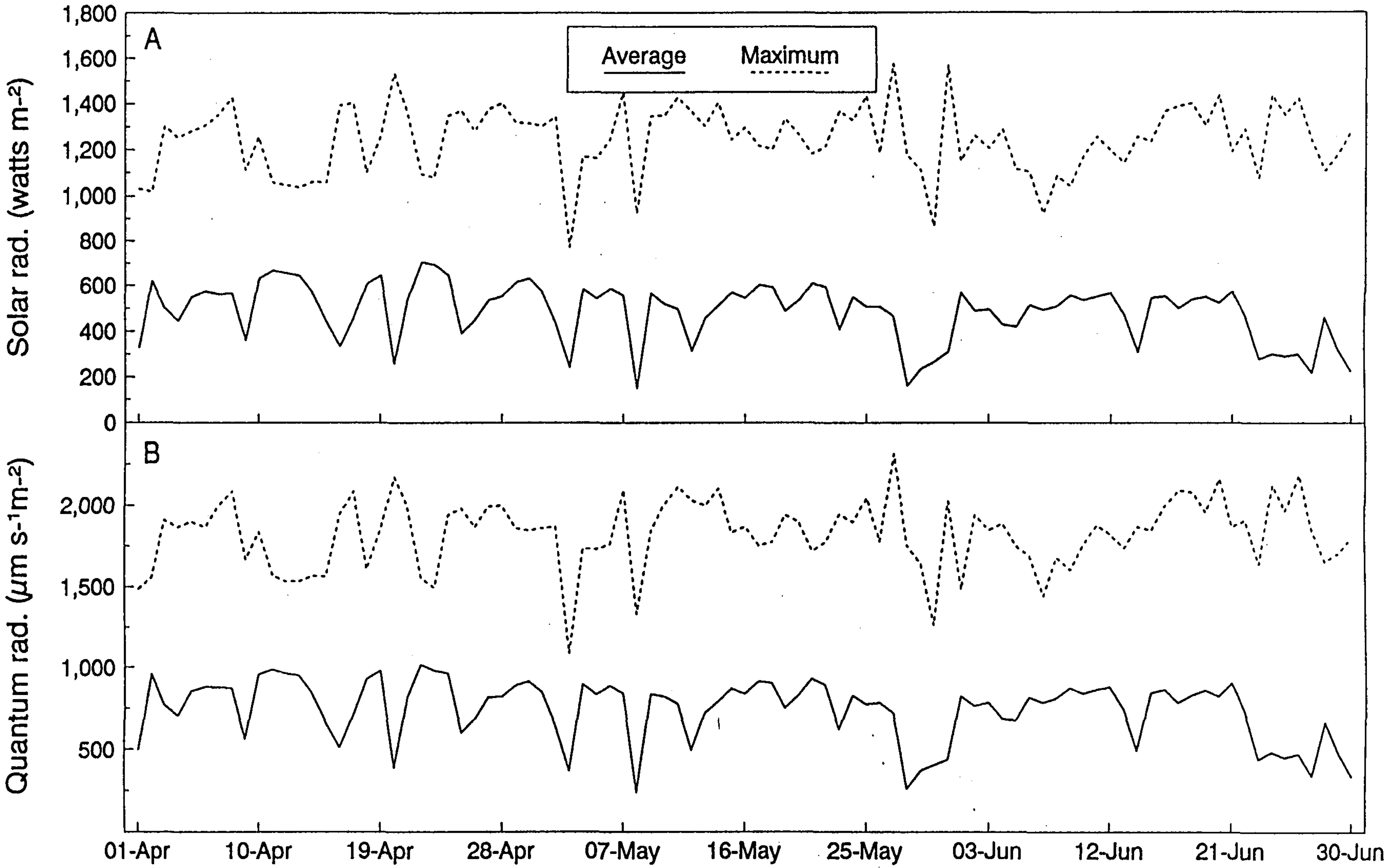

Fig. A32. (A) Average and maximum daily solar radiation, and (B) average and maximum daily quantum radiation for quarter 2, 1993 Vero Beach, Fla.

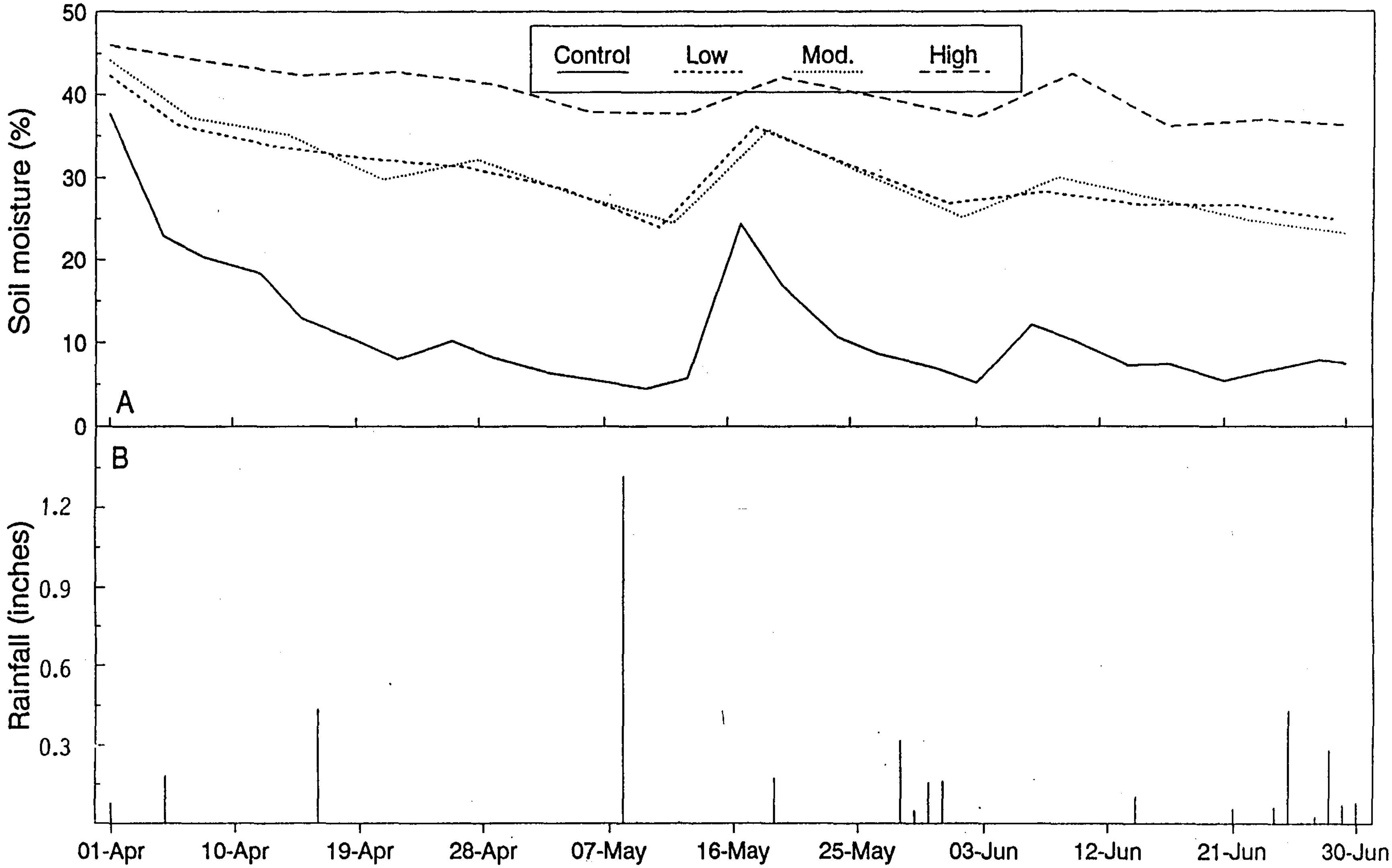

Fig. A33. (A) Mean soil moisture, and (B) daily rainfall for quarter 2, 1993, Vero Beach, Fla. (Control = canal water, low = 0.9 in/wk, mod. = 1.2 in/wk, and high = 1.5 in/wk.)

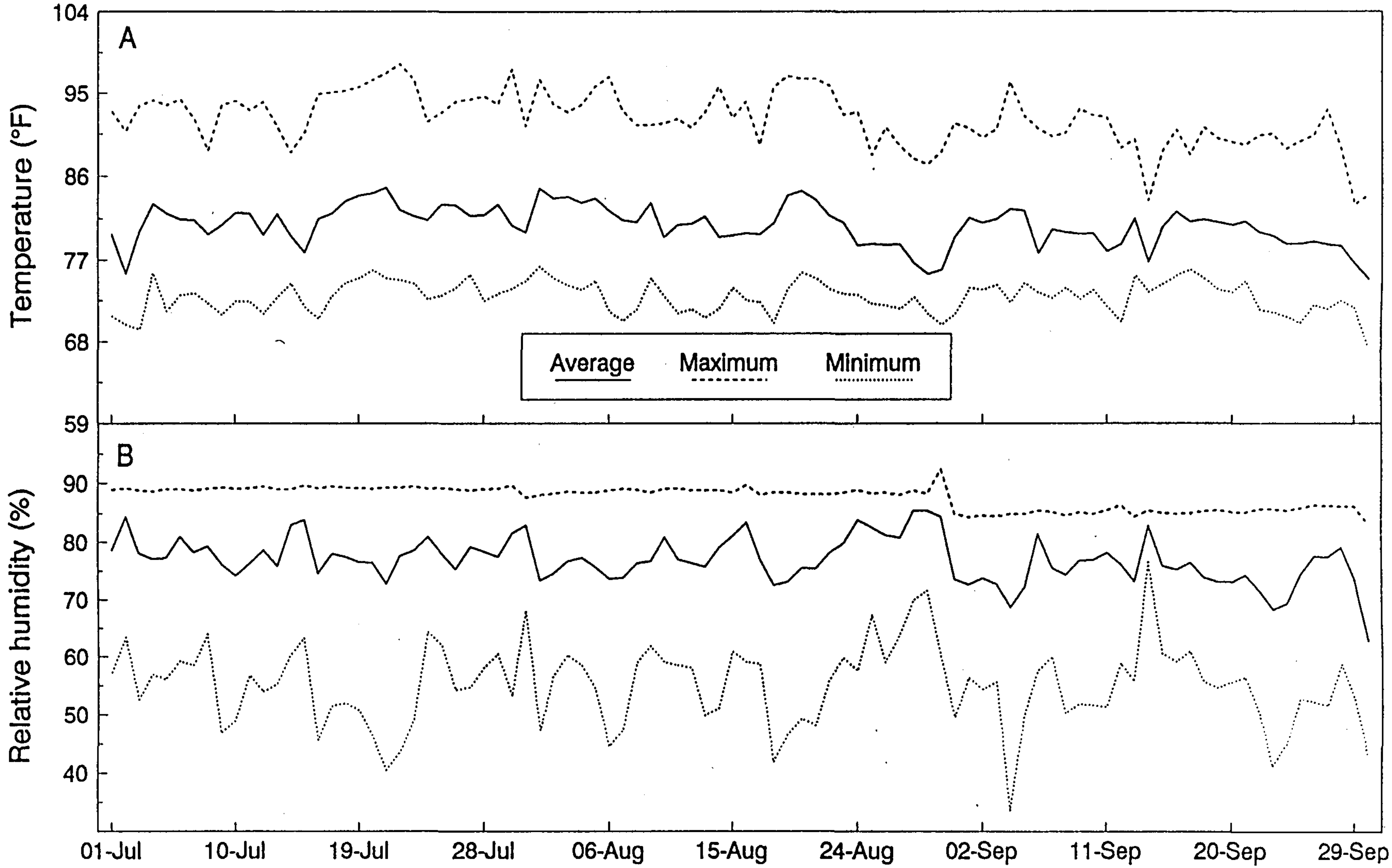

Fig. A34. (A) Average, maximum, and minimum daily temperatures, and (B) average, maximum, and minimum relative humidity for quarter 3, 1993 Vero Beach, Fla.

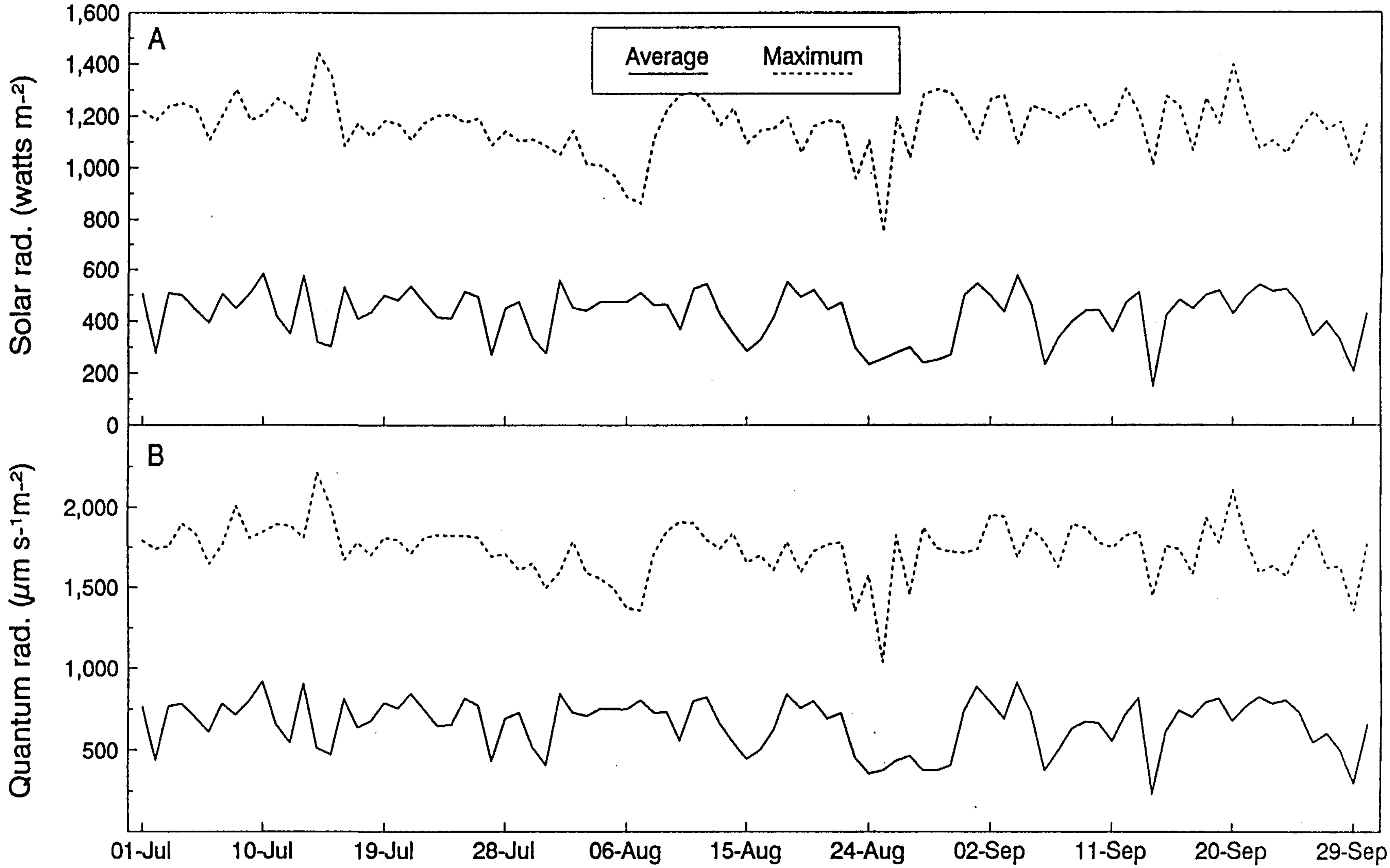

Fig. A35. (A) Average and maximum daily solar radiation, and (B) average and maximum daily quantum radiation for quarter 3, 1993 Vero Beach, Fla.

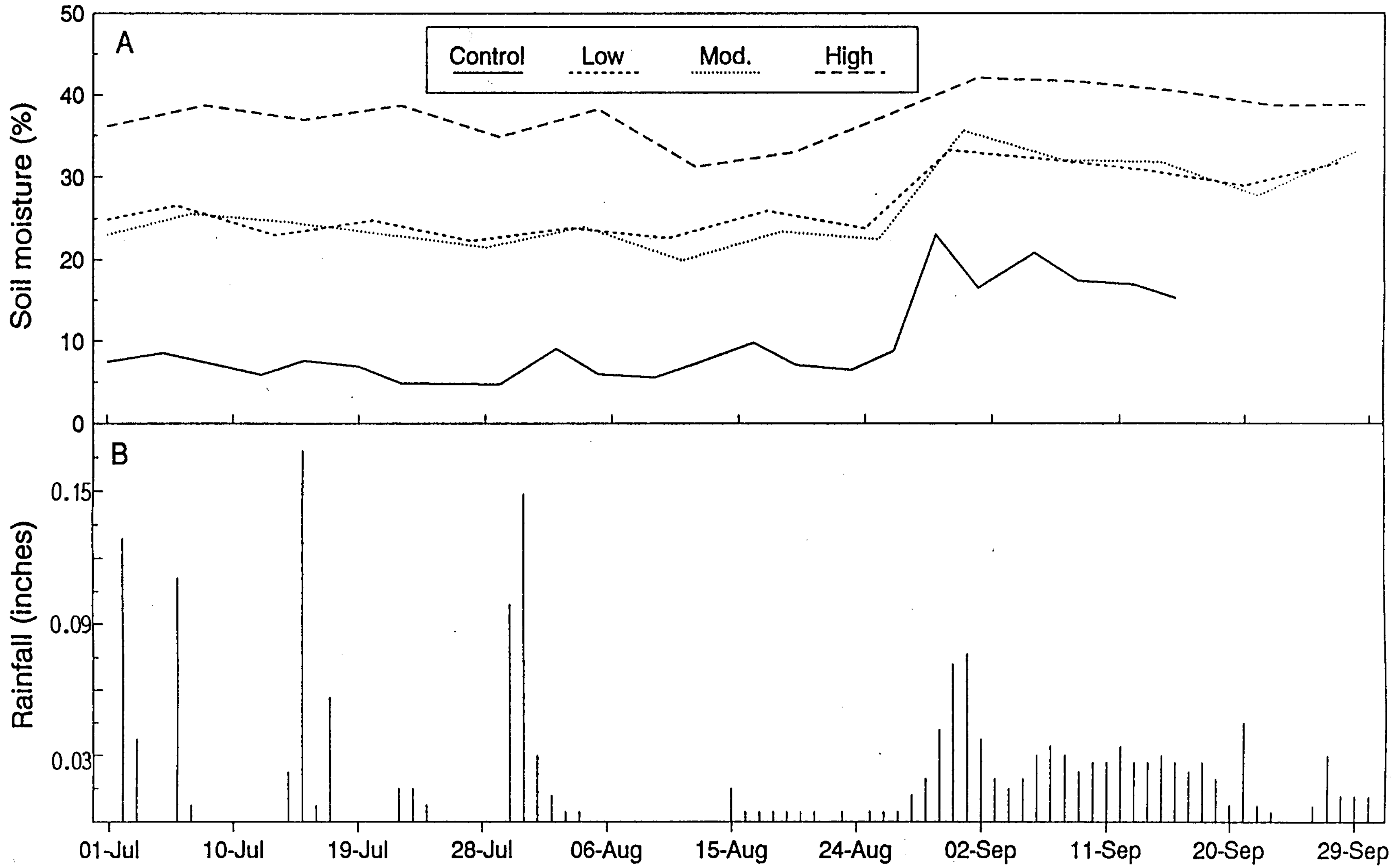

Fig. A36. (A) Mean soil moisture, and (B) daily rainfall for quarter 3, 1993, Vero Beach, Fla. (Control = canal water, low = 0.9 in/wk, mod. = 1.2 in/wk, and high = 1.5 in/wk.)

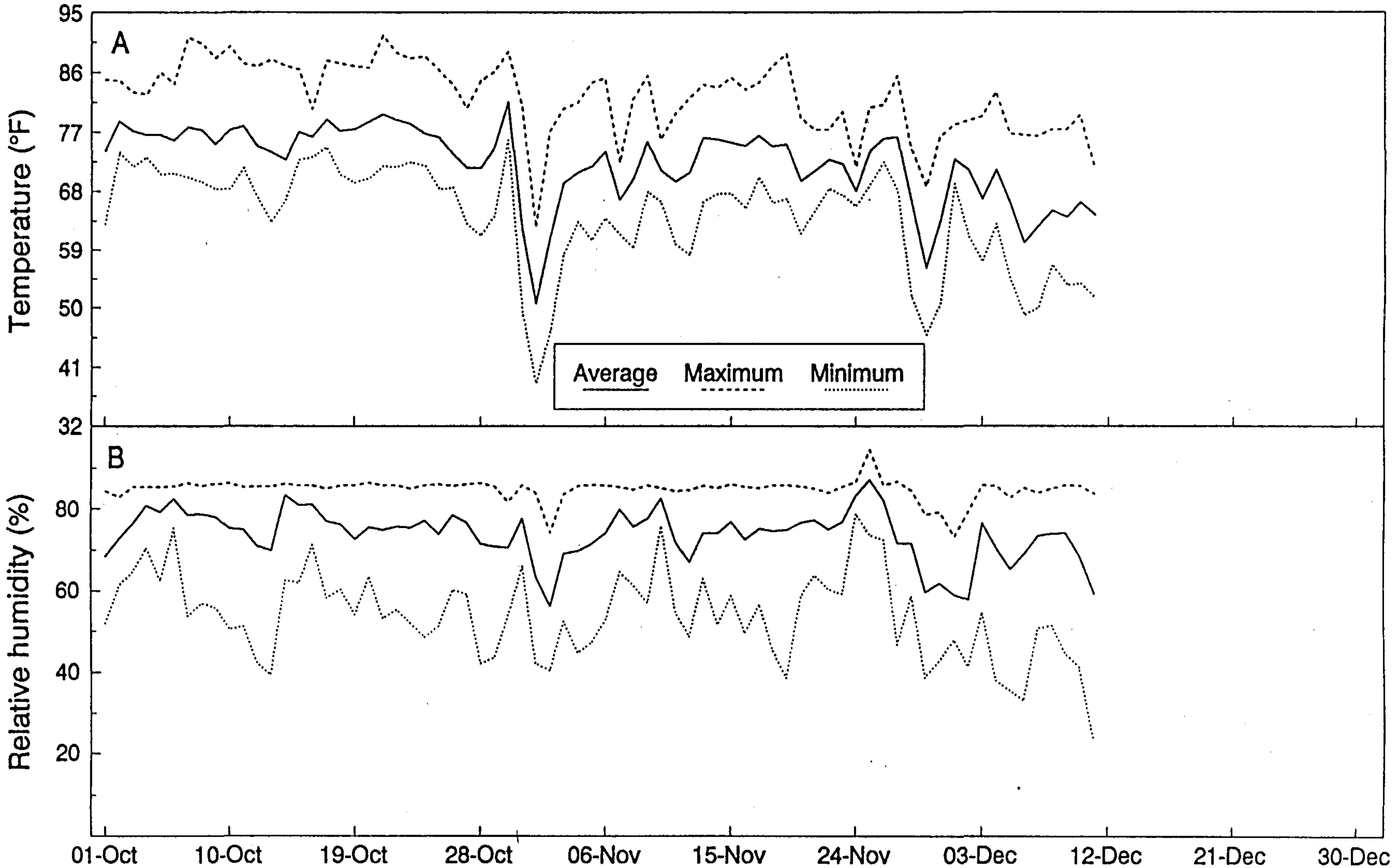

Fig. A37. (A) Average, maximum, and minimum daily temperatures, and (B) average, maximum, and minimum relative humidity for quarter 4, 1993 Vero Beach, Fla. Project terminated Dec. 12.

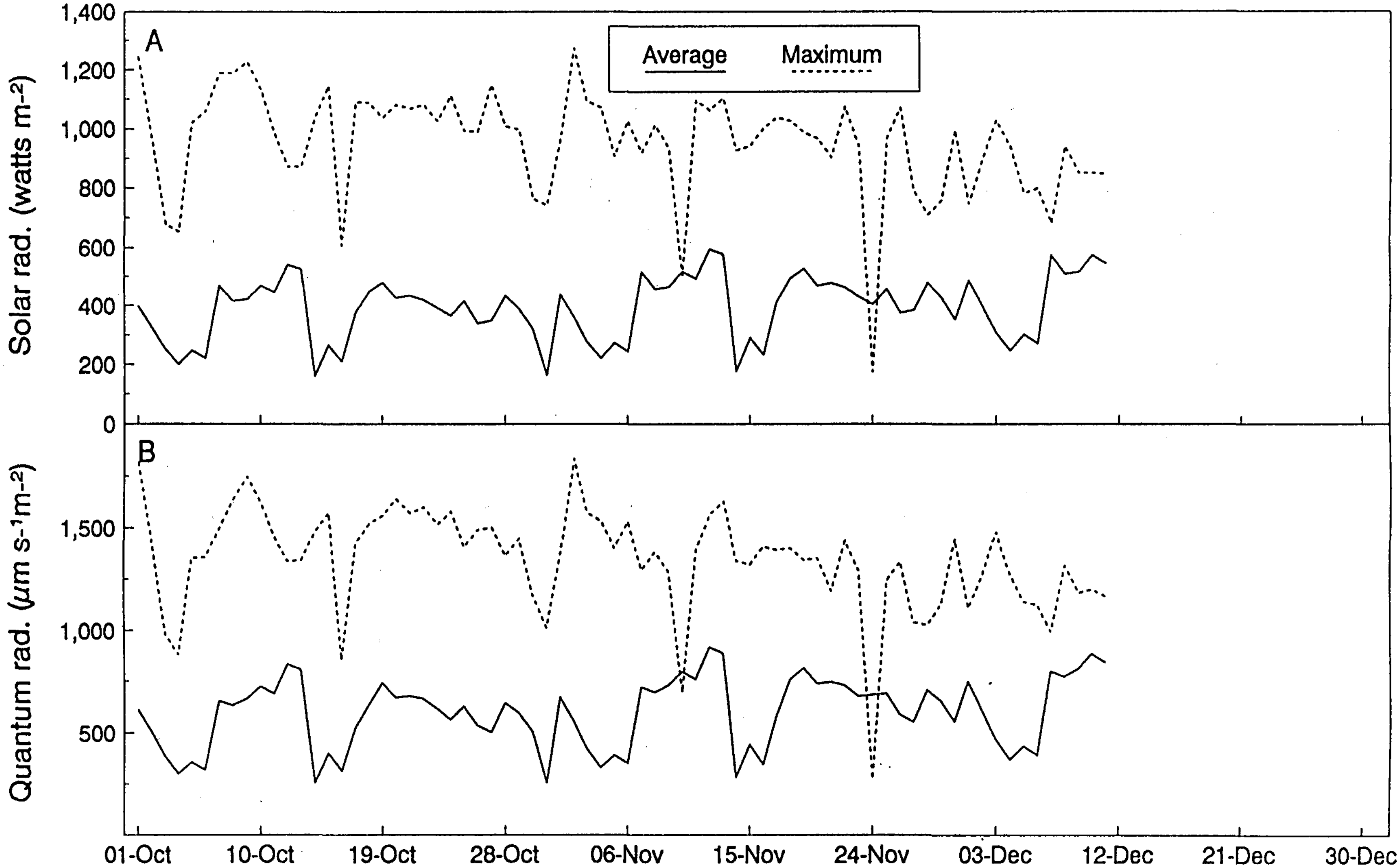

Fig. A38. (A) Average and maximum daily solar radiation, and (B) average and maximum daily quantum radiation for quarter 4, 1993 Vero Beach, Fla. Project terminated Dec. 12.

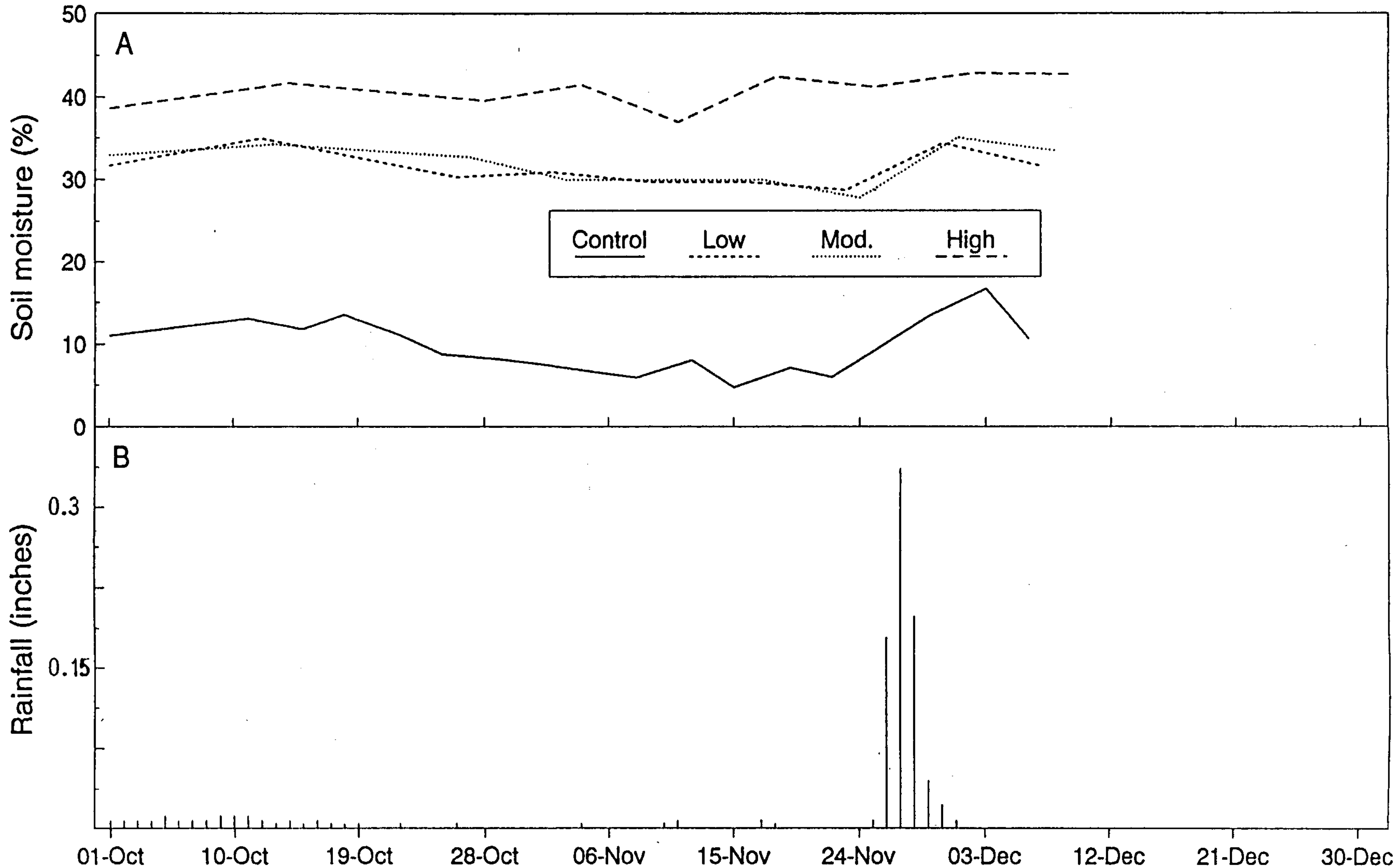

Fig. A39. (A) Mean soil moisture, and (B) daily rainfall for quarter 4, 1993, Vero Beach, Fla. Project terminated Dec. 12. (Control = canal water, low = 0.9 in/wk, mod. = 1.2 in/wk, and high = 1.5 in/wk.)