crop management practices have affected the respiratory behavior of harvested products (Alban et al., 1940; Bramlage et al., 1974; Mellenthin and Wang, 1976).

In general, belowground storage organs such as rhizomes (turmeric), roots (cassava, jicama, and salsify), and tubers (Jerusalem artichoke) had lower respiratory rates than aboveground parts such as leaves (arugula, Chinese chives, and methi), inflorescences (banana flower buds), and immature fruit (drumstick, guar, hyacinth bean, and tinda).

These results provide reasonable estimates of respiratory rates that would be expected from these crops, although individual crops should be expected to vary somewhat due to maturity, cultivar, growing and handling conditions, and other factors. Respiratory rate should not be used as an indicator of the optimum storage temperature. A number of the crops included in this study are chilling sensitive, and as a consequence, the lower temperatures may be well below the threshold for injury.

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Geographical Characterization of Greenhouse Irrigation Water

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ADDITIONAL INDEX WORDS. alkalinity, B, Ca, Cl, electrical conductivity, Mg, pH, Na, sodium adsorption ratio, SO_4

SUMMARY. Chemical analyses of 4306 randomly selected greenhouse water samples for 1995 from the United States and Canada were obtained from four analytical laboratories and graphically characterized using a distribution analysis. For pH, electrical conductivity (EC), and nutrient concentrations, a mean and median value and the percentage of samples with concentrations above or below those generally considered acceptable are presented for all samples and the 10 leading states in floricultural production. The median nutrient concentrations were more representative of the type of water found throughout the United States and Canada than that of the mean values because of the unequal distribution of the data. The overall median water source had a pH of 7.1; an EC of 0.4 dS·m⁻¹; an alkalinity of CaCO₃ at 130 mg·L⁻¹; (in mg·L⁻¹) 40 Ca, 11 Mg, 8 SO₄-S, 13 Na, 14 Cl, 0.02 B, and <0.01 F; a Ca : Mg ratio of 3.2, and a sodium adsorption ratio (SAR) of 0.7. The information presented characterizes irrigation water and may assist in developing more refined fertilizer recommendations for greenhouse crop production.

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Several limited studies have been conducted to quantify the nutrient content of different irrigation water sources (IWS) in the United States. Ludwig and Peterson (1984) conducted a study on greenhouse irrigation water, but the data were presented orally and were not published in a readily accessible journal. In our study, pH ranged from 3.3 to 10.4 (mean 7.6); electrical conductivity (EC) from 0 to 6.5 dS·m⁻¹ (mean 0.5 dS·m⁻¹); alkalinity at CaCO₃ from 2 to 575 mg·L⁻¹ (mean 147); (in mg·L⁻¹) Ca from 0 to 440 (mean 60), Mg from 0 to 300 (mean 20), Na from 0 to 1150 (mean 35), and B from 0 to 2.9 (mean 0.1) based on 662 water samples. However, a large percentage of the samples (30%) came from Ohio, which may have biased the results. Reddy et al. (1996) found that only 11% of the IWS tested contained sufficient SO₄-S (30 mg·L⁻¹) concentrations recommended for plant growth in container culture. Reddy (1996) determined that a large number of samples from states along the Atlantic coast (72%), in the northeastern (88%), and in the Pacific Northwest (83%) of the United States had SO₄-S concentrations <10 mg·L⁻¹, while states around the Great Lakes and Midwest tended to have a greater number of

samples with SO₄-S concentrations between 10 and 20 mg·L⁻¹. The concentrations of other nutrients were not reported in the last two studies.

Recommended or acceptable nutrient levels in irrigation water for greenhouse crops have been defined (Table 1). Emphasis needs to be placed on designing a water-soluble fertilizer program for container plant production based on a given medium and IWS (Bierbaum, 1992; Vetanovetz and Knauss, 1988). For example, Argo and Bierbaum (1996) demonstrated that four IWS varying in alkalinity, Ca, Mg, and SO₄-S content had a significant effect on root-medium pH and nutrient concentrations as well as shoot-tissue nutrient concentrations with impatiens. Recognizing differences in irrigation water between states or geographical regions is important when making recommendations for the nutritional management of container-grown crops, but to our knowledge, little information about regional differences in water quality exists. Our objective was to characterize the irrigation water used in the greenhouse industry geographically.

Materials and methods

Analyses of 4306 randomly selected greenhouse water samples from 1995

were obtained from three commercial laboratories (Fafard Analytical Services, Athens, Ga.; Scotts Analytical Services, Allentown, Pa.; and Sun Gro Analytical Services, Warwick, N.Y.) and one university laboratory (Michigan State Univ. Soil and Plant Nutrient Laboratory, East Lansing). All four laboratories measured pH, EC, alkalinity, NO₃-N, PO₄-P, K, Ca, Mg, Na, Cl, and B. Only Fafard and Sun Gro laboratories measured SO₄-S and F. The possibility that fertilizer solutions might be included in the samples was reduced by removing any sample with NO₃-N at >20 mg·L⁻¹ or PO₄-P at >10 mg·L⁻¹. We could not account for duplicate analyses from the same source, the possibility that greenhouse operations with a given type of water were more or less likely to submit water samples for analyses, or changes in water quality from a single source over time.

Mean and median values were calculated from the overall data set and on a state-by-state basis. Data are presented from the 10 leading states in floricultural production (USDA Floriculture Crop Summary, 1994, Washington, D.C.). These 10 states accounted for 70% of the wholesale value of floricultural crops in 1994 and for 57% of the total number of samples. Of the samples, 5% came from Canada

Table 1. Suggested minimum (min) and maximum (max) acceptable pH, electrical conductivity (EC), alkalinity, nutrient concentration, and sodium adsorption ratio (SAR) for irrigation water used for greenhouse plant production. Units of measure are as follows: EC, dS·m⁻¹; alkalinity CaCO₃ at mg·L⁻¹; and Ca, Mg, SO₄-S, Na, Cl, B, and F, mg·L⁻¹.

	Bierbaum (1994) ^a		Fafard (1996) ^b		Gabriels (1978)		Nelson (1991) ^c		Rose et al. (1995)		Scotts (1996) ^d		Sungro (1996) ^e	
	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
pH	5.5	7.0	5.0	7.0	NA ^f	NA	NA	NA	5.0	7.0	NA	NA	5.0	7.5
EC	0.2	0.8	0	1.0	0	0.85	0	0.75	0	1.5	0.2	1.3	0	1.0
Alkalinity	40	160 ^g	0	100	NA	200	0	40	0	100	40	150 ^h	75	150 ⁱ
Ca	25	75	40	120	0	120	NA	NA	40	120	25	100	40	80
Mg	10	30	6	24	0	25	NA	NA	6	24	15	50	20	40
SO ₄ -S	0	40	NA	NA	NA	NA	NA	NA	0	80	NA	NA	30	60
Na	0	20	0	50	NA	NA	0	70	8	50	0	50	0	80
Cl	0	20	0	20	0	70	0	100	0	140	0	70	0	80
B	0	0.1	0	0.5 ^g	0	0.75	0	1.0 ^g	0.2	0.8	0	0.5 ^g	0	0.5
F	0	0.1	0	0.75 ^g	0	1.0	0	0.5 ^g	0	1.0	0	1.0 ^g	0	1.0
SAR	NA	NA	0	4	NA	NA	NA	NA	0	4	NA	NA	NA	NA

^aSuggested target values from water analysis. A broader range of acceptable values was also presented.

^bFafard Analytical Services, Athens, Ga.

^cSuggested concentrations at which no nutritional problem should occur.

^dScotts Analytical Services, Allentown, Pa.

^eSun Gro Analytical Services, Warwick, N.Y.

^fNA = not available.

^gAverage suggested alkalinity concentration. The actual acceptable suggested alkalinity concentrations depends on the container size. With plugs (in CaCO₃ mg·L⁻¹), 40 to 80; while with 15-cm pots, 120 to 180.

^hAverage suggested alkalinity concentration. The actual acceptable suggested alkalinity concentrations depends on the container size. With plugs (in CaCO₃ mg·L⁻¹), 40 to 120; bedding flats, 40 to 140; 10- to 12-cm pots and large bedding flats, 40 to 160; and 15-cm pots or larger, 60 to 200.

ⁱIf plugs are grown, alkalinity values on the lower end of the range are suggested.

^jThe concentration that can cause toxicity in certain crops may be much lower.

and were included in the overall mean and median values. Only Ontario had enough samples (93) to be included with the state data. The suggested nutrient ranges found in Rose et al. (1995) were used as the comparative values for the presented data (unless otherwise indicated) because it has been our experience that the values from Peterson are the suggested ranges most often reported.

Frequency distributions were cal-

culated from the data using arbitrary ranges that we consider to have potential cultural significance: 0.4 for the pH; 0.2 dS·m⁻¹ for EC; 40 mg·L⁻¹ for alkalinity; 20 mg·L⁻¹ for Ca; and 10 mg·L⁻¹ for Mg, SO₄-S, Na, and Cl. The Ca : Mg ratio was calculated using our concentrations mg·L⁻¹. Sodium adsorption ratio (SAR) was calculated as

$$\text{SAR} = \frac{\text{Na}}{[(\text{Ca} + \text{Mg})/2]^{1/2}} \quad [1]$$

from Allison et al. (1954), where Na, Ca, and Mg are in meq·L⁻¹.

Results and discussion

The mean values calculated in this study were similar to those reported by Ludwig and Peterson (1984). However, for many of the nutrients, the mean value was larger than the median value, indicating an unequal distribution of the data caused by a large proportion of the samples having rela-

Table 2. Geographical characterization of the average and median pH, electrical conductivity (EC), alkalinity, water-soluble nutrient concentrations, Ca : Mg ratio, and sodium adsorption ratio (SAR) measured in greenhouse irrigation water from the United States and Canada. Water Ca : Mg ratio was calculated using the concentrations of those nutrients in mg·L⁻¹ and SAR was calculated from Eq. [1] using nutrient concentrations in meq·L⁻¹. The number of samples in which SO₄-S was measured is less than the total sample number because only two laboratories did SO₄-S analysis.

Sample no. ^y (SO ₄ -S No.)	Total 4306 (2276)	CA ^z 329 (123)	FL ^z 280 (181)	TX ^z 289 (181)	MI ^z 342 (201)	OH ^z 118 (50)	NY ^z 211 (111)	PA ^z 247 (111)	NJ ^z 92 (39)	NC ^z 375 (206)	IL ^z 192 (55)	ON ^z 101 (93)
<i>pH</i>												
Average	7.0	7.1	7.0	7.1	7.1	7.3	7.1	7.0	6.8	6.6	7.1	6.9
Median	7.1	7.1	7.2	7.2	7.3	7.4	7.2	7.0	7.0	6.7	7.4	7.0
<5.0 (%) ^x	3	2	5	2	1	1	1	1	8	5	6	<1
>7.0 (%)	55	63	63	60	68	72	65	51	50	36	63	41
<i>EC (dS·m⁻¹)</i>												
Average	0.6	1.0	0.4	0.8	0.6	0.6	0.5	0.6	0.4	0.3	0.7	0.7
Median	0.4	0.9	0.4	0.6	0.6	0.6	0.4	0.4	0.3	0.2	0.7	0.5
>1.5 (%)	4	20	1	8	3	4	2	6	3	1	2	10
<i>Alkalinity (CaCO₃ at mg·L⁻¹)</i>												
Average	160	170	140	180	200	190	160	140	100	120	220	170
Median	130	150	140	170	200	160	140	120	90	90	200	170
<40 (%) ^w	18	20	12	10	8	9	11	20	27	28	13	8
>100 (%)	61	63	70	71	77	66	73	59	47	49	72	66
<i>Ca (mg·L⁻¹)</i>												
Average	52	78	58	64	69	73	58	54	34	25	66	78
Median	40	61	46	61	69	71	45	42	23	14	74	66
<40 (%)	50	38	41	40	26	30	41	49	69	77	28	33
>120 (%)	6	22	7	10	8	9	3	8	3	<1	5	14
<i>Mg (mg·L⁻¹)</i>												
Average	19	34	13	15	22	24	15	15	10	6	32	21
Median	11	31	10	8	22	15	11	11	7	3	36	19
<6 (%)	33	9	29	34	8	10	19	28	49	73	10	13
>24 (%)	26	63	13	20	43	37	16	21	9	4	63	30
<i>SO₄-S (mg·L⁻¹)</i>												
Average	27	33	16	42	30	74	27	40	14	4	74	35
Median	8	17	3	21	20	23	8	21	10	0	20	10
<30 (%) ^y	76	69	90	59	63	54	83	60	85	98	60	83
>80 (%)	8	14	5	16	5	20	6	13	<1	<1	29	10
<i>Na (mg·L⁻¹)</i>												
Average	33	63	16	64	27	33	24	40	20	30	31	28
Median	13	49	8	30	9	17	14	11	11	9	15	11
>50 (%)	17	48	8	32	12	18	12	13	10	15	17	8
<i>Cl (mg·L⁻¹)</i>												
Average	33	62	26	58	27	32	34	63	20	18	28	44
Median	14	43	12	35	16	17	19	14	15	6	17	14
>140 (%)	3	8	3	9	2	3	4	3	<1	1	3	7

continued on next page

Table 2. Continued.

Sample no. (SO ₄ -S No.)	Total 4306 (2276)	CA ^a 329 (123)	FL ^a 280 (181)	TX ^a 289 (181)	MI ^a 342 (201)	OH ^a 118 (50)	NY ^a 211 (111)	PA ^a 247 (111)	NJ ^a 92 (39)	NC ^a 375 (206)	IL ^a 192 (55)	ON ^a 101 (93)
<i>B (mg·L⁻¹)</i>												
Average	0.22	0.67	0.03	0.17	0.79	0.09	0.06	0.08	0.19	0.18	0.16	0.10
Median	0.02	0.18	0.02	0.06	0.04	0.03	0.01	0.02	0.02	0.01	0.06	0.02
>1.0 (%)	3	15	<1	2	1	2	<1	1	3	4	1	4
>0.4 (%) ^u	8	30	<1	10	9	3	2	4	7	12	14	8
<i>Fluoride (mg·L⁻¹)</i>												
Average	0.15	0.04	0.15	0.25	0.13	0.55	0.10	0.04	0.07	0.23	0.13	0.13
Median	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
>1.0 (%)	10	2	12	17	11	35	8	4	6	10	10	13
<i>Ca : Mg ratio</i>												
Average	5.0	2.9	8.5	7.2	3.7	4.4	4.5	4.5	5.5	6.8	2.6	4.2
Median	3.2	2.3	3.9	4.7	3.2	3.5	3.9	3.5	3.4	3.3	2.0	3.3
<i>Sodium adsorption ratio (SAR)</i>												
Average	2.6	2.5	0.7	5.7	1.7	1.4	1.4	3.7	3.3	3.4	2.8	1.8
Median	0.7	1.6	0.4	1.2	0.4	0.7	0.7	0.6	0.6	0.8	0.6	0.5
>4 (%)	9	11	<1	21	7	7	6	9	11	14	6	4

^aCA, California; FL, Florida; TX, Texas; MI, Michigan; OH, Ohio; NY, New York; PA, Pennsylvania; NJ, New Jersey; NC, North Carolina; IL, Illinois; and ON, Ontario, Canada.

^bSample number. Values inside parentheses are the SO₄-S sample number.

^cAcceptable pH, EC, nutrient ranges, and SAR for irrigation water were obtained from Rose et al. (1995) unless otherwise noted.

^dMinimum alkalinity concentrations obtained from Biernbaum (1994).

^eMinimum SO₄-S concentrations obtained from Reddy et al. (1995).

^fMaximum B concentrations obtained from W. McElhannon, Fafard Analytical Services, personal communications.

tively low concentrations, whereas a small number of samples contained relatively high concentrations.

The pH of the water samples ranged from 2.7 to 11.3. The overall mean pH value of all water samples was 7.0, while the overall median value was 7.1 (Table 2), and the distribution was skewed (Fig. 1). Of the samples, 44% were within the suggested range of 5 and 7 (Rose et al., 1995), while 53% of the samples were >7. Water samples from North Carolina had the lowest median pH (6.7); Ohio and Illinois samples had the highest median pH (7.4) (Table 2).

The EC of the water samples ranged from <0.01 to 9.8 dS·m⁻¹. The overall mean EC of all water samples was 0.6, and the overall median value was 0.4 (Table 2). Of the samples, 96% had an EC within the suggested range of <1.5 dS·m⁻¹ (Rose et al., 1995), and 71% had an EC <0.6 dS·m⁻¹. Water samples from North Carolina had the lowest median EC (0.2 dS·m⁻¹), and the California samples had the highest median EC (0.9 dS·m⁻¹) (Table 2).

The alkalinity concentration of the water samples ranged from CaCO₃ at 0 to 1120 mg·L⁻¹. The overall mean alkalinity of all water samples was CaCO₃ at 160 mg·L⁻¹, the overall median value was CaCO₃ at 130 mg·L⁻¹

(Table 2), and the samples were more uniformly distributed over a wider range than any other factor analyzed (Fig. 1). Of the water samples, 22% contained an alkalinity concentration within the suggested range of CaCO₃ at 40 to 100 mg·L⁻¹ (Biernbaum, 1994; Rose et al., 1995). Water samples from New Jersey and North Carolina had the lowest median alkalinity concentration (CaCO₃ at 90 mg·L⁻¹), and the Illinois and Michigan samples had the highest median alkalinity concentration (CaCO₃ at 200 mg·L⁻¹) (Table 2). Based on the similar concentration of Na and Cl and low SAR value measured in the samples (Table 2), it is likely that the major source of alkalinity comes from Ca and Mg salts.

The Ca concentration in the water samples ranged from 0 to 560 mg·L⁻¹. The overall mean Ca concentration of the water samples was 52 mg·L⁻¹, and the overall median value was 40 mg·L⁻¹ (Table 2). Of the samples, 44% were within the suggested range of 40 to 120 mg·L⁻¹ (Fig. 1) (Rose et al., 1995). Water samples from North Carolina had the lowest median Ca concentration (14 mg·L⁻¹), and the Illinois samples had the highest median Ca concentration (74 mg·L⁻¹) (Table 2).

The Mg concentration in the

water samples ranged from 0 to 190 mg·L⁻¹. The overall mean Mg concentration of the water samples was 19 mg·L⁻¹, and the overall median value was 11 mg·L⁻¹ (Table 2). Of the samples, 70% were within the suggested range of 6 and 24 mg·L⁻¹ (Rose et al., 1995), but 48% of the samples contained Mg at <10 mg·L⁻¹ (Fig. 1). Water samples from North Carolina had the lowest median Mg concentration (3 mg·L⁻¹), and the Illinois samples had the highest median Mg concentration (36 mg·L⁻¹) (Table 2).

The Ca : Mg ratio in the water samples ranged from <0.1 to 152. The overall mean Ca : Mg ratio of the water samples was 5.0, and the overall median value was 3.2 (Table 2). Of the samples, 27% had a Ca : Mg ratio of >5 (Fig. 1). Water samples from Illinois had the lowest median Ca : Mg ratio (2.0), and the Texas samples had the highest median Ca : Mg ratio (4.7) (Table 2).

The SO₄-S concentration in the water samples ranged from 0 to 750 mg·L⁻¹. The overall mean SO₄-S concentration of the water samples was 27 mg·L⁻¹, while the overall median value was 8 mg·L⁻¹ (Table 2). Of the samples, 15% were within the suggested range of 30 to 80 mg·L⁻¹ (Fig. 1) (Reddy et al., 1994; Rose et al., 1995). Water

samples from North Carolina had the lowest median $\text{SO}_4\text{-S}$ concentration ($<1 \text{ mg}\cdot\text{L}^{-1}$), and the Ohio samples

had the highest median $\text{SO}_4\text{-S}$ concentration ($23 \text{ mg}\cdot\text{L}^{-1}$). These data support the conclusion of Reddy (1996)

that most water sources in the United States (77%) are low in $\text{SO}_4\text{-S}$ (Table 2), but that states around the Great

Fig. 1. Frequency distribution based on water pH; electrical conductivity (EC); alkalinity, Ca, Mg, $\text{SO}_4\text{-S}$, Na, and Cl concentrations; and the Ca : Mg ratio and sodium adsorption (SAR) ratio. The Ca : Mg ratio was calculated independently for each sample with Ca and Mg concentrations in $\text{mg}\cdot\text{L}^{-1}$. The SAR was calculated independently for each sample with Eq. [1] using Ca, Mg, and Na concentrations in $\text{meq}\cdot\text{L}^{-1}$. The number of samples in which $\text{SO}_4\text{-S}$ was measured (2276) is less than the total sample number (4306) because only two laboratories did $\text{SO}_4\text{-S}$ analysis. Average and median values for the data used to make the graphs are found in Table 2.

Fig. 2. Classification of the water samples using salinity and sodium hazard based on recommendations found in Allison et al., 1954.

Lakes (Illinois, Michigan, and Ohio) tend to have greater $\text{SO}_4\text{-S}$ concentrations than those states on the east coast of the United States (Florida, North Carolina, New Jersey, New York, and Pennsylvania).

The Na concentration in the water samples ranged from 0 to 2500 $\text{mg}\cdot\text{L}^{-1}$. The overall mean Na concentration of the water samples was 33 $\text{mg}\cdot\text{L}^{-1}$ and the overall median value was 13 $\text{mg}\cdot\text{L}^{-1}$ (Table 2). Of the samples, 83% were below the suggested maximum concentration of 50 $\text{mg}\cdot\text{L}^{-1}$ (Rose et al., 1995), with 41% of the samples containing Na at <10 $\text{mg}\cdot\text{L}^{-1}$ (Fig. 1). Water samples from Florida had the lowest median Na concentration (8 $\text{mg}\cdot\text{L}^{-1}$), and the California samples had the highest median Na concentration (49 $\text{mg}\cdot\text{L}^{-1}$) (Table 2).

The SAR concentration in the water samples ranged from 0 to 280. The overall mean SAR of the water samples was 2.6, and the overall median value was 0.7 (Table 2). Of the samples, 92% were below the suggested maximum SAR of 4 (Fig. 1) (Rose et al., 1995), and 62% of the samples had an SAR <1. Water samples from Florida and Michigan had the lowest median SAR (0.4), and the California samples had the highest median SAR (1.6) (Table 2). Based on recommendations from Allison et al. (1954), most of the water samples had a low potential for SAR hazard, but medium to high potential for salinity hazard (Fig. 2).

The Cl concentration in the water samples ranged from 0 to 1480 $\text{mg}\cdot\text{L}^{-1}$. The overall mean Cl concentration of the water samples was 33 $\text{mg}\cdot\text{L}^{-1}$, the overall median value was 14 $\text{mg}\cdot\text{L}^{-1}$ (Table 2), and the distribution was similar to that of Na (Fig. 1). Of the samples, 97% were below the suggested maximum concentration of 140 $\text{mg}\cdot\text{L}^{-1}$ (Rose et al., 1995), with 40% of the samples containing Cl at <10 $\text{mg}\cdot\text{L}^{-1}$. Water samples from North Carolina had the lowest median Cl concentration (6 $\text{mg}\cdot\text{L}^{-1}$), and the California samples had the highest median Cl concentration (43 $\text{mg}\cdot\text{L}^{-1}$) (Table 2).

The B concentration in the water

samples ranged from 0 to 11.7 $\text{mg}\cdot\text{L}^{-1}$. The overall mean B concentration of the water samples was 0.22 $\text{mg}\cdot\text{L}^{-1}$, and the overall median value was 0.02 $\text{mg}\cdot\text{L}^{-1}$ (Table 2). Of the samples, 97% were below the suggested maximum concentration of 1.0 $\text{mg}\cdot\text{L}^{-1}$ (Rose et al., 1995), and 39% of the samples contained B at <0.01 $\text{mg}\cdot\text{L}^{-1}$. However, the potential for B toxicity in certain species may be at a much lower concentration. For example, Fafard Analytical Services suggests that B at >0.4 $\text{mg}\cdot\text{L}^{-1}$ may produce toxicity symptoms (W. McElhannon, personal communications). Overall, 8% of the samples contained B at >0.4 $\text{mg}\cdot\text{L}^{-1}$ and, within the individual states, ranged from <1% in the Florida samples to 30% in the California samples (Table 2). Water samples from Pennsylvania had the lowest median B concentration (0.01 $\text{mg}\cdot\text{L}^{-1}$), and the California samples had the highest median B concentration (0.2 $\text{mg}\cdot\text{L}^{-1}$) (Table 2).

The F concentration in the water samples ranged from 0 to 8.3 $\text{mg}\cdot\text{L}^{-1}$. The overall mean F concentration of the water samples was 0.15 $\text{mg}\cdot\text{L}^{-1}$, and the overall median value was <0.01 $\text{mg}\cdot\text{L}^{-1}$ (Table 2). Of the samples, 90% were below the suggested maximum concentration of 1.0 $\text{mg}\cdot\text{L}^{-1}$ (Rose et al., 1995), and 89% of the samples contained F at <0.01 $\text{mg}\cdot\text{L}^{-1}$. As with B, the potential for F toxicity in certain species may be at

a much lower concentration, but the data indicates that F is either present at concentrations above the suggested maximum concentration (>1.0 $\text{mg}\cdot\text{L}^{-1}$) or is absent from the water. All states contained some samples with F above the maximum suggested concentration, but the median value for each state was <0.01 $\text{mg}\cdot\text{L}^{-1}$.

Conclusion

The suggested range for IWS pH and alkalinity is CaCO_3 at 5 to 7 and 40 to 100 $\text{mg}\cdot\text{L}^{-1}$, respectively. In our opinion, IWS outside these ranges are not detrimental to plant growth as long as the pH of the medium is maintained within an acceptable range. Argo and Biernbaum (1996) demonstrated that IWS alkalinity, not pH, is the primary factor influencing medium pH management. A relatively high number of samples contained Ca, Mg, and $\text{SO}_4\text{-S}$ concentrations below those recommended for container plant production. Argo and Biernbaum (1996) demonstrated that it was the concentration of Ca, Mg, and $\text{SO}_4\text{-S}$ in the nutrient solution that was composed of the IWS and WSF that influenced uptake. Thus, Ca, Mg, and $\text{SO}_4\text{-S}$ in the IWS can be supplemented or the proper balance obtained by adding water-soluble fertilizers containing those ions, as recommended by Biernbaum (1992) and Vetanovetz and

Knauss (1988). A relatively small number of samples contain Na, Cl, B, or F concentrations at potentially toxic levels, but high concentrations of these ions occurred in every state.

Using these data, greenhouse operators can characterize a given water source and how it compares to other water sources being used by the greenhouse industry. These data also may be helpful in determining research priorities in the area of water quality for greenhouse crop production. As the greenhouse industry changes to low- and nonleaching irrigation systems, understanding differences in IWS is one key in developing more refined state and regional fertilizer recommendations for greenhouse crop production.

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Effects of Cooling by Over-tree Sprinkler Irrigation on Fruit Color and Firmness in 'Sensation Red Bartlett' Pear

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SUMMARY. Over-tree sprinkler irrigation cooling treatments were applied to 'Sensation Red Bartlett' pear trees during the final 30 days of fruit maturity in 1992 and 1993 when orchard air temperatures were $>29^{\circ}\text{C}$. Fruit from cooled trees were more red and less yellow than fruit from noncooled trees, resulting in lower hue values by the middle of the harvestable maturity period in both years of study. In 1992, cooled fruit had a greater portion of the fruit surface covered with red blush than fruit that were not cooled. Fruit firmness decreased more rapidly in fruit from cooled trees than in fruit from noncooled trees, indicating advanced maturity. Accordingly, cooled fruit should be harvested earlier than noncooled fruit to maintain postharvest quality. Differences between cooled and noncooled fruit with respect to hue, surface blush, and rate of firmness loss were more pronounced in a warm season requiring frequent cooling than in a cooler season.

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Red color development in fruit is influenced by cultural and environmental factors. The most important environmental factors are temperature and light (Creasy, 1968; Faragher, 1983; Saure, 1990). Temperature has a profound effect on the accumulation of anthocyanin and consequent red color formation; low temperatures during the growing season generally promote anthocyanin synthesis, while high temperatures tend to inhibit this process (Mazza and Miniati, 1993; Saure, 1990).

Cooling by over-tree sprinkler irrigation has been effective in enhancing red color in apple and currently is practiced in apple production (Unrath, 1972; Williams and Mayles, 1990). Cooling may promote anthocyanin formation in a warm climate by reducing the negative effect of heat on anthocyanin accumulation and decreasing the fruit respiration rate, thereby conserving energy and providing substrate for anthocyanin synthesis (Ryugo, 1988; Saure, 1990). Over-tree sprinkling also removes dust particles from leaves, thus improving their photosynthetic capacity (Ryugo, 1988).

The fruit of 'Sensation Red Bartlett' pear appear dark red during most of the growing season. As the fruit approach maturity, the fruit appear less red, described by growers as "fading." Our objective was to measure the effects of modifying temperature by cooling during the final 30 d of fruit maturity on fruit color and firmness in 'Sensation Red Bartlett' pear. Fruit firmness is the principal index of harvestable maturity in pear (Williams et al., 1978).

Materials and methods

Thirteen-year-old 'Sensation Red Bartlett' pear trees on *Pyrus communis* rootstock spaced 10×12.5 feet (3×3.8 m) were cooled by over-tree sprinkler irrigation in Medford, Ore., in 1992 and 1993. Each cooled tree was paired with a noncooled tree located two to three trees distant in the row. Four cooled–noncooled replicate pairs of trees were selected randomly along the row. Two spinning micro-sprinklers were installed 4 inches (10 cm) apart above each cooled tree. Each sprinkler delivered water at 308 gallons/min per acre ($2881 \text{ L} \cdot \text{min}^{-1} \cdot \text{ha}^{-1}$) over a radius of 3.8 feet (1.15 m). The over-tree system was activated manually at $\approx 29^{\circ}\text{C}$ (84°F) (Lombard et al.,