of fresh-market-quality peaches is the low damage caused by machine-harvesting. Of the 16 harvests, only two yielded a mean of 12% culls, while most yielded ≈5% culls (Tables 1 and 2). This damage level should not hinder acceptance of machine-harvesting, since it is similar to damage levels produced by hand-harvesting (unpublished data). Samples of cold-stored 'Bounty', 'Loring', 'Redskin' and 612615 peaches that were machine-harvested showed no external or internal evidence of bruising.

Our tests show that nonuniformity of maturity is a problem for once-over harvesting of peaches. Even when our optimum harvest criterion of nearly equal amounts of green and over-ripe fruits was met, only two of seven cultivars had >80% of the crop in the firm-ripe stage of maturity. This fact limits the prospects for a once-over harvest. Estimating the harvest date by visual observation was very difficult because of the variability among trees. A better technique will have to be developed. A relatively high percentage of small fruit was also a problem with some genotypes when only firm-ripe fruit were considered. The feasibility of once-over mechanically harvesting peaches will depend largely on the selection of peach cultivars that either ripen more uniformly or can remain firm for prolonged periods on the tree, while less-mature fruit ripen. With slight revision, the criterion that we used and the methodology used in this study can be used to test advanced peach breeding lines for their adaptability to once-over mechanical harvesting.

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Scheduling Irrigations for Cucumbers

James E. Ells[1], E. Gordon Kruse[2], and Ann E. McSay[3]
Colorado State University, Fort Collins, CO 80523

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Abstract. **Cucumber (*Cucumis sativus* L.) irrigation scheduling was studied during the 4 years of 1983–1986. Tensiometers were used during the first year to determine when to irrigate, and the USDA irrigation scheduling program was used to determine the amount of water to apply. The data from the first year's study indicated that the plants had not been stressed; therefore, the following year, estimates of the available water depletion were made with the USDA irrigation scheduling program, with tensiometers used only for comparison. After 4 years of study, we concluded that the best combination of high yield, high water use efficiency, and fewest number of irrigations was obtained if cucumbers were irrigated when the original scheduling program determined that 40% of the available water was depleted, applying only 70% of the water that the program indicated was required. This signaled that the program was overestimating the rate at which water was being depleted. Therefore, as a final step, a revised set of cucumber coefficients that approximated daily evapotranspiration (ET) more closely was determined. When using the revised coefficients, cucumbers should receive the exact amount of water called for by the irrigation program.**

Water is applied to crops to prevent yield reduction due to drought. Since irrigation is costly and can be harmful if excessive, means of accurately predicting when and how much water to apply are continuously being sought.

The purpose of this study was to find a method of scheduling irrigation of cucumbers that would result in the fewest irrigations and least amount of water applied, consistent with optimum yields and water use efficiency.

Gypsum blocks and tensiometers have been used to monitor soil moisture and to indicate when a crop should be irrigated (2). Another way of determining when to irrigate is based on empirical relations of crop evapotranspiration to measured evaporation from an evaporation pan or atmometer (1).

The USDA irrigation scheduling program is based on energy and aerodynamics equations that were first used in combination by Penman (6) to make theoretical estimates of evaporation rates from meteorological data. Jensen (3, 4) and Wright (7) later adapted the equations for computer use in a package that accounts for type of crop and its growth stage and computes soil water deficit.

The USDA program requires daily values of wind, rain, temperature, humidity, and solar radiation to calculate "reference crop" evapotranspiration (ET_r), the evapotranspiration from vigorously growing, well-watered alfalfa. For the crop to be scheduled, ET_r needs to be adjusted for the type of crop and stage of growth, as expressed by the crop

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[1] Associate Professor, Dept. of Horticulture.

[2] Agricultural Engineer, USDA/ARS Irrigation and Drainage Research Unit.

[3] Researcher I, Dept. of Horticulture.

Table 1. Equations, dates, and crop coefficient values[z] for USDA irrigation scheduling procedures for cucumbers, 1983–1986.

Crop coefficient values	
Original	Revised
Before effective cover	
A −2.06	A −1.3493
B 3.739	B 2.4490
C −1.059	C −0.6936
D 0.342	D 0.2240
After effective cover	
A 0.00005336	A −0.000001054
B −0.002601	B 0.000121
C 0.01469	C −0.004225
D 0.94	D 0.6322
K_{co} Range[y]	
Minimum 0.10	Minimum 0.15
Maximum 1.00	Maximum 0.70

[z] Crop coefficients are computed by: $K_{co} = Ar^3 + Br^2 + Cr + D$, where: K_{co} is the crop coefficient for use in the USDA irrigation scheduling program. Before effective cover, r is the fraction of time from planting to effective cover. After effective cover, r is the number of days beyond the effective cover date. See Figs. 1 and 2.

[y] K_{co} values listed above are valid for cucumber planting dates from 31 May to 20 June. Effective cover was assumed to occur on 9 Aug. in all years.

coefficients, and for the soil water depletion and degree of wetness of the soil surface. Soil water depletion in the root zone can then be calculated knowing the water holding capacity of the root zone, the rooting depth, and the amounts and timing of irrigation and precipitation.

At the start of this study, little was known about appropriate crop coefficients for cucumbers. Some information was obtained from unpublished sources on seasonal crop coefficient curves for muskmelons that were grown under desert conditions (5). This information was used to synthesize a curve and then polynomial equations for crop coefficients were obtained by curve-fitting (Fig. 1). These tentative coefficients were used to schedule irrigations of the field plots during 1983–1986 (Table 1).

During each year of the study, an initial degree of soil water depletion (the depth of water necessary to return the soil in the assumed root zone to field capacity) was established by gravimetric soil moisture analysis on the day that scheduling began. The irrigation scheduling program was used to estimate depletions for the rest of each season.

Field research. All studies (1983–1986) were conducted on the Colorado State Univ. Horticulture Research Center, Fort Collins, on a Nunn clay loam soil (Aridic Argiustoll). Laboratory pressure plate analyses showed an available water holding capacity of 9.9 $cm \cdot m^{-1}$ between 33 and 1500 kPa, a low value for clay loam.

Each growing season, 'Triplemech' cucumbers were planted on beds that were spaced 90 cm after the ground had been fertilized according to recommendations and worked. Germination moisture was provided with impact sprinklers that later were removed. Irrigation treatments used level furrow irrigation after the crop was established. Herbicides were generally not used, with the few weeds present being controlled by hand.

After crop emergence, plots 7 m long were laid out in a randomized complete block design with four replications. Each plot consisted of two rows and three furrows with a buffer row between plots. The plants were thinned to 15 cm apart, giving a final stand of 163,000/ha. The furrows were blocked off at both ends so that they would pond irrigation water until infiltration was complete. Because of the blocked furrows, all rainfall was also held on the plots until it had infiltrated.

Water from a domestic supply (80 ppm dissolved salts) was used for irrigating in preference to available well water, which is saline enough to cause yield reduction of sensitive crops.

Weather station instruments on site were read daily. These consisted of an anemometer, rain gauge, hygrothermograph, and maximum and minimum thermometers. Total solar radiation values were obtained from a pyranometer located on the CSU Foothills campus ≈14 km southwest of the study site.

Pest control was not necessary. Fruit were harvested once or twice weekly during the harvest season, resulting in four to 14 pick-

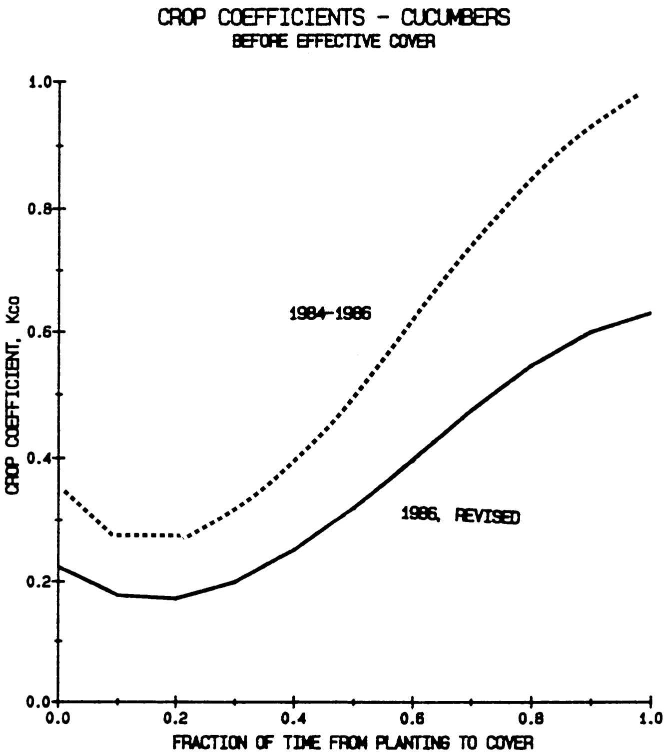

Fig. 1. Crop coefficient curves for irrigation scheduling of cucumbers before effective cover. Dotted line represents curve used during study. Solid line is the revised curve as a result of the study.

Table 2. Cucumber irrigation treatments, 1983–1986.

Treatment number	Depletion applied[z]	Tensiometer reading (kPa) or fraction of AWC[y] depletion
	1983[x]	
1	1.0	20[w]
2	1.0	30[w]
3	1.0	40[w]
4	1.0	50[w]
5	1.0	60[w]
	1984[x]	
1	1.00	0.33
2	1.25	0.33
3	1.00	0.50
4	1.25	0.50
5	1.00	0.67
6	1.25	0.67
7	1.00	50[w]
8	1.00	60[w]
	1985[x]	
1	0.40	0.33
2	1.25	0.33
3	0.40	0.67
4	0.70	0.67
5	1.00	0.67
6	1.25	0.67
7	1.00	60[w]
8	1.00	60[v]
	1985[u]	
1	1.0	0.4
2	0.7	0.4[t]
3	1.25	0.4[t]
4	1.0	0.7
5	0.7	0.7[s]
6	1.25	0.7[s]

[z] Depletion is based on the USDA crop irrigation scheduling program, using daily meteorological measurements.

[y] Available water content (AWC) in assumed rootzone depth.

[x] Rooting depth assumed to increase from 15 to 60 cm between planting and effective cover date.

[w] Fifteen-centimeter depth.

[v] Thirty-centimeter depth.

[u] Rooting depth assumed constant at 60 cm throughout growing season.

[t] Irrigated on the same day as treatment 1.

[s] Irrigated on the same day as treatment 4.

Table 3. Number of irrigations, amount of water applied, and rainfall received by cucumbers during the growing seasons, 1983–1986.

Treatment	May	June	July	Aug.	Sept.	Total	Total + rain
	Irrigation or rain frequency (no./mm of water)						
				1983			
Irrigations							
1			4/130	7/150		11/280	348
2			3/190	6/147		9/256	324
3			2/79	5/142		7/221	289
4			2/91	3/112		5/203	271
5			1/51	3/155		4/206	274
Rain		3/13[z]	5/30	4/25		12/68	
				1984			
Irrigations							
1			2/66	3/109		5/175	244
2			2/84	3/135		5/219	288
3			2/71	3/109		5/180	249
4			2/89	3/135		5/224	293
5			1/38	4/155		5/193	262
6			1/46	4/193		5/239	308
7			1/43	4/137		5/180	249
8			1/43	2/107		3/150	219
Rain		1/1[z]	9/38	9/30		19/69	
				1985			
Irrigations							
1		3/21	8/92	17/165		28/278	411
2		3/50	5/21	7/197		15/368	501
3			4/58	8/142		12/200	333
4			3/80	5/149		8/229	362
5			2/81	4/167		6/248	381
6			2/95	4/209		6/304	437
7			1/54	2/124		3/178	311
8			1/56	2/142		3/198	331
Rain		2/16[z]	10/114	5/3		17/133	
				1986			
Irrigations							
1		2/49	5/117	6/155	2/50	15/371	472
2		2/34	5/86	6/119	2/35	15/269	370
3		2/61	5/146	6/195	2/63	15/465	566
4		1/31	3/121	2/89	2/97	8/338	439
5		1/22	3/85	2/62	2/68	8/237	338
6		1/39	3/152	2/111	2/121	8/423	524
Rain	1/13[z]	5/31	8/23	6/30	6/17	26/101	

[z] Rain received after planting.

Table 4. Yield of marketable cucumbers and water use efficiencies, 1983–1986.

Treatments[z]	1983	1984	1985	1986
	Year			
		Fruit yield (1000/ha)[y]		
1	444	593	691 b	866 a
2	440	662	845 a	805 a
3	464	608	687 b	944 a
4	462	689	520 d	727 b
5	433	573	563 cd	712 b
6		711	677 bc	712 b
7		642	462 d	
8		600	470 d	
	NS	NS		
		Water use efficiencies (1000 fruit/ha per mm)[y]		
1	1.28 b	2.43 ab	1.68 b	1.83 b
2	1.36 b	2.30 ab	1.69 b	2.18 a
3	1.61 a	2.44 ab	2.06 a	1.67 c
4	1.71 a	2.35 ab	1.44 b	1.66 c
5	1.58 a	2.19 b	1.48 b	2.11 a
6		2.31 ab	1.55 b	1.35 d
7		2.58 ab	1.49 b	
8		2.74 a	1.42 b	

[z] Treatments were independent each year.

[y] Values in a column followed by different letters are significantly different at the 5% level.

ings in each year of the study. The fruit from each plot were size-graded, counted, and weighed. However, we only report fruit numbers.

1983. Cucumbers were seeded on 15 June. Sodium 2-[1-naphthalenylaminocarbonyl]benzoate (naptalan) and *S*-(*O,O*-diisopropylphosphorodithioate) ester of *N*-(2-mercaptoethyl)benzene sulfonamide (bensulide) were used as pre-emergence herbicides. Timing of irrigation was based on water potential at a depth of 15 cm, as determined by tensiometers (Table 2). The USDA program was used to estimate soil water content throughout the season. Whenever prescribed water potentials were reached, as determined by tensiometers, the USDA program was used to determine the amount of water (in millimeters) to apply.

The number of irrigations, amount of water applied, and rainfall received by cucumbers are shown in Table 3. Water applied varied from 271 to 348 mm, with the lower negative water potential treatments receiving greater amounts. Cucumbers were harvested once per week (Table 4). Seasonal totals varied from 433,000 to 464,000 fruit/ha, with no statistical differences between treatments. Because of the different volumes of irrigation applied, there were significant differences in the water use efficiency (WUE) values. WUEs were lower for the two treatments irrigated at slight negative water potentials (−20 and −40 kPa) than for the three more highly negative water potential treatments (−40, −50, −60 kPa).

The irrigation timing in 1983 was based on tensiometer readings. The fact that there were no significant differences in yields implied that water potentials more negative than the 60 kPa that the tensiometers can reliably register would be necessary to stress the plants enough to decrease yields significantly.

1984. Cucumbers were planted on 20 June. Treatments with low negative water potential were not used in 1984 because 1983 results had shown that they produced neither higher yields nor higher WUEs. Since the USDA irrigation scheduling program was used to determine how much water to apply to the plots, it seemed appropriate to also base the timing on this program. The USDA irrigation scheduling program used untested crop coefficients. Therefore, six treatments were devised to determine the validity of tentative crop coefficients for cucumbers and, also, the sensitivity of cucumbers to soil water stress by varying the time and amount of water applied. Two additional treatments were irrigated according to prescribed tensiometer readings (Table 2).

Irrigation applications plus rainfall ranged from 219 to 308 mm (Table 3). Cucumbers were harvested twice weekly for 3 weeks. There was, again, no significant difference in seasonal yield for the different treatments (Table 4). WUE values were also uniform, except that treatment 8, based on tensiometer readings, resulted in significantly higher WUE than treatment 5, the USDA treatment with lowest WUE. Unfortunately, the selected variations on the scheduling procedure in 1984

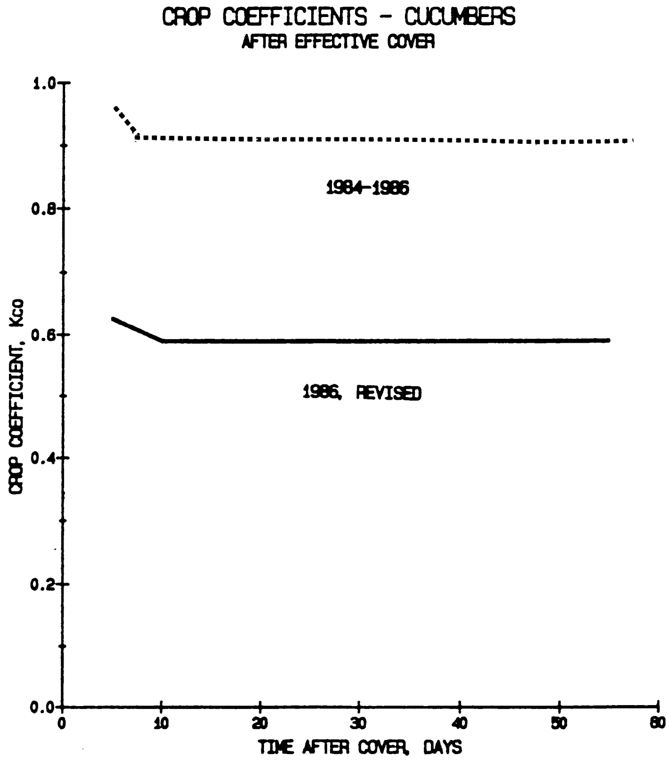

Fig. 2. Crop coefficient curves for irrigation scheduling of cucumbers after effective cover. Dotted line represents curve used during study. Solid line is the revised curve as a result of the study.

did not produce significant yield differences.

1985. Cucumbers were planted on 31 May. Eight irrigation treatments were used (Table 2).

Total irrigation plus rainfall ranged from 311 to 501 mm (Table 3). This range of water produced a wide range of yields, with seasonal values varying from 470,000 to 845,000 fruit/ha (Table 4). WUE values were much less variable, with only treatment 3 being significantly higher than the others. Treatment 3 was one of the drier treatments with good, but not the highest, yields. It was irrigated by applying 0.4 of estimated depletion when 0.67 of root-zone water was depleted.

The fact that treatment 3 produced well, while receiving only 0.4 of the estimated water requirement, is a good indication that the use of water was being overestimated by the program. Treatment 2, which used the most water, produced the greatest yield, while treatment 3, which produced the highest WUE, ranked third in yield (Table 4).

1986. Cucumbers were planted on 6 June and six irrigation treatments were imposed, all scheduled by the USDA irrigation program (Table 2).

Total water received by the cucumbers from all sources ranged from 338 to 566 mm throughout the season. The most-frequently irrigated treatments received 15 irrigations, the others only eight (Table 3).

The more frequently irrigated treatments consistently produced the most fruit, 805,000 to 944,000/ha. WUEs were highest for the two treatments that were irrigated to replace 0.7 times estimated soil water depletion (Tables 2 and 4). Of these, treatment 2 produced more fruit, but required proportionately more water to do it (Table 3).

The 1986 study identified an irrigation treatment (treatment 2) that combined high yields with high WUE and a minimum number of irrigations, thereby achieving the goal of this study. The best treatment, based on the least water applied, the highest WUE and yields, and the fewest irrigations, was achieved with the USDA irrigation program that assumed a constant rooting depth of 60 cm throughout the season and called for applications equal to 0.7 times the estimated depletion when 40% of available water was depleted from the root zone of treatment 1 (Table 2).

During 1984 and 1985, the USDA treatments that received less water than the estimated depletion rapidly reached the allowable depletion for the next irrigation. Thus, irrigations were frequent. The feature of the program that increases estimates of daily ET soon after an irrigation to account for evaporation from the wet soil surfaces led these treatments to receive more water than might otherwise be expected. As a result, there was not enough difference in total seasonal irrigation applications to produce the desired differences in yields and WUEs.

In 1986, this problem was avoided by irrigating associated treatments on the same day so that they would all lose the same amount to surface evaporation. Therefore, the 0.4-depletion treatments (T_1, T_2, T_3) were all irrigated on the same day and the 0.7-depletion treatments (T_4, T_5, T_6) received water on the same day (Table 2). With this stipulation, surface evaporation was eliminated as a variable and seasonal irrigation amounts differed enough to produce significant differences in yield and WUE. The following discussion is based largely on the 1986 results.

Crop coefficient revision. The common rule of thumb for irrigation scheduling of crops is to supply water when half the available water storage capacity of the root zone has been depleted. Cucumber yields were higher in 1986 for the three treatments that allowed only 40% of the available water to be depleted (Table 4). Of these treatments, the highest WUE resulted when 70% of the estimated root zone depletion was replaced by irrigation on the day that the 1.0-depletion treatment had lost 40% of its available water. This would indicate that the USDA program was estimating ≈30% more water depletion than actually took place.

The 1986 field studies confirmed indications of earlier years that the crop coefficients assumed at the beginning of this study were causing overly high estimates of ET. The 1986 studies did give, in treatment 2, a sequence of irrigation timing and amounts that produced high yields with high water use efficiency. Therefore, following the field studies, the crop coefficients used in the USDA irrigation scheduling program were revised, by trial and error, until resimulations with 1986 weather data showed that the program would predict an irrigation regime very similar to that applied to T_2 in 1986, and would do so by calling for irrigation amounts equal to the estimated soil water depletion on the day of each irrigation (Table 1).

Figure 2 shows the revised crop coefficient curves. Using the revised crop coefficients with the 1985 data would have produced an irrigation regime intermediate between the one that gave the highest yield and the one that gave the best water use efficiency. Data from the three previous years could not be resimulated because of the manner in which irrigations were scheduled.

Rooting depth. The optimum irrigation treatment in 1986 assumed that the effective root zone depth was 60 cm, from planting to the end of the season. Obviously, plants in their seedling stage were not rooted 60 cm deep. The revised crop coefficients, as described above, gave better results when a constant 60 cm root zone was assumed than when, for example, a more intuitively correct progression from 15 to 60 cm during the first half of the season was assumed. The program, with revised coefficients and 60-cm root zone, predicts proper frequency of irrigations early in the season. If root-zone depth was assumed to vary, the allowable percentage of soil water depletion at irrigation would also have to be varied to compensate, causing unnecessary complications in the scheduling program.

Summary. Other combinations of soil water depletions, rooting depths, and percentages of depletion applied at each irrigation might result in similar yields and WUEs as those estimated by the revised scheduling program. We recommend, however, that the USDA program with the revised coefficients be used, because it will schedule an irrigation regime that offers a good combination of high yields and high water use efficiencies, without excessive numbers of irrigations, for cucumbers in areas similar to northern Colorado.

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Supplementary Lighting and CO_2 Mist Influence Rooting of *Camellia japonica*

Christopher J. French[1] and James Alsbury

Agriculture Canada, Saanichton Research and Plant Quarantine Station,
8801 East Saanich Road, Sidney, B.C. V8L 1H3, Canada

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Abstract. **Supplementary irradiance from high-pressure sodium lamps (HPS) at 75 μmol·s^{-1}·m^{-2} stimulated rooting of difficult-to-root *Camellia japonica* 'Lady Clare' when applied from sunrise to sunset in a heavily shaded greenhouse (20% light transmission). There was no effect of HPS on the easy-to-root cultivar Blood of China. Irradiance from HPS either at 45 μmol·s^{-1}·m^{-2} for 16 hr/day or at 75μmol·s^{-1}·m^{-2} from sunrise to sunset had little effect on rooting in a 35% transmission greenhouse. CO_2 mist inhibited rooting of both cultivars when applied in fall propagation. In spring, CO_2 mist during the day stimulated root number of 'Lady Clare' when combined with a night-break treatment from incandescent lamps (INC). Carbon dioxide mist had little effect under a natural photoperiod. With 'Blood of China', plants under CO_2 mist had more roots only under a natural photoperiod, and CO_2 mist was ineffective when INC were used. The effects of supplementary CO_2, irradiance, and increased photoperiod on rooting varied with season and cultivar.**

Use of supplementary CO_2 in greenhouses to stimulate growth and production is a well-established commercial practice (1). Carbon dioxide enrichment has also been employed during propagation of woody and herbaceous plants with varying results, dependent on plant species and season of application (2, 4, 7). Similarly, use of supplementary lighting to increase either irradiance and photoperiod, or both, during rooting results in a variety of responses (7, 14).

Camellia japonica cultivars are widely cultivated as ornamental landscape plants in temperate climates and are generally propagated from stem cuttings or by grafting (9, 12). Little information was available on environmental factors influencing rooting of stem cuttings, and few studies have been conducted on irradiance, photoperiod, or CO_2 effects during rooting (10).

Richards (11) found that the cultivar Lady Clare was difficult to root from stem cuttings. Also, previous investigations into the effects of CO_2 mist on propagation implied that more-difficult cultivars may respond favorably to CO_2 enrichment (7). Therefore, the present study investigated rooting of 'Lady Clare' in relation to CO_2 mist and supplementary lighting. An easy-to-root cultivar, Blood of China, was used as a comparison. In all experiments, there were eight replications of five cuttings per treatment. Data were subjected to analysis of variance.

Experiment 1. Greenhouse facilities (light transmission 35%), CO_2 mist system, and supplementary high-pressure sodium lighting (HPS) were as described (4, 7). Supplementary HPS irradiance was provided from 0400 to 2000 HR at 45 μmol·s^{-1}·m^{-2} (400–700 nm). Carbon dioxide mist (10 sec per 10 min), resulting in an air enrichment of 1100 μl·liter^{-1}, or tap water mist were provided to coincide with the HPS treatment. Propagation was conducted for 12 weeks at two seasons; fall (14 Oct. to 7 Jan.) and spring (8 Feb. to 2 May). A 2 × 2 × 2 factorial experiment was employed with season (fall/spring), HPS (+/−), and CO_2 mist (+/−) as main effects.

Experiment 2. Propagation was conducted from 8 Feb. to 2 May in the same greenhouse. Supplementary night lighting was provided by incandescent (INC) lamps from 2000 to 0400 HR at 3.4 μmol·s^{-1}·m^{-2}. A CO_2 or tap water mist was provided from sunrise to sunset. A 2 × 2 factorial experiment was used with INC (+/−) and CO_2 mist (+/−) as main effects.

Experiment 3. Greenhouse facilities (light transmission 20%) and supplementary HPS were as described (3, 5). One group of cuttings was treated with supplementary HPS lighting at 75 μmol·s^{-1}·m^{-2} from sunrise to sunset. A control group received only natural daylight. Propagation was conducted from 8 Feb. to 23 May. Mean separation was by Student's t test at $P = 0.05$.

Stem cuttings for all tests were taken from 25-year-old field-grown stock plants and trimmed of lower leaves and flower buds. The stem was shortened to 8 cm and the terminal vegetative bud and three lateral leaves and buds were retained. Cuttings were wounded by removing a 2.5-cm strip of bark from one side of the cutting base and then dipped into 0.8% indolebutyric acid in talc. Cuttings were inserted into steam-sterilized wooden flats containing 1 peat : 2 perlite (v/v). Bottom heat was maintained at 21 ± 2C in the root zone. Air temperatures were set at 10C minimum and 28C maximum. Actual temperatures ranged from 10 to 14C (night) and 17 to 30C (day).

Experiment 1. Rooting of 'Lady Clare' was relatively low, 30% to 50% in spring and 20% to 65% in fall (Table 1). 'Blood of China' rooted easily—100% in spring and 80% to 100% in fall. With 'Lady Clare', CO_2 mist reduced rooting percentage in the fall by 43%, whereas rooting in 'Blood of China' was inhibited by 17%. In both cultivars, CO_2 mist had no significant effect during spring propagation. Supplementary HPS did not affect rooting of 'Lady Clare'. With 'Blood of China', an interaction between HPS and CO_2 was observed for number of roots per cutting; HPS increased root numbers by 20% when applied at atmospheric levels of CO_2. There was no effect of HPS when applied with CO_2 mist.

Experiment 2. Application of supplementary HPS lighting for 16 hr/day resulted in three, possibly conflicting, effects; increased photoperiod, increased irradiance level, and, consequently, an increased photosynthetic period. To investigate the effects of increased photoperiod, night lighting was applied in combination with CO_2 enrichment during the day (Table 2). With both culti-

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[1] Present address: Agriculture Canada, Research Station, Vancouver, B.C. V6T 1X2, Canada.