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THE EFFECT OF HEATING SYSTEM ON STOMATE RESISTANCE AND WATER STRESS IN *CALCEOLARIA*

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Two years of production in an FRP-covered greenhouse, where one section was heated by infrared heat and the other section by forced hot-air, showed no effect of heating system on behavior of *calceolaria*.

CGGA Bulletins 407, 408, and 409 described preliminary results obtained at the Colorado State University Bay Farm, where the west section was heated with an infrared system and the east section with a forced, hot-air, fan-jet system. Essentially, the 60 × 110-foot, fiberglass-covered Bay Farm greenhouse was divided into two 30-foot, north-south oriented houses, by means of a double plastic wall under the central gutter. In the west section, two radiating pipe lines ran the length of the greenhouse immediately under roof (Fig. 1), supplied by Combustion Research Corporation, with a total BTU/hr input of about 520,000. The forced, hot-air system in the east house consisted of two natural gas fired unit heaters (ca 600,000 BTU/hr) blowing into a fan-jet, with heat distributed the length of the house through a polyethylene tube. Each heating system was two-staged and controlled by a Hewlett-Packard model 85 desk computer and two HP 3421A digital acquisition/control units. This system executed every 90 seconds throughout the period of the study, with the data accumulated and stored. All control functions were identical, with the average of four shielded and aspirated temperature sensors used as the control comparison. Each house also had a wet-bulb for humidity determination, a glass-covered pyranometer to measure solar radiation, and a remote sensing, infrared thermometer, focused on carnations, to sense plant temperature. CO_2 was provided from Johnson Burners whenever ventilation was off.

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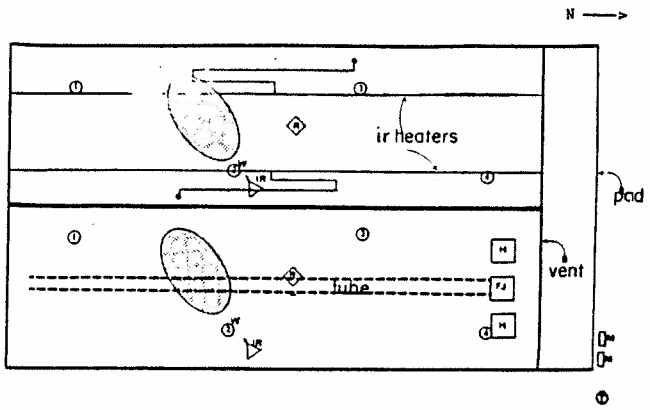

Figure 1. Diagram of greenhouse used to compare forced-air heat and infrared heat. The west section contained the infrared heat system, whereas the east contained the forced-air system. Labels indicate:

#1-4. aspirated thermocouple tubes,
W. wet bulb thermocouples,
R. pyranometers,
IR. infrared thermometers,
H. unit heaters,
FJ. fan jet,
M. gas meters,
T. outside aspirated thermocouple.

Calceolaria x *herbeohybrida* cv 'Multiflora Mix' plants were grown just north of the shaded area. The shaded ovals indicate the areas toward which infrared thermometers were aimed (carnations). The wall separating the two greenhouses was double polyethylene.

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Seeds of *Calceolaria* x *herbeohybrida* cv 'Multiflora Mix' were sown on 5 dates in the fall of 1984 and in 1985 in a 1:1:1 mix of peat moss, perlite, and vermiculite, later shifted to 6-inch plastic pots, which were placed under either forced hot-air or infrared heat, with air temperatures controlled at 62°F day and 52°F nights. The transplanted units were arranged so that there were five plants per sowing per bench, with six benches in each of the two sections. Pots were randomized on each bench, and spaced at one per sq. ft. These were hand-watered and fertilized by automatic injection.

Plants with one-third of all flower buds open were used for all measurements. The plants were watered 24 hours before measurements were taken. The following day, stomatal resistance readings were taken on the upper surface of one young, fully expanded leaf on each plant during the periods 1100 to 1130 hours and 1500 and 1530 hours, using a leaf-clamping device that measured water vapor loss from the leaf, with units expressed in seconds per centimeter resistance.

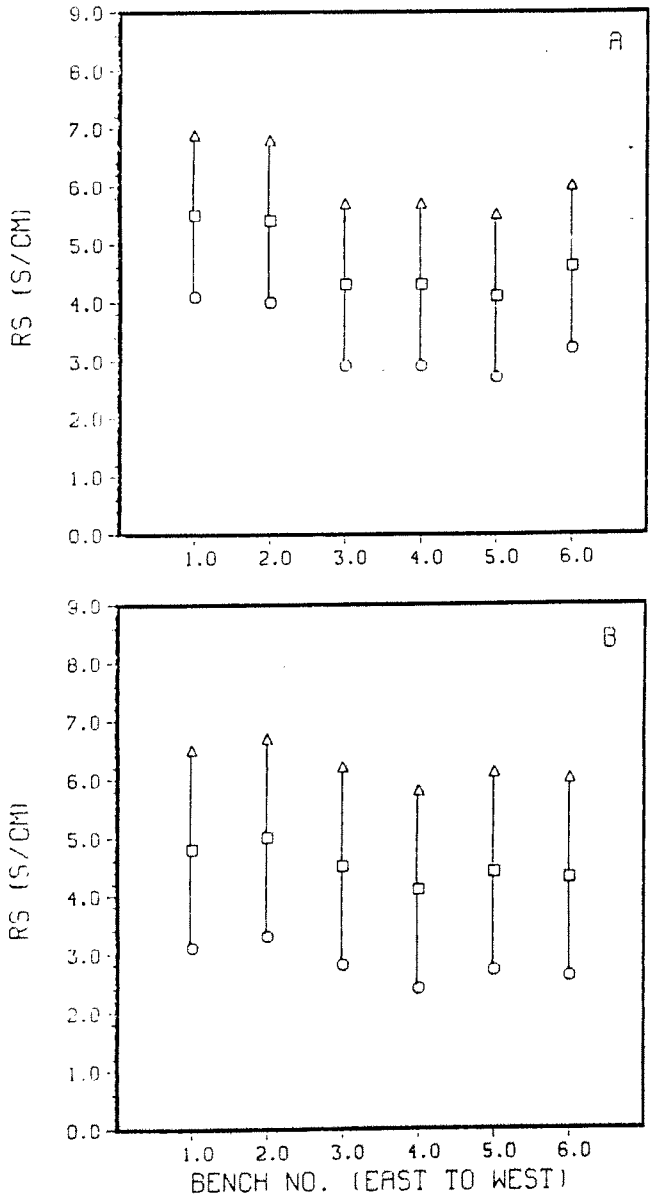

Figure 2. Effect of heating system on stomatal resistance (rs) in *calceolaria* cultivar 'Multiflora Mix.' Data were from the 1984-85 winter on plants grown in infrared (A) or forced hot-air (B) heat. Means were averages of 10 measurements. Tukey's HSD tests calculated at the .05 level. Measurements taken from 1100 to 1130 hr. Data for 1500 to 1530 hrs were similar. See Table 1 for general environmental conditions.

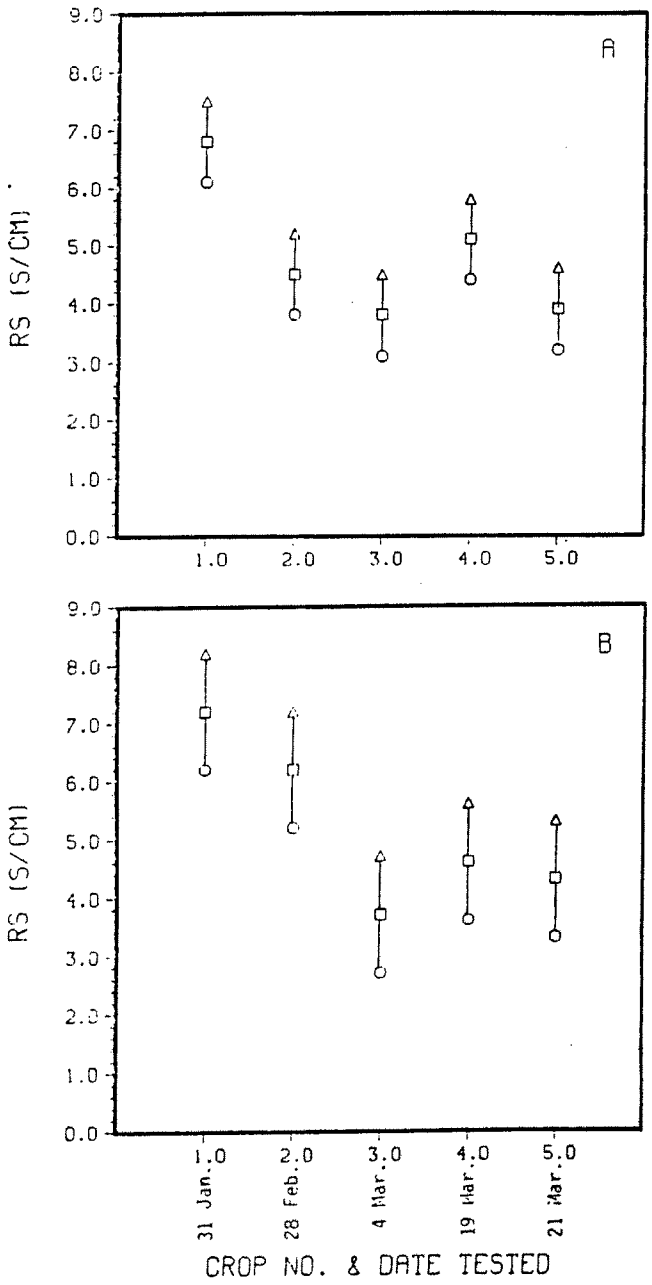

Figure 3. Effect of crop on stomatal resistance (rs) in *calceolaria* cultivar 'Multiflora Mix.' Data were from the 1984-85 winter on plants grown in forced hot-air or infrared heat. Means were averages of 24 plants. 1100 hr (A) and 1500 hr (B). Tukey's HSD tests calculated at the .05 level. See Table 1 for general environmental conditions.

Immediately following stomatal resistance measurements, xylem water potentials (negative pressure in the xylem of flower peduncles) were determined with a pressure bomb in the same order. Readings were taken during 1130 to 1200 hours and 1530 to 1600 hours MST. A pre-dawn pressure reading was also taken from 0530 to 0600 hours, when the heating load in the houses would usually be maximum.

Replications of the treatments were not feasible. Instrumentation, however, was extensive, with replication in time (two years), with results reported from the first year. Data for the two years was comparable.

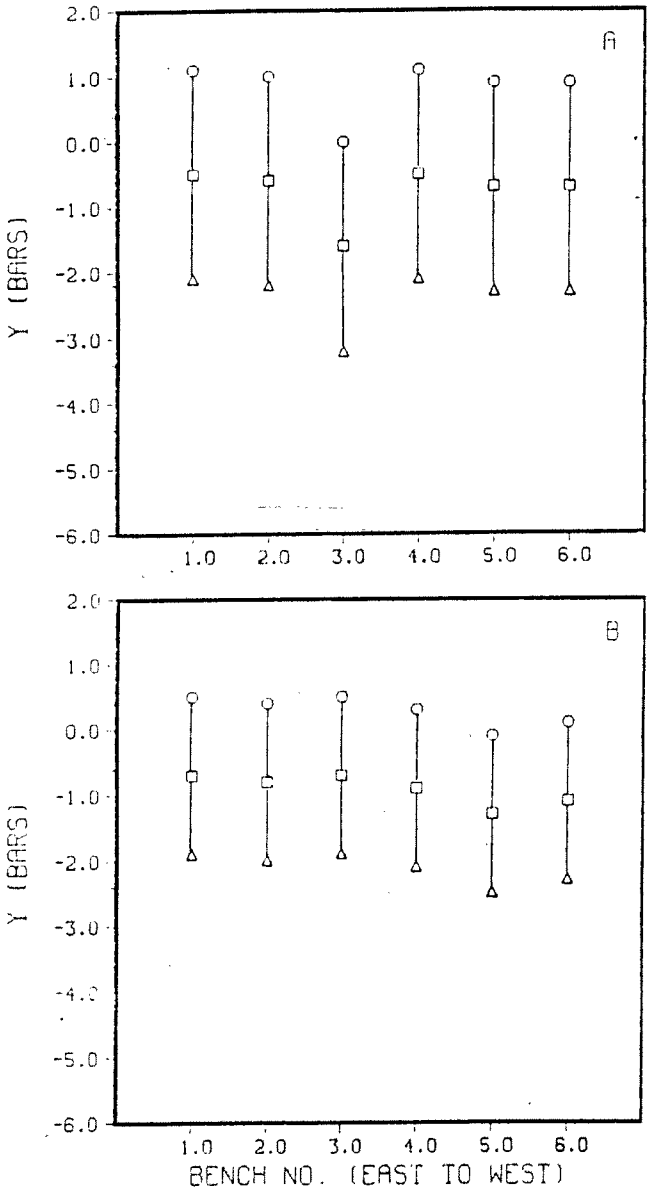

Figure 4. Effect of heating system on xylem water potential (Y) in *calceolaria* cultivar 'Multiflora Mix.' Data were from the 1984-85 winter on plants grown under forced hot-air (A) or infrared (B) heat. Means were averages of 25 plants with measurements made at 0530 hr. Tukey's HSD tests were calculated at the .05 level. See Table 1 for general environmental conditions.

Results

There were no statistically significant differences between heating systems in regard to stomatal resistances. During the 1100 to 1130 hour readings, the plants in the east benches of both greenhouses showed the highest resistances, whereas plants in the west benches showed the lowest (Fig. 2). There were differences among crops (sowings), over all benches in both greenhouses (Fig. 3). Resistances were highest with crop 1 (31 Jan. 1985) and lowest

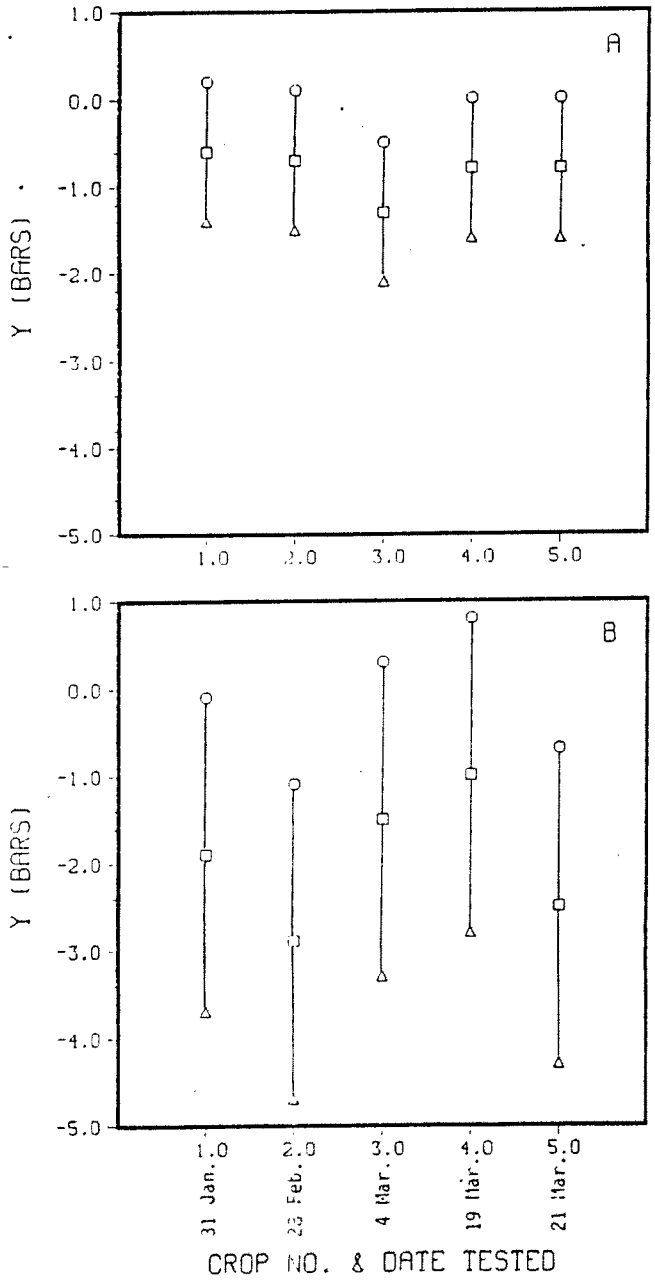

Figure 5. Xylem water potential (Y) in *calceolaria* cultivar 'Multiflora Mix' on 5 dates. Data were from the 1984-85 winter on plants grown in forced hot-air or infrared heat. Means were averages of 30 measurements. Tukey's HSD tests were calculated at the .05 level. Measurements were taken at 0530 to 0600 hr (A) and 1130 to 1200 hr (B).

with crop 3 (4 March 1985). These differences could be attributed to differences in total radiation between measurement periods. There were no significant differences in water potential between heating systems or among benches or crops (Fig. 4).

Discussion

These results provide evidence that there was no difference in plant response of *calceolaria* to the heating systems tested. The slight differences found among benches and crops can be attributed to the greenhouse arrangement and seasonal changes (Table 1). The trends that did appear were expected as the result of structure and heating system arrangement, which visibly altered solar radiation distribution in the houses. The *calceolaria* were essentially "two dimensional" (width and length), as contrasted to a tall cut flower crop such as carnations or chrysanthemums — which could be called "three dimensional" (width × length × height). It would be expected that a flat crop might not show differences as the result of energy distribution provided by the different heating systems. A survey of the scientific literature has shown variable results from infrared heating on potted crops, and there are few studies that have been conducted on such a large scale as this in comparable installations, with replication, at least in time. In our estimation, the utilization of either of these two heating systems for a two-dimensional crop should be based upon factors other than that which produces the "best" crop.

Table 1. Daily average outdoor and indoor air temperature (°F) and greenhouse radiation levels (KJ m^{-2} day^{-1}) for each of the test dates when stomatal resistances and xylem water potentials were measured on *calceolaria* cultivar 'Multiflora Mix' grown under forced hot-air (FA) or infrared (IR) heat during the 1984-85 winter. Data accumulated at 90 sec intervals throughout the experiment. Note the difference in total daily radiation between FA and IR heated greenhouses.

Crop #	Test Date	Outdoor Temp.	Radiation Level		Indoor Temp.	
			FA	IR	FA	IR
1	1-31	1.4	52	41	64	64
2	2-28	46	95	75	66	68
3	3-4	30	102	86	70	70
4	3-19	50	66	57	64	66
5	3-21	54	122	98	66	68