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THE EFFECT OF GREENHOUSE COVER AND SHADING ON 'ROYALTY' ROSE YIELD

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When grown in four identically controlled greenhouses, 'Royalty' was found to produce 76.7 flowers per plant over a 15.5 month period under a double air inflated polyvinyl fluoride cover at a 71% radiation transmittance and an average weekly gas consumption of 445.2 CCF. The installation of a thermal and shade screen apparently reduced transmittance to 61% and yield to 69.6 flowers per plant while reducing gas consumption by 33%.

Introduction

The initial impetus for this research was to explore the idea that appropriate shade screens during Colorado summers would reduce concomitant water stress and increase yield. To examine this aspect, four identically controlled greenhouses were fitted with two covers and two automatic shade screens and planted to 'Royalty' roses grafted on *R. manetti* in the spring of 1985 with records kept on climate from Dec., 1985, to Jan., 1987, and records on rose yield from Oct., 1985, to Jan., 1987.

Methods and materials

The conditions to which 'Royalty' roses were subjected over the approximate 15 month period of this investigation have been described in previous CGGA bulletins (442, 437, 430, and 420). Briefly, the control setpoints in four identically operated, 960 sq. ft. greenhouses were:

1. Night temperature heating to 62° F and 72 day with cooling fan lockout at night when outside temperature was below the inside. These set-points were adjusted in accordance with climatic conditions. Thus, for example, cooling was not allowed until inside temperature was at least 2° F above basic set-point, and was adjusted upward from that minimum, depending upon outside temperature. When the difference between inside and outside air temperatures exceeded 30° F, cooling was usually inhibited regardless of irradiance.
2. Humidity was controlled according to the vapor pressure gradient (VPG), which was the difference between actual vapor pressure of the air and vapor pressure at 100% relative humidity at the same temperature. The VPG was set to allow a maximum difference of 10 millibars[2] (ca 65 to 75% RH), with mist added via a high pressure system, which was turned off at night. Based upon work reported in Bulletin 442, the system now controls continuously, and a dehumidification routine has been incorporated to operate when the VPG is less than 0.5 mb.
3. CO_2 was injected during the day to maintain a concentration of 35 Pascals whenever radiation was below 100 watts/sq.m., and increased 0.2 Pascals for every additional watt/sq.m. above 100. Injection occurred at 1st and 2nd stage cooling, directly into the rose bench, with no delay. CO_2 samples were taken from the rose canopy. At Fort Collins' altitude, a partial pressure of 27 Pascals[3] is about 335 ppm, or 335 ppm equals 32 Pascals at sea level.
4. Two houses were covered with single, corrugated, PVF-coated, fiber-reinforced plastic (FRP) and two with a double layer, air-inflated polyvinyl fluoride (PVF or Tedlar®). One house of each type cover had installed an automatic shade screen with a manufacturer's specification of 40% shade reduction. This screen was closed during the day when inside radiation exceeded 700

[1] *Graduate student and Professor, respectively.*

[2] *1000 mb ≈ atmosphere ≈ 14.7 psi = 100 kilopascals*
[3] *1 pascal = 0.01 mb*

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watts/sq.m.[4], and opened when outside radiation was below 600 watts/sq.m. If the outside temperature was below the inside temperature at night, the screens closed. A 60 minute delay was incorporated to prevent rapid screen movement under cloudy conditions. This delay was bypassed at night at first call for closing, and in the morning at first call for opening.

5. The system switched to day settings when outside radiation exceeded 70 watts/sq.m., with a delay to allow slow heating to the day setpoint without maximum equipment operation or temperature override. The system returned to night set-point when the outside radiation dropped below 10 watts/sq.m. The difference between night and day avoided rapid switching under cloudy conditions.

6. 'Royalty' on *R. manetti* understock were planted Spring, 1985, in a north-south oriented bench in 8 inches of pea gravel at a density of one plant per sq.ft. The bench was divided into six plots with 'Sonia' as buffers between each plot and at the bench ends.

   The roses were irrigated with six lines of trickle tubing per bench. Watering took place simultaneously in all benches when the system switched to day settings. Thereafter, watering occurred whenever the total radiation in a particular house reached an accumulated value of 2300 kiloJoules per sq.m[5]. The standard Colorado State University nutrient solution was injected at each watering of 8 minute duration.

7. During December, 1985, the procedure of "cutting up" resulted in rose height getting out-of-hand. We undertook a drastic procedure of undercutting to reduce height, and instituted a cutting method to maintain the roses at a workable height:

   A. Up to the third caging support (about 3 feet):
      1) Cut to the second 5 leaflet leaf in fall,
      2) Cut to the first 5 leaflet leaf in spring, and
      3) Any canes less than 3/16-inch diameter, cut to origin.
   B. Between third and fourth caging support (3 to 4 feet):
      1) Cut to knuckle,
      2) When parent cane had three or more cut flower stems, undercut to below the third caging support,
      3) Any canes less than 3/16-inch diameter, cut below third support or to origin, and
      4) Remove blind wood as convenient.
   C. Above fourth caging support (5 feet):
      1) Cut to knuckle, or undercut, if possible, to below third caging level, and
      2) Cut any canes less than 3/16-inch diameter to origin, including blind stems.
   D. Large bottom breaks:
      1) Cut to first caging level, leaving a minimum of 2 to 5 leaves.

   Harvesting was on a daily basis, with yield and quality accumulated on a weekly basis.

8. Throughout the period covered by this report, the fan-jets were not "enabled". That is, fan-jets were on only when the system called for heat. Again, on the basis of the report in Bulletin 442, an "enabling" mode was written into the software so that fan-jets now operate continuously up to when third stage cooling comes on. Intermittent fan-jet operation meant that we were unable to control the environment as well as we should have since we did not always know the wind speed inside the houses.

Data collected through this period were extensive. The system executed every 60 seconds, and the climatic values were recorded and accumulated every 60 seconds with updating of maximum and minimum values. To avoid carry-over to either day or night regime of high or low values, the maximum and minimums were set to zero one hour after switchover to night or day. All these data were printed out on summary sheets for each night and day period, and then accumulated on a weekly basis with a weekly summary printed every Saturday night. At varying periods throughout the study, instantaneous climate data were recorded and stored for future use at 10 or 15 minute intervals. The data collected included:

1. Average air temperatures for each of the three aspirated stations in each house, the average for each house, and maximum-minimums, including outside,
2. Average temperatures of the rose canopy and maximum-minimums,
3. Average relative humidity and vapor pressure of each house, including maximum-minimums, determined by aspirated wet-bulb sensors and by capacitance humidity probes, and outside humidity,
4. CO_2 concentration during the day in each house and outside, sampled every 18 minutes during the day, including maximum-minimums,
5. Total accumulated solar radiation in each house and outside, including maximums,
6. Total number of irrigations per day,
7. Total minutes shade screens were closed day or night, and
8. Total gas consumption of each house, day or night periods.

Not all of these data have been reported in this article. They are still being summarized.

Results and discussion

Environment — The average air and plant temperatures varied less than ±2° F between treatments **(Table 1)** for the study's duration. Due to the great number of data, the small differences in weekly averages were statistically significant. However, the system used to measure temperature is usually considered to have an absolute accuracy of about ±2° F. The average air and plant temperature differences between treatments might be considered as unremarkable. In actuality, of course, the environments varied much more than would be evident from average values **(Figures 1-3)**. Due to the higher heat requirements of the single cover FRP, it was necessary to correct for "temperature droop" in the FRP houses by changing inside temperature setpoints upward 0.055° C for each ° C difference between inside and outside air temperatures as contrasted to only

[4] 1 gram-calorie cm^{-2} min^{-1} = 698 watts m^{-2} ≈ 6700 foot-candles (sunlight) = 221.1 BTU hr^{-1} ft^{-2}.

[5] 2300 KJ m^{-2} = 638.9 watt-hours m^{-2} = 0.92 gram-calories cm^{-2} = 202.5 BTU ft^{-2}.

1 watt = 1 Joule sec^{-1}

1 watt-hour = 3600 Joules

0.01° C for the double PVF houses. This was necessary to maintain equal air temperatures in all treatments. The consistently higher rose canopy temperature under single FRP during October through January, 1986-87 **(Figure 1)** may have resulted from the fact that the fan-jets were operating a greater period in the heating mode as compared to other treatments. This may also be the reason for the generally lower plant temperatures under PVF, with a screen in the winter.

Screen installation tended to result in higher humidities **(Figure 2),** as did the use of a double cover. The variation in weekly average humidity was less under a double cover compared to a single FRP. The average weekly humidity for a PVF with a screen was significantly higher than humidity in the other three treatments. But, under FRP, a screen resulted in higher weekly humidity through the summer-spring-fall, and was reversed in the winter periods **(Figure 2).** Since the misting system was turned off at night, there was no humidity control. Bulletin 442 showed that extremely low humidities could occur with a single cover under heavy heating loads (ca 15% RH). Although humidity was measured at night, these data are not included here.

Since CO_2 and irrigation frequency were partially controlled by radiation level, the average values tended to follow the pattern set by the total average weekly accumulated radiation in each treatment **(Table 1).** The high CO_2 concentrations during April-May, 1986 **(Figure 3),** resulted from a leak in the CO_2 supply line outside the houses. CO_2 injection times were recorded, and these will be reported at a later date.

The greatest differences between treatments were solar radiation levels as a consequence of greenhouse cover and presence of screens. The screens, acting as shades during the day, never closed between September through March, 1986-87. But, as thermal screens, they almost invariably closed every night of the investigation, with the screen under FRP closing more often, for longer periods, than the screen under PVF — both day and night. A single layer FRP roof transmitted an average 77.6% of the outside radiation **(Table 2).** A double PVF cover, on the other hand, transmitted 70.7%, nearly 8% less energy than the single

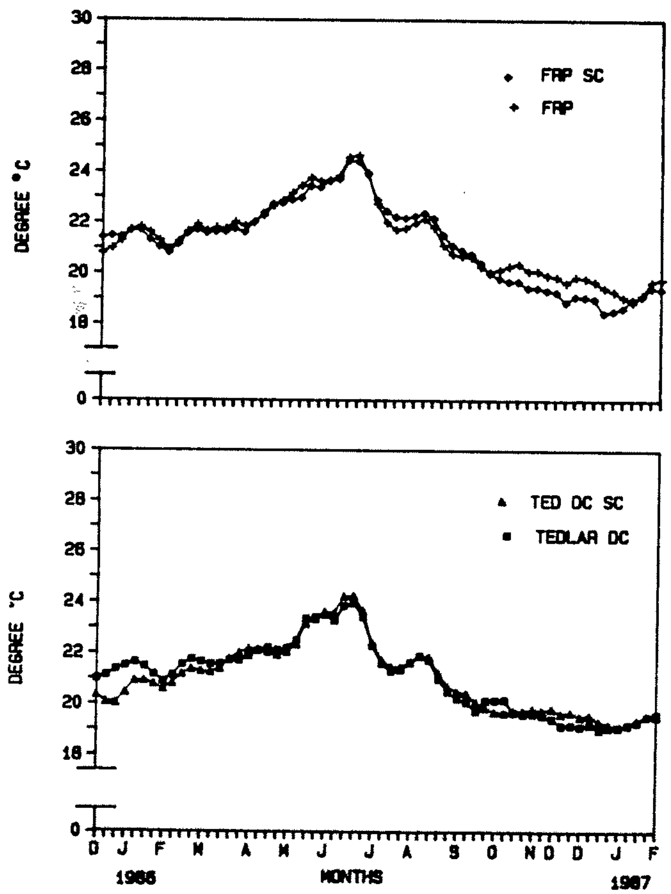

Fig. 1: Smoothed curves of average weekly 'Royalty' temperature (day and night) from Dec. 15, 1985, to Feb. 15, 1987.
FRP – Single layer, corrugated fiberglass
FRP SC – FRP with shade screen installed
TEDLAR DC – Double layer polyvinyl fluoride
TED DC SC – Double layer PVF with shade screen

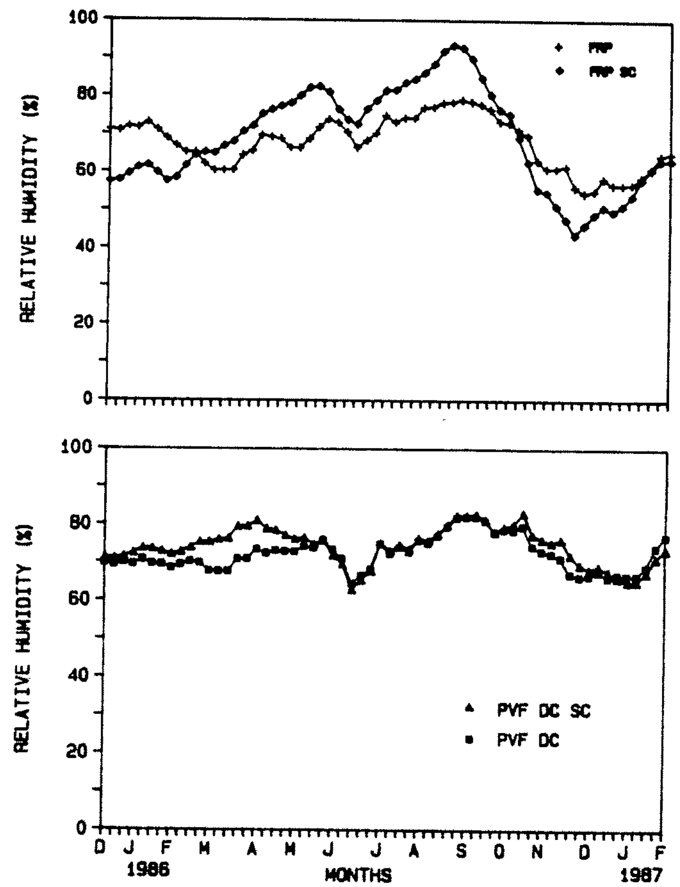

Fig. 2: Smoothed curves of average weekly relative humidity in four identically controlled greenhouses from Dec. 15, 1986, to Feb. 15, 1987.
FRP – Single layer, corrugated fiberglass
FRP SC – FRP with shade screen
PVF DC – Double inflated polyvinyl fluoride
PVF DC SC – PVF with shade screen

cover. Shade screens, however, had a greater effect on total energy under FRP compared to a screen under PVF **(Figure 4).** The shade screen reduced total transmittance by more than 14% under FRP, but only 10% under PVF. This would be expected due to the greater time of a closed screen under FRP in the summer. However, the presence of overhead structure to support the screens, even while open, still had a consistent effect on reducing energy available to roses. While the differences were slight **(Figure 4),** this occurred during the period (winter) when small variations in radiation would be highly critical.

Gas consumption — As would be expected from previous reports, gas consumption between covers and thermal screens varied significantly **(Table 2, Figure 5).** Thus, a double cover reduced total gas consumption by nearly 45% compared to a single FRP over a year's time; although, of course, from the middle of June through the first of September, there was no added benefit **(Figure 5).** Fitting a thermal screen to single layer FRP reduced total consumption by 25% as compared to installing a screen under double PVF, which reduced total consumption by an additional 33%. Fuel usage by double PVF with a screen was 63% less than the single FRP without a screen. However, the screen under PVF reduced total solar energy transmitted into the house 10% over the entire experimental period **(Table 2).** Although computations on transmission from one season to the next **(Figure 4)** have not been carried out, we suspect that the small differences in the winter likely had a disproportionate effect on rose growth. It should be mentioned that there was a decided position effect on gas consumption which was estimated to be 5 to 10% in favor of the leeward (east) house which was the double, air-inflated PVF with a thermal screen. Even with this allowance, the possible fuel saving of a double cover with thermal screen would still exceed 50% on a seasonal basis compared to FRP.

'Royalty' yield — We suggest that the differences in yield between treatments **(Table 2)** can be attributed mainly to variation in available solar radiation as contrasted to the small, although significant, differences found in average weekly temperatures, CO_2, etc. We would also suggest, on

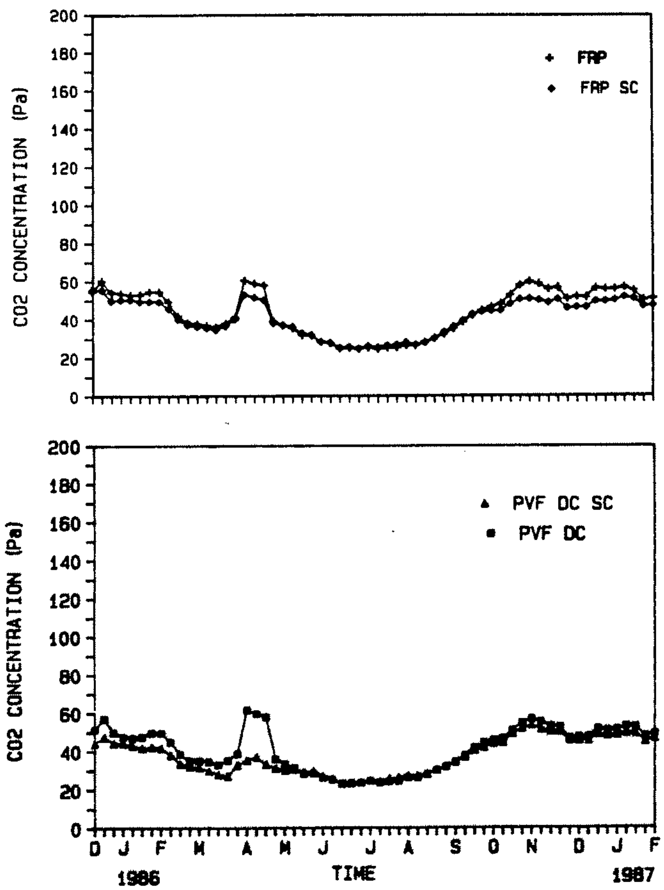

Fig. 3: Average weekly CO_2 concentration in a 'Royalty' rose canopy from Dec. 15, 1985, to Feb. 15, 1987. Values are in Pascals (pressure). Thirty-two Pascals roughly equivalent to 400 ppm at Fort Collins' elevation.
FRP — Single layer, corrugated fiberglass
FRP SC — FRP with shade screen
PVF DC — Double air inflated polyvinyl fluoride
PVF DC SC — Air inflated PVF with shade screen

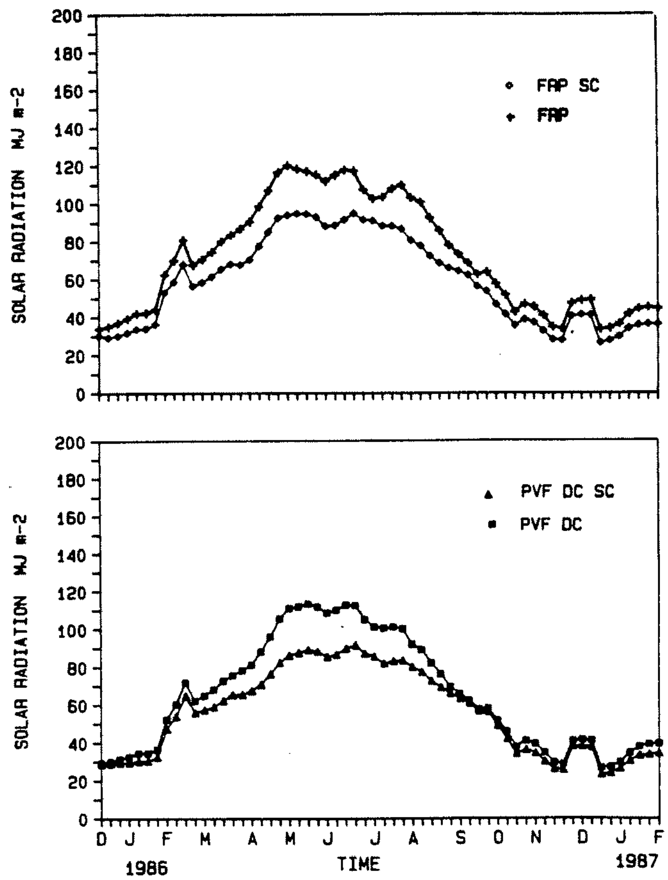

Fig. 4: Smoothed weekly total of solar radiation in four identically controlled greenhouses from Dec. 15, 1985, to Feb. 15, 1987. Radiation measured three feet above ground, units in MegaJoules/sq.m.-wk.
FRP — Single layer, corrugated fiberglass
FRP SC — FRP with shade screen
PVF DC — Double layer polyvinyl fluoride
PVF DC SC — Double, air inflated PVF with shade screen

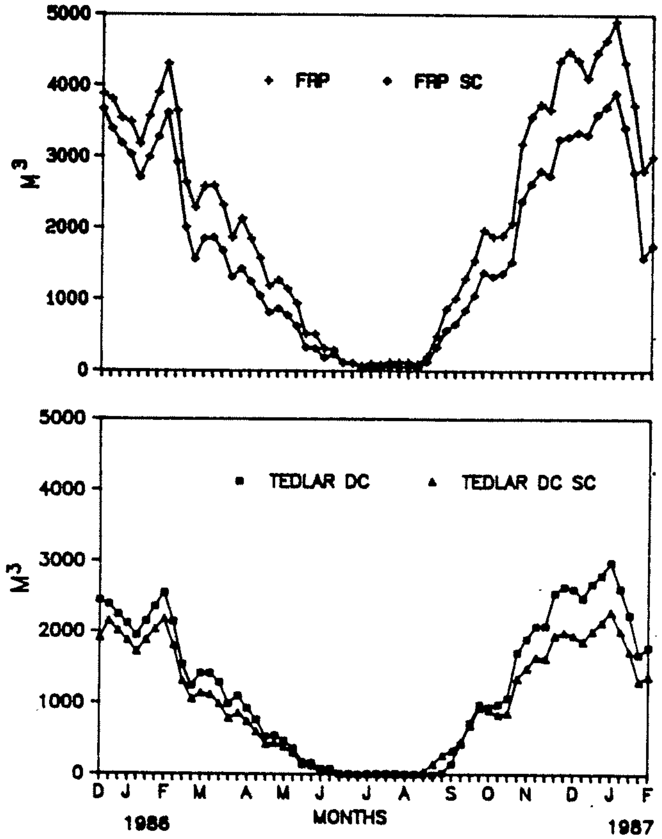

Fig. 5: Weekly gas consumption (cubic meters) in four identically controlled greenhouses (960 sq.ft. ground area from Dec. 15, 1985, to Feb. 15, 1987. One cubic meter = 35.3 cubic feet. Note houses were arranged with TEDLAR DC on the west followed by FRP, FRP SC, and TEDLAR DC SC on the east. There was a distinct windbreak effect which accounted for a 5 to 10% lower gas consumption in the leeward TEDLAR DC SC house.
FRP = Single layer, corrugated fiberglass
FRP SC = FRP with shade screen
TEDLAR DC = Double, air inflated polyvinyl fluoride
TEDLAR DC SC = Double, air inflated PVF with shade screen

the basis of these data from 'Royalty', that energy transmission can have a very significant effect on yield when percent transmittance of the structure goes much below 65% of the total outside radiation under Colorado conditions. On the other hand, a shade screen under FRP offered no significant advantage, reducing yield per plant 3.7 flowers per year compared to FRP without a shade screen **(Table 2).** It appeared that a shade under FRP also interfered with crop cycling **(Figure 6),** causing more-or-less steadily decreasing production into the winter months as contrasted to the other treatments. Note that total transmittance by FRP with shade was below the limit we previously suggested.

With the exception of FRP with shade, all other treatments maintained, more or less, a regular cyclic interval in cropping. Roses grown under PVF without a shade screen appeared to cycle ahead of roses grown under FRP without shade, producing an average 3 more cut flowers per plant-year. A shade screen, however, delayed peak flower production and reduced the peaks **(Figure 6),** resulting in 6.2 fewer flowers per plant-year under PVF **(Table 2).** Under the conditions of this study, the change in cycling and production apparently begin to occur in the early summer under PVF, and in mid-summer under FRP. This would tend to substantiate the conclusion that shade screens of the particular type installed (40% shade) had a deleterious effect, with the only benefit being energy conservation. Roses in all treatments produced over 70% of their total flowers in 21-inch and greater stem lengths. The only apparent advantage of a shade screen was increase of 3% in the 21, 24, and 27-inch stem lengths compared to PVF or FRP without a screen.

Conclusion

In general, a double PVF cover with a thermal screen can reduce yearly energy consumption to half of a single cover without a screen, but at the cost of reducing rose yield significantly (10%). Double PVF is a good cover for Colorado conditions, with transmittance preferably around 70% of the

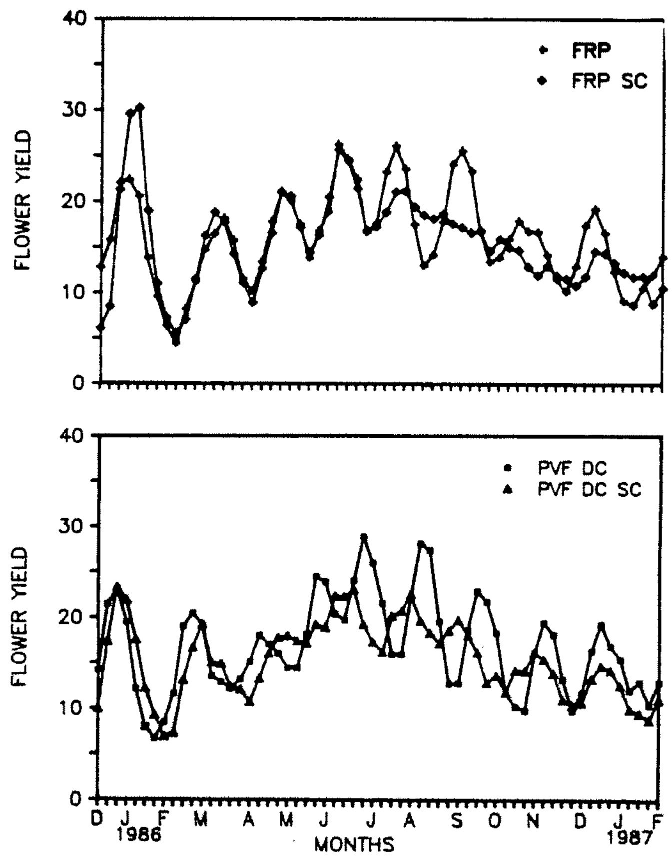

Fig. 6: Weekly smoothed curves of 'Royalty' average yield per plot, grown in four identically controlled greenhouses from Dec. 15, 1985, to Feb. 15, 1987.
FRP = Single layer, corrugated fiberglass
FRP SC = FRP with shade screen
TEDLAR DC = Double, air inflated polyvinyl fluoride
TEDLAR DC SC = Double, air inflated PVF with shade screen

outside. Keep in mind that a dividing line of 65% in Colorado is not the same as 65% in other, darker regions. It may be that a shade screen with less shading effect would be better, but we were unable to test that hypothesis.

Additional information on studies with 'Sonia' and 'Samantha', under the same conditions, will be published in the near future.

Acknowledgements

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Table 1: Climatic conditions in four identically controlled greenhouses with different covers and screens for the period Dec. 15, 1985, to Jan. 25, 1987. Values are averages per week. Thermal and shade screens installed Feb. 2, 1986.

Treatment	Air temperature		Plant temperature		Solar radiation (MJ/sq.m.)	Day relative humidity %	CO_2 concentration (Pascal)	Total Gas consumption (CCF)	Times irrigated
	Night (°F)	Day (°F)	Night (°F)	Day (°F)					
Single corrugated fiberglass	61.3	73.4	65.1	75.7	70.9	65.5	44.0	807.7	30.9
FRP with thermal screen	62.1	73.4	65.3	75.0	57.9	65.4	41.7	609.5	27.1
Double air inflated PVF	62.1	74.3	64.8	75.0	64.6	65.4	41.4	445.2	28.9
Double PVF with thermal screen	62.4	74.7	65.1	74.7	55.4	71.1	37.7	299.6	25.5
Difference required for statistical difference	0.2	0.2	0.4	0.4	2.1	1.5	2.0	537.1	1.1

Table 2: Total solar radiation, percent transmitted, gas consumption, and yield of 'Royalty' roses grown in four identically controlled greenhouses. 'Royalty' grafted on *R. manetti,* at one plant per sq.ft., in gravel and irrigated automatically with drip irrigation, using automatic nutrient injection. Yield data from Oct. 25, 1985, through Jan. 25, 1987, and Feb. 2, 1986, through Jan. 25, 1987. Shade screens installed Feb. 2, 1986. Radiation data from Dec. 15, 1985, through Jan. 25, 1987.

Treatment	Total radiation (MJ/sq.m.)	Weekly average radiation[1] (MJ/sq.m.-wk)	Percent radiation transmitted	Gas consumption[1]		Total yield		Yield per plant	
				Total (CCF)	Per sq.ft. (cu.ft.)	15.5 mo.	12 mo.	15.5 mo.	12 mo.
FRP no screen	4396.9	70.9	77.6	807.7	84.1	4432	3459	73.9	57.7
FRP with screen	3592.1	57.9	63.4	609.5	63.4	4261	3242	71.0	54.0
PVF no screen	4004.2	64.6	70.7	445.2	46.4	4604	3644	76.7	60.7
PVF with screen	3435.4	55.4	60.7	299.6	31.2	4177	3262	69.6	54.5
Difference for significance		2.1		537.1					1.3

[1]*Averages per week*