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ENVIRONMENTAL CONDITIONS CREATED BY PLASTIC FILM GLAZINGS

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The environment created in four quonset shaped greenhouses covered with: 1) new double layer, air inflated, 4 mil Japanese PVC; 2) new monsanto 603 double polyethylene; 3) 2 year old double walled, 4 mil PVF (DuPont Tedlar) and 4) a single layer of 5 oz. tedlar coated lascolite FRP panels (4 years old) was evaluated. The fuel used in the double glazed structures ranged from 34 to 40 percent less than that required for the single layer FRP treatment. During the evaluation period, 17 September 1982 to 2 May 1983 the average percent of total sunlight transmitted was 10 to 17% lower under the double glazings than in the single FRP treatment. Black and white surface temperatures due to the cover treatment varied, but those of the plant foliage were similar. The 4 mil PVC material was not suited to the winter conditions of Colorado, and removal of condensate between the double layers of the PVF cover was required for maximum transmission of solar radiation.

Introduction

The use of double glazings for structural covers has been widely accepted. Experiments at CSU during the 1982-1983 winter season compared the environment created by three double layer film glazings to that in a fiberglass reinforced plastic panel covered structure.

Materials and Methods

The four 20 × 48 ft quonset-type greenhouse structures used in the experiment have been described. They were north-south oriented and identical in design except for the covers. The following glazings were used:

- Polyvinyl fluoride (DBL PVF) DuPont Tedlar, 4 mil film, double layer on steel frame, 2 years old;
- Fiberglass reinforced plastic panels (SGL FRP), Tedlar coated Lascolite, 5 oz., single layer corrugated, 4 years old;
- Polyethylene (DBL POLY) Monsanto 603, 6 mil film, double layer air inflated, new;
- Polyvinyl chloride (DBL PVC) Achilles, 4 mil film, double layer air inflated, a Japanese material.

The growing environment within each house, including air temperature, carbon dioxide level and relative humidity was comparable and designed for the optimum production of cut roses. The controls were set to maintain 61F night and 70F day temperatures with fan-pad cooling starting at 81F.

Temperature measurements included surface temperatures of horizontal black and white painted surfaces and plant

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canopy, night heat loss and nocturnal temperatures without mechanical heating. Infrared thermometer measurements on black and white painted surfaces provided an indication of the heat load caused by the transmitted solar radiation in the greenhouse. Measurements were taken with a Barnes Instatherm infrared thermometer during January and February 1983, on cloudless days at noon, when the greenhouse temperature reached 70 to 81F and no mechanical heating or cooling was in use. Ambient air and the external glazing and the plant canopy surface temperatures were also determined. Night temperatures inside and outside the structures were recorded from 20 May to 15 June 1983 after plant growth studies were completed and mechanical heating stopped for the summer.

Instruments for global and transmitted radiation located 3 ft above ground level in each structure, were continuously recorded from 15 October 1982 to 15 April 1983. Photosynthetically active radiation (PAR), was measured as well as spectral analysis of the transmitted radiation at solar noon on cloudless days.

Results and Discussion

Temperature Measurements

Both black and white surface temperatures under the FRP glazing were significantly warmer than those in the polyethylene treatment (Table 1). There were no significant differences in surface temperatures between any of the double covered greenhouses. The air temperature at equilibrium was higher under the double PVC structure than in the other cover treatments. There were no significant differences in the rose canopy temperatures, possibly because of the presence of free water from the mist system used to maintain the humidity.

Preliminary observations of night heat loss were made on February 20, 1983, when the heaters were turned off in all structures for 90 minutes. The outside temperature was 25F and all inside temperatures were 61F at the beginning of the test. The single FRP structure cooled the fastest and of the double glazed structures, polyethylene cooled first. After 90 minutes, the temperatures inside the houses were 45F for the single FRP, 46F for the double polyethylene and 48F for both the PVC and PVF structures (Fig. 1).

A second experiment was conducted 20 May to 15 June 1983 when all mechanical cooling was discontinued for the summer. Data (Table 2) showed the same pattern as obtained in the winter. Night temperature, in the FRP treatment, was significantly lower than those under the PVF and PVC structures. Night temperature was lower in the double polyethylene house than under the other double layer structures.

Table 1: Average temperature of the air, black and white horizontal surfaces, and plant canopy under four different plastic greenhouse covers. Measurements taken in January and February, 1983, at solar noon on cloudless days (°C).

Cover	Air	Black Surface	White Surface	Plant Canopy
SGL FRP	23	39	29	23
DBL POLY	23	33	25	23
DBL PVC	24	37	27	23
DBL PVF	23	36	28	24
HSD 5%	1	6	3	2

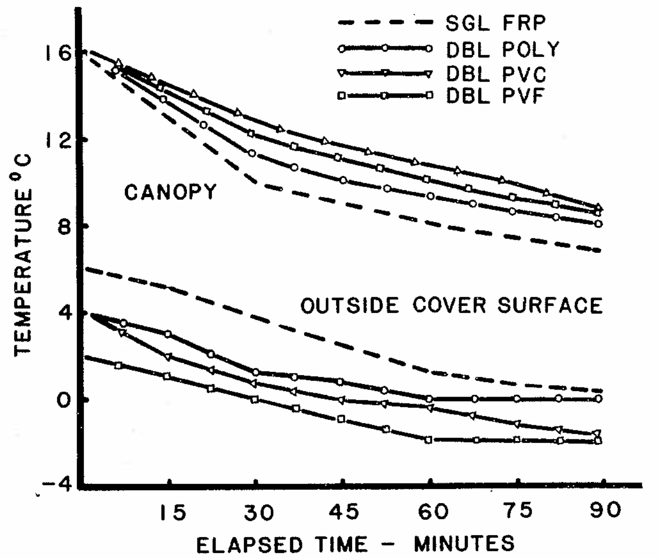

Fig. 1: Heat loss in the rose canopies and on the exterior surface of four different plastic greenhouse glazing materials when heat was turned off at 2100 hrs, 20 February 1983 for 90 min. Outside air temperature was -4°C (25F).

Table 2: Night air temperature (°C) 20 May to 15 June 1983, created in four different plastic covered greenhouses with no heat HSD = 2 C at 5% level.

	Temperatures		
Cover	Average	Minimum	Maximum
SGL FRP	10	6	14
DBL POLY	11	8	14
DBL PVC	12	9	16
DBL PVF	12	9	16
OUTSIDE AIR	7	2	11

These data indicated that air temperatures inside a double layer covered structure during the coolest portion of a spring night are approximately 9°F warmer than the outside temperature.

Radiation Measurements

Solar radiation transmitted through the FRP cover was significantly higher than in any of the double glazed treatments (Table 3). It was 17, 14 and 11% more than through double PVF, polyethylene and PVC, respectively. There were no differences in the energy transmitted by the double covers.

Table 3: Percentage of TOTAL and photosynthetically active (PAR) outside radiation transmitted through four greenhouse covers.

	TOTAL			PAR		
Cover	Min	Max	Ave	Min	Max	Ave
SGL FRP	70	81	76	65	88	77
DBL POLY	56	66	60	54	72	65
DBL PVC	61	71	65	-	-	-
DBL PVF	56	64	59	51	79	68
HSD 5%		4			7	

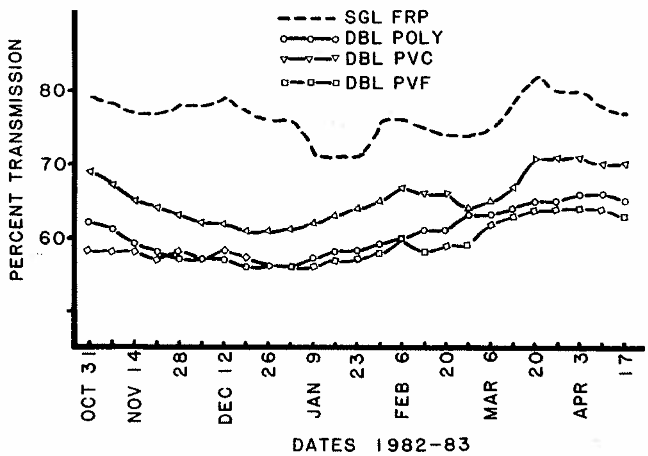

Fig. 2: Smoothed curve of percent of total outside solar radiation received at plant level (3 ft above ground surface) under four different greenhouse glazings from 15 October 1982 to 15 April 1983.

The poly and PVC covers were similar and PVC had the highest percentage of total transmission of the double covers. There was no transmission difference for PAR between double PVF and polyethylene. The highest percentage transmission was found under the FRP cover.

The quality of sunlight transmitted through each cover did not differ from the outside; however, the intensity varied (Fig. 3). The single FRP material had the best overall transmission, and there was little difference between the double layer glazings. The double PVF had higher transmission in the blue than polyethylene, but was lower in the yellow and red portion of the spectrum.

PAR readings were slightly higher than global radiation readings, because PAR was recorded at solar noon when the sun was at maximum altitude and minimum shade occurred in the structure, while TOTAL radiation was recorded continuously throughout the day. PAR and TOTAL radiation data under FRP were more comparable because of the light diffusion characteristics of the material.

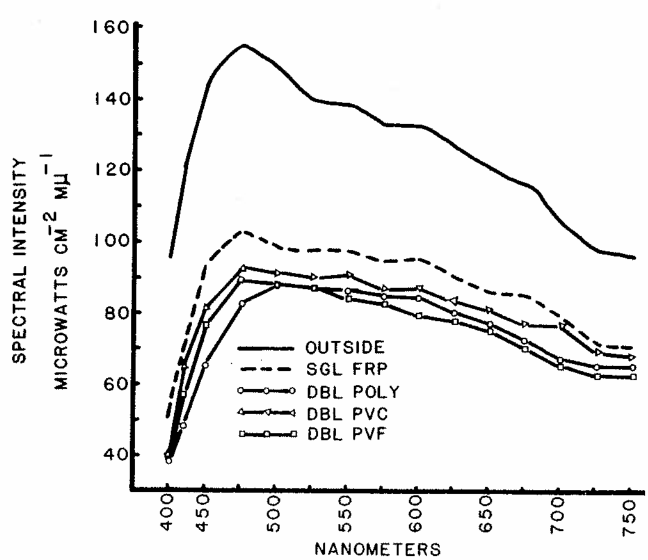

Fig. 3: Spectral transmission curves of radiation in the visible range (400-750 nm) received at plant height under four different plastic greenhouse covers. Measurements were taken 10 May 1983 at solar noon in cloudless conditions.

All covers periodically condensed water on the inside surface; however, radiation transmission of the double PVF material was affected the most. Both PAR and TOTAL radiation transmission were reduced 15% by the presence of condensate. The condensate was removed by periodically purging the panel cells with dry air. The PVC glazing formed a microscopic condensate film on the inside layer, which attracted dirt by the end of the experiment.

Natural Gas Consumption

Double glazed structures used 34 to 40% less natural gas than the single FRP greenhouse (Table 4). The differences between the double cover treatments however were not significant. Temperatures reached the cooling set point of 81F, one-half hour earlier in the double PVC treatment than in the other structures. Day and night natural gas consumption for February, 1983, substantiate the solar heating concept because the lowest daytime fuel requirements were in the double PVC treatment. The night fuel consumption, approximately 70% of the total fuel consumed, was in agreement with previous reports (CGGA Bul. 381).

Cover Durability

The double PVC cover did not effectively resist wind and winter snow. Winds of more than 50 mph and heavy snow seriously damaged the 4 mil PVC film. None of the other covering materials were affected (Table 5). Durability of single FRP and double PVF, 5 and 2 years old, respectively, at the end of the experiment, was excellent. The double polyethylene did not show any degradation.

Table 4: Natural gas consumption (cubic meters) required by greenhouse structures covered with four types of plastic glazings.*

	Month of February 1983		Season Fuel Consumption
Cover	Night	Day	15 Sept 1982 - 4 May 1983
SGL FRP	714 [64]	395 [36]	12095 (-)
DBL POLY	498 [65]	274 [35]	7434 (-39)
DBL PVC	524 [71]	210 [29]	7244 (-40)
DBL PVF	512 [65]	272 [35]	7958 (-34)
HSD 5%			(9)

[ ] Percent of total fuel consumed day and night.
( ) Percent of fuel used compared to FRP consumption.
* 1 cubic meter = 35.3 cubic feet.

Table 5: General characteristics of the covering materials.

Cover	Resistance to wind	Resistance to snow	Condensate	Durability
SGL FRP	++	++	+	++
DBL POLY	+	+	+	?
DBL PVC	--	--	+	--
DBL PVF	++	+	-	++

++ Very good
\+ Good
\- Poor
-- Very poor
? Unknown

Conclusion

The results of this study indicated that a single layer of FRP transmitted approximately 78% of outside global radiation through the 1982-83 winter months and the double layered materials transmitted 10 to 17% less. However, the double glazed greenhouses required 34 to 40% less natural gas than the single layer FRP. The durability of the double PVF (Tedlar) was excellent, but the 4 mil PVC, although it did have excellent radiation transmission and energy saving characteristics, was not adapted to the winter conditions of Colorado. Condensate formation was a problem in all structures, and reduced light transmission in the double PVF greenhouse significantly when dry air was not used to periodically purge the system.

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