COLORADO FLOWER GROWERS ASSOCIATION, INC.

IN COOPERATION WITH COLORADO STATE UNIVERSITY
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Advantages of Clear-day Climatic Regions for Greenhouse Production

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It is an accepted fact that geographical regions with a large number of clear days and high solar radiation have a considerable advantage over other areas with less light. However, it has not been shown just how great that advantage may be. Recent data suggests that the difference in plant growth as the result of variations in solar radiation from one region to another may not be directly proportional to the difference in solar radiation. In other words, as available solar radiation decreases, the reduction in yield is likely to become greater. Above certain values of solar radiation outside the greenhouse, the amount of usable energy is more or less constant. Below these values, the percentage of light available becomes increasingly less. Net radiation, or the amount of energy for growth, becomes very small.

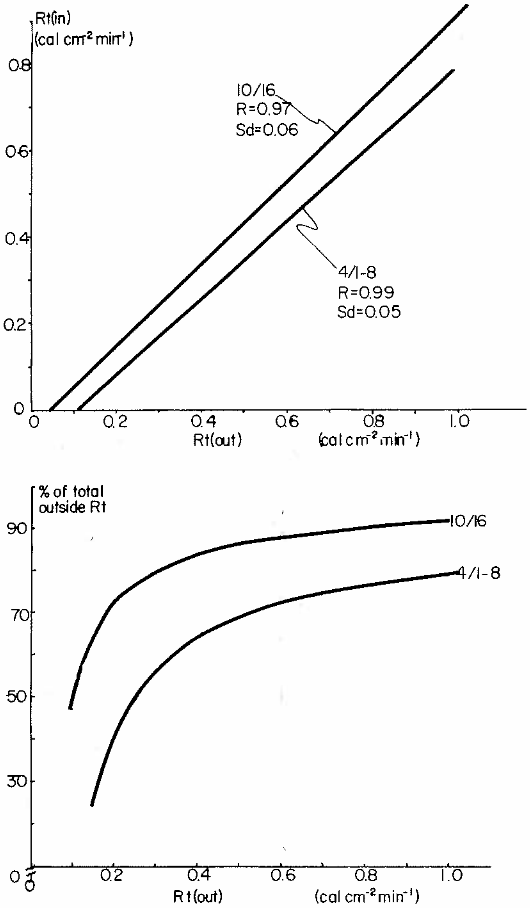
Methods

During the weeks beginning April 1, and October 14, 1967, the CSU weighable lysimeter recording system was used to determine radiant energy relationships in an east-west oriented, glass-covered greenhouse of conventional construction. Carnations for the April 1 recording period were benched August, 1966, and for the October 14 period, July, 1967. The instruments were standard Epply pyranometers employed by the U.S. Weather Bureau for measuring direct, sky and diffuse radiation between wavelengths of 0.3 to 3 microns. One pyranometer was located outside the greenhouse, one inside the greenhouse above the carnation plants, and one placed upside down above the plants to measure reflected radiation. Data inside the greenhouse was obtained at ten minute intervals for the October period, at hourly intervals for the April period.

Results and Discussion

Figure 1 shows the computed relationship between outside radiation and radiation within the greenhouse for the two recording periods. The standard deviations (S_d) are low, and the correlations (R) very high, indicating that such curves may be used with reasonable accuracy to give transmittancy of similar greenhouses either from Weather Bureau data or simple measurements of outside total radiation. The difference between the two curves represents variation in the position of the sun from one period to the next. Data for additional periods are now being analyzed. From a series of such measurements, we expect to be able to derive one or more curves that will represent the light transmission efficiency of the greenhouse. It should be possible to evaluate greenhouses and climatic regions on the basis of this information. The higher transmittance for the October 16 period resulted from the lower altitude of the sun, hence a more perpendicular angle of the sun's rays to the

Fig. 1. Relationship between outside solar radiation and radiation inside an east-west oriented, glass covered greenhouse. Upper: Computed regression lines for April and October, 1967. Lower: Ratio of solar radiation inside greenhouse to that outside (R_t (in) / R_t (out)) expressed as a percentage of that outside the greenhouse.

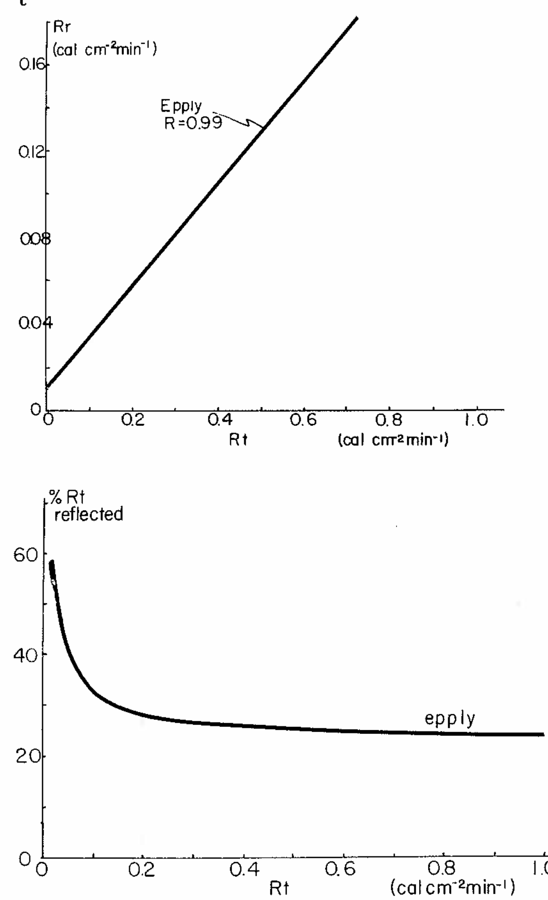


sloping greenhouse roof, resulting in higher light transmittance. The slope of the line is a constant that may be used to characterize the greenhouse.

When the data is plotted as a percent of total outside radiation transmitted, the lower part of Fig. 1 shows that the actual amount of radiation inside the greenhouse decreased rapidly as total outside radiation decreased below approximately 0.4 cal. cm^{-2} min^{-1}. As a general rule, outside radiation in Colorado, on clear days, will exceed 0.4 cal. at any time of the year. On cloudy days, at any time of the year, radiation may drop below 0.4, depending upon cloud cover, and may even reach values less than 0.1 during the winter. It is not so much the radiation intensity during a clear day that determines suitability of a geographical location for greenhouses, but the number of clear days.

The problem of obtaining usable radiant energy for growth is compounded when the reflectivity of the crop inside the greenhouse is taken into account. Figure 2 (upper) shows the relationship between radiation reflected (R_r) and total radiation inside the greenhouse (R_t). The fact that there was still outgoing radiation at zero R_t was due to the fact that the warm plants will radiate energy to the cool glass and sky. This radiation is in the invisible infrared part of the spectrum. As with Figure 1, plotting the reflected radiation as a percent of total radiation (Fig. 2 Lower)

Fig. 2. Relationship between total solar radiation inside an east-west, glass covered greenhouse, and the radiation reflected (R_r) from carnation plants. Upper: Computed regression line. Lower: Ratio of total radiation inside the greenhouse to that reflected (R_r/R_t), expressed as percent of total reflected, compared with R_t.



showed that the outgoing radiation became a greater part of the total as incoming radiation became less than 0.2 cal. cm^{-2} min^{-1}. Above 0.2, reflectivity of the plants was more or less a constant at about 25%. That is, 25% of the incoming radiation above levels of 0.2 cal. is reflected and not available for photosynthesis or evaporating water.

In Table 1, the October data was used to calculate actual energy available to the carnations for various levels of outside total solar radiation. At outside levels of 0.4 cal. and above, the net percent of total

Table 1. Computations of net solar radiation within an east-west oriented glass-covered greenhouse, at varying levels of total outside radiation for October 16, 1967. Values in cal. cm^{-2} min^{-1}.

Total outside	Total inside	Percent transmitted	Total reflected	Percent reflected	Net available	Net percent of total outside
0.8	0.719	89.8	0.178	24.8	0.541	67.6
0.6	0.527	87.8	0.133	25.2	0.394	65.7
0.4	0.335	83.8	0.088	26.3	0.247	61.8
0.2	0.143	73.0	0.043	30.1	0.100	50.0
0.1	0.047	47.0	0.020	42.6	0.027	27.0

outside radiation available varied within 10%. However, when outside radiation dropped 0.2 cal. below 0.4, the net percent dropped more than 11%; and with a further change of only 0.1 cal., the corresponding change in net percent was nearly 25%.

There are some implications: 1) The number of clear bright days may be considered as the most important criterion for locating a greenhouse range in any region. The effect of air pollution (smog or dust) should be considered. 2) The greenhouse design should be such as to maximize light transmittance during the low light periods of the year (late fall through early spring). We have known these points for several years, but perhaps we can now put a value upon them in considering location and greenhouse design.