COLORADO FLOWER GROWERS ASSOCIATION, INC.

IN COOPERATION WITH COLORADO STATE UNIVERSITY
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Some Observations on Radiation in Greenhouses

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The conversion of solar radiation into growth in greenhouses is one of the most complicated aspects of the environment. The agronomist may assume that his field is infinite in size, the upper portion behaving as a flat surface. Therefore, any flat surfaced instrument placed above the crop to measure solar radiation behaves as a small portion of the crop below it. He need not even consider the change in the sun's position during the day. Not so in greenhouses where structure, orientation, kind of cover, heating system and arrangement of plants inside may modify radiation. In fact, we do not know how to measure radiation received by carnations in a greenhouse bench. The use of instruments presently available may be subject to unknown errors - aside from those due to location in respect to plant and structure. The use of different covers may modify the amount and quality of radiation received, and completely alter plant characteristics. But to evaluate effect of radiation on growth, it is necessary to start someplace.

Methods

Some results on radiation transfer were presented in CFGA Bulletin 217. Those data were reported for an east-west oriented, glass covered greenhouse, with the instruments located 5 to 10 inches below the south roof, midway between eave and ridge to avoid unwanted shading effects by the superstructure. The following year (1968-69), the apparatus was moved to a north-south oriented, fiberglass covered house, where the instruments were located 10 to 20 inches below the west roof, midway between ends and the eave and ridge.

The sensors employed were: 1) an Epply pyranometer, measuring total shortwave, incoming radiation, between the wavelengths of 0.3 to 3 microns, and located outside the greenhouse, 2) an upward facing Epply, with similar characteristics inside the greenhouse, 3) a downward facing Epply for measuring reflected shortwave radiation from the crop, inside, and 4), a net radiometer inside which measured both incoming and outgoing shortwave and longwave radiation between wavelengths of 0.3 and 25 microns. This last instrument automatically subtracted outgoing radiation from incoming, giving the actual energy received for use in photosynthesis and water loss. Measurements were made during the daylight hours at 10-minute intervals, the data being subjected to a moving means, smoothing process.

The Sun's Position and Total Shortwave Radiation Inside

It is obvious that the amount of radiation coming into the greenhouse will depend upon the sun's position in the sky and the orientation of the greenhouse structure. For purposes of discussion, Fig. 1 plots the path of the sun in respect to north-south and east-west oriented greenhouses for the longest and shortest days of the year at Fort Collins. On June 22, the sun will rise and set north of the east-west axis. But, at 40°N. latitude its maximum angle above the horizon, at noon, will be 74°, and south of the east-west axis. As the days become shorter, the azimuth moves further south, with maximum altitude becoming less and less until December 22, at which time the maximum solar altitude at Fort Collins will be 27° at noon. As one moves north, the sun will rise and set further north, during the summer, but its altitude at noon will be less than 90° at Fort Collins. This is a primary reason for Whittle and Lawrence's conclusion (5) that an east-west greenhouse was most efficient in England - since maximum transmittance is obtained when the rays from the sun are perpendicular to the greenhouse roof.

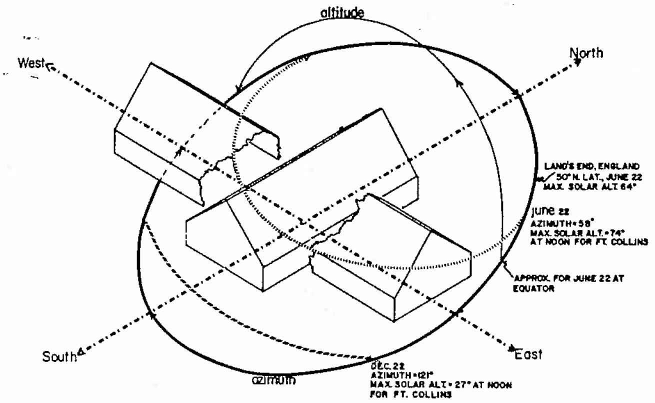

Fig. 1. Path of the sun during shortest and longest days of the year at Fort Collins in respect to an east-west and a north-south oriented greenhouse. Altitude is the angular distance of the sun above the horizon. Azimuth is the angular distance the sun rises or sets at the horizon. Maximum solar altitude at Fort Collins at noon varies from 27° on December 22 to 74° on June 22. At the equator, on the same date, the entire path of the sun will be north of the east-west axis and slightly less than 90°, being directly overhead (90°) on the vernal equinox, and south on December 22.

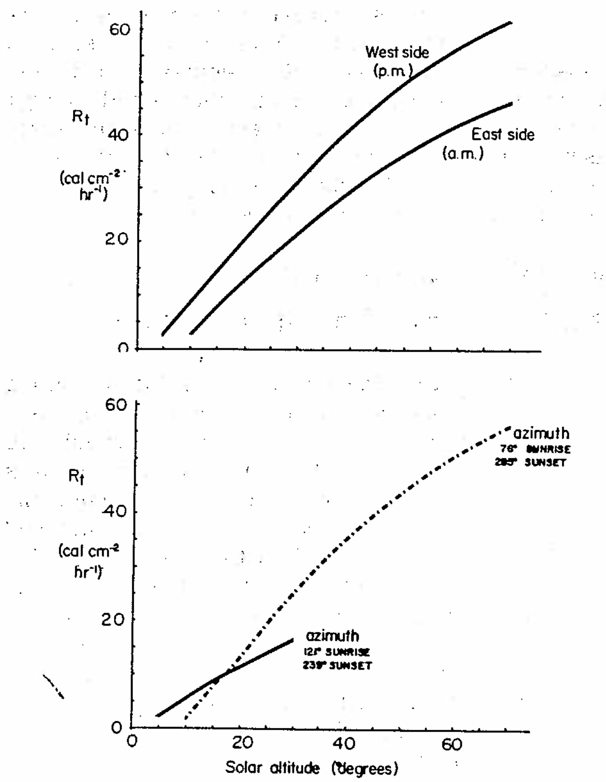

Fig. 2. Upper: Total shortwave radiation inside a fiberglass greenhouse with a north-south orientation during the morning and afternoon. Instrument for measuring the radiation located under the west facing roof. Lower: Total shortwave radiation inside a fiberglass covered greenhouse with north-south orientation, at two times of the year, compared with solar altitude. Short line for December, longer line for April.

The effect of solar altitude on total shortwave radiation inside the greenhouse is given in Fig. 2 (lower), where radiation inside is compared with angle above the horizon at two different times of the year for the fiberglass greenhouse. This also emphasized the importance of clear days. At outside radiation levels below 20 gm-cal/cm^2/hour, very little growth may occur, and any cloudy conditions only serve to make a bad situation worse. We can appreciate the reason for the considerable research by European investigators on greenhouse transmittance (e.g., 1, 2, 5).

It is possible to deduce from Fig. 1 that advantages of an east-west greenhouse over a north-south house disappear as one moves closer to the equator. At the equator, the sun will reach a 90° altitude, and moves north of the east-west axis at noon during our summer. For maximum solar radiation inside, a flat-roofed house might be more efficient.

Fig. 2 (upper) shows radiation transmittance as a function of the sun's position in a north-south fiberglass greenhouse. With the instruments located under the west roof, more energy was received with the sun in the western hemisphere. The situation probably would have been reversed had the instruments been located under the east roof. This leads to another climatic implication in radiation transfer in north-south greenhouses. The presence or absence of persistant cloudy conditions during morning or afternoon will interact with the greenhouse orientation. In Colorado we quite often have cloudy afternoons during the summer, which probably reduce radiation much below what might normally be received in north-south houses. However, it has been observed in the field on numerous occasions, that higher radiant intensities may be obtained during partly cloudy conditions due to reflection from the cloud's undersurfaces (3).

When total shortwave radiation inside the north-south fiberglass, and east-west glass houses were compared with solar altitude under all conditions, there did not appear to be much choice between them (Fig. 3). Various regressions were run on the data in order to determine the importance of solar altitude and azimuth. The inclusion of azimuth did not add significantly to the correlation between solar position and radiation inside. For practical purposes solar transmittance may be considered, under the conditions in which these data were obtained, as a function of solar altitude alone. At latitudes approximating Fort Collins' there is probably an advantage of an east-west house over a north-south house. There are two factors that are more important than house orientation. First, the closer a greenhouse can be located to the equator the better the potentialities for maximum radiation transfer. Second, regions with a preponderance of clear days offer maximum advantages.

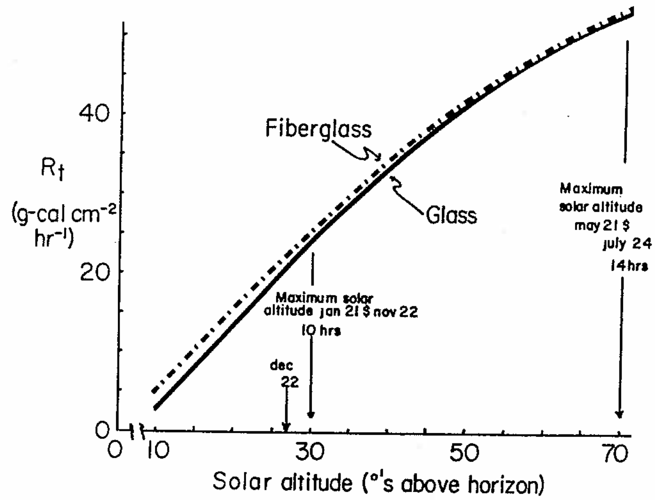

Fig. 3. Relationship between mean total, shortwave radiation inside a north-south fiberglass, and an east-west glass greenhouse as a function of solar altitude.

Radiation Inside the Greenhouses

Fig. 4 presents typical radiation values obtained in the fiberglass house for selected days. Similar curves were also obtained for the glass house. Outside, inside and reflected radiation went to zero during the night, but net radiation was usually negative at night since the outgoing, thermal radiation exceeded incoming. Reflected radiation varied only slightly in comparison to the other three, with net radiation almost less during the day than total inside or outside radiation.

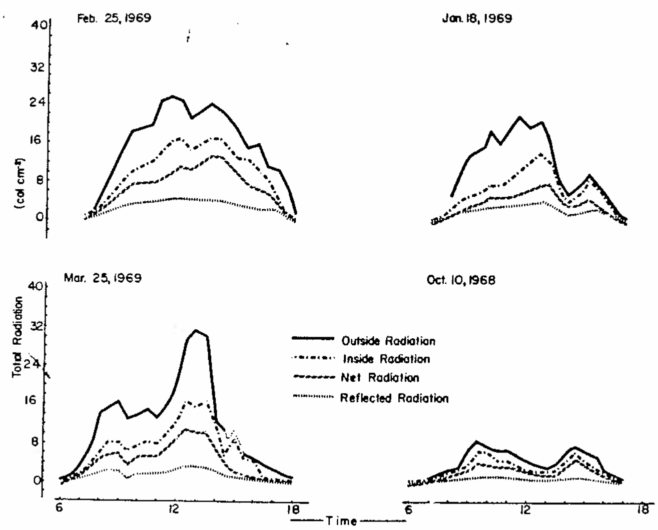

Fig. 4. Typical radiation measurements in a fiberglass covered greenhouse on selected days.

The values of total shortwave radiation inside and outside the greenhouses were grouped regardless of solar position and external weather, and the actual radiation transmitted compared on the basis of that outside. In Fig. 5 (lower), total inside (R_t) is plotted as a function of total outside (R_o). At high outside radiation levels, fiberglass transmitted less than glass, but this difference gradually disappeared as outside radiation decreased. In fact, if inside energy

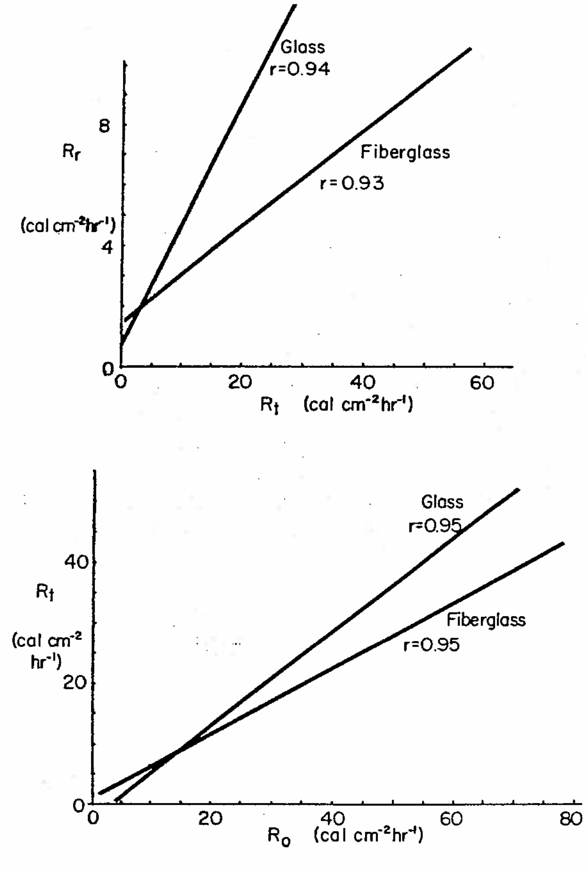

Fig. 5. Upper: Relationship between reflected radiation (R_r) and total shortwave radiation (R_t) in glass and fiberglass greenhouses. Lower: Relationship between total shortwave radiation inside and outside fiberglass and glass covered greenhouses.

was plotted as a percentage of that outside, the behavior of fiberglass was directly opposite to that of glass as reported in Bulletin 217, with maximum efficiency at the lowest outside light levels. Goldsberry (4) has shown that differences between covers become much less at low radiation levels, and, if we consider instrument accuracy in addition to the small measured differences, there is no advantage of fiberglass over glass, or vice versa, at outside radiation levels much below 20 gm-cal/cm^2/hr. We have generally come to the conclusion in Colorado that maximum radiation transmittance is undesirable for best plant growth, and that the primary advantage of fiberglass is its lower radiation transmittance under high light conditions typical of this area.

Reflected Radiation

Aside from the effect of cover on total shortwave radiation transmitted, the cover also had considerable effect on the radiation reflected from carnations. Whether this resulted from a change in the characteristics of the carnation leaf or directly from the cover is not known. Reflectivity at high radiation levels was much less under fiberglass than under glass (Fig. 5-upper). Reflected radiation, as measured in this study, could be transmitted by the greenhouse covers since it consisted of wavelengths less than 3.0 microns. Both covers are opaque to wavelengths of 3 to 25 microns (Goldsberry and Vickers, unpublished data). The curves, in effect, state that more shortwave radiation was absorbed by plants under fiberglass than for carnations under glass. What implications this might have in terms of carnation growth is unknown.

Net and Total Inside Shortwave Radiation

A consideration of net radiation is more complicated than either ingoing or outgoing shortwave radiation. The heating system, depending upon its location in respect to the plants may increase energy absorbed due to thermal longwave radiation. The use of infrared heating systems is an example of thermal radiation. Similarly, plants may radiate longwaves to a cold greenhouse roof, decreasing net energy. Or if the sun heats the roof, radiation may occur to the carnations resulting in a net increase in energy. In general, it was found that the lower the outside shortwave radiation (R_o) in conjunction with low outside temperatures, the smaller the amount of net radiation inside the greenhouse. This is shown in Fig. 6 which compares the ratio between net and total radiation for fiberglass (upper) and glass (lower) under different conditions. On May 20, the sky was overcast with outside temperatures about 10^o below the inside.

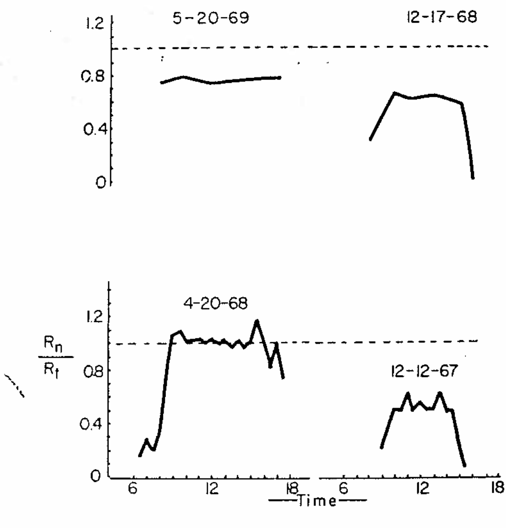

Fig. 6. Variation of the ratio between net radiation (R_n) and total shortwave radiation (R_t) inside glass (lower) and fiberglass (upper) greenhouses on selected days.

December 17 had moderately high outside radiation, but the temperatures were close to freezing. On December 12, the sky was also clear, but with low outside temperatures. However, on April 20, temperatures outside were close to those inside, with radiation intensities approaching 60 gm-cal/cm^2/hr. Under the latter conditions, net radiation increased, and occasionally exceeded total inside radiation, whereas in all the others, the outgoing thermal and shortwave radiation reduced the amount of energy absorbed by the carnations below the incoming shortwave sunlight. These results imply that as total outside radiation decreases during the winter months, an increasing proportion of the energy in the greenhouse is unavailable for food production and water loss, a considerable portion likely being used to maintain plant temperature. The results also imply that greenhouses are really extremely inefficient structures for plant production under low light conditions and in cold regions. In such climates artificial, high intensity lighting is likely to be more practical. If we could rely entirely on artificial irradiation in growth rooms, we might be better off in the long run.

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The following abstracts are from the 1968 Annual Report of the Glasshouse Crops Research Institute, Rustington, Littlehampton, Sussex, England.