CCEA Newsletter

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CCEA is a research organization dedicated to the improvement and vitality of the Controlled Environment Agriculture Industry. CCEA is funded by Industrial and Grower Partners who contribute a yearly partnership fee. Satellite partnership is also available to growers. Information about **CCEA** is available from:

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Vision Statement

CCEA, The Center for Controlled Environment Agriculture of NJAES of Rutgers University, a partnership among growers, industry, and researchers, will devote itself to research and transferring information required for an economically viable and environmentally aware controlled environment agriculture industry. We will particularly strive to identify future trends, critical issues, appropriate emerging technologies and provide leadership for opportunities which challenge world-wide controlled environment agriculture in the 21st century.

Improving two-way communication

A.J. Both, Director CCEA

In early November, the Dean of Research at Cook College awarded a $3,000 grant titled: "Reinvigorating a healthy dialogue with New Jersey's Greenhouse Industry about its partnership with research and extension at Cook College". The goals of the proposal are to:

1) Identify several research areas that have the promise of significantly impacting the industry,
2) Identify sustainable funding sources for the research,
3) Set up a communication forum where all stakeholders can have meaningful input,
4) Integrate multiple disciplines, including industry representatives, in a single problem solving team,
5) Maintain and further develop the current Greenhouse IPM Program.

We, a group of 25 extension agents, specialists, and faculty, are working on identifying key greenhouse industry representatives. We propose to organize several informal meetings to allow for a free flow of ideas. The outcome of these meetings will serve as a basis for a more substantial program development grant that will hopefully provide funding for continued research in those areas that were identified during our dialogue with the industry. The funding is provided by the New Jersey Agricultural Experiment Station and its support indicates a strong commitment to the New Jersey Greenhouse Industry.

It is obvious that this proposal is in line with the objectives of CCEA. Therefore, I would like to ask you to identify those issues that you think are important to our industry (and not necessarily limited to New Jersey). How can CCEA improve its communication with its stakeholders (primarily our grower and industry partners) and what are the best vehicles for that communication (meetings, newsletters, web sites, etc.)? Any suggestions you may have are much appreciated and will be duly considered. What better way to start the new millenium (January 1, 2001!) with improved communication and a renewed and better sense of direction!

Happy New Year!

PHYSICS OF THE GREENHOUSE ENVIRONMENT

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ABSTRACT

Various aspects of radiation physics in the greenhouse environment are discussed in this study.

The so-called "greenhouse effect" is a very misleading term. Although the term originated from the greenhouse itself, the higher temperature in a greenhouse is not due to the same effect which is predominant in global warming. On the contrary, air temperature in a greenhouse is sometimes lower than that outside.

Thick films seem to be effective as heat barriers, but convective heat transfer resistance of the air inside the greenhouse is a much larger factor than the resistance to heat flow through a film.

Film color difference is very clear to the human eye, but the differences in transmitted energy through various colored films are not so significant. Plant response to radiation is dependent on wavelength and it is different from the sensitivity of the human eye. Lux meters are only indicators for the human eye and are not suitable for plants. These facts are demonstrated by numerical simulations and experimental data.

Introduction

Greenhouse structures including mulch, floating mulch and small tunnels are mainly constructed with transparent covering materials and are simple, but energy transfer mechanism through greenhouses are complicated and should be understood precisely. Several facts which are misleading are explained and demonstrated by numerical simulations and measured data.

Greenhouse Effect

The so-called "greenhouse effect" is a very misleading term. Although the term originated from the greenhouse itself, the higher temperature in a greenhouse is not due to the same effect which is predominant in global warming. On the contrary, air temperature in a greenhouse is sometimes lower than that outside.

The definition of greenhouse effect is that the inside of a greenhouse is warmer than the outside, and this phenomenon due to trapping of radiation is described as "mouse trap theory." Solar radiation enters a greenhouse because it is shortwave and can pass through glass or plastic sheets, but once it is absorbed on the ground or by plants inside the greenhouse, it cannot go out because it has become longwave radiation (see Fig. 2). Businger (1963), who studied the greenhouse physical environment, demonstrated the amount of warming due to the greenhouse effect by steady-state analysis. His conclusion was that this radiation absorbed by the covering accounts for only 20 to 30% of the warming in a greenhouse, and the main cause of warming is a lack of ventilation in the greenhouse. One of the definite supporting studies is the experiment in 1900 by Wood in which he compared two model greenhouses (Businger, 1963); one was conventional glass type, and the other was constructed with quartz which is transparent to longwave radiation. He found very slight higher inside air temperature in the greenhouse with the glass cover compared to the quartz-covered greenhouse. Businger suggested the use of the term "atmospheric effect" for global warming of the Earth, but the expression "greenhouse effect" was already popular and easy to remember since greenhouses are so familiar in our lives.

Fig. 1 shows the effect of emissivity of the cover and air flow rate on maximum inside air and soil surface temperatures.

In this study, simulation analysis using a dynamic model was conducted to examine the influence of various factors on temperatures in a greenhouse. The dynamic greenhouse model used in this study was fully described by Takakura (1993), and in the first test, only two parameters, emissivity of the cover and air flow rate, were changed from the original model.

Typical results for a simulation run with 20°C outside air temperature are shown in Fig. 1. It is clear that the inside air temperature is almost the same as the outside when air flow rate is high, but the temperature inside is much higher than the outside when the air flow rate is low. This result confirms Businger's explanation that low air flow rate inside the greenhouse is the key to the temperature increase. On the other hand, results for different emissivities tell a different story from his explanation because covering material with higher emissivity does not cause higher inside air temperature nor soil surface temperature. This means that the so-called "greenhouse effect" of radiation absorption by the covering material does not exist in this case. Several other runs were conducted for sensitivity analysis of emissivity, and it was found that radiation heat transfer around a greenhouse is well connected to and is not isolated from other heat transfer paths such as convection and heat capacity of the covering material.

Fig. 2 shows a comparison of the mechanism of the "greenhouse effect" in the global environment and the heat transfer mechanism around a greenhouse. It is understood that the Earth atmosphere plays a similar role to the glass sheet in the greenhouse, and it sets a mouse trap. However, it is clear from the same figure that the difference is the convective heat transfer from the covering surfaces for the greenhouse, but not from the Earth's atmosphere. Through several simulation runs, it was found that in addition to convective heat transfer, the very small heat capacity of the covering material plays an important role in the radiation balance for a greenhouse. If the covering material is a double film layer with a good insulation air gap between, the effect of emissivity on inside air temperature is reversed; that is, higher emissivity results in higher inside air temperature (Takakura *et al*., 1999). It is well known, on the other hand, that a glass sheet known as Horti-Plus which has an outer coating to reduce emissivity to around 0.25 was developed to reduce radiation loss and retain heat inside. The large heat capacity of the soil layer, not high emissivity, is the main factor in keeping soil temperature high, but this is not the case for plant leaves.

Film Insulation

Thick film seems to be effective as a heat barrier, but convective heat transfer resistance of the air inside a greenhouse is a much larger factor than the resistance to heat flow through a film. A greenhouse can be insulated, of course, by applying covering materials with low thermal conductivity. A simple form of insulation can be realized by two plastic films with a small air gap between.

Heat flow from the inside air to the inside covering surface is the same as that through the covering material by conduction, and is the same as that from the outside covering surface to the outside air. The heat flow is continuous. If there is a large resistance in this flow, the total flow is reduced. In conventional greenhouses, glass of 4 mm thickness is used, and plastic houses use film of 0.1 mm thickness. The difference in thickness between these two covering materials is 40 times. Resistance to heat conduction through rigid materials is proportional to thickness and is inversely proportional to thermal conductivity of the material. Resistance for the glass is then about 1/200 $^oC\ m^2/W$ and that for plastic film is about 1/6000 $^oC\ m^2/W$. The heat transfer coefficient at the outside surface due to convection and radiation is 15 $W/m^2/^oC$ and is relatively large. On the other hand, the heat transfer coefficient at the inside surface is mostly due to free convection and is about 5 $W/m^2/^oC$. Resistances for these surfaces are then 1/15 and 1/5 $^oC\ m^2/W$, respectively. Of course these values will change due to factors such as outside wind. Since the heat flow is continuous, all resistances are located in series; that is, from the inside to the outside, resistance at the inside surface is 1/5, in the middle 1/200 for glass and 1/6000 for plastic film, and at the outside 1/15. The resistance in the middle is very small and is less than 2% of the total for glass and for plastic. The main resistance is determined by that at the inside surface, and the contribution of the resistance through covering materials is negligible. It means that the thickness of the covering material, either glass or plastic, does not have a major role in the heat flow through the covering materials.

Since the thermal resistance of the covering material is inversely proportional to the thermal conductivity, good insulation materials such as two thin film layers with a very thin air layer between have a large thermal resistance although the thickness of these materials is very thin.

Photoselective Films

Film color difference is very clear to the human eye, but the differences in transmitted energy through various colored films are not so significant. Plant response to radiation is dependent on wavelength, and it is different from the sensitivity of the human eye. Fig. 3 shows measured transmissivity curves of two different photo- selective films. The films are labeled blue and violet according to how they appear to the human eye. The difference between the two curves is large in the wavelengths under 400 nm, but in this region our eyes cannot see at all, that is, cannot see the difference. Therefore the only difference we can see is the small difference in the wavelength range of 500 to 750 nm. The transmissivity difference is only several percent of the total. The radiation energy transmitted through these films is almost the same. Figure 3 shows the transmissivities of two different films.

Photosynthetically Active Radiation

The importance of the spectral response of photosynthesis has been discussed in several papers (*i.e.,* Barnes *et al*., 1993), but it is not yet fully understood. Lux meters are only indicators for the human eye and are not suitable for plants. Lux meters have a filter with sensitivity very similar to human eye. The sensitivity is highest in the middle green region and lower in the other regions. In contrast, Fig. 4 shows sensitivity curves for the photosynthetic response of a typical leaf and for an idealistic photon flux meter which is more suitable for measuring light characteristics for plants. These curves are different from that of a lux meter. Instruments to measure photon flux should have sensitivity as close as possible to the solid curve in the figure and not to the dotted curve. The discrepancy between the two curves results in another response difference, and furthermore, real response curves of photon flux meters are different from this dotted curve. For example, suppose we have a meter with a response curve similar to the dotted curve shown in the figure. If plants are illuminated by light with wavelengths only in the region from 700 to 800 nm, then the meter would show 0 output which means no energy for photosynthesis, even though light energy for photosynthesis is actually present.

Literature Cited

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Horticultural Engineering Website

http//aesop.rutgers.edu/~horteng

There are links to other University websites, reference sources for the controlled environment industry and helpful cooperative extension sites. Drop in and learn more about us and our research activities and other websites which can be an asset to your operation and programs. New pictures of the Rutgers open-roof research greenhouse and the finished floor are posted.

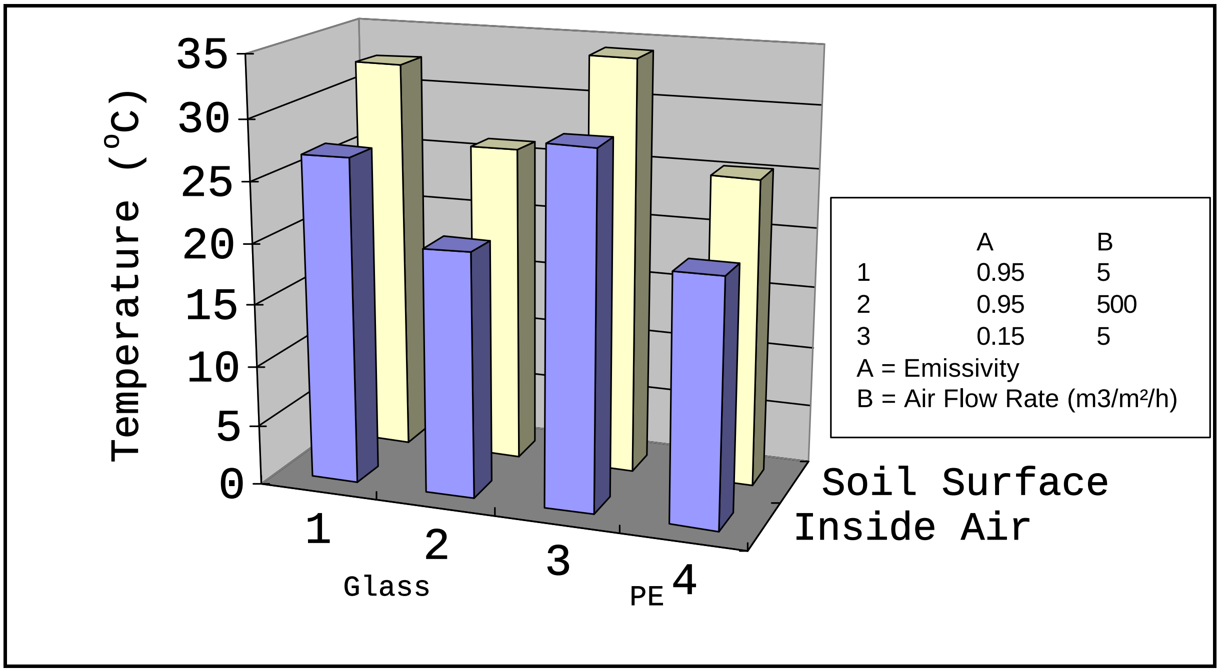

Fig. 1. The effect of emissivity of the cover and air flow rate on maximum inside air and soil surface temperatures.

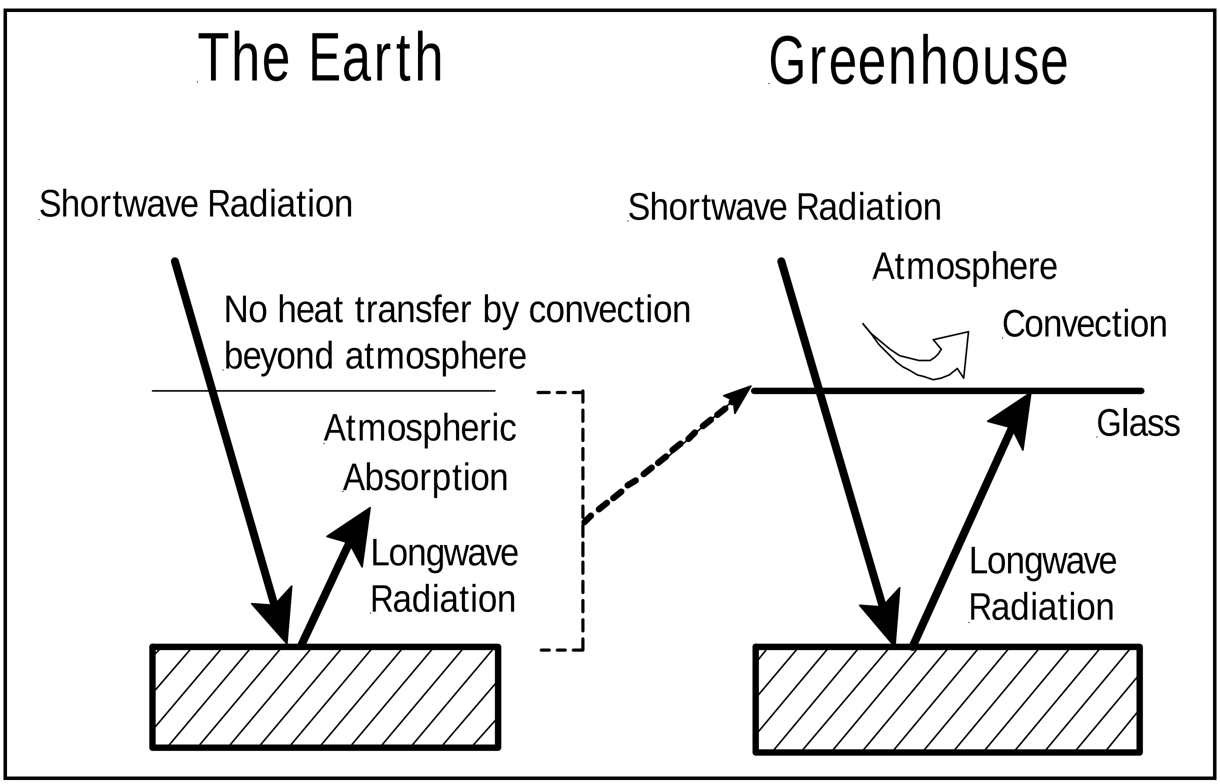

Fig. 2. Greenhouse effect in the global environment is not the same as the greenhouse effect in the greenhouse.

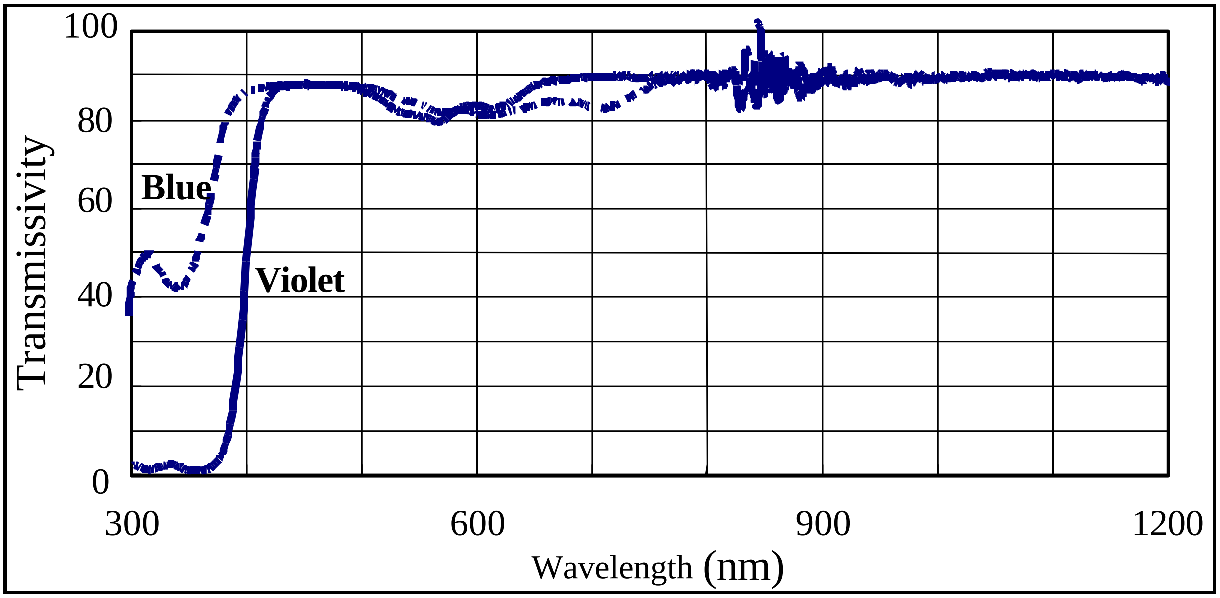

Fig. 3. Transmissivities of two different films

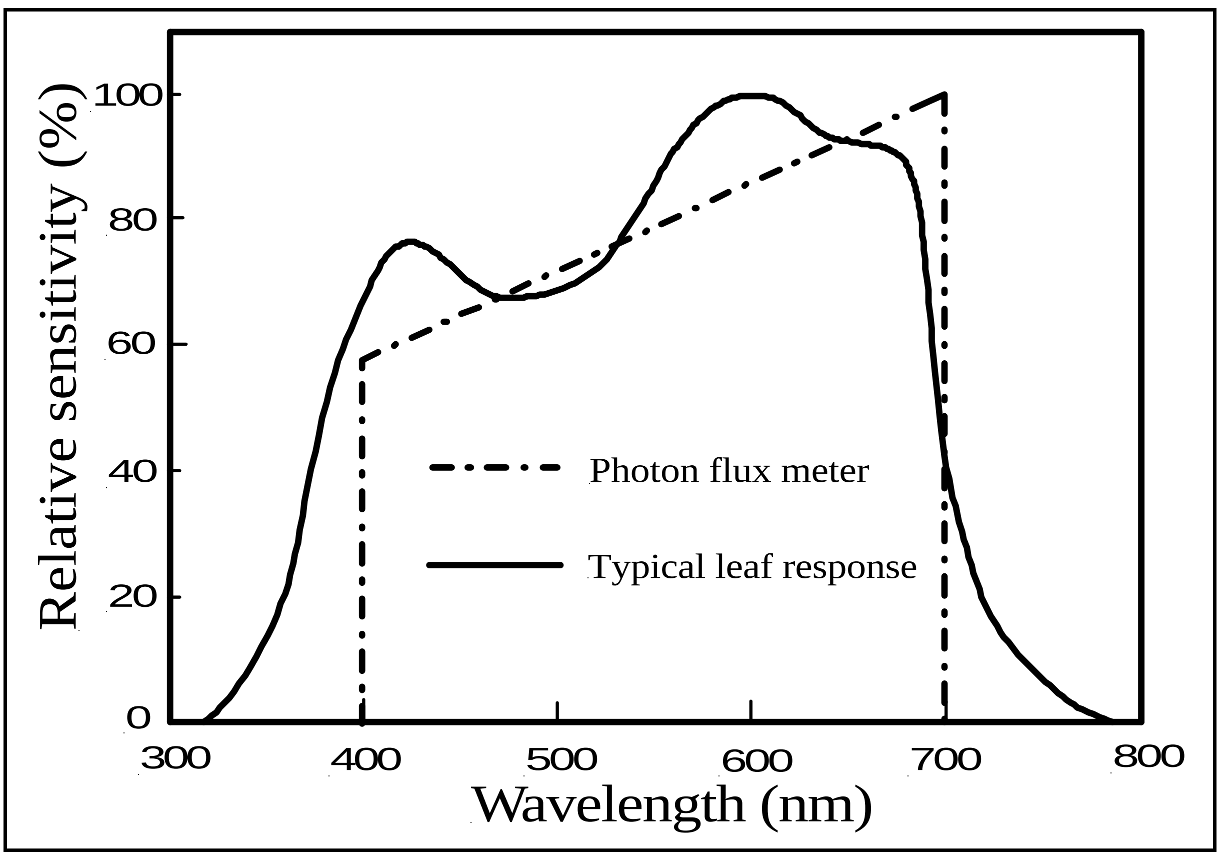

Fig. 4. Relative sensitivities of photon flux meter and average leaf response to photosynthesis.