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Food Crops

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Understanding direct vs. diffuse light in the greenhouse environment

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The diffuse light component in sunlight delivers light to underside of plants where direct light cannot reach. Therefore, previous research showed the yield enhancement of greenhouse crops by installing diffuse glazing materials. This article introduces the basic understanding of diffuse light, its benefit by improving horizontal and vertical light distribution, and additional considerations in designing a greenhouse that can achieve high crop productivity.

Diffuse light basics

Figure 1. Looking through a diffuse film (right) and a non-diffuse film (left). These films have nearly identical PAR transmission. Photo by C. Kubota.

Sunlight reaches the ground in two forms – direct light and diffuse light. Direct light is the photons traveling straight from the sun. Therefore, the incident angle of the direct light is determined by the solar elevation (or also known as solar zenith angle). In contrast, diffuse light is 'omnidirectional' as it is light scattered by atmosphere (clouds, aerosols, and other small particles, etc.) and reflected by surrounding objects of the measurement site. The omnidirectional nature of diffuse light means it can reach the area shaded by obstacles blocking direct light. At a given time of the day and location, the ratio between diffuse and direct light in sunlight is largely dependent on the weather conditions (cloudiness) and moisture content in the air. On overcast days, sunlight at a given time has a low intensity (PPFD – photosynthetic photon flux density) and consists mostly of diffuse light, while clear sky days, sunlight has high PPFD and typically is a mix of direct light and diffuse light at varied ratios. For crops growing at high density (a high leaf area index), diffuse light is an important attribute of plant light environment, since shaded leaves mainly receive diffuse light to drive their photosynthesis. Diffuse light is also important for more uniform light distribution. This is why on overcast days (100% diffuse light), there are no clear shadows created over the ground.

Diffuse materials for greenhouse glazing

One of the key design considerations for a new greenhouse is the type of glazing to install. Most glazing materials (glass, ETFE film, etc.) have options to add diffuse characteristics (Figure 1). Diffuse materials can partially convert direct light to diffuse light by scattering light upon transmission through the material. However, in some cases particularly with a low-cost film glazing (such as polyethylene film), diffuse options may significantly reduce the overall transmission of photosynthetically active radiation (PAR). Therefore, it is important to understand PAR transmission (ideally hemispherical transmission, not just perpendicular beam transmission) of a diffuse glazing material. However, the accurate transmission measurement of diffusing material is not easily done since it requires specialized equipment. Unfortunately, as far as we know, there are no public institutions in North America who have the capability of evaluating glazing materials light transmission characteristics accurately. Wageningen University LightLab in the Netherlands offers unique measurement services for evaluating greenhouse glazing materials.

Some thoughts on impact of diffuse glazing in greenhouse orientation

Enhanced diffuse light without reducing PAR transmission can benefit greenhouse crop production in many ways. Previous research conducted in the Netherlands showed 4.3-9.7% yield increase in cucumber in a greenhouse with diffuse glass compared with clear glass with the same hemispherical PAR transmission (Hemming et al., 2008a; van Steekelenburg et al. 2025). Greenhouse engineers and suppliers can also take advantage of diffusing nature of the glazing into design consideration. Greenhouse orientations largely affect the spatial uniformity of light inside the greenhouse. Intensive research was done many years ago to find the sunlight transmission in greenhouse as affected by orientation, design, season, and latitudes of the site (e.g., Kozai 1977; Kozai and Kimura, 1977). These theoretical analyses showed that east-west (E-W) oriented greenhouses are more advantageous for greater average winter light transmission while north-south (N-S) oriented greenhouses are preferred for more uniform light distribution over the plants. Gutters are the most significant structural components creating shadows over the floor. With a N-S orientation, a more uniform light environment is created as shadows created by gutters move from west to east as the sun moves from east to west (in Northern hemisphere), making N-S orientation preferred for gutter-connected multi-span greenhouses. Conventional recommendation as stated in the American Society of Agricultural and Biological Engineers (ASABE) standard is shown in Box 1. The particular specification of latitude "40 deg N latitude" is due to the low solar elevation in winter, which creates greater reflection of sunlight at glazing surfaces. Orienting greenhouses E-W can improve the incident light angles and reduce the reflection (and thereby increase the transmission).

Box 1. Recommendation found in ASAEB EP460 standard 'Commercial Greenhouse Design and Layout (ASAEB, 2004).

"6.2.3 The ridge in either single span greenhouse or a gutter-connected range should run east-west in areas above 40 deg N latitude to transmit maximum winter sunlight to the plants. Gutters shading the same area during each day may result in uneven growth in some plants. The potential for uneven growth in east-west ridge orientation is a tradeoff against general reduction in winter light if ridges run north-south".

Figure 2. Greenhouse covered with a diffuse film does not create distinct shadow patterns on the floor (right). In contrast, a reference greenhouse covered with a clear film shows shadows by greenhouse structural components. Both photos were taken on the same clear sunny day (photo credit by AGC Green-Tech Co., Ltd.)

However, we must be aware that these recommendations were originally developed based on simulating direct light transmission in the greenhouse. One question that is warranted for further evaluations is the recommended greenhouse orientation when high-transmitting diffuse type glazing is employed. With the capacity of improving the horizontal and vertical light distribution of sunlight in the greenhouse, E-W greenhouse orientations may be more advantageous for both single and multi-span greenhouses covered with diffuse glass or film glazing. Short stature crops such as pot plants and leafy greens would enjoy the high PAR transmission with greater uniformity in PPFD distribution. Tall, high-wire crops (e.g., tomato, cucumber, and pepper) would receive more light in the lower side of plants. However, they may still need to orient their crop rows in N-S (in E-W greenhouses), depending on the light distribution.

Another consideration is the regional climate conditions that affect the efficacy of diffuse type of glazing. Amount of diffuse light in sunlight is dependent on the climate conditions. For example, monthly averages of diffuse light percent in sunlight are mostly above 70% in temperate oceanic climate in the Netherlands while they are less than 30% in semiarid climate in the Southwestern U.S. (Hemming et al., 2008b). Impact of diffuse glazing in the greenhouse may be more pronounced in areas with lower diffuse light.

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