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Application of a new film for horticultural use to convert UV-light to photosynthetic active radiation

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Abstract

Except for near visible light waves (about <340 nm), ultraviolet radiation (UV-B and part of UV-A) are harmful to all living organisms due to the destruction of DNA. The Hasegawa film (H-film) was developed through modification and chemical reaction on special film with europium (Eu); the H-film transforms UV-A radiation (300-350 nm) to a near peak photosynthetic active wave (600-650 nm). To understand how to use the H-film in horticulture efficiently, we applied it to crop production in greenhouse facilities. This report introduces the basic information on the H-film and its application for several crops during autumn and winter, when incident radiation is low. Therefore, we tested how to overcome this limited sunlight production environment by applying the H-film. We found tendencies for accelerated growth rates in Swiss chard (*Beta vulgaris* var. *cicla*) and spinach (*Spinacia oleracea*). As we expected, the growth acceleration was clearly observable through autumn and winter even with shorter daylight hours. Also, we will introduce our greenhouse facilities.

Key words: Robust greenhouse platform, The Hasegawa film (H-film), Ultraviolet ray radiation (UV), Photosynthetic active radiation (PAR), growth acceleration

Introduction

Green infrastructure is an urgent political matter for increasing the environmental richness of our daily lives. In general, except for UV-A, UV radiation is harmful and usually kills living organisms (Larcher, 2003). Of course, UV-A (320-340 nm) is necessary for the coloring of eggplants. We use vinyl greenhouses mainly for leafy vegetable production, even in winter. However, it is too costly, especially when oil prices are a determining factor. During winter, the cumulative amount of sunshine (photosynthetic active radiation in middle and high latitudes) is smaller than in spring and early autumn. The similar practices are performed in western Australia; LLEAF, a product developed by New South Wales University, Australia (Future Food Systems, 2021), is being tested near Sydney. LLEAF is a pink film that converts green light to photosynthetic production. How can we overcome the difficulties during winter when there is a shortage of photosynthetic radiation? We should use natural renewable resources as much as possible to maintain our daily lives and reach our sustainable development goals (SDGs).

To increase and sustain stable crop production in agriculture and forestry even in the winter, we started to use a newly developed film that transforms ultra-violet (UV) light (300-350 nm) to photosynthetic active light (600-650 nm, Hasegawa et al., 2003; Kataoka et al., 2014; 2021; Hasegawa, 2018, 2020). We call this new film developed by Professor Y. Hasegawa (Hokkaido University) "Hasegawa film" (H-film). To maintain higher and stable crop production, the engineering technology and agriculture faculties have collaborated closely since 2018 (Hokkaido University Robust Platform, 2020). The Hokkaido University Research and Education Center for Robust Agriculture, Forestry, and Fisheries Industry (The Robust Platform) is the center for this collaboration. Here, "Robust" means having internal resilience and the ability to withstand changes brought about by external environmental disturbances

Figure 1. Views of the robust greenhouse; Upper: outside of green house, Lower inside of greenhouse.

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such as climate change (Kitaoka et al., 2021).

By incorporating the concept of engineering technology into the agriculture, forestry, and fishing industries, our target is to make food-value-chains and sustainably produce foods under rapid environmental change, such as an increase in NOx, PM, Ozone. This report outlines one of the projects, "the Robust Greenhouse Project." Also, we will briefly introduce the nature of UV, the H-film, its application, and preliminary results with vegetative crops.

The Robust Greenhouse Project using the H-film for crop production

Hokkaido University established the greenhouse project to support researchers in developing and applying new technologies:

- heat and light management technology for the climate conditions of Hokkaido, northern Japan;
- verification of new production methods that match the characteristics of vegetative crop products;
- development of fundamental technologies that contribute to improving the productivity of horticulture;
- development of agricultural support robots.

The greenhouses are a "research platform" (Fig. 1) where it is possible to create a research environment to test "research seeds" for the future. The greenhouses are a creative site.

The role of UV light in nature

UV radiation is classified as UV-C (<280* nm), UV-B (280-320 nm), and UV-A (320-380 nm) (*some literature use 290 nm) (Fig. 2). Except for UV-A, most ultraviolet radiation (UV) harms living organisms (Larcher, 2003; Kitaoka, 2012). UV-A usually enhances the purple coloring of eggplants. UV-B is very harmful to living organisms, destroying DNA. At the same time, almost no UV-C from the sun reaches the ground surface due to the protection of stratospheric ozone. Based on the sun's light spectrum, active photosynthetic radiation (PAR) is 380-710 nm (Larcher, 2003). However, we usually use a PAR of 400-700 nm after McCree (1972)

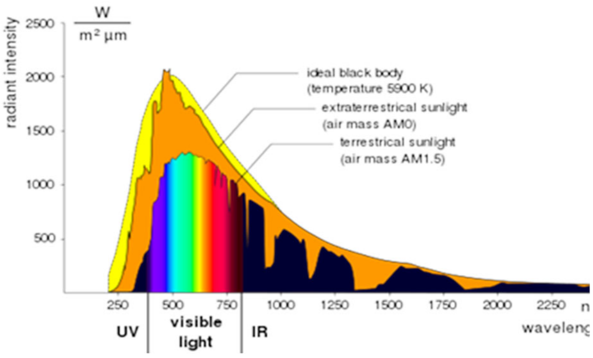

Figure 2. Wave length of sunlight
The original uploader was Degreen at German Wikipedia. Improved Baba66 (opt Perhelion) on request; En. translation Locusta Fr. translation Eric Bajart Nl. translation BoH, CC BY-SA 2.0 DE, via Wikimedia Commons.

and Lambers et al. (1998). If a productive environment, such as the proper temperature, adequate nutrients, and sufficient CO_2, is present, light is the essential environmental resource for the growth and survival of green plants. During late autumn and part of winter, the light intensity of PAR decreases to about 40% of that of summer in Sapporo (43ºN) (Ishii et al., 2004).

In Sapporo, in winter, the level of UV is 30% less than the summer (Ishii et al., 2004). However, previous

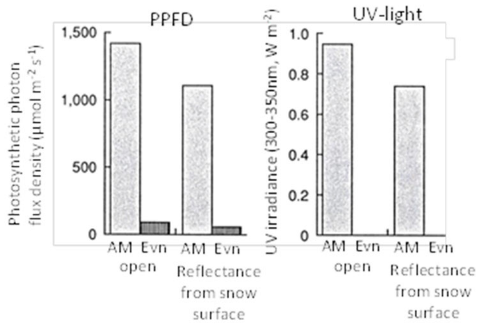

Figure 3. Importance of Ultra Violet (UV)-radiation reflected from snow surface (modified from Kitaoka 2002) Abb: PPFD: 380~720 nm, UV-light: 300~34 nm detected by a UV monitor of Akitsu-keisoku, Tokyo). Abb: AM; 9:00~10:00, Evn; 14:00~15:00 during late November to early December in 2001.

studies suggested snow-cover and clouds play a significant role in diffusing the refraction of UV (Fig. 3) (Kitaoka, 2002; Sabburg and Calbó, 2009; Lee et al., 2015). Therefore, we expect to improve crop productivity during late autumn to early winter, when there is a shortage of sunshine, by using H-film to convert UV to PAR. There is the possibility of improving light regulation in the greenhouse, especially the reflectance of PAR (=PPFD) and UV from the snow surface (Fig. 3) (Kitaoka, 2002).

Application H-film to the production of hybrid larch (F_1)

Several trials in forestry research regulated light quality to the forest floor to establish natural regeneration of light-demanding tree species (alder; *Alnus hirsuta*; Japanese larch, *Larix kaempferi*) (Harada, 1918; Asawaka et al., 1974; Mizui, 1978).

Aboveground biomass of alder and Japanese larch increased with increasing light intensity (μW cm^{-2}), but its degree was in the order of Red (minus: -Green & Blue), Yellow (-Blue), Neutral, and Blue (-Red). However, the epicotyl weight of Japanese larch was enhanced significantly in the Blue (-Red) box under constant temperature (Fig. 4). In contrast, the Blue box did not enhance the hypocotyl growth of alder seedlings, irrespective of all light intensities (Mizui, 1978).

In Hokkaido, local governments must find a way to produce sufficient planting stock from the cuttings of current-year seedlings of hybrid larch F_1 (*Larix gmelinii* var. *japonica* x *L. kaempferi*, larch F1). We believe a possible solution is to use H-film during winter because larch F_1 seedlings are mainly cultivated in

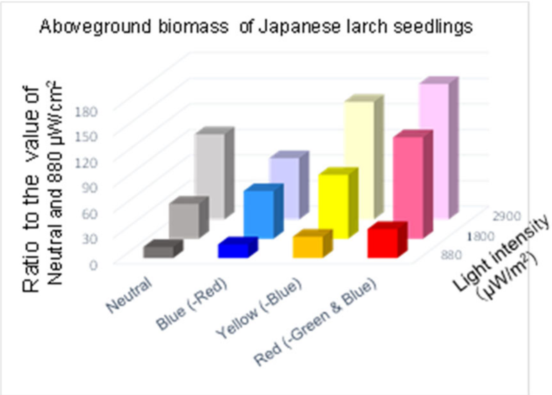

Figure 4. Effects of different light quality and intensity on growth of aboveground biomass (mg) of Japanese larch seedlings under regulated temperature. Illustrated from Mizui (1978).

Original point of the relative value is located at left-first position. Minus (-) in color treatment means omitted wave length by color film as shown by Asakawa et al. (1974).

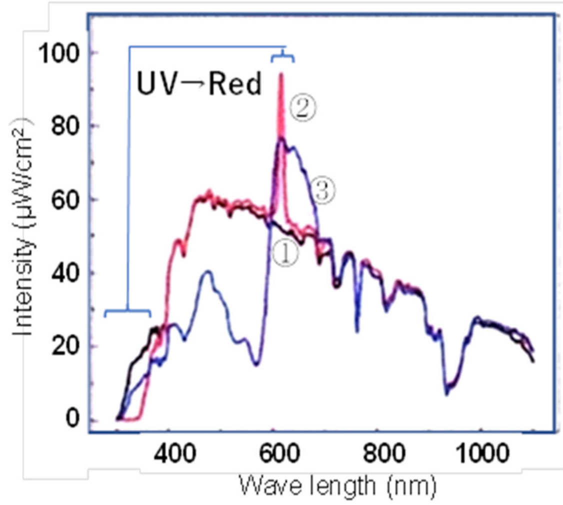

Figure 5. High transmittance capacity was realized by the H-film (After Hasegawa 2018).

Light intensity after transformation of full sunlight to ①: with no special chemicals, ②: Europium (Eu)-Complex polymer = the H-film, ③ : Commercial organic pigment (BASF lumogen R305)

greenhouses to shorten the cultivation period (Fig. 4). Larch, in general, is a typical light-demanding tree species (Kitaoka et al., 2020).

Development of a light transformation film (The H-firm)

The Hasegawa laboratory publications provide detailed information (Hasegawa et al., 2003; Kataoka et al., 2014; Hasegawa 2018, 2020) on the film's creation. The simple explanation is that they added a complex rare-earth element (Europium: Eu; Atom No. 63, a lanthanoid) to a polymer film, creating a highly efficient luminescent (Fig. 5).

H-film can keep high light transmittance and high illuminance of red color (600-615 nm) by applying UV (300-340 nm). Finally, we can see red light transformed from UV, even under full sunlight.

Application of the H-film and tentative results

As mentioned, the H-film can transform a part of UV to PAR (=PPFD) at 600-615 nm and significantly increase biomass and leafy greens in preliminary studies of Swiss chard (*Beta vulgaris* var. *cicla*; Suzuki, 2020; Kitaoka et al., 2021) and spinach (*Spinacia oleracea*; Sugai et al., 2016). A preliminary study of spinach (Fig. 6a) is very promising from a commercial viewpoint. The perimeter of the leaf blade grown under the H-film was the longest (Sugai et al., 2016).

In general, the photosynthesis rate is higher with a long perimeter length (Koike, 1996). Although leaf thickness detected by a micro-meter (Mitsutoyo, Kawasaki-Kanagawa, Japan) was the same for all individuals grown in several light conditions under several different films. The leaf area was the largest in spinach grown under the H-film (Figs. 5b, and c). These results suggest that the photosynthetic production of spinach grown under the H-film will be higher.

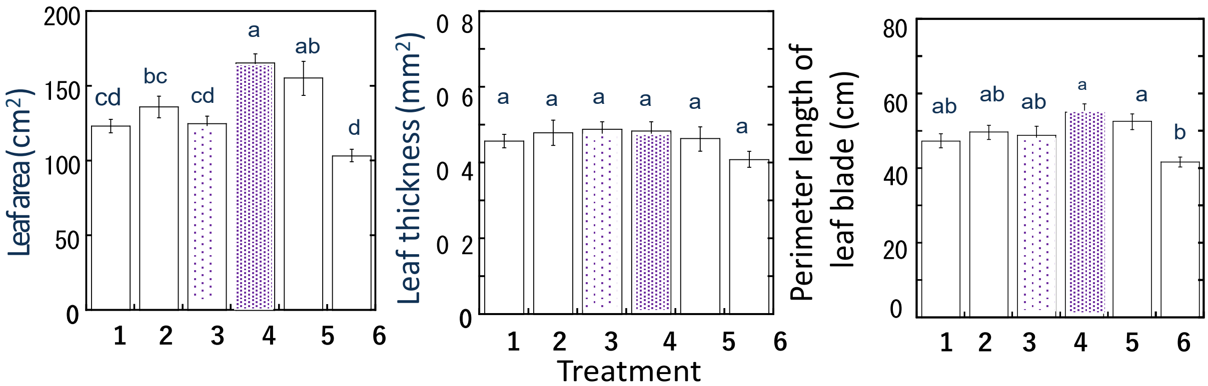

Figure 6. Preliminary results of spinach seedlings treated with different films including the H-film (adopted from Sugai et al. 2016; with the author's permission).

The numbers of treatments indicate, 1: UV-absorption, 2: Film with no treatment (EVA: ethylene vinyl acetate), 3: Film with less rare earth element, 4: Film with much rare earth element, 5: commercial visible light

Conclusion

Our Robust Greenhouse Project will allow researchers to test their promising technology to increase crop production, especially vegetables, during autumn and winter when there is less sunshine than in the growing season. We are slowly applying the technology to several crops, such as Swiss chard, spinach, and horseradish. Finally, we would like to develop the ideal method for using the H-film in agriculture production.

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