No. A-5.1 Assessment of the Effects of Enhanced Ultraviolet-B Radiation on Crop Production

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Total budget for FY1990-1992 30,369,000 Yen

Abstract To investigate the effects of enhanced UV-B radiation caused by stratospheric ozone depletion on plants, three cucumber cultivars and 17 rice cultivars were irradiated for 3 weeks in sun-lit environmental glass chambers and for 2 months in the fields under UV-B (290 - 320 nm) irradiation from fluorescent sunlamps using 0.10 mm polyvinyl chloride or cellulose acetate films and UV-B free control conditions using 0.10 mm polyester film. In the sun-lit environmental glass chambers, cucumber plants were irradiated with three levels (0, 244 and 381 mW m^{-2}) of biologically effective UV-B ($UV\text{-}B_{BE}$) for 8 h (8 a.m. to 4 p.m.) a day. The levels of $UV\text{-}B_{BE}$ irradiance at Tsukuba (36 °N latitude) were about 200 mW m^{-2} at noon in summer under clear sky conditions. Visible foliar injury (yellow lesions and glazing) due to UV-B irradiation occurred on the leaf surface. The leaf area and dry weight of whole plants of the three cultivars of cucumber were significantly reduced and decreased with increasing intensities of $UV\text{-}B_{BE}$ irradiation. Growth parameters of the relative growth rate (RGR), the net assimilation rate (NAR) and leaf area ratio (LAR) were reduced by medium and high $UV\text{-}B_{BE}$ irradiation throughout irradiation periods. Specific leaf area (SLA) decreased remarkably due to UV-B, which indicates that plants exposed to UV-B increase their leaf thickness. This increase of leaf thickness might be an adaptation mechanism against increased UV-B radiation. On the other hand, in the field experiments, rice plants were irradiated at a predefined proportion (1.5 times control plots) to the global solar UV-B radiation from August 25 to October 23, 1992 by UV irradiation modulation system. No significant influence of UV-B radiation was detected on any growth parameters studied in all the cultivars.

Key Words Cucumber, Growth reduction, Injury symptoms, Rice, UV-B,

1. Introduction

The release of chlorofluorocarbons into the atmosphere appears to be the main cause of the reduction of the stratospheric ozone layer. One consequence of ozone depletion would be an increase in the proportion of ultraviolet-B radiation (UV-B, 280-320 nm) reaching the earth's surface. A 1% decrease in ozone depletion would result in an approximately 2% increase in biologically effective UV-B ($UV\text{-}B_{BE}$) radiation at temperate latitudes. It is important to assess adverse the effects of UV-B on terrestrial ecosystems, Many studies concerning the effects of UV-B on plants have been conducted over the past two decades in the USA and western Europe[1,2]. In Japan, however, such studies are still rare. The aim of the present study was to examine the effects of UV-B radiation on plants using cucumber and rice seedlings exposed to relatively high levels of UV-B radiation.

2. Materials and methods

(1) UV-B irradiation in sun-lit environmentally controlled grass chambers for cucumber plants

Germinated cucumber seeds were sown individually in a 0.6 L plastic pot with commercial culture soil (Kureha chemical Co.). Plants were grown in an environmentally controlled glass chamber (2 m (d) x 2 m (w) x 1.8 m (h)) at a 27/22 ^{o}C day/night temperature regime under natural light. UV-B irradiation began 3 to 5 days after plants emerged above the soil surface.

UV-B irradiation experiments were carried out in the three environmentally controlled glass chambers under natural light. Supplemental UV-B radiation for a 1 m (d) x 1 m (w) plot was supplied by filtered six FL 20 w fluorescent sunlamps (Toshiba, FL20SE). Lamps were suspended above the plants and filtered either with a 0.10 mm polyvinyl chloride film (Cutting sheet 000C, Nakagawa Chemical Co., Tokyo) for supplemental UV-B radiation or filtered with a 0.10 mm polyester film (Lumilar, Toray Co., Tokyo) as a control. The cutting sheet and lumilar films do not allow transmission of wavelengths shorter than 290 and 320 nm, respectively. Spectral irradiance at plant height under the lamps was measured with a spectroradiometer (OptResearch Co., model MSR-7000, Tokyo). The absolute spectral irradiance was weighted the general plant response action spectrum normalized at 300 nm[3)]. Due to the absorption characteristics of the glass, there was no solar UV-B radiation in the glass chamber. The height of lamps above plants was 25 cm and was adjusted frequently as the plants grew. The different levels of UV-B_{BE} irradiance were obtained by inserting a cheesecloth (percent transmittance: 64 %) between the lamps and the cutting sheets. The supplemental UV-B_{BE} irradiances in the three UV-B treatments were 0 (control), 244 (medium) and 381 (high) mW m^{-2}. Global solar UV-B_{BE} irradiance at Tsukuba (36 ^{o}N latitude) was about 200 mW m^{-2} during the summer solstice under clear sky conditions. Plants were irradiated with UV-B for 8 h (8 a.m. to 4 p.m.) each day for 3 weeks. Since the transmittance of filters decreases with the time of irradiation, the filters were renewed at weekly intervals. On the other hand, since the lamp boxes made shade, solar photosynthetic photon flux density (PPFD, 400-700 nm) at plant heights under lamp boxes in the glass chambers was 25 % of the ambient at noon under clear sky conditions.

(2) Continuous proportional control system of supplemental UV-B radiation in the fields for rice plants

Seeds of 17 lowland rice cultivars (Akenohoshi, Akihikari, Koshihikari, Nipponbare, Sasanishiki, Aoniwai, Nankin 11, IR 26, Banten, Ketan, Dular, Jamuna, Kele, Bomba, Raffaelo, Lemont, CP 231) were obtained from Laboratory of heterosis, National Agriculture Research Center, Tsukuba, and were sown into seedling box on July 6, 1992. After the seedlings were grown in a greenhouse for 1 month, the seedlings were transplanted into individual pots (200 cm^2 in surface and 29.5 cm in height) on August 6. Exposure to UV-B irradiation were initiated on August 25 and terminated on October 20.

The continuous proportional control system of supplemental UV-B radiation is designed to monitor solar UV-B radiation and deliver a desired supplemental UV-B irradiance by controlling the output of fluorescent sunlamps. Supplemental UV-B radiation for 1.8 m (d) x 1 m (w) plot was supplied by filtered eight 40w fluorescent sunlamps (Philips, F40UVB). Lamps were suspended above the plants and filtered either a 0.10 mm cellulose acetate film for supplemental UV-B radiation or filtered with 0. 10 mm mylar film as a control. The light intensity of fluorescent sunlamps was regulated by the signal from a personal computer. Solar UV-B radiation at open space and supplemental UV-B lamps at plant height were monitored continuously with UV-B pyranometers (Eiko Seiki Co., MS-210D), which were selected because corresponds to spectra response function of DNA action spectrum. The UV lamps were adjusted weekly at 30 cm above top of plant canopy throughout the experiment as the plant grew. The cellulose acetate film for the UV-B and mylar film for the control treatments were renewed every 1 and 2 week, respectively.

(3) Measurement of UV-B

The spectral irradiances of the lamps and solar radiation were measured with a spectroradiometer with a 1.0 m long quartz fiber-optic cable and a sensor head at an angle of 45° with a white sulfuric magnesium plate. The spectroradiometer was calibrated using a deuterium arc lamp ultraviolet standard of spectral irradiance and a regulated power supply.

(4) Measurement for biomass

Ten to 13 cucumber plants were harvested from each UV treatment for weekly monitoring of plant responses. Leaf area was measured using a leaf area meter (Hayashi Denkoh Co. Ltd., AAM-7, Tokyo). Leaves, stems and roots were weighed after drying at 70 °C for 72 h.

3. Results and discussion

(1) Cucumber

Daily solar UV-B_{BE} irradiance at Tsukuba was 4 kJ m^{-2} during a cloudless the summer solstice day. Our measurement of global solar UV-B_{BE} irradiance with the spectroradiometer at Tsukuba under sunny conditions was about 60 % of that calculated by the Green et al. model[4]. The discrepancy between calculated and measured clear sky solar UV-B_{BE} irradiance might be due to local weather factors such as air mass, aerosol levels and tropospheric air pollutants. Cucumber plants were irradiated at three levels (0, 244 and 381 mW m-2) of UV-B_{BE} irradiance for 8 h a day, which is equivalent to a total daily biologically effective irradiance of 0, 7.0 and 11.0 kJ m^{-2} UV-B_{BE} at plant height. Daily UV-B_{BE} irradiance in the medium and high supplemental UV-B treatments were 1.75 and 2.75 times higher than ambient UV-B_{BE} irradiance on a clear in summer day.

Visible injury (large yellow lesions) occurred on the upper surface of leaves. The most typical foliar symptoms were large yellow lesions on the leaf margin at lower positions after 1 to 3 days at 244 and 381 mW m^{-2} UV-B_{BE} irradiation. The effects of the three levels of UV-B_{BE} irradiation for 3 weeks on the total biomass of the three cucumber cultivars are shown in Fig. 1. The total biomass of the three cucumber cultivars was significantly reduced and decreased with increasing UV-B_{BE} irradiation. The reduction of total biomass in the three cultivars ranged from 14 to 49% and 17 to 77% of that of the control plants by 244 and 381 mW m^{-2} UV-B_{BE} irradiation at 3 weeks, respectively. However, the degree of total biomass reduction by UV-B irradiation was vastly different with each season of treatment. Total biomass of "Tsukemidori" cultivar decreased slightly for up to 3 weeks when plants were irradiated with UV-B in summer (July 17 to August 3), while a large reduction in total biomass was observed when plants were irradiated with UV-B in winter (December 3 to 26). These results indicate that growth reduction tended to increase with decreasing ambient solar radiation. It is well known that plants are apparently more sensitive to a given UV-B_{BE} irradiance in low levels than in high levels of PPFD. Thus the apparent increase in UV-B sensitivity in low levels of PPFD is probably due to reductions in photoprotective and photoreactivation mechanisms by visible light.

Data obtained from the above cucumber cultivars exposed to UV-B were examined in

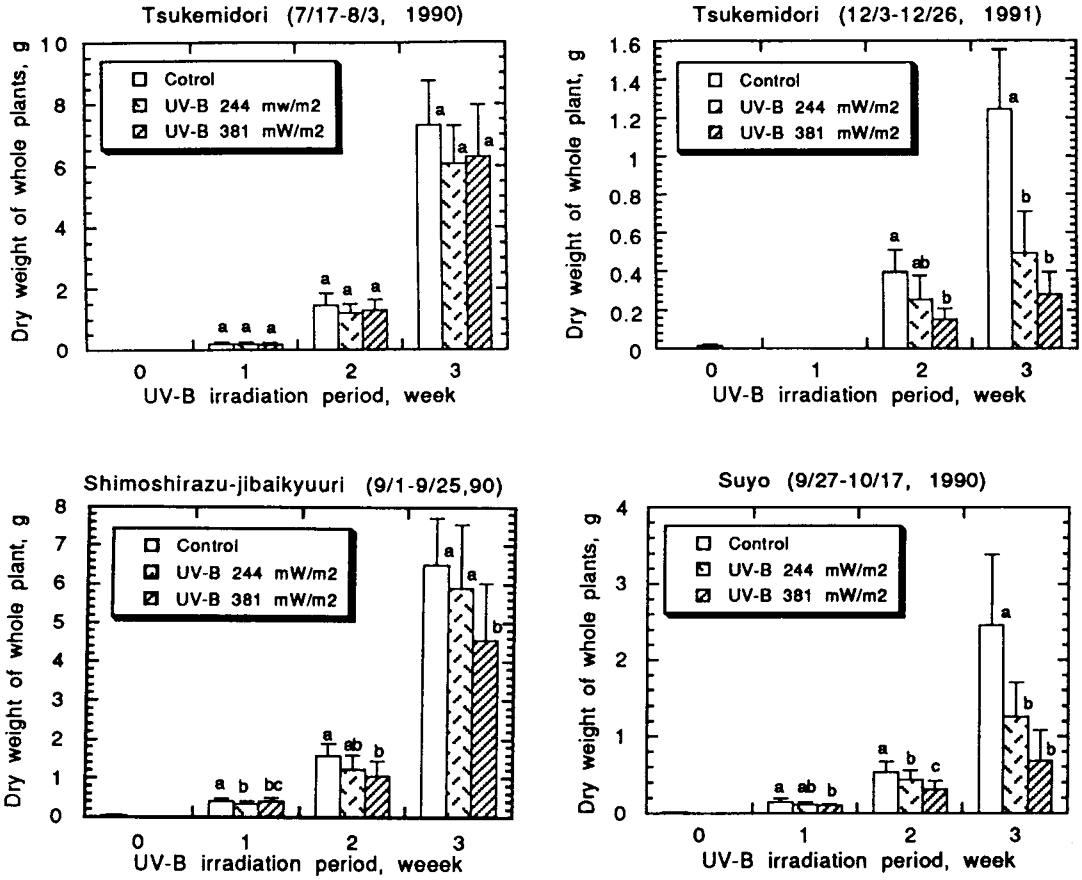

Fig. 1. Changes in dry weight of the whole plants of three cucumber cultivars irradiated with 0, 244 and 381 mW m^{-2} UV-B_{BE} for 3 weeks. Each bar is the mean of 10 to 13 plants ± SD. The treatments at each time-point marked by the same letters are not significantly different at the 5 % level using Scheffe F-test.

more detail through growth analysis. In general, the relative growth rates (RGR), net assimilation rate (NAR) and leaf area ratio (LAR) in "Suyo", "Shimoshirazu-jibaikyuuri" and "Tsukemidori" cultivars were reduced by medium and high UV-B_{BE} irradiation compared to those in the control throughout irradiation periods for 3 weeks (data not shown). Since RGR is the product of NAR and LAR, the reduction of RGR in the UV-B irradiated plants resulted from the reduction of both NAR and LAR. Reduced NAR suggests that UV-B reduced the photosynthesis rate. The LAR, an index of a plant's leafiness, is further divided into specific leaf area (SLA) and leaf weight ratio (LWR). The SLA was decreased remarkably by UV-B and with increasing UV-B_{BE} irradiation (Table 1), while the LWR tended to increase slightly by UV-B. A substantial reduction of LAR in the plants exposed to UV-B could be mainly attributed to the reduction of SLA. Since the reciprocal of SLA is an index of leaf thickness, the great reduction of SLA in the plants exposed to UV-B indicates that plants increase their leaf thickness and thereby prevent a greater proportion of UV from reaching sensitive organelles in mesophyll tissues. Therefore, the increase of leaf thickness might be one of the mechanisms for plant adaptation to enhanced UV-B radiation.

Table 1. Effects of UV-B irradiation on leaf area ratio (LAR) and specific leaf area (SLA) of the three cultivars of cucumber.

Cultivars	$UV\text{-}B_{BE}$ irradiance, $mW\ m^{-2}$	LAR, cm^2g^{-1} irradiation period, week 1	2	3	SLA, cm^2g^{-1} irradiation period, week 1	2	3
Suyo	0	292	348	331	443[ab]	548[a]	475[a]
(9/27-10/17)	244	298	308	305	460[a]	456[b]	470[a]
	381	282	279	294	429[b]	406[c]	444[a]
Shimoshirazu-	0	256	348	305	440[a]	593[a]	528[a]
jibaikyuuri	244	245	301	266	433[b]	474[b]	438[b]
(9/1-9/25)	381	237	291	255	398[a]	440[b]	409[b]
Tsukemidori	0	267	305	264	487[a]	504[a]	436[a]
(7/17-8/3)	244	240	283	256	397[b]	464[a]	419[a]
	381	239	274	245	409[b]	444[a]	400[a]
Tsukemidori	0		308	328		491[a]	514[a]
(12/3-12/26)	244		253	278		389[b]	424[a]
	381		235	242		354[b]	361[b]

LAR (L/W) = SLA (L/L_w) x LWR (L_w/W)
where L, W and L_w represent leaf area, total dry weight and leaf weight, respectively. The data show average values of 10 to 13 plants. The differences at each sampling point in SLA marked by the same letters are not significant at the 5 % level.

(2) Rice

No significant effect of UV-B irradiation was observed on plant height and tiller number at monthly observations during the growing season. Furthermore, leaf area and dry weight of whole plants at the harvest were not significantly reduced by the UV-B treatment for any cultivars. We conclude that rice growth under field conditions seem to be insensitive to the projected enhancements of UV-B radiation. However, Teramura et al.[5] reported that a total of 16 cultivars from different geographical regions were grown in greenhouse for 12 weeks under conditions simulating a 20% ozone depletion. The results imply a significant decrease in total biomass with increased UV-B radiation for about one-third of all cultivars. Since it is well known that plants are apparently more sensitive to a given UV-B dose in greenhouse conditions than in field conditions, our results may provide more reliable estimates of potential impacts associated with anticipated increases in solar UV-B radiation. Therefore, the present study indicates that UV-B may less adverse impacts of enhanced UV-B on agricultural crops than initial anticipated.

Literature

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