Microclimate for *Cryptomeria japonica* seedlings in treeshelters

−Mitigation of severe condition by seedling transpiration−

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We studied the microclimate inside treeshelters to examine how they affected growth of Japanese cedar (*Cryptomeria japonica*) seedlings in western Japan. Air temperature (T), relative humidity (RH), and photosynthetic active radiation (PAR) were measured inside and outside of commonly used design of tubular treeshelters made of translucent polypropylene at a nursery throughout a year. Vapor pressure deficit (VPD) was calculated from T and RH data. Results indicated that the inside T and VPD above the seedling foliage were extremely higher than ambient air. However, T within the seedling foliage showed 2.7 °C higher than ambient T even though 10.3 °C higher above the foliage in August. The VPD within seedling foliage was lower than ambient VPD in summer, and increased with decreasing RH when the precipitation was low. Microclimate in an empty treeshelter showed higher T and VPD than those in treeshelter with seedling. These results indicated that high T and VPD were mitigated by transpiration from needle leaves of seedling, and Japanese cedar seedlings could grow in treeshelters at sufficient water supply.

Keywords; air temperature, relative humidity, vapor pressure deficit, photosynthetic active radiation, weather condition

Introduction

Treeshelter, a long plastic tube covering a single seedling, was mainly developed in Europe, especially in England (Potter 1991), and applied to various sites to reduce browsing damages by herbivores on planted seedlings since the 1970s (Potter 1991; Kerr 1996). The physical protection by treeshelters decreased the browsing damages by herbivores (Tuley 1985; Gillespie and Rathfon 1996; Sharpe et al. 1999), and their installation also enhanced seedling survival and growth (Tuley 1985; Potter 1991; Sharpe et al. 1999; Barton et al. 2015). In Japan, treeshelters were introduced to the forestry sector in the 1990s (Nakagawa 1996; Nakamura and Amikura 1998), however, in the western Japan, some reforestation sites protected by treeshelters received severe damages while some other treesheltered sites showed good performance (Nomiya et al. in press).

Treeshelters in the previous studies had diverse specifications on materials (Sharpe et al. 1999; Maruyama 2001; Devine and Harrington 2008; Oliet et al. 2019), height (Mayhead and Boothman 1997; Bellot et al. 2002; Chaar et al. 2008), and ventilation hole (Bergez and Dupraz 2000; Chaar et al. 2008). Such differences in specifications might affect the failure and success of the installation of treeshelters as well as differences in environmental conditions. Treeshelters that were applied in plantations in semi-arid regions helped to maintain humidity around the seedlings, reducing transpiration and raising the boundary-layer resistance to water movement within the treeshelter (Kjelgren 1994; Bellot et al. 2002; del Campo et al. 2006). In contrast, some studies reported that treeshelter installation might increase seedling mortality due to high temperature (Skousen et al. 2013) and insufficient irradiance (Bardon et al. 1999). In addition, different seedling species showed different mortality and growth responses even in the identical type of treeshelter (Burger et al. 1996; Jones et al. 1996). Therefore, it is necessary to clarify the species-specific responses in targeted treeshelter when we evaluate treeshelter installation (Bellot et al. 2002; Puértolas et al. 2010; Oliet et al. 2019).

The previous studies have focused on the microclimate inside the treeshelter, measuring variations in light transmittance, air temperature (T), vapor pressure deficit (VPD), CO_2 concentration, and ventilation effects, all closely related to plant gas exchange and growth. Some studies had confirmed that T and VPD showed higher in treeshelter than ambient condition (Potter 1991; Bellot et al. 2002; Devine and Harrington 2008). Excessively high T and VPD were confirmed inside treeshelter, and it was harmful for seedlings planted in high temperature environment with severe summer droughts (Kjelgren and Rupp 1997; Oliet and Jacobs 2007).

Japanese cedar (*Cryptomeria japonica*) is one of popular timber species, and the planted seedlings were seriously suffered from sika deer (*Cervus nippon*) browsing in reforestation sites for a few decades (Masaki et al. 2017). Treeshelters are getting commonly used in Japanese cedar reforestation sites recently. However, there is still few studies of microclimate for the cylindrical polypropylene treeshelters that are commonly used recently in western Japan. In this study, we measured micro climate in treeshelter for a year-round term at a nursery. From these measuring, we discuss how the microclimate within treeshelters affected growth of Japanese cedar seedlings.

Materials and Methods

Study site

This study was conducted at a nursery of the Shikoku Research Center, Forestry and Forest Products Research Institute (FFPRI-Shikoku) in Kochi City, Shikoku Island, Japan (33° 32' 30" N, 133° 28' 33" E, 45 m above the sea level). The mean annual temperature and annual precipitation during the experimental period (March 2020 to February 2021) were 17.4 °C and 3144 mm, respectively (Kochi Local Meteorological Observatory, Japan Meteorological Agency 2021; Figure 1).

Measuring microclimate in the treeshelter

The treeshelters used in this experiment were circular tubes made of translucent white polypropylene, 140 cm tall and 10 cm in diameter, with a wall thickness of 0.4 mm. The treeshelter had three ventilation holes of 18 mm diameter positioned at 20, 40, and 60 cm above the ground. Three Japanese cedar (*C. japonica*) seedlings were planted in an open area in 2018 and treeshelters were installed in March 2020. The mean height and basal stem diameter of the seedlings were 72.7 ± 2.1 cm (± SD) and 1.0 ± 0.1 cm before measuring microclimate, respectively.

Air temperature (T) and relative humidity (RH) were measured at 10-min intervals using Ondotori RTR500 series devices (T&D Cooperation, Japan) from March 2020 to February 2021. Three sensors were set at different heights: at 10 cm (below the seedling foliage), at 80 cm (above seedling foliage), and at 130 cm (near upper end of treeshelter) in each treeshelter. To avoid heating the sensors by sunlight, they were covered with a cylinder of plastic mesh (3 cm in diameter) with an aluminum roof. The sensors were placed at the center of the treeshelter using a stick at each height and held horizontally. Vapor pressure deficit (VPD), more suitable indicator than humidity on physiological processes of plants (Potter 1991), was calculated from the following equations using simultaneous T and RH data:

$$VPD = e_{s(T)} \times (1–h/100)$$

$$e_{s(T)} = 6.1078 \times 10^{[7.5T/(T+237.3)]}$$

where $e_{s(T)}$ is saturated water vapor pressure at air temperature T, and h is RH.

During this study, the positions of the sensors remained unchanged. During experimental period, the seedlings grew in height, reaching 149.3 ± 8.3 cm (mean ± SD) in January 2021. The sensors at 80 cm height in treeshelter were covered by needle leaves of seedlings from July 2020. So, the sensor location changed gradually from ‘above seedling foliage’ to ‘inside seedling foliage’.

We compared the maximum T (T_{max}) and VPD (VPD_{max}) among different weather conditions, such as sunny, cloudy and rainy days in summer, because previous study reported that direct sunlight to shelter wall affected air temperature in the treeshelter (Hisatake 1999). Sunny days were picked up from the meteorological data which recorded as ‘sunny’, ‘sunny and sometimes cloudy’ and ‘sunny and cloudy’ throughout a day by the Kochi Local Meteorological Observatory. Likewise, ‘cloudy’, ‘cloudy and sometimes sunny’ and ‘cloudy and sunny’ were categorized as cloudy day; the data of ‘rain’, ‘rain and sometimes cloudy’, ‘rain and cloudy’, ‘heavy rain’ and ‘heavy rain and rain’ as rainy day. We selected the data in June 2020, because we found the well-balanced number of sunny, cloudy and rainy days (4, 6 and 5 days, respectively). The data in July and August, when the ambient air temperature was high, were not selected for the comparison due to many rainy days in July and few cloudy and rainy days in August 2020 (Figure 1b).

In order to clarify effects of physiological activities of planted seedling, T and RH were measured in an empty treeshelter. The measuring was conducted at the same height to measuring in treeshelter with seedling. Ambient T and RH were measured at 80 cm height.

Photosynthetically active radiation (PAR, 400‒700 nm) was measured inside and outside treeshelter in summer (from August to September 2020) because light transmittance varied depending on the materials of the shelter wall (Sharpe et al. 1999). PAR was measured at 80 cm height inside and outside of the empty treeshelter by using PAR sensors (MIJ-14PAR Type 2/K2; Environmental Measurement Japan Co. Ltd.). To evaluate PAR_{in}:PAR_{out} ratio, PAR in clear sunny throughout daytime data was selected (21 September 2020) (Figure 6a). PAR data in 20 September 2020 was selected for cloudy because the weather was recorded as cloudy.

During our measuring, we observed that air temperature at 130 cm height inside treeshelters was approximately 10 °C higher than the ambient air temperature even in the end of autumn (November 2020). To examine the reason of excessive air temperature increment in the treeshelter, we forcedly circulated the air inside a treeshelter with seedling, because many studies mentioned the importance of air circulation and ventilation for air temperature increment inside treeshelter (Swistock et al. 1999; Bergez and Dupraz 2000; Bellot et al. 2002; Bergez and Dupraz 2009). We set an electric fan of 10 cm diameter connected to DC 12 V battery (Bigfan120U; Timely Ltd.) on the top of the treeshelter for 2 consecutive sunny days (from 1 to 2 December 2020). The fan was operated for 24 hours. Then we measured T and RH inside and outside treeshelter.

Results

Seasonal change of microclimate inside and outside treeshelters

The monthly means of daily maximum T (T_{max}), minimum T (T_{min}), minimum RH (RH_{min}), and maximum VPD (VPD_{max}) were shown in Figure 2. Seasonal change of the T_{max} and T_{min} in the treeshelters followed a trend similar to that of the ambient T (T_{out}) (Figure 2a, 2b). T_{max} at a height of 130 cm in the treeshelter ($T_{\mathrm{max\text{-}130}}$) showed the highest values among measuring heights ($T_{\mathrm{max\text{-}10}}$, $T_{\mathrm{max\text{-}80}}$), and 8.2–14.9 °C higher than the maximum ambient T ($T_{\mathrm{max\text{-}out}}$) throughout the year. The $T_{\mathrm{max\text{-}130}}$ showed the highest value in August 2020 (47.9 ± 1.8 °C (± SD), n = 93), and exceeded 30 °C even in winter (December 2020 and February 2021). Differences between the $T_{\mathrm{max\text{-}80}}$ and $T_{\mathrm{max\text{-}out}}$ were significant in all months (t-test, $p < 0.05$), but the difference was only 2.7 °C in August 2020 (Figure 2a). T_{min} inside treeshelter were lower than ambient T_{min} throughout the experimental period, but no significant difference was detected between inside and outside treeshelter (t-test, $p > 0.05$) (Figure 2b). Variation of T_{min} was high in winter (ex.–7.6 – 10.2 °C in ambient T_{min} in January 2021). The RH_{min} at 10 cm and 80 cm in treeshelter ($RH_{\mathrm{min\text{-}10}}$, $RH_{\mathrm{min\text{-}80}}$) were higher than ambient RH_{min} ($RH_{\mathrm{min\text{-}out}}$) during the experimental period (t-test, $p < 0.05$) (Figure 2c). Difference between $RH_{\mathrm{min\text{-}130}}$ and $RH_{\mathrm{min\text{-}out}}$ was not significant from March to September 2020 (t-test, $p > 0.05$) (Figure 2c). The VPD_{max} at 130 cm height in the treeshelter ($VPD_{\mathrm{max\text{-}130}}$) fluctuated parallel with the ambient VPD_{max} ($VPD_{\mathrm{max\text{-}out}}$), with 0.9–2.0 kPa higher than $VPD_{\mathrm{max\text{-}out}}$ and the maximum value (5.3 ± 0.8 kPa, n = 93) in August 2020 (Figure 2d). The $VPD_{\mathrm{max\text{-}80}}$ showed in similar values to $VPD_{\mathrm{max\text{-}130}}$ at the beginning of measuring (March 2020), and fluctuated parallel with the $VPD_{\mathrm{max\text{-}10}}$ (Figure 2d). In August 2020, remarkable increments of VPD_{max} were observed at all measuring heights.

The monthly means of the maxium RH and the minimum VPD showed almost 100 % and 0 kPa at each measuring height throughout the measuring period, respectively.

Microclimate in treeshelters under the different weather conditions

In cloudy days, mean $T_{\text{max-130}}$ reached 42.3 ± 3.8 $^{\text{o}}$C and the value was not significantly different with $T_{\text{max-130}}$ in sunny condition (Tukey's HSD test, at $\alpha = 0.05$ level) (Figure 3a). Similar results were observed in $T_{\text{max-10}}$ and $T_{\text{max-80}}$ (Figure 3a). In rainy days, T_{max} at each measuring height ranged from 25.0 ± 2.9 to 28.1 ± 5.2 $^{\text{o}}$C and the values were not significantly different among the measuring points (Figure 3a).

In similar to $T_{\text{max,}}$ means of VPD_{max} were not significantly different between sunny and cloudy days when we compared at the same measuring height, except for 10 cm height inside the treeshelters (Figure 3b). In rainy days, the values were not significantly different among the measuring points (Figure 3b).

Diurnal change of microclimate inside and outside treeshelters in summer

Diurnal changes of T, RH and VPD in sunny and cloudy days in August 2020, when the ambient T (T_{out}) showed the highest value in the year (Figure 1), were shown in Figure 4. The number of the days recorded as sunny and cloudy in August 2020 were 9 and 1 day, respectively. Diurnal change of each environmental factors showed small fluctuation in sunny days, and large in cloudy days. T at 130 cm height in treeshelters (T_{130}) increased rapidly from 06:00 and exceeded 40 °C for more than 9 hours (07:50 to 17:30) for both sunny and cloudy days (Figure 4a, 4b). The T_{130} was approximately 10 °C higher than T_{out}, and recorded the maximum value as 47.4 ± 1.6 °C ($n = 27$) and

47.5 ± 0.8 °C (n = 3) in sunny and cloudy days, respectively (Figure 4a, 4b). T_{80} also increased from 06:00 and was 2–3 °C higher than T_{out} during midday (Figure 4a, 4b). RH at 10, 80, and 130 cm height in treeshelter (RH_{10}, RH_{80} and RH_{130}) showed almost 100 % during night time, and decreased rapidly from 06:00 until 09:00 (Figure 4c, 4d). RH_{10}, RH_{80} and RH_{130} had less fluctuation in daytime, and the mean values in the midday (12:00–14:00) were 55.0 ± 1.0, 71.3 ± 0.5 and 54.5 ± 0.4 % in sunny days, respectively (Figure 4c). The VPD at 130 cm height in treeshelter (VPD_{130}) was the highest value among the measuring heights and the highest value was 5.0 ± 0.8 kPa (n = 27) in sunny days. The VPD_{80} was the lowest value among the measuring heights and lower than VPD_{out} (Figure 4e). The VPD_{80} increased until around 09:00 and then remained at around 2 kPa until 16:30.

Microclimate inside treeshelters with and without seedling in summer

At 80 cm height in an empty treeshelter, T and VPD were higher than those in treeshelters with seedling and the ambient condition in August 2020 (Figure 5a, 5c). The maximum T and VPD in empty treeshelter reached to 45.7 °C and 6.3 kPa, respectively. RH in no seedling treeshelter was lower than that in treeshelter with seedling and the ambient condition, and the value decreased until 36 % (Figure 5b)

Light conditions inside and outside treeshelters

Inside PAR (PAR_{in}) increased rapidly in parallel with ambient PAR (PAR_{out}) and reached 1100 µmol m^{-2} s^{-1}, and remained around 1000–1100 µmol m^{-2} s^{-1} during midday (Figure 6a). The ratio of PAR_{in} to PAR_{out} was 0.86–0.94 from 07:30 to 08:20 and around 0.6 during midday in the sunny day. In the cloudy day, PAR_{in} frequently fluctuated in parallel with PAR_{out}, and reached approximately 800 µmol m^{-2} s^{-1} (Figure 6b). Then the ratio of PAR_{in} to PAR_{out} was 0.51–0.69 from 7:00 to 18:00.

Air circulation effect on microclimate in treeshelter

During the electric fan activated on the top of the treeshelter, mean T_{10}, T_{80} and T_{130} in midday (11:00–14:00) were 18.6 ± 1.1, 21.5 ± 1.4 and 22.9 ± 1.8 °C, respectively. Mean T_{10}, T_{80} and T_{130} in treeshelter without the fan in the midday of the same day were 22.5 ± 2.4, 26.0 ± 3.8 and 33.8 ± 2.6 °C, respectively. The ambient *T* was 19.3 ± 1.3 °C at that time. We confirmed that air temperature difference between inside and outside treeshelter decreased by the forced air circulation.

Discussion

PAR_{in} increased until 10:00 and kept less fluctuation around midday in sunny days (Figure 6a). Solar radiation angle to shelter wall decreased with increasing solar zenith angle, then relatively stable PAR might be occurred by decreasing light transmittance (Bergez and Dupruz 2009). Even in cloudy days, PAR in the treeshelter reached 800 µmol m^{-2} s^{-1} (Figure 6b). This PAR value almost reached light saturation point for photosynthesis on Japanese cedar (Kusano et al. 2007). So, sufficient sunlight irradiance reached to Japanese cedar seedlings located inside the treeshelter.

Above seedling foliage inside the treeshelters, T_{max}, RH_{min}, and VPD_{max} were always higher than the ambient values (Figure 2a, 2c, 2d). These results corresponded with the previous studies (Potter 1991; Kjelgren 1994; Kjelgren and Rupp 1997; Oliet and Jacobs 2007; Devine and Harrington 2008; Bergez and Dupruz 2009). After sunrise, PAR_{in} increased rapidly, in parallel with PAR_{out} with high light transmittance in the morning in sunny day (Figure 6a). Air temperature increased rapidly inside treeshelter in the morning (Figure 4a). This result also corresponded with Bergez and Dupruz (2009) which reported that rapid increase of air temperature in morning might be influenced by the high transmittance of solar irradiation through shelter wall when the sunlight perpendicularly irradiated to the shelter wall from low solar zenith angle. Also, we observed the rapid temperature increment in the treeshelter even in cloudy days with lower light transmittance from low PAR. This result meant that scattered light and occasional direct light in cloudy days also increased the air temperature in the treeshelter.

After warming the air in treeshelter, ventilation might affect thermal condition. Several studies reported that ventilation reduced increment of air temperature in treeshelter (Swistock et al. 1999; Bergez and Dupraz 2000; Bellot et al. 2002). The treeshelters used in this study had three ventilation holes at the lower part (from 20 to 60 cm above the ground), but there were no holes in the upper part. In this study, we confirmed the decrease in air temperature inside the treeshelter due to the enhancement of air circulation by the electric fan. This result indicated that air temperature increment in the upper part of treeshelter might be caused by less air circulation even though the measured points (130 cm height) were near to the upper end of treeshelter. Bergez and Dupruz (2009) mentioned that seedling foliage offered significant resistance to air flow and degreasing ventilation rate in treeshelter. Thus, air retention might be one of the reasons for air temperature increment in the treeshelter.

The T_{max} in the upper part of the treeshelter was recorded as 47.9 °C in August 2020 (Figure 2a). Extremely high air temperature affects the physiological processes in the plants. Thylakoid membranes are especially sensitive to heat. As air temperature rises, photosystem II is inhibited and then carbon metabolism becomes unbalanced

(Larcher 2003). In this study, the upper part of the seedling foliage was exposed to high temperature exceeding 40 °C for 9 hours in August (Figure 4a). These conditions might give heat stress on the photosynthesis of the Japanese cedar seedlings. This condition occurred in the treeshelters not only in sunny days but also in cloudy days (Figure 3, 4, 6). It seemed severe condition for Japanese cedar seedlings to grow, as Negisi and Satoo (1961) reported that the photosynthetic rate of Japanese cedar rapidly decreased and the net assimilation rate was reduced to zero when air temperature exceeded 40 °C.

However, $T_{\text{max-80}}$ and $VPD_{\text{max-80}}$ in treeshelter did not increase remarkably in the seedling foliage (Figure 4a, 4b, 4e, 4f). Temperature difference between $T_{\text{max-80}}$ and $T_{\text{max-out}}$ was only 2.7 °C in August 2020 and $VPD_{\text{max-80}}$ was lower than $VPD_{\text{max-out}}$ from July to November 2020 (Figure 2a, 2c). In constant, $T_{\text{max-130}}$ showed remarkably higher values than ambient air during the periods (Figure 2a, 2c). Kjelgren (1994) reported that air temperature in treesheltered seedling foliage showed intermediate values between the ambient and the inside treeshelter, and mentioned that leaf transpiration might affect decrease in temperature in treeshelter. Several studies have stated that transpirational cooling could effectively prevent overheating if sufficient water was available, with leaves remaining 4─6 °C cooler and in extreme cases even 10─15 °C cooler (Larcher 2003). We confirmed that T and VPD in the empty treeshelter were higher than those in the treeshelter with seedling (Figure 5a, 5c). These results meant that Japanese cedar seedling reduced the increment of air temperature and VPD in a treeshelter. Even in August, the hottest month, the $T_{\text{max-80}}$ remained below 40 °C in the seedling foliage (Figures 1a and 4a). Thus, increases in air temperature and VPD in the seedling foliage might be prevented by transpirational cooling.

From September, the air temperature difference between $T_{\text{max-80}}$ and $T_{\text{max-out}}$ increased, with the difference being 10 °C by January 2021 (Figure 2a). In Kochi City, there tends to be high precipitation during summer and low precipitation during winter (Figure 1a). Previous studies reported that Japanese cedar did not change the water use efficiency under dry treatment, and tended to close their stomata to regulate transpiration and avoid drought-induced damage (Nagakura et al. 2004; Kenzo et al. 2021). Low precipitation might affect stomatal opening and hence low transpiration on Japanese cedar seedling. Air temperature in the seedling foliage was higher than that in the ambient air in winter (Figure 2a), perhaps because transpirational cooling might be limited in drought conditions. Monthly precipitation was much lower in August 2020 (92 mm month^{-1}) than in July and September 2020 (952 and 455 mm month^{-1}, respectively) (Figure 1a). This few precipitation in August might cause the decrement of RH and increment of T and VPD in August 2020 (Figure 2c, 2d). When drought conditions occur in a high temperature season, air temperature and VPD in the seedling foliage would also increase and perhaps exceed the critical temperature through limitations on transpirational cooling. Our results also indicated that seedlings might not suffer from severe conditions providing that the moisture conditions were satisfactory, while low rainfall and low irrigation might result in temperature and VPD increases through reduced seedling transpiration. Therefore, it was necessary to examine carefully to install treeshelters in Japanese cedar reforestation sites at soil xeric sites in low precipitation areas.

The $T_{\text{max-130}}$ and $T_{\text{max-80}}$ during winter (from December to February) reached 29.8–33.3 °C and 23.9–26.8 °C, respectively (Figure 2a). Warmer temperature might elongate the growth period of the seedlings due to earlier spring flush and later growth halt (Yamamoto et al. 2004). Increment of growth period might affect the growth pattern of Japanese cedar. On the other hand, some studies reported that earlier spring flush and late growth halt sometimes lead to heavy damage on seedlings when it gets colder temperature than usual in treeshelter not only in cool temperate (Akashi and Fukuchi 2003) but also in warm temperate zone (Gillespie and Rathfon 1996). In this study, low temperature below zero degree occasionally occurred at research site in winter (recorded −7.6 °C in January 2021). So, there is a risk that seedlings have damage in winter even in warm temperate zone in western Japan. To evaluate the effects of treeshelter installation on Japanese cedar seedlings, it was important to clarify how the warmer condition throughout a year changes the growth pattern and cold resistance on Japanese cedar.

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Figure legends

Figure 1. Monthly precipitation and means of the maximum and the minimum air temperatures in Kochi City from March 2020 to February 2021 (Kochi Local Meteorological Observatory, Japan Meteorological Agency, 2021)

Figure 2. Seasonal changes in the monthly means of the daily (a) maximum air temperature ($T_{\max}$), (b) minimum air temperature ($T_{\min}$), (c) minimum relative humidity ($RH_{\min}$), and (d) maximum vapor pressure deficit ($VPD_{\max}$) in three treeshelters during March 2020 to February 2021. ‘Outside,’ ’10,’ ’80,’ and ‘130’ show the measurements for ambient air, 10 cm, 80 cm, and 130 cm heights inside treeshelters, respectively. Asterisks represent significant difference at p = 0.05 level and NS represents no significant difference between RH at 80 cm height and ambient condition (t-test).

Figure 3. Mean values of (a) maximum air temperature ($T_{\max}$) and (b) maximum vapor pressure deficit ($VPD_{\max}$) in sunny (4 days), cloudy (6 days) and rainy days (5 days). ‘Outside,’ ’10,’ ’80,’ and ‘130’ show the measurements for ambient air, 10 cm, 80 cm, and 130 cm heights inside treeshelters, respectively. Different letters are significantly different at $\alpha = 0.05$ level (Tukey’s HSD test). Error bars represent standard deviation.

Figure 4. Diurnal changes in mean (a) air temperature (T), (c) relative humidity (RH), and (e) vapor pressure deficit (VPD) in three treeshelters in sunny days (9 days) in August 2020. Diurnal change of (b) T, (d) RH and (f) VPD in cloudy day (1 day) in August 2020. ‘Outside,’ ’10,’ ’80,’ and ‘130’ show the measurements for ambient air, 10cm, 80cm, and 130cm heights inside treeshelters, respectively.

Figure 5. Diurnal changes in mean (a) air temperature (T), (b) relative humidity (RH), and (c) vapor pressure deficit (VPD) at 80 cm height inside treeshelters with and without a seedling, and ambient condition in sunny days in August 2020.

Figure 6. Diurnal changes in photosynthetic active radiation (PAR) at 80 cm height inside and outside a treeshelter on a (a) sunny day (21 September 2020) and (b) cloudy day (20 September 2020).

Figure 1.

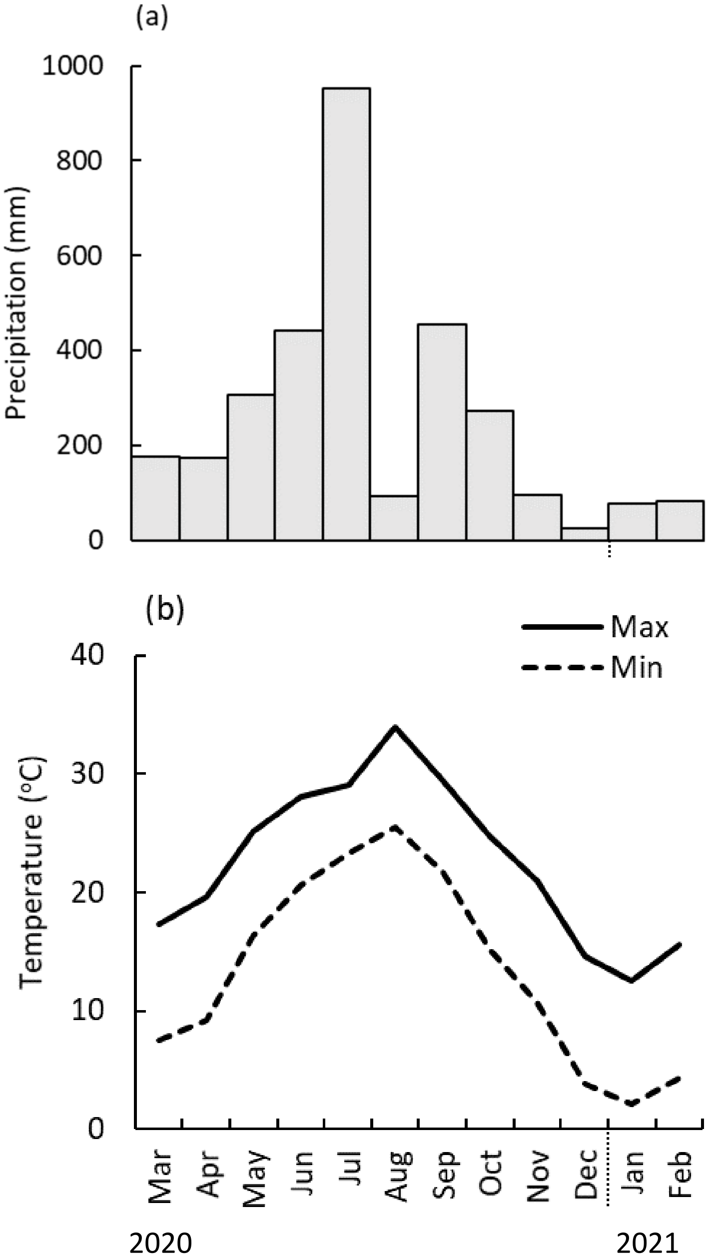
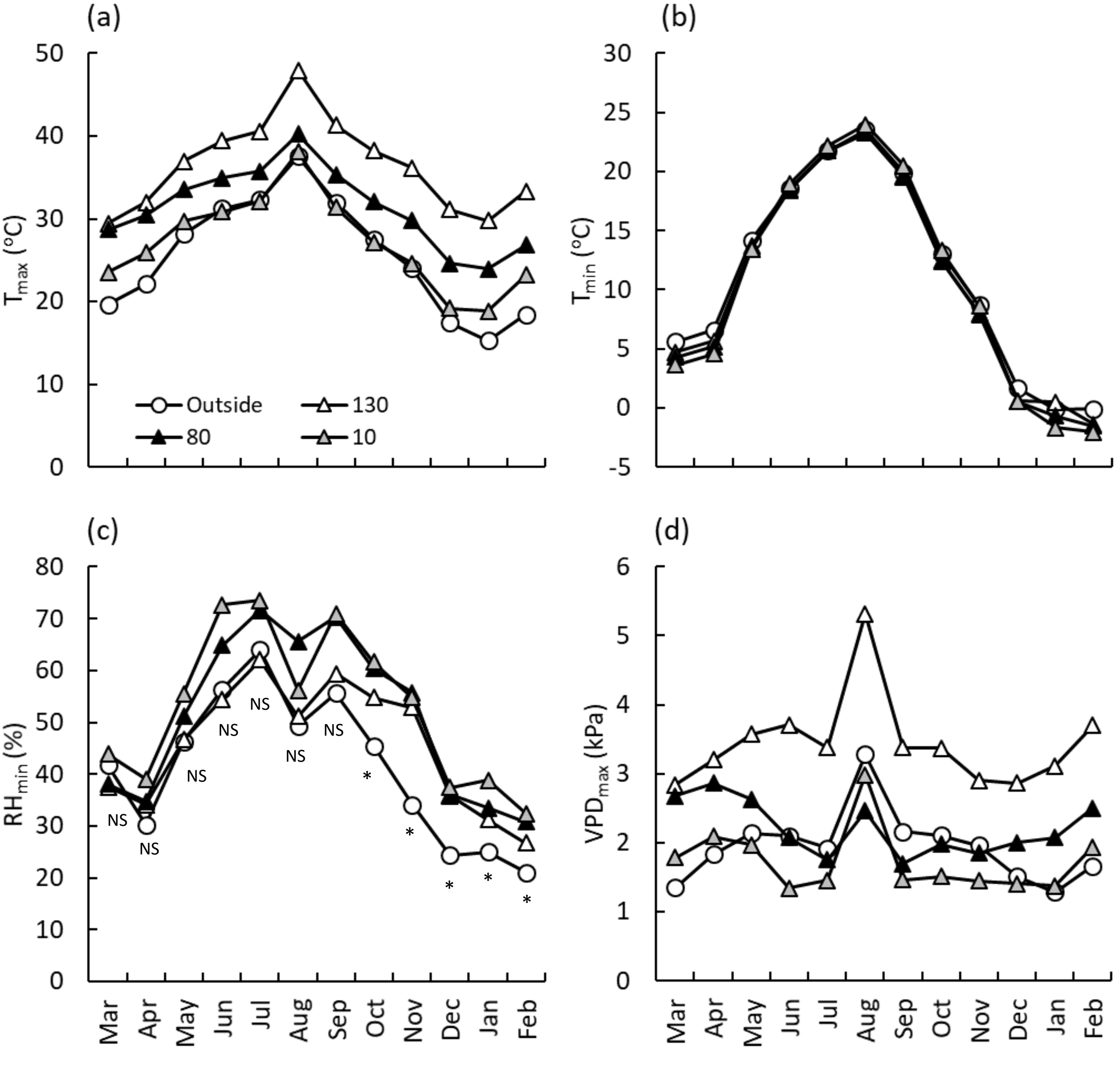
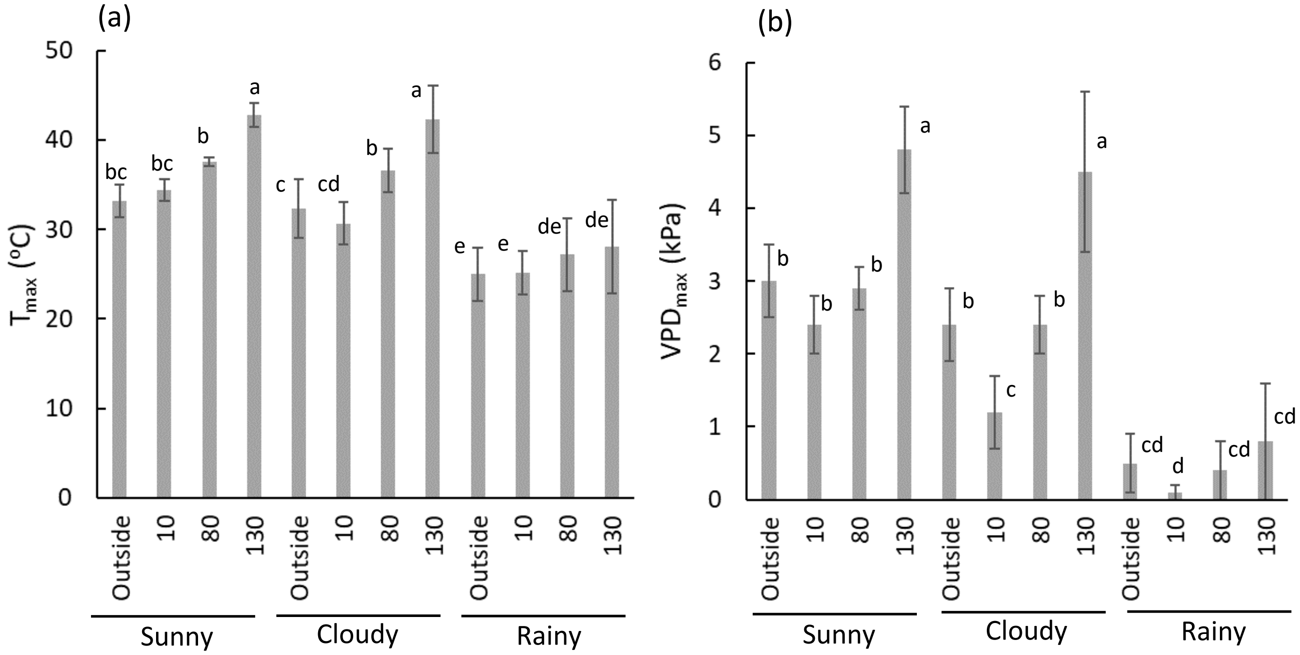

(a)
1000
800
600
400
200
0
Precipitation (mm)
(b)
Max
Min
40
30
20
10
0
Temperature (°C)
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
2020
2021

Figure 2.



(a)
(b)
(c)
(d)
50
40
30
20
10
0
T$_{max}$ (°C)
Outside
130
80
10
30
25
20
15
10
5
0
-5
T$_{min}$ (°C)
80
70
60
50
40
30
20
10
0
RH$_{min}$ (%)
NS
NS
NS
NS
NS
NS
NS
*
*
*
*
*
6
5
4
3
2
1
0
VPD$_{max}$ (kPa)
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb

Figure 3.



(a)
Tmax (ºC)
0
10
20
30
40
50
bc
bc
b
a
c
cd
b
a
e
e
de
de
Outside
10
80
130
Outside
10
80
130
Outside
10
80
130
Sunny
Cloudy
Rainy
(b)
VPDmax (kPa)
0
1
2
3
4
5
6
b
b
b
a
b
c
b
a
cd
d
cd
cd
Outside
10
80
130
Outside
10
80
130
Outside
10
80
130
Sunny
Cloudy
Rainy

Figure 4.

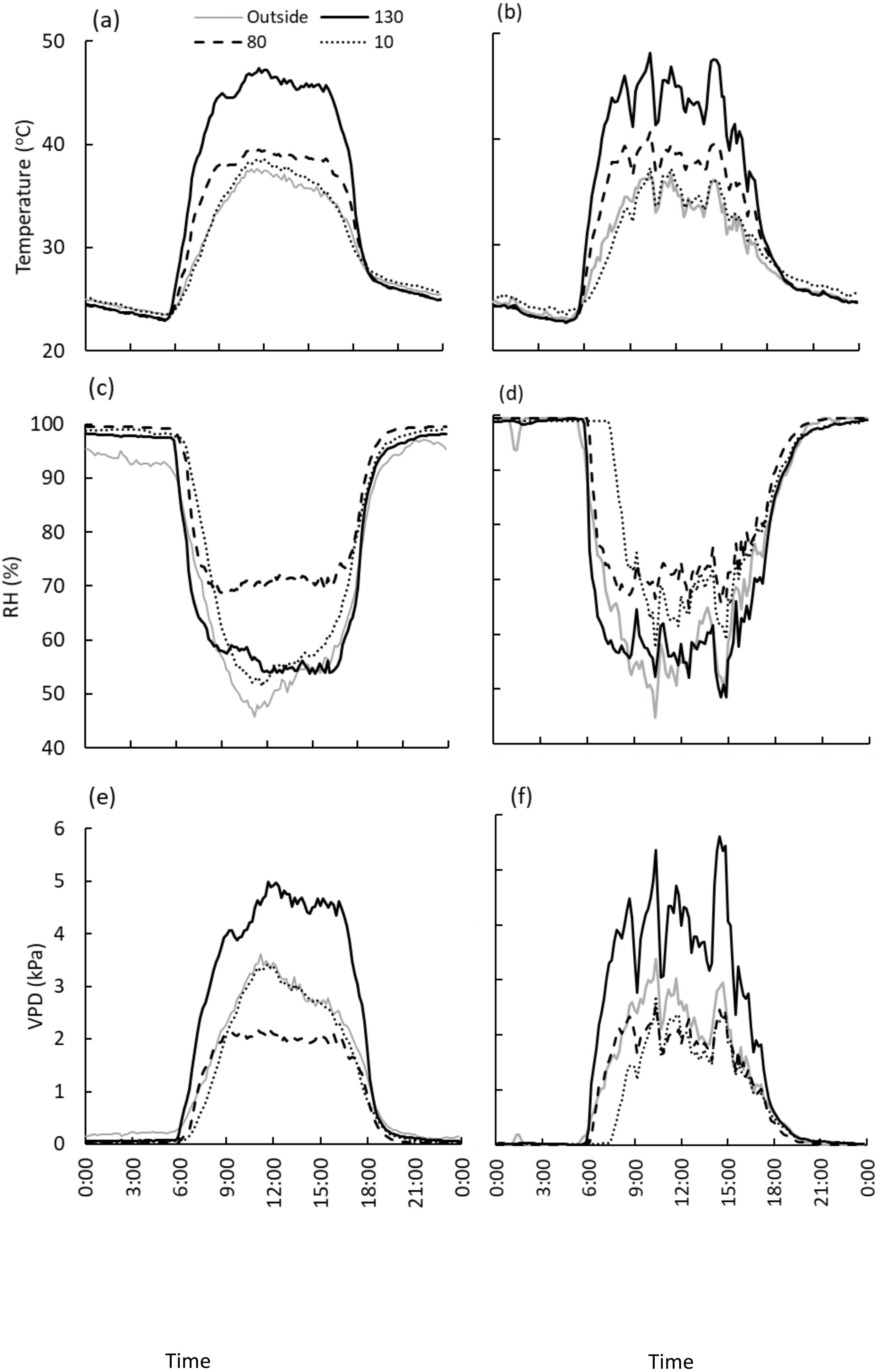

(a)
Outside
130
80
10
(b)
Temperature (°C)
50
40
30
20
(c)
(d)
RH (%)
100
90
80
70
60
50
40
(e)
(f)
VPD (kPa)
6
5
4
3
2
1
0
0:00
3:00
6:00
9:00
12:00
15:00
18:00
21:00
0:00
Time
Time

Figure 5.

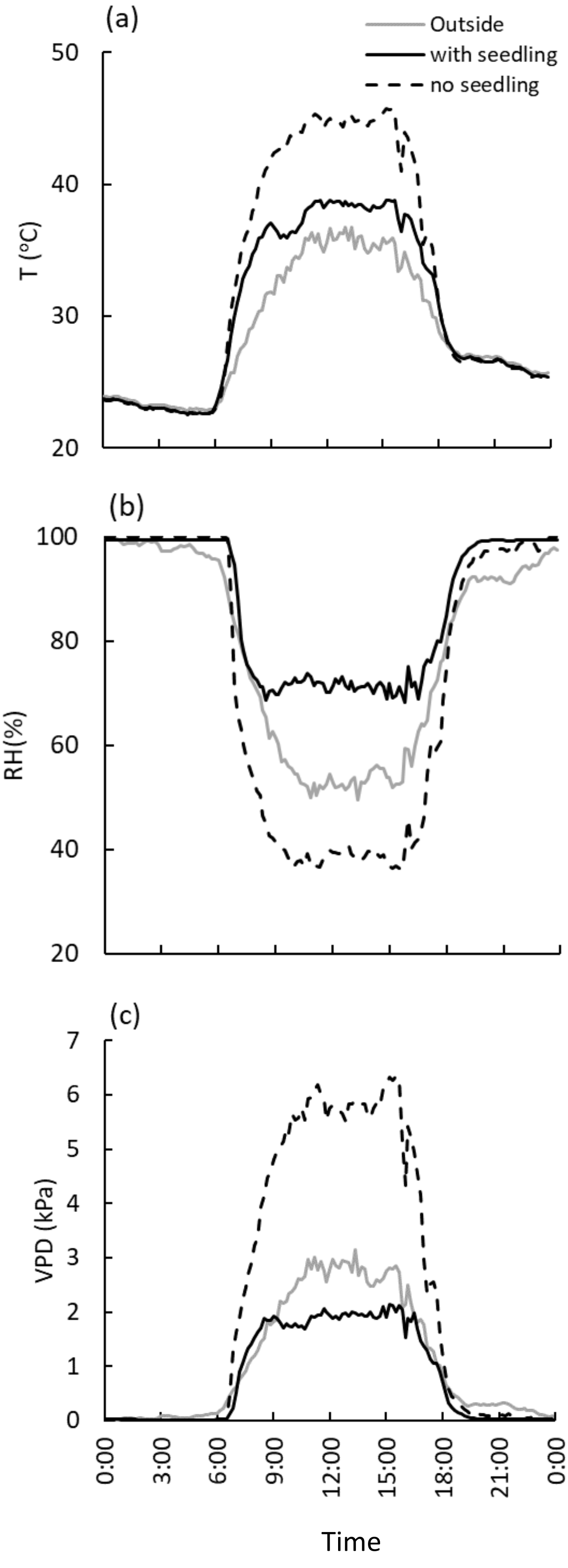
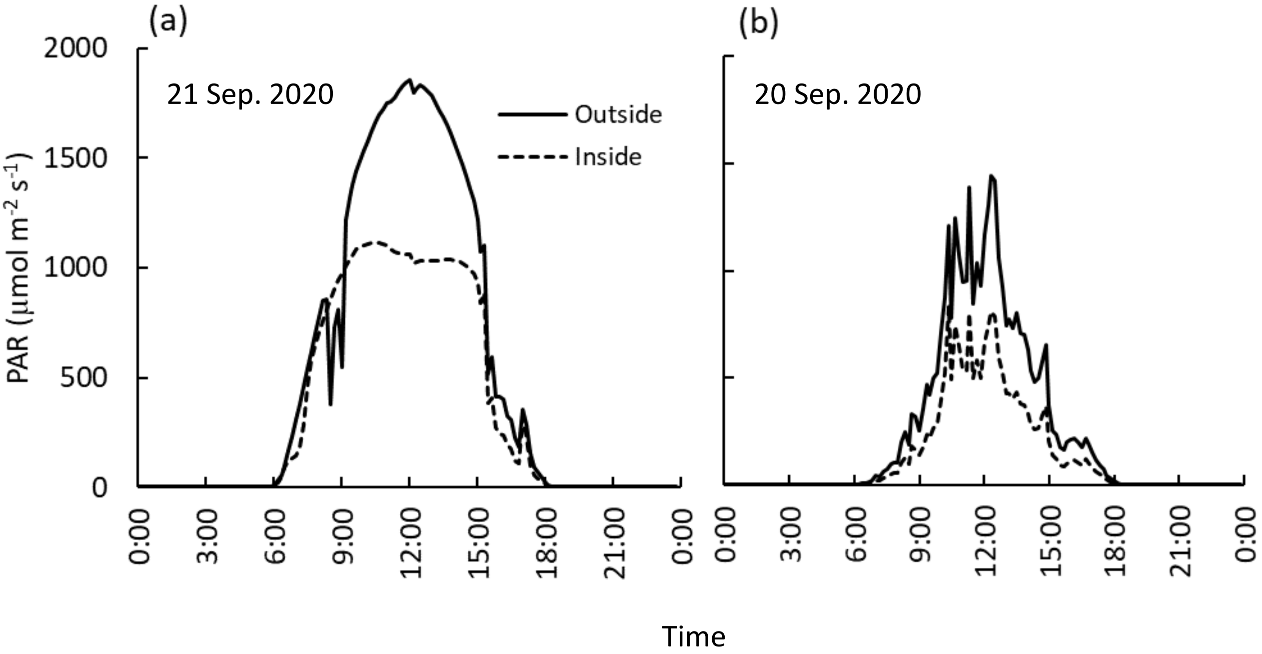

(a)
Outside
with seedling
no seedling
T (°C)
50
40
30
20
(b)
RH(%)
100
80
60
40
20
(c)
VPD (kPa)
7
6
5
4
3
2
1
0
0:00
3:00
6:00
9:00
12:00
15:00
18:00
21:00
0:00
Time

Figure 6.


(a)
(b)
21 Sep. 2020
20 Sep. 2020
Outside
Inside
PAR (μmol m-2 s-1)
2000
1500
1000
500
0
0:00
3:00
6:00
9:00
12:00
15:00
18:00
21:00
0:00
Time