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Scientific note

Seasonal changes in soil temperature on an upper windy ridge and lower leeward slope in *Pinus pumila* scrub on Mt. Shogigashira, central Japan

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Abstract: The seasonal changes in soil temperature at 5 cm below the surface were monitored on an upper windy ridge (2675 m a.s.l.) and lower leeward slope (2640 m a.s.l.) in *Pinus pumila* scrub on Mt. Shogigashira in central Japan, from October 2001 to September 2002. The scrub heights were *ca*. 20 cm and 100 cm on the upper windy ridge and lower leeward slope, respectively. The soil temperature on the upper windy ridge decreased from the autumn to mid-February and increased thenceforth. The soil temperature was sometimes lower than −10°C in winter. In contrast, the soil temperature on the lower leeward slope was relatively stable at about −1°C during the winter. It appears that accumulation of snow prevented cooling of the soil surface. In the snow-free period, the daily maximum soil-temperature was higher on the upper windy ridge than on the lower leeward slope. This difference was evident in May after the snowmelt, and decreased gradually toward the autumn. The solar radiation was highest at around the summer solstice. Much solar radiation penetrated to the soil surface on the upper windy ridge because of its poorly developed canopy, which increased the soil temperature. Thus, this study shows that seasonal changes in soil temperature are different between the upper windy ridge and lower leeward slope due to snow accumulation, canopy development and seasonal changes in solar radiation.

key words: alpine zone, *Pinus pumila*, seasonal change, soil temperature

Pinus pumila Regel is the most representative tree species in the alpine zone above timberline in Japan (Yoshino, 1978). Many researchers have examined *P. pumila* scrub from various aspects such as environmental conditions (Sekine *et al*., 1984; Okitsu and Ito, 1984, 1989; Takahashi and Sato, 1996), dry matter production (Kajimoto, 1989, 1990, 1994), seedling establishment (Kajimoto *et al*., 1998; Kajimoto, 2002), ecophysiological studies (Kajimoto, 1992; Maruta *et al*., 1996; Takahashi, 2003a) and relationships between shoot elongation and environmental conditions (Sano *et al*., 1977; Okitsu, 1988; Kajimoto, 1993; Takahashi, 2003b). Many studies have revealed that the growth and survival of *P. pumila* are largely affected by environmental conditions because the alpine zone is characterized by harsh environments such as cold air and strong winds. For example, the shoot elongation of *P. pumila* on windy ridges is reduced by strong winds, which brings about the short stature of *P. pumila* scrub (Kajimoto, 1993; Takahashi, 2003b). Therefore, the observation of environmental conditions is important for understanding the growth and survival of *P. pumila*.

Soil temperature is one of the important environmental factors affecting germination, growth and survival of alpine plants because low soil temperature directly reduces root activity of plants and often causes frost disturbance of seedlings (Körner, 1999). Low soil temperature also reduces net photosynthetic rates (Babalola *et al*., 1968; DeLucia and Smith, 1987). However, the observation of soil temperature in *P. pumila* scrub is still limited (*e.g.* Sekine *et al*., 1984; Takahashi, 1995; Takahashi and Sato, 1996). Furthermore, these studies examined soil temperatures only from summer to autumn; there are few observations of soil temperature throughout a year. In addition, there is also no study that has compared soil temperatures between windward and leeward sites in *P. pumila* scrub, although *P. pumila* is widely distributed from windy ridges to leeward slopes. Thus, the purpose of this study was to monitor soil temperatures throughout a year on an upper windy ridge and lower leeward slope in *P. pumila* scrub on Mt. Shogigashira in central Japan.

This study was carried out near the summit of Mt. Shogigashira (2699 m above sea level, 35˚48´N, 137˚50´E) in Nagano Prefecture, central Japan. The prevailing winds come from the west in this region (Fukuyo *et al*., 1998). The mean monthly air-temperature ranged between −11.4˚C (January) and 13.9˚C (July), and the mean annual temperature was 1.3˚C during October 2001 to September 2002 (Fig. 1) at the bottom of Senjojiki Cirque (2612 m a.s.l., *ca*. 3.5 km from the study area).

P. pumila was distributed only near the summit of Mt. Shogigashira (Takahashi, 2003b). Its altitudinal distribution ranged from timberline (2630 m a.s.l.) to the summit (2699 m a.s.l.). The observation of soil temperature was conducted at 2675 m a.s.l. (upper windy ridge) and 2640 m a.s.l. (lower leeward slope) on the east-facing slope of Mt. Shogigashira. The scrub heights of *P. pumila* at 2675 m a.s.l. and 2640 m a.s.l. were *ca*. 20 cm and 100 cm, respectively. Snow depth is a maximum in late March or early April in this region (Fig. 1). Kajimoto (1989) observed the depth of snow on the same slope of this study in late March 1985, and reported that the depth of snow was 80 cm at 2665 m a.s.l. and 300 cm at 2600 m a.s.l. The depth of snow at 2675 m a.s.l. (the site of this study) is expected to be less than that at 2665 m a.s.l. because the scrub height of *P. pumila* is almost equivalent to the depth of snow in a wind-exposed environment (Okitsu and Ito, 1984).

The soil temperature at 5 cm below the surface was automatically recorded on an upper windy ridge (2675 m a.s.l.) and a lower leeward slope (2640 m a.s.l.) at 1-hour intervals from October 2001 to September 2002, by using a thermometer with data logger (TidbiT, Onset Computer Corporation, Pocasset, MA, USA). This thermometer is a very durable instrument and is completely sealed in epoxy. A thermistor is placed inside the thermometer, and its accuracy is ±0.5˚C. One thermometer was buried at 5 cm below the soil surface at each site. In July 2002, the measurements were not conducted for approximately one week on the lower leeward slope and for two weeks on the upper windy ridge.

In this study, a freeze-thaw day was defined as a day having daily maximum and daily minimum soil temperatures above and below 0˚C, respectively. The freezing period of soil in autumn was defined as successive days from the day when the daily minimum soil-temperature fell below 0˚C to the day when the daily maximum soil-temperature fell below 0˚C. The thawing period in spring was defined as successive days from the day when the daily maximum soil-temperature rose above 0˚C to the day when the daily minimum soil-temperature rose above 0˚C. Frozen period of soil was defined as successive days when the daily maxi-

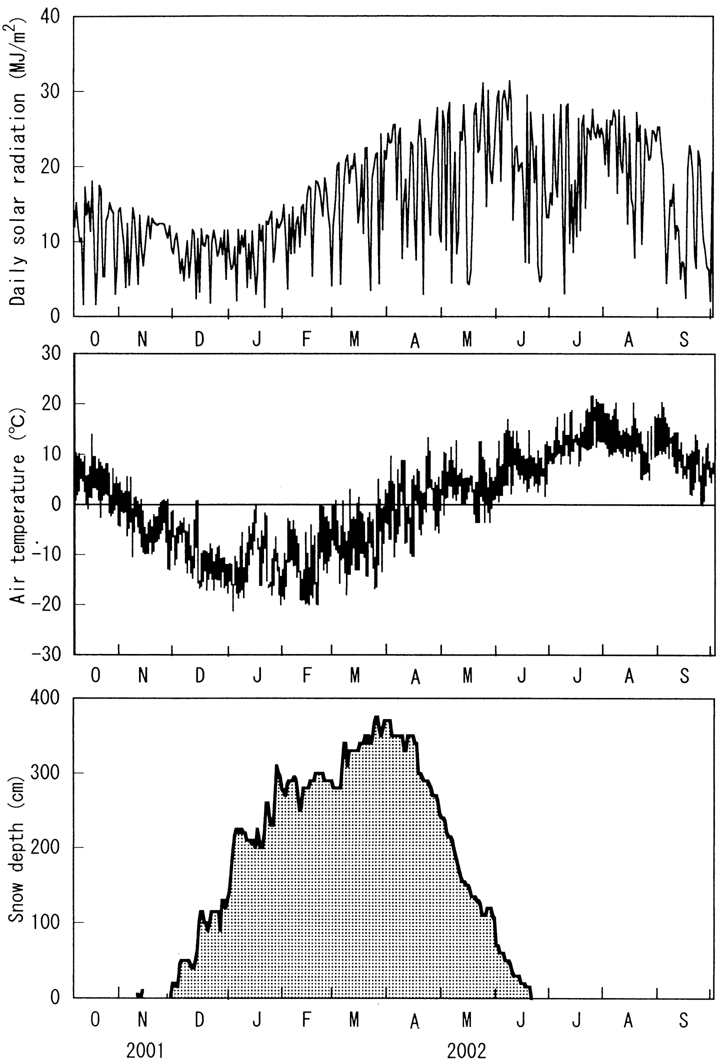

Fig. 1. The seasonal changes in daily solar radiation recorded at Matsumoto (610 m a.s.l.) (upper), air temperature (middle) and snow depth (lower) at Senjojiki (2612 m a.s.l.). The daily maximum and minimum air-temperatures are expressed by a vertical bar for each day.

mum soil-temperature was below 0°C. This study used the solar radiation recorded at Matsumoto Weather Station (36°15′N, 137°58′E, 610 m a.s.l., 45 km from the study site) to examine the seasonal changes in soil temperature.

The minimum air-temperature was sometimes subzero at Senjojiki during mid- to late October 2001 (Fig. 1). The freezing period of soil at a depth of 5 cm lasted from mid-October to early November on the upper windy ridge (total 18 days), while the freezing period was hardly observed on the lower leeward slope (Fig. 2). The frozen period started in early November at both sites (Fig. 2). The soil temperature on the upper windy ridge decreased by mid-February and increased thenceforth (Fig. 2). The observed minimum soil-temperature was −12.7°C in mid-February. The soil temperature on the lower leeward slope decreased until the end of November, and then the soil temperature was rather stable at about −1°C from early December (Fig. 2). Snow accumulation was observed at Senjojiki from early December (Fig. 1). Generally, soil temperature is rather constant at about 0°C in winter if snow depth is deep enough to insulate the soil surface from cold air (*e.g.* Takahashi, 1995; Takahashi *et al.*, 2002). Therefore, it is thought that the stable soil temperature on the lower leeward slope was due to the accumulation of snow and that snow hardly accumulated on the upper windy ridge due to strong winds.

The thawing period in the study area was observed from the end of April or early May, although the snow depth at Senjojiki was still greater than 2 m (Figs. 1 and 2). Senjojiki is located within a cirque so that the snow accumulation is much greater than at the site of this

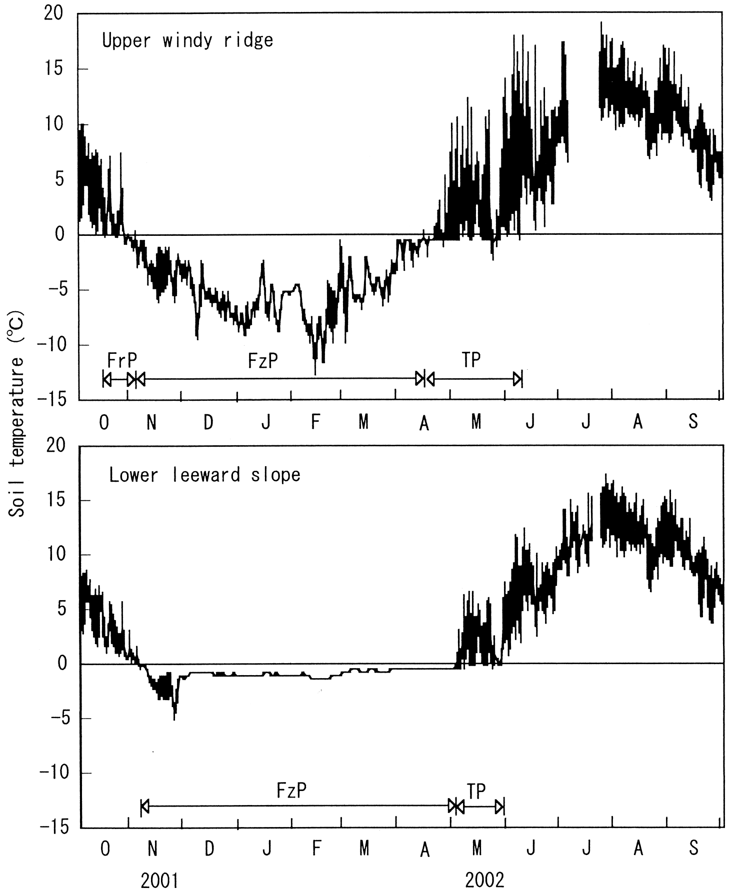

Fig. 2. The seasonal changes in soil temperatures at 5 cm below the surface at the upper windy ridge and the lower leeward slope in *P. pumila* scrub on Mt. Shogigashira in central Japan. The daily maximum and minimum soil-temperatures are expressed by a vertical bar for each day. "FrP", "FzP" and "TP" mean the freezing period, the frozen period and the thawing period, respectively.

study on a ridge. The thawing period started about two weeks earlier on the upper windy ridge than on the lower leeward slope, probably because of less accumulation of snow, but this period lasted longer on the upper windy ridge (Fig. 2). The thawing periods were 49 days on the upper windy ridge and 26 days on the lower leeward slope (Fig. 2). The total numbers of freeze-thaw days were 40 and 17 days on the upper windy ridge and the lower leeward slope, respectively, during October 2001 to September 2002. Takahashi and Hasegawa (1996) and Takahashi (1998) reported that the numbers of freeze-thaw days were 40 to 55 days a year on the wind-blown bare ground above timberline on Mt. Sugorokudake and Mt. Koizumidake. The number of freeze-thaw days which we observed on the upper windy ridge was similar to these values, while that on the lower leeward slope was much less.

The daily maximum soil-temperature in May (the thawing period) was 2.7°C higher on average on the upper windy ridge than on the lower leeward slope, while the daily minimum soil-temperature was similar between the two sites (Figs. 2 and 3). Although the daily maximum soil-temperature in June (after the thawing period) was still 2.9°C higher on average on the upper windy ridge than on the lower leeward slope, the daily minimum soil-temperature was 1.7°C lower on average on the upper windy ridge than on the lower leeward slope (Figs. 2 and 3). Thus, the diurnal changes in soil temperature were larger on the upper windy ridge than on the lower leeward slope (Fig. 4). Much solar radiation probably penetrated to the ground surface on the upper windy ridge because of its poorly developed canopy, which increased the soil temperature in the daytime (Fig. 4). On the contrary, it is considered that the well-developed canopy had an adiabatic effect on the lower leeward slope in the nighttime, *i.e.*, less nighttime emission of long-wave radiation from the soil surface (*cf.* Araki, 1995). Another possible factor affecting soil temperature is accumulation of litter. The well-

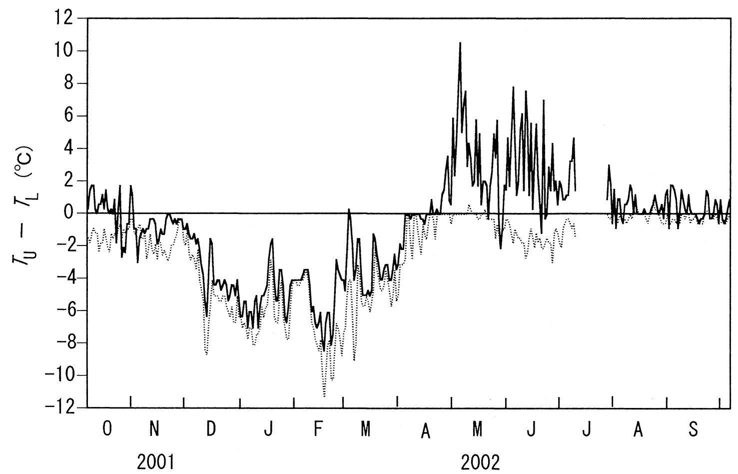

Fig. 3. The difference in soil temperature at 5 cm below the surface between the upper windy ridge (T_U) and the lower leeward slope (T_L) in *P. pumila* scrub on Mt. Shogigashira in central Japan. The difference in soil temperature between the two sites is expressed as $T_U - T_L$ (the soil temperature on the upper windy ridge minus that on the lower leeward slope). Solid and dotted lines represent the maximum and minimum soil temperatures, respectively.

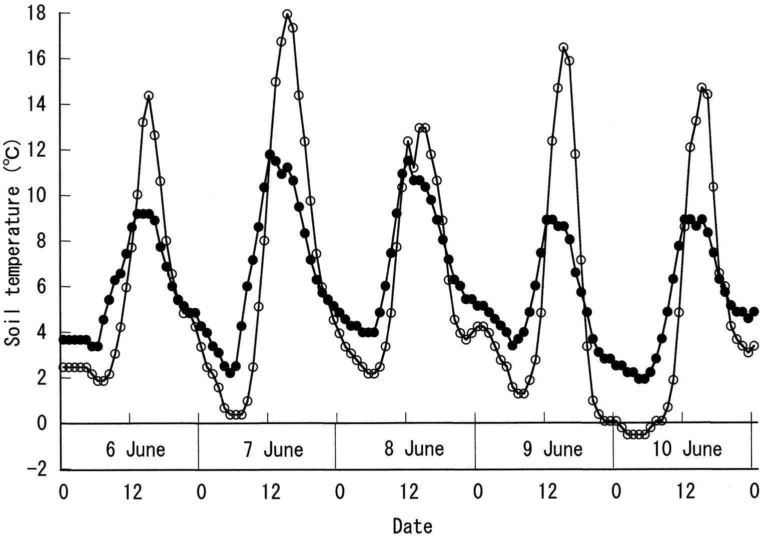

Fig. 4. An example of the diurnal changes in soil temperatures at 5 cm below the surface, from 6 to 10 June 2002, on the upper windy ridge (open circle) and the lower leeward slope (solid circle) in *P. pumila* scrub on Mt. Shogigashira in central Japan.

developed canopy provides much litter on the forest floor, which reduces the diurnal changes in soil temperature due to its adiabatic effect (Takahashi and Sato, 1996; Takahashi and Hasegawa, 2003).

The difference in the maximum soil-temperature between the two sites decreased gradually from the snowmelt toward the autumn (Fig. 3). This pattern is attributable to the seasonal changes in solar radiation. The solar radiation was highest at around the summer solstice, and decreased toward the winter solstice (Fig. 1). Therefore, much solar radiation reached the soil surface after the snowmelt on the upper windy ridge than on the lower leeward slope, which resulted in a large difference in daily maximum soil-temperature between the two sites.

Thus, this study showed that the seasonal changes in soil temperature were different between the upper windy ridge and lower leeward slope due to snow accumulation, canopy development and seasonal changes in solar radiation. Generally, not only the scrub height of *P. pumila* but also vegetation cover is low on windy ridges (Okitsu and Ito, 1984). This suggests the difficulties of seedling establishment there. Frost-heave events in late spring and droughts in early summer are major causes of seedling mortality of *P. pumila* (Kajimoto, 2002). The long duration of the thawing period in spring and high temperature of the soil surface in early summer on the upper windy ridge probably reduce the seedling establishment of *P. pumila* there. In addition, the repetition of freezing and thawing brings about mass movement on slopes (Sawaguchi, 1987), which possibly damages the seedling establishment of *P. pumila*. Therefore, further studies are necessary to examine the growth and survival of *P. pumila* in relation to thermal soil conditions.

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