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Change in Soil Temperature and Moisture Content After Removal of the A_0 Layer in *Pinus densiflora* Forest: A Case Study of a Mountain Where Matsutake Mushrooms (*Tricholoma matsutake*) Grow

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Abstract

One of the recommended methods for managing a red pine (*Pinus densiflora*) forest, where Matsutake mushrooms (*Tricholoma matsutake*) are cultured, is to remove the surface litter layer (A_0 layer). In this study, we evaluated the effect of removing the A_0 layer on soil temperature and moisture content. Two study plots, one of which had the A_0 layer removed and the other with the A_0 layer left intact, were established on a sloping terrain in a *P. densiflora* forest in Ina City, Nagano Prefecture, Japan. Soil temperature and moisture content were recorded in the two survey areas (and at two positions of the slope in each area) from July 2016 to April 2017. Although there were no clear changes in soil temperature, the removal of the A_0 layer rendered the soil temperature more susceptible to external temperature. Conversely, there was a clear difference in soil moisture content between the two study plots, whereby removing the A_0 layer significantly increased the soil moisture content. The poor permeability of the A_0 layer may have promoted a high runoff of surface flow down the slope.

Keywords: A_0 Layer; Forest Management; Matsutake; Permeability; Soil Moisture; Soil Temperature

Introduction

The fruiting body of the Matsutake mushroom, *Tricholoma matsutake*, grows in autumn in Japan, and is one of the few profitable forest products. Therefore, various methods to increase the harvest of Matsutake mushrooms have been developed in areas where they grow. A management policy was formed for the maintenance of the mountains where Matsutake mushrooms grow, which is the result of the experience of the mushroom producers combined with forestry test data that has been collected over many years, and its makes several recommendations [1]. However, there are few studies of the effects of each recommendation, which mainly rely on assumptions. These recommended practices are carried out, despite not all being successful in creating or maintaining mountains to be conducive to the production of Matsutake mushrooms [1]. Nevertheless, verifying the effects of the recommendations on land management for the mountains where Matsutake mushrooms grow should be conducted in a multifaceted manner. One of the recommendations is the removal of the surface litter layer (A_0 layer) from the forest floor. The A_0 layer reduces the penetration of water into the lower soil layers [2]. The forest floor is not managed in Japanese red pine (*Pinus densiflora)* forests, and the lower layer vegetation where the A_0 layer has developed has a high soil moisture content at the surface and a lower moisture content in soil layers deeper than 20 cm [3]. In addition, the thick layer of *P. densiflora* litter has a low permeability to rainwater, thereby promoting high runoff of surface flow [3].

Previous studies suggested that temperature and soil moisture content are important for growing Matsutake mushrooms [4], and that the soil where they grow is poor in nutrients [5]. In particular, cold stimulation is important for the formation of the *T. matsutake* fruiting body primordium [6]. Removal of the A_0 layer is recommended to create the environmental conditions that are suitable for growing Matsutake mushrooms. For example, the removal of the A_0 layer increases soil temperature [4] and decreases soil water retention [7]. However, the excessive removal of the A_0 layer is counterproductive for Matsutake mushroom culture [1], as it makes the soil conditions too dry and exposes them to direct sunlight. Furthermore, the removal of the A_0 layer affects the biological community [8] and reduces the abundance of soil microorganisms that compete with *T. matsutake*.

In this study, we examined the effects of removing the A_0 layer on soil temperature and soil moisture content, which is expected to cause rapid changes in the mountains where Matsutake grows, to provide data for the management of these areas for the effective production of Matsutake mushrooms.

Materials and Methods

Survey Area

Two survey areas, A and B, of about 100 m^2 were established in the over 60-year-old *P. densiflora* forest, distributed on the southwestern-westward slope of Ina City, Nagano Prefecture, Japan (35°49.4′ N, 138°0.5′ E, altitude 803 m, inclination 20-35°) (Figure 1). Survey areas A and B were contiguous and occurred on a sloped terrain. Each area contained one Shiro, which represented the location of the hyphae and mycorrhiza of *T. matsutake* that produce Matsutake mushrooms. No human activity had occurred in the surrounding areas or within the two survey areas since the 1970s. In addition to *P. densiflora*, *Chamaecyparis obtusa*, *Quercus serrata*, *Lyonia ovalifolia*, and *Ilex pedunculosa* also occurred in the survey area. There was almost no undergrowth in the forest, as seedlings of *I. pedunculosa* were scattered. The A_0 layer ranged from 3 cm to 15 cm deep, and *Sarcodon scabrosus* occurred throughout the forest. In survey area A, a metal rake was used to remove the A_0 layer between May and June 2016. Leaves that fell after July 2016 were left within the survey area.

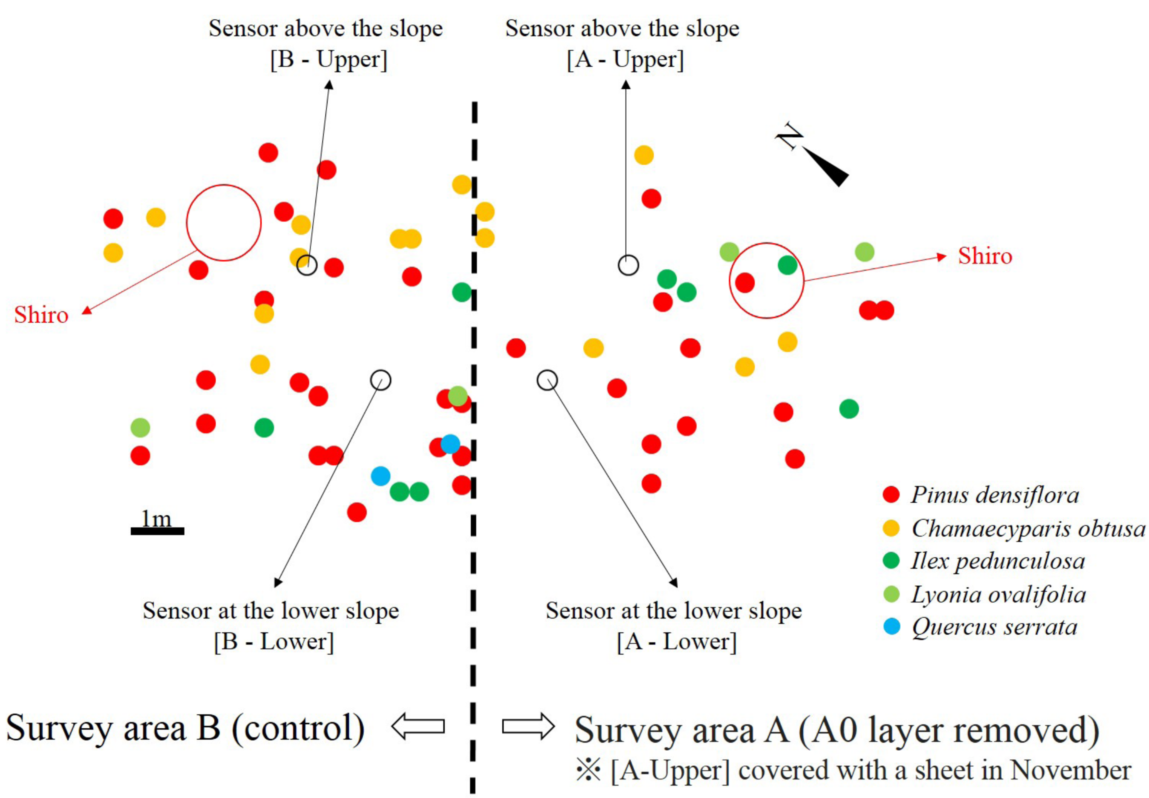

Figure 1: Overview of the survey area.

In each study area, we measured the trees and created a position map of trees that were 120 cm or more in height. We measured the diameter at breast height (DBH) of all trees with DBH > 5 cm. To prepare the standing position map, a tape measure was fixed horizontally at the center of the survey area, and the distance from the tape measure to each stand was measured using a laser range finder (GLM 7000, BOSCH, Japan).

Measurement of Soil Temperature and Soil Moisture Content

A data logger (Em50, 5 ch, Decagon Company) was installed between survey areas A and B and four soil moisture and temperature sensors (5TM, Decagon Company) were embedded within a 5 m radius therefrom, i.e., sensors were positioned in “A-Upper” and “B-Upper” on the top of the slope, and in “A-Lower” and “B-Lower” further down the slope (Figure 1). There was one Shiro within 5 m of each of the sensors installed on “A-Upper” and “B-Upper,” and several Matsutake mushrooms were harvested from each Shiro every year before 2015. Excavations of a portion of the Shiro showed that the hyphae and mycorrhiza of *T. matsutake* that produce Matsutake mushrooms were distributed from the surface of the soil (after the A_0 layer was removed) to a depth of 1 cm to 10 cm. In survey area A, the sensor was buried at a depth of about 5 cm from the soil surface. In survey area B, the A_0 layer was temporarily removed, and the sensor was buried at a depth of about 5 cm from the soil surface, before returning the A_0 layer. The thickness of the A_0 layer in “B-Upper” was about 3 cm, and that of the A_0 layer in “B-Lower” was about 10 cm. The cable portion exposed to aboveground was covered using PVC pipe. The soil temperature and moisture content were recorded at 1 h intervals from July 2016 to April 2017.

Pinus densiflora litter is known to reduce the permeability of soil [3]. Therefore, we assumed that soil temperature and soil moisture content would change as *P. densiflora* litter accumulated, and we partly covered the ground using a semi-permeable sheet. Specifically, we installed a 1 × 1 m sheet from November 2016 to April 2017, covering the “A-Upper” and continued to record soil temperature and soil moisture content.

Meteorological data stored in AMeDAS (Automated Meteorological Data Acquisition System) -Ina (35°49.5’ N, 137°57.3’ E, altitude 633 m) corresponding to the study period were compared with the data (i.e., the mean) obtained from the four sensors. The maximum, minimum, and daily averages were obtained from the data loggers and used to compare between survey areas. The monthly soil temperature recorded by each of the four sensors, the diurnal difference in soil temperature, and soil moisture content were compared using Tukey’s method ($\alpha = 0.05$).

Harvest Time and Weight of Matsutake

From mid-September 2016, we visited survey areas A and B once or twice per week, and the harvest date for Matsutake mushrooms and their weights at the time of harvest were recorded.

Results and Discussion

Tree Distribution

Five species of woody plants >120 cm occurred in the surveyed areas: *P. densiflora*, *C. obtusa*, *Q. serrata*, *I. pedunculosa*, and *L. ovalifolia* (Figure 1). There were 34 *P. densiflora* (average DBH: 16.9 cm, standard deviation: 8.09 cm), 15 *C. obtusa* (average DBH: 17.8 cm, standard deviation: 8.06 cm), 2 *Q. serrata* (all DBH < 5 cm), 8 *I. pedunculosa* (average DBH; 7.4 cm, standard deviation; 1.17 cm), and 4 *L. ovalifolia* (3 DBH < 5 cm, 1 DBH 7.3 cm).

Soil Temperature

The average soil temperature differed between the four sensors with a maximum difference of 3.27˚C (November 25: between "A-Lower" and "B-Lower"), and a minimum of 0.25˚C (October 19: between "A-Lower" and "B-Upper"). The average soil temperature from July to September 2016 was comparable to the lowest temperature from AMeDAS-Ina, and then remained comparable to the average temperature (Figure 2). The difference between average daily soil temperature and average monthly soil temperature is shown in Table 1. The average maximum soil temperature was 21.3˚C (August 7: "A-Lower") and the average minimum was 0.8˚C (January 27: "A-Lower"). In addition, the daily range in soil temperature was <5˚C throughout the study period.

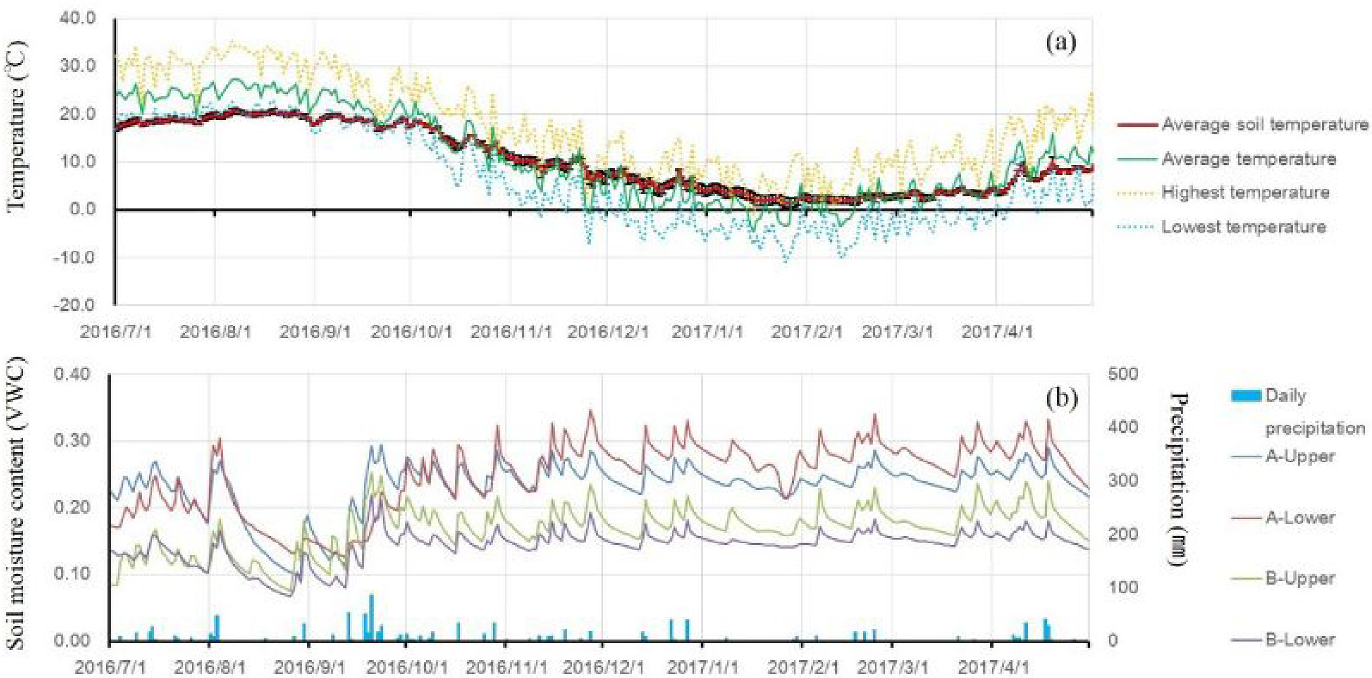

Figure 2: Soil temperature and soil moisture content from July 2016 to April 2017. (a) The average soil temperature (the black line represents the standard deviation) at four sensors and the daily change in average temperature, maximum, and minimum temperature from AMeDAS-Ina. (b) Daily change in soil moisture content (lines) at four sensors and daily precipitation from AMeDAS-Ina (bars).

			2016						2017			
			Jul	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**Apr**
Average soil temperature (˚C)	Survey Area A	A-Upper	18.7	20.0	18.4	14.6	8.8	5.5	2.4	2.1	3.2	7.3
		A-Lower	19.0	20.4	18.8	14.5	8.5	5.1	2.1	1.9	3.1	7.6
	Survey Area B	B-Upper	18.3	19.7	18.3	14.7	9.1	5.7	2.6	2.1	3.3	7.1
		B-Lower	18.0	19.6	18.5	15.4	10.3	7.1	4.1	3.3	4.1	7.3

Average temperature (˚C)	AMeDAS Ina		24.1	25.1	21.7	15.2	7.1	3.2	0.1	1.1	3.8	10.3
Average value of daily difference (˚C)	Survey Area A	A-Upper	1.3	1.4	1.2	1.2	1.2	1.1	0.5	0.6	1.2	1.7
		A-Lower	1.3	1.4	1.1	1.3	1.4	1.3	0.4	0.6	1.1	2.1
	Survey Area B	B-Upper	1.0	1.1	0.9	1.0	1.1	1.0	0.4	0.5	1.0	1.6
		B-Lower	0.6	0.7	0.6	0.6	0.6	0.6	0.2	0.2	0.4	0.7
	AMeDAS Ina		10.5	11.5	9.1	10.6	11.4	12.3	11.4	11.5	12.2	14.0

Table 1: Average daily difference and monthly soil temperature.

The daily range of soil temperature was smaller in “B-Lower” than was recorded at the other three sensors. In addition, soil temperature at “B-Lower” was low in the summer and high in the winter (Figure 3). Between July and August 2016, there was a difference in daily temperature between “A-Upper”, “A-Lower”, and “B-Upper”, but no other clear difference (Figure 3). The “B-Lower” sensor was about 10 cm deep in the A_0 layer, and the distance from the surface to the sensor was 15 cm greater than the other sensors. The “B-Upper” sensor was about 3 cm deep in the A_0 layer, and the distance from the ground to the sensor was 8 cm, while the “A-Upper” and “A-Lower” sensors were 5 cm deep. In the future, it is necessary to increase the number of replicate sensors; however, our comparison of the four sensors at different depths within the A_0 layer showed that the soil around the Shiro took longer to cool, owing to thick A_0 layer. However, in instances when the A_0 layer was about 3 cm thick, it is expected that the removal of the A_0 layer would have less of an effect on the soil temperature.

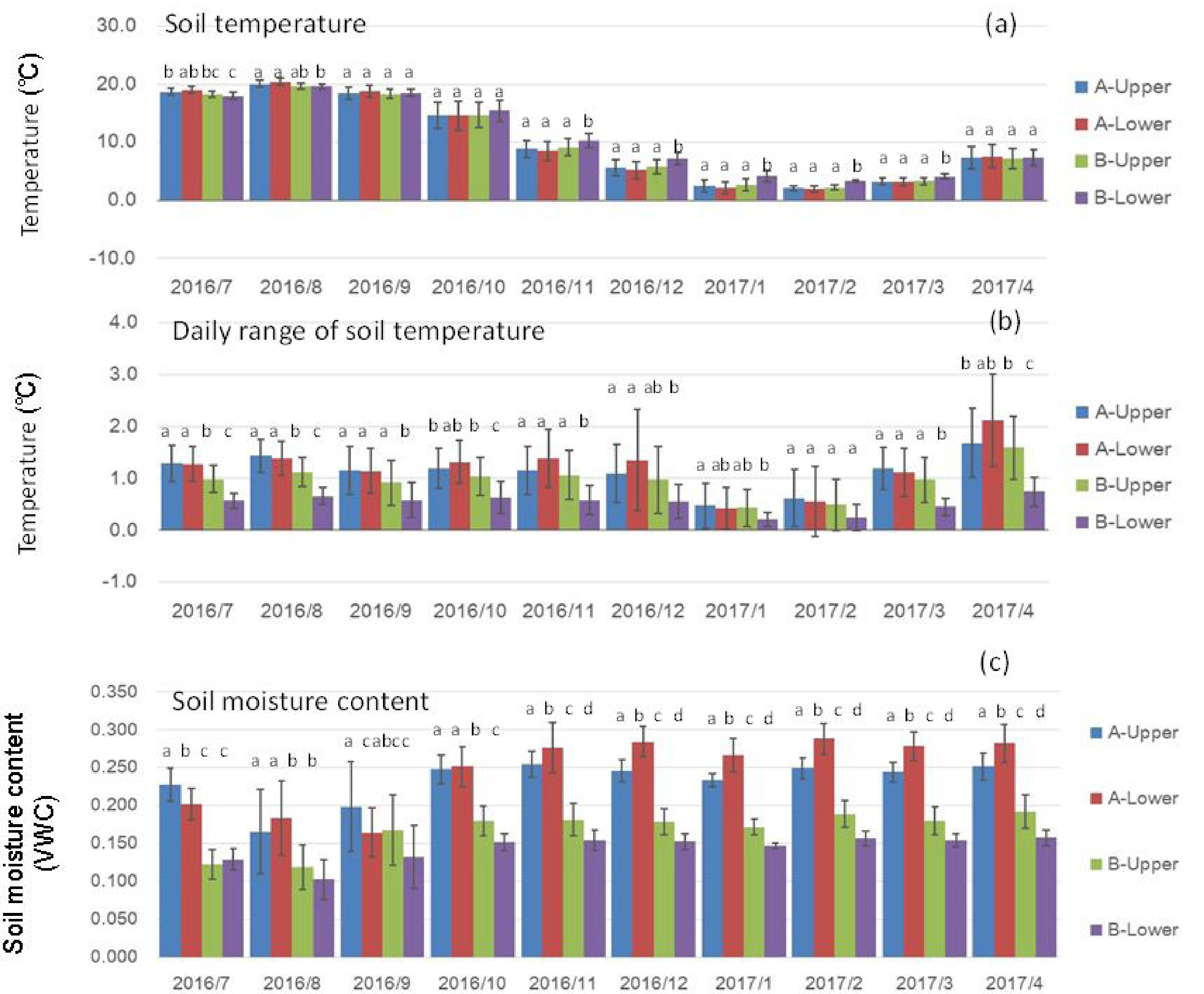

Figure 3: (a) Soil temperature, (b) daily range of soil temperature, and (c) soil moisture content between July 2016 and April 2017. Bars shows the averages, and black lines show the standard deviations. Different letters across months represent significant differences ($P < 0.05$).

Soil Moisture Content

The soil moisture content depends greatly on precipitation, and its increase coincided with the precipitation data recorded in AMeDAS-Ina (Figure 2). The soil moisture content was always higher in survey area A than in survey area B (Figure 2, Figure 3), except from late August to September 2016. The soil moisture content at “A-Upper” was higher than at “A-Lower” until October 2016; however, after the sensor was covered in mid-November 2016, soil moisture content decreased and was higher at “A-Lower” (Figure 2, Figure 3). Conversely, no such clear reversal was observed in survey area B (Figure 2, Figure 3).

Covering the sensor with a semi-permeable sheet decreased the soil moisture content around it (Figure 2, Figure 3). The covering of a sloping mountain with a plastic sheet resembled the effect of the deposition of semi-permeable red pine litter [3]. The removal of the A_0 layer is likely to contribute to an increase in soil moisture content around the Shiro.

Soil Temperature and Soil Moisture Content Before and After the Appearance of Matsutake Mushrooms

A total of 1742 g Matsutake mushrooms were harvested from the Shiro near "A-Upper", from October 18 to November 5, 2016. A total of 662 g Matsutake mushrooms were harvested from the Shiro near "B-Upper" from October 13 to 22, 2016 (Figure 4). Figure 4 shows the fluctuation in soil temperature and soil moisture content before and after the appearance of Matsutake mushrooms near the Shiros at "A-Upper" and "B-Upper".

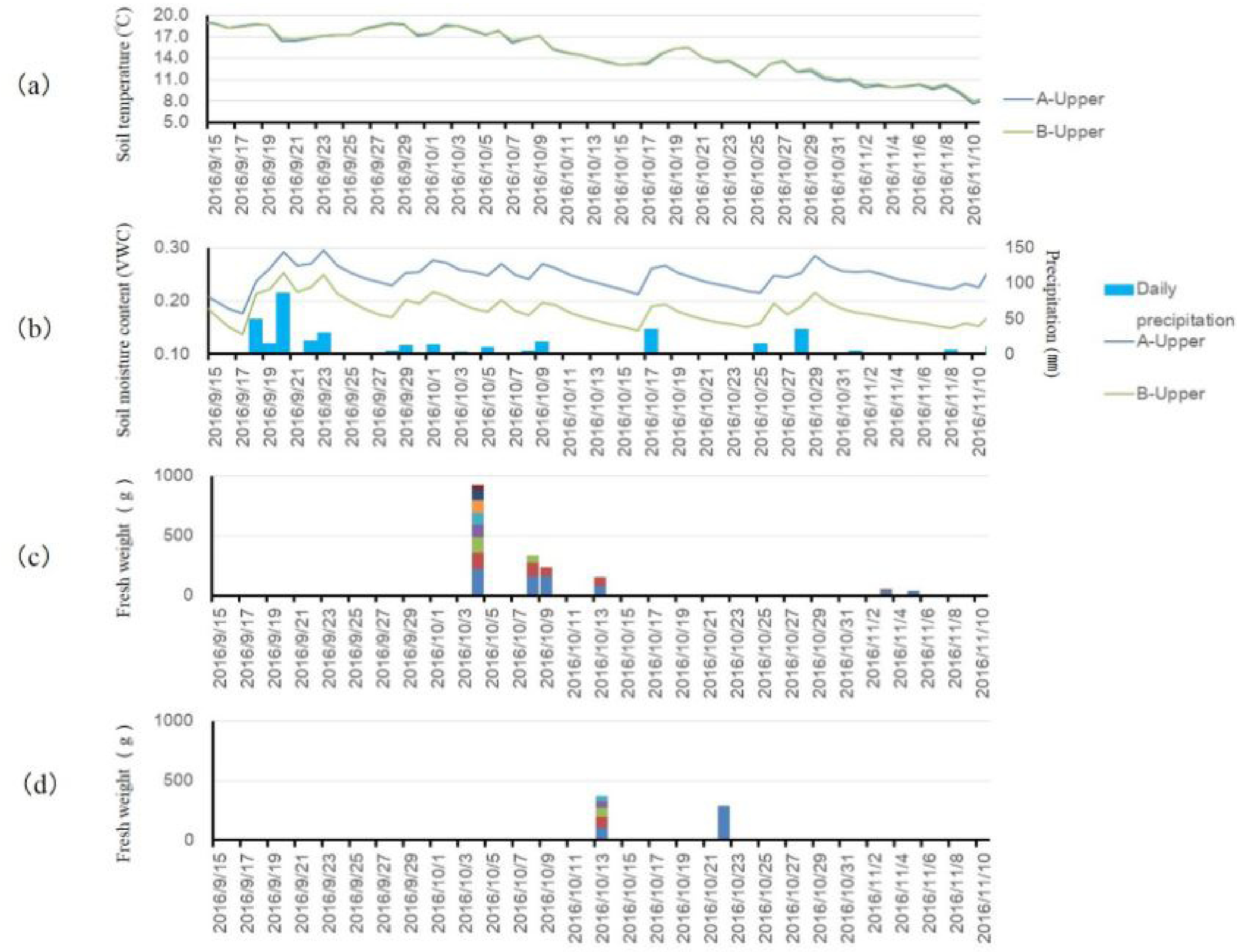

Figure 4: Soil temperature, soil moisture content, and Matsutake mushroom harvest from September 15 to November 10, 2016 before and after the Matsutake mushroom harvest period. (a) Daily change of soil temperature on A- and B. (b) Daily change of soil moisture content (lines) on A- and B - and daily precipitation from AMeDAS-Ina (bars). (c) Harvest time and yield of Matsutake mushrooms in survey area A. Color indicates different Matsutake mushroom (d) Harvest time and yield of Matsutake mushrooms in survey area B. Color indicates different Matsutake mushroom

Previous research in Nagano Prefecture showed that the temperature that stimulates the formation of the fruiting body primordia in *T. matsutake* is between 17.5˚C to 19˚C, however, it varies depending on the location. The lowest temperature for fruiting body formation is about 12˚C [9,10]. The low temperatures over the 20-21 days in 2016 may have triggered the growth of Matsutake mushrooms in these study areas. There was no clear difference in soil temperature between "A-Upper" and "B-Upper" (Figure 4). Conversely, the soil moisture content in the Shiros was about 20%, however, previous reports suggested that it is higher at around 22-28% [6]. The average soil moisture content between 15 September and 10 November 2016 was clearly different at "A-Upper" (by 25%) and "B-Upper" (by 18%) (Figure 4), suggesting that the removal of the A0 layer appears to be an effective management technique for the production of Matsutake mushrooms because it increases soil moisture content.

Conclusions

A thick A_0 layer buffers the change in soil temperature around the Shiro. In addition, the A_0 layer reduces the penetration of rainwater and buffers the increase in soil moisture content. The removal of the A_0 layer resulted in a large increase in soil moisture content near the Shiro. The recommendation involving the removal of the A_0 layer for the mountains where Matsutake grows appears to be an effective management technique, as it ensures sufficient soil moisture content and cold susceptibility required for the stimulation of the formation of the fruiting body in *T. matsutake*. However, in this study, the forest had many *C. obtusa* stands where the canopy was closed. Future studies are needed to investigate if the effect of removing the A_0 layer in young red pine forests is similar to that in red pine forests with various other vegetation species.

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