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Research Article

Effects of Vegetation Type and Management Practice on Soil Respiration of Grassland in Northern Japan

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Soil respiration rate in two types of grassland dominated with *Zoysia japonica* and *Miscanthus sinensis*, respectively, and under two management practices (undisturbed and intentionally burned) for the *M. sinensis* grassland was investigated for understanding the effects of grassland vegetation type and management practices on the relationship between soil temperature and soil respiration in northern Japan. Soil temperatures at depth of 1 cm in the *Z. japonica* (ZJ) and burned *M. sinensis* (MSb) plots had a larger temporal variation than that in the control *M. sinensis* (MSc) plot prior to early July. However, the coefficient of temperature sensitivity (Q_{10}) values, based on soil respiration rates and soil temperatures at 5 cm depth in the ZJ and MSb plots, were 1.3 and 2.9. These rates were lower than that in the MSc plot (4.3), meaning that soil respiration showed lower activity to an increase in soil temperature in the ZJ and MSb plots. In addition, monthly carbon fluxes from soil in these plots were smaller than that in the MSc plot. These results suggested that artificial disturbance would decrease soil microbial or/and plant root respiration, and it would contribute to the plant productivity. Future studies should examine the effects of the intensity and period of management on the soil respiration rate.

1. Introduction

Temperate grasslands comprise approximately 16% of the land area in east Asia [1]. In Japan, because the climax vegetation is forest, most grasslands are seminatural or artificial grasslands that require intensive management such as mowing or controlled burning [2]. The area of grassland in Japan is about 387,945 ha, or about 1% of the total land area [3]. The area of controlled burning in Japan is small, with only 0.3% of the total land area burned between April and August in 2000, a typical year [4]. Seminatural and artificial grasslands require continual management by mowing, grazing, or controlled burning. The vegetation types of grasslands differ depending on the strength and frequency of management; for example, *Miscanthus sinensis* dominated areas are cut once or twice per year, whereas *Zoysia japonica* dominated areas are cut three times per year [5].

Soil is a major carbon reserve in terrestrial ecosystems, and carbon flux from soil (soil respiration) is an important component because of the second largest carbon flux from the ecosystems. In particular, soil temperature would vary with changes in management type [6, 7], and it would influence soil respiration rate. For instance, many studies around the world reported that land use change, management, and vegetation type influenced microbial biomass and activity [8–15], soil respiration [16], and soil organic carbon content [17]. Numerous studies have found that soil respiration increases exponentially with increasing soil temperature in various types of cool temperate ecosystems in Japan [18–24]. In central Japan, the annual soil respiration rate in a *Z. japonica* grassland ranged from 719 to 1037 g C m^{-2} [25] or from 1121 to 1213 g C m^{-2} [23], which is larger than that in a deciduous forest (853 g C m^{-2}) [20] in the same area. Likewise, the maximum soil temperature at depth of 1 cm in the *Z. japonica* grassland was over 25°C [23, 25], whereas that in the deciduous forest was under 20°C [20]. Cao et al. [26] reported that the soil-temperature-dependence of

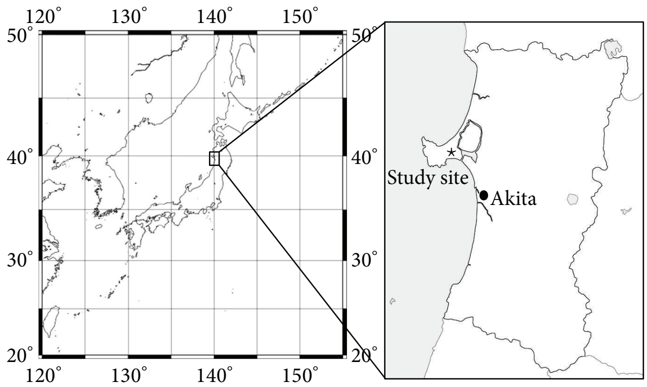


FIGURE 1: Location of the study site.

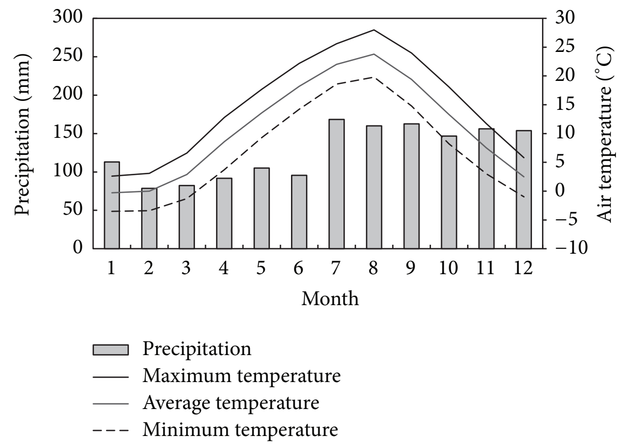


FIGURE 2: Monthly mean precipitation, and monthly mean, maximum, and minimum air temperatures at the study site from 1981 to 2010 (data from Japan Meteorological Agency).

soil respiration varied with grazing intensity on the Tibetan plateau: the soil respiration rate at the low-intensity grazing site was greater than that at the high-intensity grazing site throughout the growing season. Mukhopahyay and Maiti [27] also reported that soil respiration rate at natural grassland site was greater than that at mowed grassland site in India, in spite of maximum soil temperature at mowed grassland site being higher than that at natural grassland site. Therefore, intensive management to maintain grassland would likely affect the relationship between soil respiration and soil temperature; however, there is little information about the effect of artificial management on soil respiration. In this study, we investigated the effects of grassland vegetation type and management practices on the relationship between soil temperature and soil respiration in northern Japan. The objectives of the present study were (1) to compare soil respiration between two types of grassland (*Z. japonica* and *M. sinensis*) and between different management practices in *M. sinensis* grassland (undisturbed and intentionally burned) and (2) to clarify the effects of vegetation type and management on soil environmental factors, particularly soil temperature, as well as the relationships between soil respiration and soil environmental factors.

2. Materials and Methods

2.1. Site Description. The study was conducted in 2004 (only aboveground biomass; ABG of ZJ plot) and 2008 at Mt. Kanpu (39°55′N, 139°52′E, 355 m a.s.l.; Figure 1) in Akita Prefecture, northern Japan. From 1981 to 2010, the annual mean temperature was 11.0°C, and annual mean precipitation was 1571 mm (Figure 2; Japan Meteorological Agency). The area has snow cover from mid-November to early April. The vegetation types and management of the three plots were as follows: (1) *Z. japonica* grassland (ZJ) plot: mowing once by August every year and high treading stress by humans; (2) control *M. sinensis* (MSc) plot: mowing once every year, but the land was abandoned since 2001 and little treading stress; (3) intentionally burned *M. sinensis* (MSb) plot: the same as the MSc plot, but it was intentionally burned in early April 2008 and abandoned.

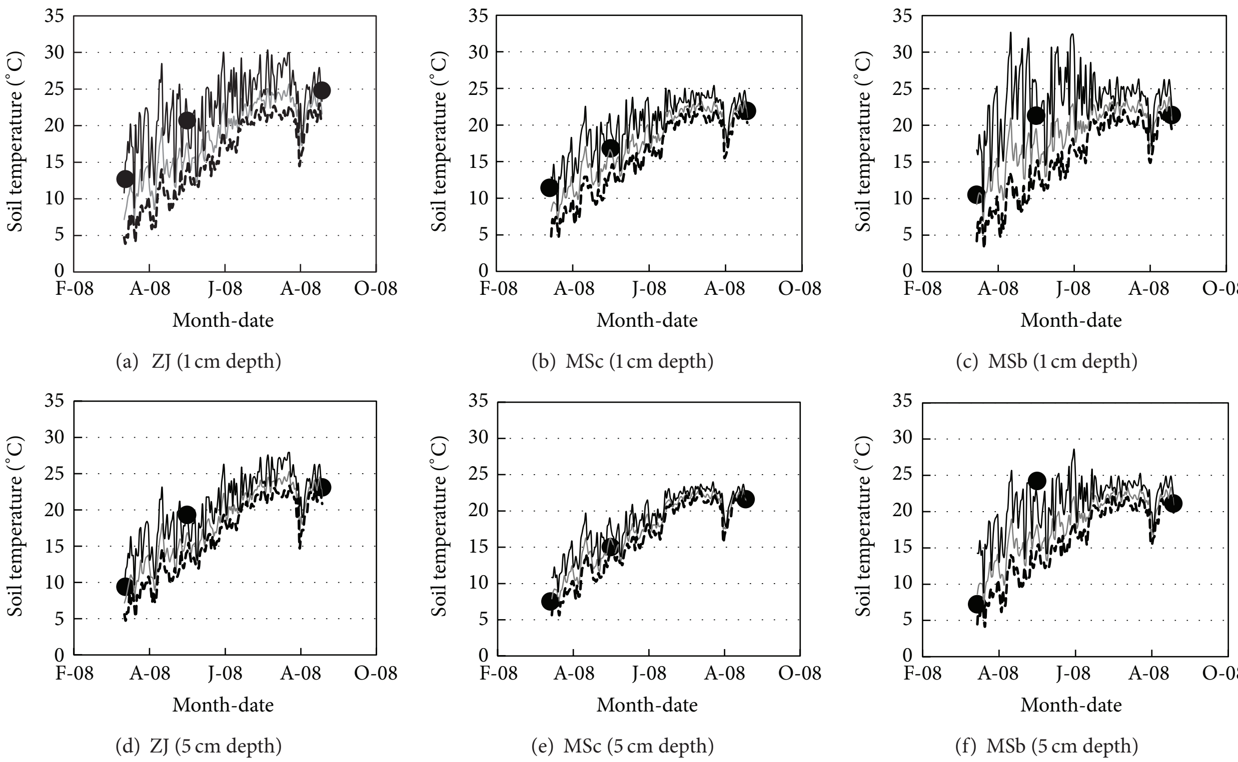
2.2. Measurement of Soil Respiration. Soil respiration (SR) rates were measured at the three sites (ZJ, MSc, and MSb plots) in April, May, and September 2008, using an LI-6400 portable photosynthesis system (Li-Cor, Lincoln, NE, USA) fitted with a SR chamber (6400-09, Li-Cor). SR in the MSb plot was measured shortly after the intentional burn in April 2008. One of 10 m × 10 m quadrat per one plot was established, and the SR rate was measured within 2 m × 2 m subquadrats ($n = 25$). Soil chamber was put on soil directly, soil color was not used. Simultaneously, soil temperature was measured at each point at depths of 1 cm (ST1) and 5 cm (ST5) using a thermometer (CT-450WR, Custom, Tokyo, Japan), and soil water content was measured at 5 cm depth with a time domain reflectometry sensor (TDR; TRIME-FM, IMKO, Ettlingen, Germany). ST1 and ST5 were continuously measured at 1 h intervals at the three sites from 7 April to 8 September 2008 using a Stowaway Tidbit Temperature Data Logger (Onset Computer, MA, USA). SR rate was regressed exponentially against ST5 as follows:

$$\mathrm{SR} = a \times \exp(\mathrm{ST5} \times b), \quad (1)$$

where a and b are coefficients. The coefficient of temperature sensitivity (Q_{10}) values of SR was calculated as follows [28]:

$$Q_{10} = \exp(10 \times b). \quad (2)$$

2.3. Plant Biomass and Soil Properties. AGB of the ZJ plot was measured in April 2004 ($n = 5$), and that of the MSb plot was measured in April 2008 ($n = 3$). All of the aboveground plants at 1 m^2 were taken as one sample and dried at 65°C during three days, and weights were measured. Nine 100 mL soil samples were taken from three plots using a soil corer (height 5 cm) in May 2008; the six samples at each plot were dried at room temperature (about 25°C) for a week, and then soil N and C contents were measured with an N/C analyzer (Sumigraph NC-22, Sumika Chemical Analysis Service, Tokyo, Japan). Bulk density was measured from the other three soil samples using fresh and dry weight which were dried at 105°C for 48 h.



(a) ZJ (1 cm depth) (b) MSc (1 cm depth) (c) MSb (1 cm depth)

(d) ZJ (5 cm depth) (e) MSc (5 cm depth) (f) MSb (5 cm depth)

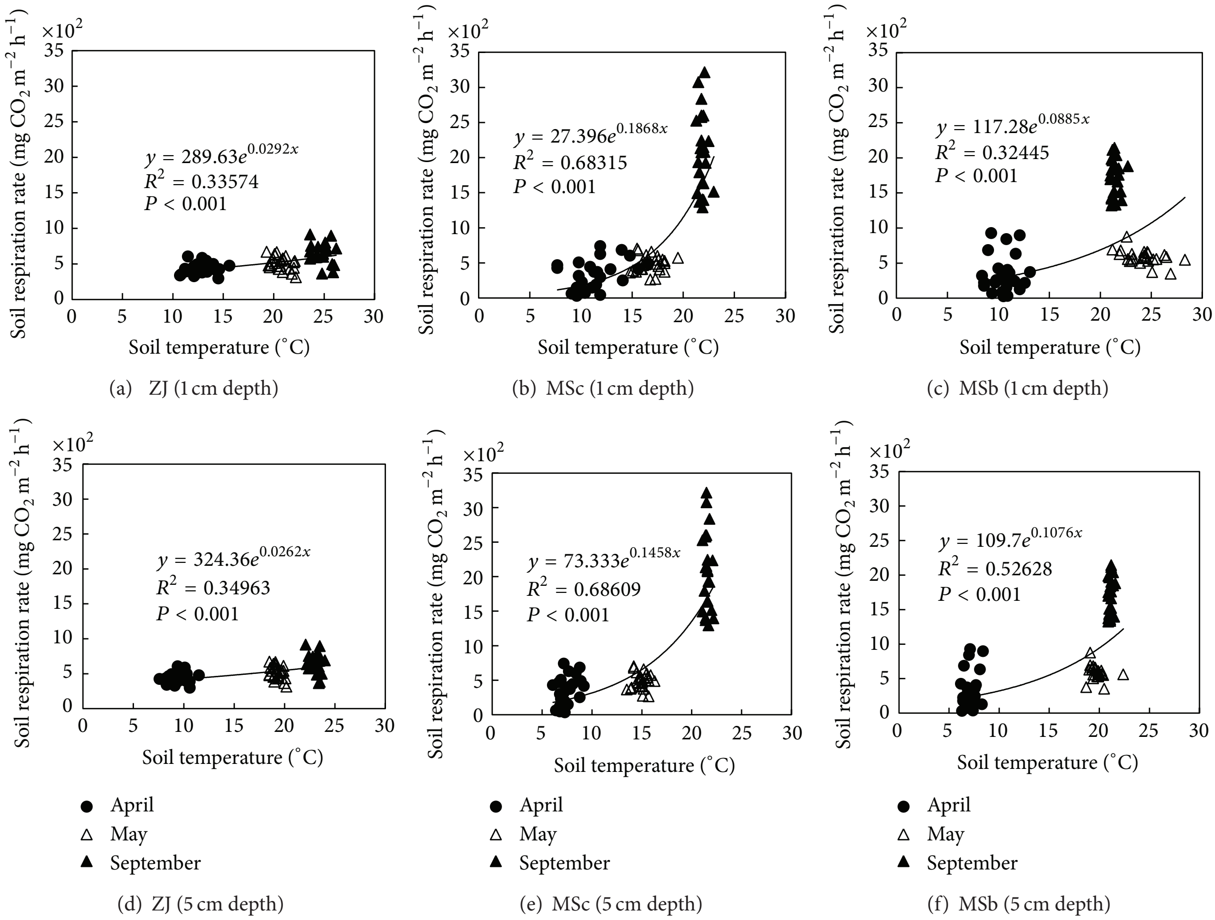
Figure 3: Seasonal variation in soil temperature at 1 cm and 5 cm depths in the ZJ plot, MSc plot, and MSb plot in 2008. The solid black line, gray line, and broken line represent daily maximum, mean, and minimum soil temperatures, respectively, from early April to early September. Closed circles represent mean soil temperature at each point where soil respiration rate was measured (n = 25).

2.4. Statistical Analyses. All statistical analyses were conducted using the Aabel 3 software package (Gigawiz Ltd. Co., OK, USA). ANOVA (Scheffé's test) was used to determine the significance of differences in soil carbon and nitrogen content, bulk density, SR rates, and soil temperatures among the ZJ, MSc, and MSbplots. Pearson product-moment correlation was used to clarify the relationship between the SR rate and ST1, ST5, and soil water content at depth of 5 cm.

3. Results

Table 1 shows AGB and soil properties of the three plots, and soil properties were not significantly different among the three plots (Scheffé's test). Differences in vegetation and management greatly influenced the temporal variation in soil surface temperature (Figure 3). In the ZJ plot, the difference between maximum and minimum ST1 was very large during April and May, and there were more than 10 days when the difference was greater than 10°C (Figure 3(a)). ST1 in the MSb plot had a larger temporal variation than that in the MSc plot prior to early July, and thereafter the soil surface temperatures were similar in both plots (Figure 3(c)). The temporal variations in soil temperatures at both soil depths were smallest in the MSc plot (Figures 3(b) and 3(e)).

SR rates in April were not significantly different among the three plots, but there were significant differences in September (Table 2, Scheffé's test, $P < 0.05$). ST1 and ST5 in the ZJ plot were significantly higher than those in the other plots in September, when the SR in the ZJ plot was significantly lower than that in the other plots. In September, the SR rate in the MSc plot was significantly higher than that in the MSb plot, despite the fact that ST1 in these plots was similar. SR showed no significant correlation with soil water content at 5 cm depth in the MSc plot (data not shown, Pearson product-moment correlation, $P = 0.623$), but SR in the ZJ and MSb plots had a significant negative correlation with soil water content at 5 cm depth (data not shown, Pearson product-moment correlation, $P < 0.001$, $r = -0.483$ in the ZJ plot; $P < 0.001$, $r = -0.564$ in the MSb plot). Seasonal variations in SR in the ZJ and MSb plots were smaller than that in the MSc plot (Figure 4). The correlation coefficients of soil temperature in the ZJ and MSb plots were lower than that in the MSc plot. The correlation coefficient between SR and ST1 was lowest in the MSb plot, because the SR rate tended to have a negative relationship with ST1 in this plot in May (Figure 4(c): open triangles; Figure 5; Pearson product-moment correlation coefficient, $P = 0.021$). In the MSb plot, ST1 in May was higher than that in September, but SR in May was much lower than that in September (Table 2). The Q_{10} values based on SR rate and ST5 using the coefficient at Figures 4(d), 4(e), and 4(f)in the ZJ and MSb plot, were 1.3 and 2.9, whereas that in the MSc plot was 4.3. The estimated soil carbon flux from April to September was estimated as 631 g C m^{-2} in the ZJ plot, 1304.8 g C m^{-2} in the MSc plot, and 1002.3 g C m^{-2} in the MSb plot (Figure 6).



(a) ZJ (1 cm depth) (b) MSc (1 cm depth) (c) MSb (1 cm depth)

(d) ZJ (5 cm depth) (e) MSc (5 cm depth) (f) MSb (5 cm depth)

Figure 4: The relationships between soil temperature at 1 cm and 5 cm depths and soil respiration rate in the ZJ plot, MSc plot, and MSb plot. The closed circle, open triangle, and closed triangle represent the data in April, May, and September 2008, respectively. P values were calculated by Pearson product-moment correlation test.

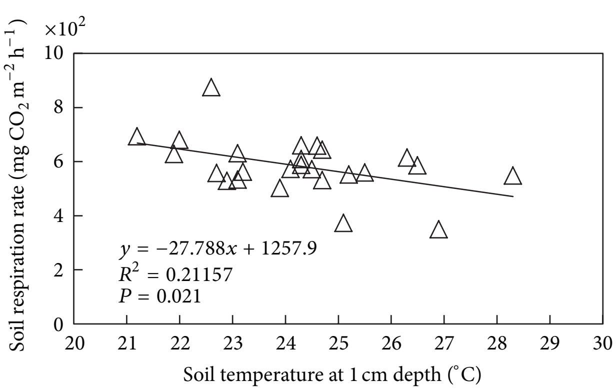


Figure 5: The relationship between soil respiration and soil temperature at depth of 1 cm in the MSb plot in May 2008.

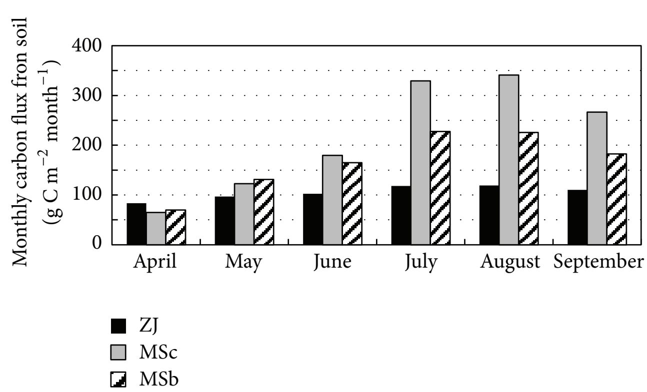


Figure 6: Monthly carbon flux from soil in the ZJ plot, MSc plot, and MSb plot from April to September 2008.

4. Discussion

The Q_{10} values indicate that SR showed lower activity to an increase in soil temperature in the ZJ and MSb plots, and the monthly carbon fluxes from soil in these plots were smaller than that in the MSc plot (Figure 6). Different mechanisms were driving the weaker SR responses to increasing soil temperature in the ZJ and MSb plots. In September, the SR rate was significantly lower in the ZJ plot than in the other plots, although ST1 and ST5 were highest in the

Table 1: Aboveground biomass (AGB), soil carbon (C) content, soil nitrogen (N) content, and bulk density in the *Zoysia japonica* (ZJ), control *Miscanthus sinensis* (MSc), and intentionally burned *M. sinensis* (MSb) plots.

Plot	AGB (g d.w. m^{-2})	C content (%) ($n = 6$)	N content (%) ($n = 6$)	Bulk density ($g\,m^{-3}$) ($n = 3$)
ZJ	330.5 ± 12.3[1]	13.16 ± 1.13	0.81 ± 0.10	0.38 ± 0.03
MSc	N.D.	12.44 ± 0.94	0.80 ± 0.05	0.33 ± 0.03
MSb	1218.1 ± 137.1[2]	12.94 ± 0.62	0.86 ± 0.05	0.38 ± 0.03

All data indicated mean ± standard deviation. [1]Measured in April 2004 (n = 5), [2]measured in April 2008 (n = 3). N.D.: no data. AGB data contained litter biomass. All soil samples were taken in May 2008, and there are not significant differences among the three plots (Scheffé's test).

Table 2: Descriptive statistics for soil respiration rates, soil temperatures at 1 cm and 5 cm depths, and soil water content at depth of 5 cm in the *Zoysia japonica* (ZJ), control *Miscanthus sinensis* (MSc), and intentionally burned *M. sinensis* (MSb) plots.

	April	May	September
Soil respiration rate (mg CO_2 m^{-2} h^{-1})			
ZJ	426.6 ± 78.0a	514.7 ± 93.1a	648.6 ± 146.1a
MSc	338.2 ± 206.6a	484.3 ± 115.8ab	2072.5 ± 545.0b
MSb	341.6 ± 261.0a	584.4 ± 101.1ac	1659.9 ± 271.2c
Soil temperature at depth of 1 cm (°C)			
ZJ	12.7 ± 1.3a	20.7 ± 0.9a	24.8 ± 0.8a
MSc	11.4 ± 2.3ab	16.8 ± 1.2b	21.9 ± 0.4b
MSb	10.5 ± 1.3b	24.2 ± 1.7c	21.4 ± 0.4b
Soil temperature at depth of 5 cm (°C)			
ZJ	9.4 ± 0.9a	19.3 ± 0.5a	23.1 ± 0.5a
MSc	7.5 ± 0.8b	15.0 ± 0.7b	21.6 ± 0.3b
MSb	7.2 ± 0.6b	19.8 ± 0.7a	21.1 ± 0.2c
Soil water content at depth of 5 cm (%)			
ZJ	29.5 ± 3.7a	24.9 ± 3.0a	N.D.
MSc	23.9 ± 6.9b	21.8 ± 6.2a	N.D.
MSb	31.4 ± 4.1a	21.3 ± 4.4a	20.2 ± 5.9

Values represent means ± SD (n = 25). Different lowercase letters within the same month indicate a significant difference between plots (Scheffé's test, $\alpha = 0.01$, $P < 0.05$). N.D.: no data.

ZJ plot (Table 2). Schmitt et al. [29] reported that plant productivity of grassland decreased due to the reduction of leaf area index by mowing and grazing. Because the ZJ plot is mowed by August every year, the SR in September would decrease with the decrease in plant productivity or root respiration after mowing. In the MSb plot, the daily maximum ST1 was similar to that in the ZJ plot until early July (Figures 3(a) and 3(c)), but the SR rate tended to have a negative relationship with ST1 in May (Figure 5). This result is consistent with that of a study in a mixed-conifer forest [30], but positive relationships were observed in a subhumid grassland [31] and a semiarid grassland [32]. In the semiarid steppe region of southeastern Spain, the SR rate also decreased with increasing soil temperature [33]. However, Hernández et al. [34] found that microbial biomass and dehydrogenase activity (an indicator of microbial activity) in burned soils were significantly lower than those in control soils. Guénon et al. [12] also reported that microbial biomass of the soil burned recently was significantly lower than that of the soils burned before. Therefore, the relatively low SR rate under high soil temperatures in MSb as compared with other grasslands may be due to low microbial activity and/or microbial biomass resulted from the intentional burning. The soil temperature was the most important factor to estimate annual or seasonal SR rate, however, in some case, SR had a negative relationship with soil temperature. The result of Figure 5 indicated that the estimation of SR rate using ST1 would be overestimated at the MSb plot, the estimated SR rate during the growth season in MSb was smaller than that in MSc. In central Africa, the SR rate in burned grassland was significantly lower than that in a control plot 1 month after burning, but there was no difference between the plots at 8 months after burning [35]. Moreover, Schmitt et al. [29] suggested that gross primary production of grassland was strongly affected by mowing and grazing in European mountain regions. Continuous investigation will be required in order to evaluate the period and quantity of the influence of intensive management. Ono et al. [36] reported that plant productivity and ecosystems respiration are generally closely coupled at paddy field of Japan. Therefore, our results suggested that artificial disturbance would decrease soil microbial or plant root respiration, and it would contribute to the plant productivity. Although defining an index of the intensity of management would be difficult, we need to further investigate the effect of management intensity and duration on SR rate.

According to this and previous studies, the maximum AGB of *Z. japonica* ranges from about 250 to 400 g d.w. m^{-2} (approximately 250 g d.w. m^{-2} [37]; 297–413 g d.w. m^{-2} [23]), which is considerably less than that of *M. sinensis* (769–837 g d.w. m^{-2} [19]; 1117 g d.w. m^{-2} [38]). The estimated soil carbon flux from April to September in the ZJ plot was 631 g C m^{-2}. This result was lower than that in *Z. japonica* grassland in central Japan (1077 and 1170 g C m^{-2} from May to October in 2007 and 2008, respectively [23]). In the present study, soil carbon flux during the growing season was estimated as 1304.8 g C m^{-2} in the MSc plot and 1002.3 g C m^{-2} in the MSb plot. In the other sites, the annual CO_2 flux from the soil in an *M. sinensis* grassland was 1387 g C m^{-2} in 2000 and 1480 g C m^{-2} in 2001 [19], and these rates are higher than the annual rates of soil carbon flux reported in Japanese forest ecosystems: 726–854 g C m^{-2} in deciduous forest [20], 592 g C m^{-2} in secondary deciduous forest [21], and 680 g C m^{-2} in the early stage of a coppice forest [24]. Dhital et al. [23] and Yazaki et al. [19] suggested that *Z. japonica* and *M. sinensis* grassland ecosystems would be equilibrium and source of CO_2, respectively; therefore, we need to investigate the relationship between carbon budget and management intensity of grassland ecosystems.

5. Conclusions

Intensive management to maintain grassland would likely affect the carbon budget; however, there is little information about the effect of artificial management on SR. Therefore, we investigated SR rates in two types of grassland and different management practices (undisturbed and intentionally burned) to understand the effects of grassland vegetation type and management practices in northern Japan. Our results indicated that SR showed lower activity to an increase in soil temperature in both of the intentionally mowing and burned grassland (ZJ and MSb plots). However, different mechanisms would be driving the weaker SR responses to increasing soil temperature in the ZJ and MSb plots. The coefficient of temperature sensitivity (Q_{10}) values and monthly carbon fluxes from soil in the intentionally mowing and burned grassland plots were also smaller than that in the undisturbed grassland plot; therefore, these results suggested that artificial disturbance would decrease soil microbial or plant root respiration, and it would contribute to the plant productivity. The previous studies suggested that grassland ecosystems in Japan would be equilibrium and source of CO_2, respectively; therefore, we need to investigate the relationship between carbon budget and management intensity of grassland ecosystems.

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