Soil Moisture Dynamics During the Growing Season in Permafrost Regions of the Qinghai-Tibet Plateau Under Short-Term Warming: Postprint

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Abstract

This study investigated the typical alpine meadow vegetation type in the hinterland of the Tibetan Plateau, employing infrared lamp heating to simulate global warming and utilizing moisture probes to obtain soil moisture content data at different soil depths of 0–100 cm during the 2012 plant growing season (May–September), and analyzed its response to warming. The results showed: Short-term warming had an enhancing effect on soil moisture content in alpine meadows, but the increase was not significant (P>0.05), with an average increase of 2.85%. Soil moisture content exhibited a trend of first decreasing and then increasing with increasing soil depth, dropping to the lowest value of 13.8% at the 10–20 cm soil depth, and reaching the highest value of 20.57% near the 60–100 cm soil depth; the soil moisture content at 10–20 cm depth over five months in the control group was significantly lower than other soil layers, while the soil moisture content at 0–20 cm depth in the warming group was significantly lower than other depths, indicating that warming had a greater impact on surface layer (0–10 cm) soil moisture content and a smaller impact on deep soil moisture content, and that short-term warming would not affect the vertical distribution trend of soil moisture. The temporal variation of soil moisture content showed an increasing trend from May to August, indicating that August is the month with the most abundant soil moisture content during the plant growing season in the Beiluhe region of the Tibetan Plateau; in September, soil moisture content began to decrease, but the decrease was not obvious across the five soil depths; the temporal variation trend of soil moisture content in the warming group was basically consistent with that of the control group.

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Full Text

Effect of Short-Term Warming on Dynamic Change of Soil Moisture Content in Growing Season in the Permafrost Regions of the Qinghai-Tibet Plateau

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Abstract

Typical alpine meadow vegetation types in the hinterland of the Qinghai-Tibet Plateau were selected as research objects. Global warming was simulated using infrared lamp heating methods, and soil moisture content values at different depths (0–100 cm) during the growing season (May to September) in 2012 were obtained using a water probe to analyze its response to warming. The results showed that: (1) Short-term warming increased soil moisture content in alpine meadows, but the increase was not statistically significant ($P > 0.05$), with an average increase of 2.85%; (2) Soil moisture content initially decreased and then increased with soil depth, reaching its lowest value (13.8%) at the 10–20 cm depth and its highest value (20.57%) at the 60–100 cm depth. Soil moisture content at 10–20 cm depth in the control group was significantly lower than in other soil layers across the five months, while in the warming group, soil moisture at 0–20 cm depth was significantly lower than in other layers, indicating that warming significantly affected topsoil (0–10 cm) moisture content but only slightly affected deep-soil moisture content, and that short-term warming had no effect on the vertical distribution of soil moisture content; (3) Soil moisture content showed an increasing trend from May to August, indicating that soil moisture content during the growing season in the Beilu River Basin of the Qinghai-Tibet Plateau gradually increased to its highest value in August, then began to decrease from September, though this decrease was not significant. The temporal change trend of soil moisture content in the warming group was basically the same as that in the control group.

Keywords: soil moisture content; alpine meadow; simulated warming; growing season; permafrost; Qinghai-Tibet Plateau

1. Introduction

Climate change has significantly impacted the Qinghai-Tibet Plateau, with surface temperatures rising at a rate of approximately 0.6°C per decade[1]. According to IPCC projections, temperatures may increase by 1.0–4.8°C by the end of the 21st century[2]. From 1981 to 2010, the warming rate in the plateau's northern regions reached 0.40°C per decade[3]. These temperature changes have profound effects on alpine ecosystems, particularly on soil moisture dynamics in permafrost regions .

Previous studies have demonstrated that warming affects soil moisture through multiple mechanisms, including altering evapotranspiration rates, modifying freeze-thaw cycles, and influencing vegetation growth [12]. The active layer of permafrost is particularly sensitive to temperature changes, with soil moisture migration patterns showing complex responses to warming . Understanding these dynamics is crucial for predicting ecosystem responses to climate change in high-altitude regions.

2. Materials and Methods

2.1 Experimental Design The study was conducted in the permafrost region of the Beilu River Basin on the Qinghai-Tibet Plateau. Warming experimental plots were established using infrared heaters to simulate a 2°C temperature increase. Control plots were maintained under natural conditions. The experimental design followed standard protocols for warming studies in alpine meadows[21].

Soil moisture content was measured at depths of 0–10 cm, 10–20 cm, 20–40 cm, 40–60 cm, and 60–100 cm using FDR (Frequency Domain Reflectometry) probes. Measurements were taken during the growing season from May to September 2012. Each measurement was replicated three times per plot.

2.2 Data Analysis Statistical analysis was performed using SPSS software. Differences between warming and control treatments were tested using independent samples t-tests. Significance was determined at $P < 0.05$. Vertical distribution patterns were analyzed using one-way ANOVA across depth intervals.

3. Results

3.1 Soil Moisture Content Under Different Treatments Short-term warming increased soil moisture content in the 0–100 cm profile by an average of 2.85%, though this increase was not statistically significant ($P > 0.05$). The effect varied by depth interval, with the most pronounced changes occurring in the surface layers.

[Figure 1: see original paper] Distribution of warming experimental plots

3.2 Vertical Distribution of Soil Moisture Soil moisture content showed a characteristic vertical pattern, decreasing from the surface to a minimum at 10–20 cm depth, then increasing with depth (Table 1). In the control group, soil moisture at 10–20 cm (13.80%) was significantly lower than in other layers

($P < 0.05$). In the warming group, the 0–20 cm layer showed significantly lower moisture content compared to deeper layers.

Table 1 Significance analysis of soil moisture content under different treatments in growing season from May to September 2012

Depth (cm)	Control moisture (%)	Warming moisture (%)	Difference (%)	P-value
0–10	17.18 ± 0.35	15.64 ± 0.36	-1.54	0.422
10–20	13.80 ± 2.07	14.80 ± 0.36	1.00	0.957
20–40	16.19 ± 0.47	20.68 ± 2.17	4.49	0.145
40–60	17.12 ± 1.80	23.65 ± 0.47	6.53	0.099
60–100	20.57 ± 6.06	25.23 ± 1.62	4.66	0.486

The vertical distribution pattern indicated that warming had the greatest effect on the 40–60 cm layer, where moisture content increased by 6.53%, though this was not statistically significant.

3.3 Temporal Variation of Soil Moisture Soil moisture content exhibited a clear seasonal pattern, increasing gradually from May through August, then decreasing slightly in September (Figure 2). This trend was consistent across both warming and control treatments, suggesting that seasonal climate patterns dominated over treatment effects.

[Figure 2: see original paper] Vertical distribution of soil moisture content under different treatments in different months

The temporal variation was most pronounced in the surface layers (0–20 cm), where moisture content fluctuated by up to 3.32% across months. Deeper layers showed more stable moisture content over time.

3.4 Interaction Effects Warming did not significantly alter the vertical distribution pattern of soil moisture ($P > 0.05$). However, it did modify the magnitude of differences between layers. The interaction between depth and treatment was not significant, indicating that warming effects were relatively uniform across the soil profile.

4. Discussion

The observed increase in soil moisture content under warming conditions contrasts with some previous studies[13],[1] , likely due to the short-term nature of the experiment and the specific characteristics of the permafrost active layer. Several mechanisms may explain these results:

First, warming accelerated permafrost thawing, which increased water availability from the melting ice-rich layer . Second, enhanced vegetation growth under warming conditions may have improved soil water retention through increased organic matter . Third, changes in surface albedo and energy balance could have altered evaporation rates[1] .

The vertical distribution pattern, with lowest moisture at 10–20 cm, reflects the typical structure of alpine meadow soils where root density is highest and water uptake is most intense[22]. Warming appeared to enhance this pattern by increasing root water uptake in the surface layer while augmenting water supply from deeper thawing layers.

The temporal pattern of increasing moisture through the growing season corresponds with monsoon precipitation patterns in the region[2] . The lack of significant difference in temporal trends between treatments suggests that seasonal climate factors exert stronger control than experimental warming over short timescales.

5. Conclusions

Short-term warming increased soil moisture content in alpine meadows of the Qinghai-Tibet Plateau by an average of 2.85%, though this increase was not statistically significant. Warming affected surface soil moisture more than deep soil moisture but did not alter the vertical distribution pattern. Soil moisture content showed a consistent seasonal increase from May to August in both warming and control treatments. These findings suggest that permafrost thawing may temporarily increase soil water availability, but long-term monitoring is needed to understand persistent effects of climate change on soil moisture dynamics in alpine ecosystems.

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Note: Figure translations are in progress. See original paper for figures.