Effects of Simulated Warming and Increased Precipitation on Soil Enzyme Activity in Typical Grasslands: Postprint

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Abstract

The impacts of climate change on ecosystems are exhibiting an increasing trend. Soil enzymes, as one of the active components in grassland soils, are closely associated with soil nutrient contents. To investigate the responses of enzyme activities and soil nutrients to climate change in semi-arid regions, a simulated warming and precipitation enhancement experiment was conducted in a typical steppe using open-top chambers from 2011 to 2016. The results demonstrated:

Warming increased nitrate nitrogen and ammonium nitrogen contents in the 0–10 cm soil layer by 40.2% and 129.1%, respectively; increased precipitation enhanced nitrate nitrogen content by 63.5% but decreased ammonium nitrogen content by 63.6%. Warming decreased catalase and sucrase activities in the 0–10 cm soil layer by 4.8% and 13.3%, respectively. Contrary to the effects of warming, increased precipitation enhanced alkaline phosphatase, sucrase, and urease activities by 7.1%, 35.7%, and 14.9%, respectively, with no significant effect on catalase ($P>0.05$). Nitrate nitrogen and ammonium nitrogen contents in the 0–10 cm soil layer exhibited increasing trends ($P<0.05$), and responses of different soil enzyme types to climate change varied, which may be associated with alterations in soil nutrient cycling under climate change trends.

Full Text

Effects of Simulated Temperature and Precipitation Increase on Soil Enzyme Activity in Typical Steppe

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Abstract: The impacts of climate change on ecosystems will be expanded in the future. Soil enzyme is one of the active components in grassland soil, and it is closely related to soil nutrient content. In this study, the top-opened growth chambers were used to simulate the temperature increase and rainfall increase in a typical steppe in 2011 so as to explore the response of soil nutrient content and enzyme activity to climate change in semiarid area. The experiment was carried out under four treatments, i.e. the wCK (controlled), T (temperature controlled), P (rainfall increased) and TP (both temperature and rainfall increased) respectively. The values of soil nutrient availability and of activity of four enzymes were measured. It was found that the contents of soil nitrate nitrogen and ammonium nitrogen were increased by 40.2% and 129.1% respectively by increasing temperature. The nitrate nitrogen content was increased by 63.5% by increasing rainfall, but the ammonium nitrogen content was decreased by 63.6%. The activities of catalase and sucrose enzyme were decreased by 4.8% and 13.3% respectively by increasing temperature. Contrarily, the activities of alkaline phosphatase, sucrose enzyme and urease were increased by 7.1%, 35.7% and 14.9% respectively by increasing rainfall, but there was no significant effect of rainfall increase on catalase ($P > 0.05$). The contents of nitrate nitrogen and ammonium nitrogen were in an increase trend under the interaction of both temperature increase and rainfall increase ($P < 0.05$). The responses of four soil enzyme activities to climate change were different, which may be related to the change of nutrient cycling with climate change.

Keywords: climate change; typical steppe; soil nutrient; soil enzyme activity

1 Introduction

1.1 Experimental Design

The study utilized top-opened growth chambers to simulate climate change scenarios in a typical steppe ecosystem. Four experimental treatments were established: wCK (control), T (temperature increase only), P (precipitation increase only), and TP (both temperature and precipitation increase). Each treatment was replicated four times in a randomized block design.

1.3 Study Site and Sampling

The experiment was conducted at a typical steppe site in Xilingol League, Inner Mongolia (44°09 49.0 N, 116°29 02.3 E, altitude 1102 m). The soil is classified as chestnut soil with 90% sand content. The study was initiated in August 2011, with soil samples collected from the 0–10 cm layer. Sampling occurred monthly during the growing season (July–September 2011; May–September 2012–2016). Each plot measured 3 m × 3 m, with 16 subplots per treatment.

The temperature increase simulation was based on the IPCC (2007) climate scenario projecting a 2°C increase. Soil physicochemical properties measured included pH, nitrate nitrogen (NO -N), ammonium nitrogen (NH -N), available phosphorus, and organic matter. Soil enzyme activities measured were catalase, urease, alkaline phosphatase, and sucrase.

1.5 Statistical Analysis

Data were processed using Microsoft Excel 2010 and analyzed with IBM SPSS Statistics 19.0. One-way ANOVA was used to test treatment effects, while two-way ANOVA examined temperature and precipitation interactions. Duncan' s multiple range test was applied for post-hoc comparisons at the $P < 0.05$ significance level.

2 Results

2.1 Effects of Temperature and Precipitation on Soil Nitrogen

Increasing temperature significantly elevated soil nitrate nitrogen and ammonium nitrogen contents by 40.2% ($P < 0.01$) and 129.1% ($P < 0.01$), respectively [Figure 1: see original paper]. Precipitation increase enhanced nitrate nitrogen by 63.5% ($P < 0.01$) but reduced ammonium nitrogen by 63.6% ($P < 0.01$). The interaction of temperature and precipitation increases showed a synergistic effect on both nitrogen forms ($P < 0.05$) .

2.2 Effects on Soil Enzyme Activity

Temperature increase decreased catalase activity by 4.8% and sucrase activity by 13.3% ($P < 0.05$). In contrast, precipitation increase significantly enhanced alkaline phosphatase activity by 7.1%, sucrase activity by 35.7%, and urease activity by 14.9% ($P < 0.05$), while showing no significant effect on catalase ($P > 0.05$) [Figure 2: see original paper]. Under combined temperature and precipitation increases, enzyme responses varied by type, suggesting differential sensitivity to climate factors .

2.3 Correlation Analysis

Soil nitrate nitrogen showed significant positive correlations with alkaline phosphatase ($r = 0.726$, $P < 0.01$) and urease ($r = 0.708$, $P < 0.01$), but negative correlations with catalase ($r = -0.565$, $P < 0.05$) and sucrase ($r = -0.655$, $P < 0.01$). Ammonium nitrogen was negatively correlated with sucrase ($r = -0.839$, $P < 0.01$) and catalase ($r = -0.740$, $P < 0.01$) .

3 Discussion

The differential responses of soil enzymes to temperature and precipitation changes reflect their distinct roles in nutrient cycling. Temperature-driven increases in nitrogen mineralization likely contributed to higher nitrate and ammonium levels, consistent with findings from semiarid grassland studies [?]. The negative response of catalase to warming may indicate reduced microbial oxidative activity, while precipitation-enhanced hydrolase activities (urease, phosphatase, sucrase) suggest improved substrate availability and microbial function under wetter conditions [?, ?].

The contrasting effects of precipitation on nitrate (increase) versus ammonium (decrease) may reflect enhanced nitrification rates and leaching dynamics. These results imply that climate change could significantly alter soil nutrient transformation pathways in typical steppe ecosystems, with potential feedbacks to plant productivity and carbon cycling [?, ?]. The lack of temperature acclimation in most enzyme activities suggests persistent effects of warming on soil biogeochemical processes [?, ?].

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