Plant nitrogen concentration, use efficiency, and contents in a tallgrass prairie ecosystem under experimental warming

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Abstract

Plant nitrogen (N) relationship has the potential to regulate plant and ecosystem responses strongly to global warming but has not been carefully examined under warmed environments. This study was conducted to examine responses of plant N relationship (i.e. leaf N concentration, N use efficiency, and plant N content in this study) to a 4-year experimental warming in a tallgrass prairie in the central Great Plains in USA. We measured mass-based N and carbon (C) concentrations of stem, green, and senescent leaves, and calculated N resorption efficiency, N use efficiency, plant N content, and C:N ratios of five dominant species (two C4 grasses, one C3 grass, and two C3 forbs). The results showed that warming decreased N concentration of both green and senescent leaves, and N resorption efficiency for all species. N use efficiencies and C:N ratios were accordingly higher under warming than control. Total plant N content increased under warming because of warming-induced increases in biomass production that are larger than the warming-induced decreases in tissue N concentration. The increases in N contents in both green and senescent plant tissues suggest that warming enhanced both plant N uptake and return through litterfall in the tallgrass ecosystem. Our results also suggest that the increased N use efficiency in C4 grasses is a primary mechanism leading to increased biomass production under warming in the grassland ecosystem.

Keywords: global warming, N concentration, N resorption efficiency, N use efficiency, tallgrass prairie

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Introduction

Global warming because of elevated atmospheric greenhouse gases has increased the Earth’s surface temperature by 0.6 °C in the past century, and the temperature will continue to increase by 1.4–5.8 °C over the 21st century (IPCC, 2001). Such unprecedented changes in temperature are predicted to influence ecosystem processes and global carbon (C) cycling substantially (Cox et al., 2000). As the most limiting nutrient for plant growth, nitrogen (N) availability and its dynamics in ecosystems and their responses to global change will have significant impacts on the long-term C sequestration in terrestrial ecosystems (Hungate et al., 2003; Luo et al., 2004). While changes in soil N pools and dynamics under global warming have been observed in various ecosystems (Shaw & Harte, 2001; Melillo et al., 2002), our knowledge on responses of plant N relationships and their potential impacts on ecosystem C processes (e.g. plant growth, net primary productivity, litter quality, and decomposition) is limited (Olszyk et al., 2003; Lewis et al., 2004).

Leaf N concentration is one of the most important plant N variables that determine photosynthetic C fixation and plant productivity. Numerous studies, mostly conducted in greenhouses and chambers, have shown that warming could either increase or decrease leaf N concentrations of trees (Hobbie et al., 2001; Luomala et al., 2003) and grasses in arctic or alpine tundra (Arft et al., 1999; Grogan & Chapin, 2000). Responses of leaf N concentration to warming are often different among plant function groups, even in the
same ecosystem. For example, Read & Morgan (1996) reported that leaf N concentration decreased in *Bouteloua fractivis* (C4 grass) but increased in *Pascopyrum smithii* (C3 grass) under warming. Different responses of plant functional groups to warming can lead to shifts in plant community structure (Lilley et al., 2001a), plant N uptake (Lilley et al., 2001b), and partitioning (Read & Morgan, 1996).

In addition to leaf N concentration, many other plant N variables may affect ecosystem C and N processes. For example, plant N resorption efficiency and its response to warming could significantly impact plant and ecosystem N use efficiency and cycling (Norby et al., 2000). Enhanced plant N uptake (Ineson et al., 1998a, b), rather than increased N use efficiency (Maranville & Madhavan, 2002), resulted in stimulation of plant C accumulation under warming. Altered C:N ratio in plant litter in response to global change affects rates of decomposition and N release from plant litter (Norby et al., 2000; Billings et al., 2003). The N amount retained in organic plant material and soil N availability, as affected by changes in net primary productivity and altered plant N concentration and litter C/N ratio may feedback to change plant growth, net primary, and ecosystem productivity (Luo et al., 2004). Thus, understanding the responses of plant N relationships to warming is critical for predicting ecosystem C and N cycling in future climatic scenarios.

As part of a comprehensive project investigating experimental warming in a tallgrass prairie (Luo et al., 2001; Wan et al., 2002a, b, 2005; Zhang et al., 2005), this study examined possible changes in plant N relationships and their potential impacts on ecosystem C and N processes under experimental warming in a tallgrass prairie. Our objectives are to examine (1) differences among species and functional types in response of leaf N concentrations to warming; (2) effects of warming on plant N use efficiency at both species and ecosystem levels; (3) responses of plant N resorption efficiency to experimental warming; and (4) potential impacts of the warming-induced changes in plant N relationships on ecosystem C and N processes.

Materials and methods

Experimental design

Plant material used in this study was collected from a warming × clipping experiment in a natural grassland ecosystem. The experimental site is located at a tallgrass prairie in the US Great Plains in McClain Country (34°58′54″N, 97°31′14″W), 40 km southwest from Norman campus of the University of Oklahoma. This site has not been grazed for 20 years. The grassland is dominated by C4 grasses (*Schizachyrium scoparium* and *Sorghastrum nutans*) and C3 forbs (*Ambrosia psilostachya*, *Aster ontarionis*, and *Aster ericoides*). The mean annual temperature is 16.0 °C, with monthly mean temperature of 3.1 °C in January and 28.0 °C in July. The mean annual precipitation is 967.2 mm (average values from 1948 to 1999, data from the Oklahoma Climatological Survey). The soil is part of the Nash–Lucien complex (sand: 32%; silt: 60%; clay: 8%), which is characterized as having a low permeability rate, high available water capacity, and deep and moderate penetrable root zone (Wan et al., 2005).

The experiment used a split-plot design, with warming as the main factor and clipping nested within warming. There were six pairs of 2 × 2 m² plots. In each pair, one plot had been warmed continuously using infrared heaters since 21 November, 1999 with the other control plots at ambient temperature. One 165 × 15 cm² infrared heater (Kalglo Electronics Inc., Bethlehem, PN, USA, radiation output of about 100 W m⁻²) was suspended 1.5 m above ground in each warmed plot. In a control plot, one ‘dummy’ heater with the same shape and size as the infrared heater was suspended 1.5 m high to simulate the shading effects of the heater (Fig. 1). For each pair of plots, the distance between control and warmed plots was approximately 5 m in order to prevent heating of the control plot by the infrared heater. Distances between the individual sets of paired plots varie from 20 to 60 m. The daily mean and minimum air temperatures increased by 1.1 and 2.3 °C in the heated plots, respectively, in comparison with those in control plots (Wan et al., 2002a). Soil temperatures at a depth of 2.5 cm increased by 2.6 °C, 2.7 °C, 2.4 °C, and 2.0 °C in 2000, 2001, 2002, and 2003, respectively, in the warmed plots compared with those in the control plots (Wan et al., 2002a).

Each 2 × 2 m² plot was divided into four 1 × 1 m² subplots (Fig. 1). Two diagonal subplots in each plot were clipped 10 cm above the soil every year; the other two were the unclipped controls. After clipping, plants were allowed to grow until next clipping. The four treatments in the experiment were unclipped control, unclipped warmed, clipped control, and clipped warmed. Plant materials used in this study were from clipped plots only. As the unclipped subplots were designed to have minimal disturbances over the long term, no plant materials were taken from the unclipped plots.

Tissue sample collection and chemical analyses

Plants were clipped at 10 cm above soil on 28 July, 2000, 24 July, 2001, 24 July, 2002, and 26 September, 2003, respectively, in the clipped subplots. The clipped plants
were unclipped controls. Two diagonal subplots were clipped and the other two were unclipped controls. The shallow-red color (minus either green or senescent leaves of the five species at both warmed replicates for each type of tissues (e.g., stem, green, and control plots, and the total sample size was 552 senescent leaves) from the five species at both warmed plots. We did not calculate NUE of C3 grass because we only had one C3 grass species in our study.

Each plot (2 × 2 m²) was divided into four 1 × 1 m² subplots, in which two diagonal subplots were clipped and the other two were unclipped controls.

Fig. 1 Experimental layout for each warmed or control plot.

Concentrations of C and N in plant tissues were used to calculate the following parameters:

1. Plant N content (PNC): The ground-area-based aboveground plant N content was the sum of N contents in grasses and forbs, which were calculated by %N × biomass. At our experimental site, C₄ grasses accounted for more than 95% of the total aboveground biomass of grasses. Thus, we used an averaged leaf N concentration of the two C₄ grasses (NG) multiplying aboveground biomass of grasses (BG) to approximate N contents in grasses (NCG) in each plot. To estimate N contents of C₃ forbs (NCF), we separated the aboveground tissues into two categories: leaves and stems, and weighted by leaves (LW) and stems (SW) separately. We multiplied LW and SW with an averaged N concentration of both leaves and stems of the two C₃ forbs, separately, to approximate the N contents in leaves (NLF) and stems (NSF), and then summed them up for the N content of forbs in each plot. Thus, PNC = NCG + NCF in each plot. The aboveground biomass data were reported by Wan et al. (2005).

2. N respiration efficiency (NRE): Mass-based N respiration efficiency for each species was calculated by the following equation:

\[
NRE = \frac{N_g - N_s}{N_g} \times 100\%.
\]

where \(N_g\) is the green leaf N concentration and \(N_s\) is the senescent leaf N concentration.

3. Relative response of N to warming (RR): The relative response of N to warming on a mass basis for each species was calculated by

\[
RR = \frac{|N_c - N_w|}{N_c} \times 100\%.
\]

where \(N_c\) is the leaf N concentration in the control plots and \(N_w\) is the leaf N concentration in the warmed plots.

4. N use efficiency (NUE): We based N use efficiency on total biomass produced per unit plant N (Wilkins et al., 1997; Maranville & Madhavan, 2002; Knops et al., 2002), and NUE of two plant functional groups (C₃ forbs and C₄ grasses) and of the whole ecosystem were calculated by the following equations:

\[
\text{NUE of C₄ grass} = \frac{BG}{(BG \times NG)} = 1/NG,
\]

\[
\text{NUE of C₃ forbs} = \frac{(LW + SW)}{(NLF + NSF)},
\]

\[
\text{NUE of ecosystem} = \frac{(BG + LW + SW)}{PNC}.
\]

We did not calculate NUE of C₃ grass because we only had one C₃ grass species in our study.

Data analyses

Concentrations of C and N in plant tissues were used to calculate the following parameters:

were sorted into three categories, C₃ grasses, C₃ forbs, and C₄ grasses, and were oven-dried at 65°C for 48 h, and weighted by category. From the available tissue, green and senescent leaves from two C₄ grass species (*Dichanthelium oligosanthes* and *A. psilostachya*) and two C₃ forb species (*Sporobolus asper* and *A. ericoides*) were selected for analyses of N and C concentrations. The five species accounted for 85–90% of total aboveground biomass in each plot. We identified green or senescent leaves of the three C₃ species (*D. oligosanthes*, *A. psilostachya*, and *A. ericoides*) and one C₄ grass (*S. asper*) according to their distinguishable shoot characteristics. The shallow-red color of leaves was the main trait used in identification of recent senescent leaves of *S. scoparium*. We also analyzed C and N concentrations of stems for the two forb species. Thus, we had 4 years of samples for each species (except *D. oligosanthes* in September 2003), 12 replicates for each type of tissues (e.g., stem, green, and senescent leaves) from the five species at both warmed and control plots, and the total sample size was 552 (minus either green or senescent leaves of *S. asper* in 2003) in this study. The C and N concentrations were analyzed with a LECO CNS-2000 Elemental Analyzer (LECO Corp., St Joseph, MI, USA). We used LECO soil standard to verify the accuracy of the analysis instrument and duplicate samples in every 10 samples to verify the precision of measurements.

Data analysis used SAS 8.0 software to test for a significant difference between warmed and control plots.

**Results**

N concentrations in both green (Fig. 2a–e) and senescent (Fig. 2f–j) leaves tended to be lower in the warmed than control plots for all species. The decreases were statistically significant ($P < 0.05$) in green leaves in the last 2 years (2002 and 2003), except for *S. asper* in 2003 (Fig. 2b). *D. oligosanthes* also exhibited significantly ($P < 0.05$) lower N under warming than control in 2001 (Fig. 2c). Warming had no effect on stem N concentration for the two C₃ forbs in any year (Fig. 3a–b). N concentrations were significantly higher in green than in senescent leaves in warmed or control plots (Fig. 2). Among the three plant function groups, C₃ forbs (*A. psilostachya* and *A. ericoides*) had the highest

**Fig. 2** N concentrations in green (a–e) and senescent (f–j) leaves of (a, f) *S chizachyrium scopariums*; (b, g) *Sporobolus asper*; (c, h) *Dichanthelium oligosanthes*; (d, i) *Aster ericoides*; and (e, j) *Ambrosia psilostachya*. The data are shown as means and standard errors, with $n = 6$. * and ** represent statistical significance at $P < 0.05$ and $P < 0.01$, respectively.
N concentrations in green and senescent leaves while C4 grasses (S. scopariums and S. asper) had the lowest N concentrations. The differences between C3 and C4 species were statistically significant ($P < 0.05$), but no significant difference ($P > 0.05$) was found among the three C3 species in the warmed or control plots (Fig. 2). C3 grass was the most responsive to warming in terms of the relative N concentration whereas C4 grasses were the least responsive (Fig. 4).

Although warming reduced leaf N concentrations, N contents of green and senescent plant tissues were greater in the warmed than control plots (Fig. 5a–b) because of the substantial increases in biomass growth (Wan et al., 2005). Wan et al. (2005) observed that aboveground biomass was significantly ($P < 0.05$) increased by 36.7%, 57.1%, and 57.4% in C4 grasses and by 27.0%, 29.8%, and 41.3% in ecosystem (C4 grasses plus C3 species), but there was no significant change in C3 forbs in 2001–2003, respectively, under warming compared with those under control in our experimental site. Warming only significantly ($P < 0.05$) increased N contents in senescent plants by 29.75% and 32.65% in 2001 and 2002, respectively.

Warming tended to decrease N resorption efficiency in most of the 4 years (Fig. 6). But the decreases were not statistically significant ($P > 0.05$), except for D. oligosanthesin in 2002 (Fig. 6d). Reduced N resorption efficiency resulted from greater N decrease in green than in senescent leaves. There were weak ($r = –0.41$ and 0.50) but statistically significant ($P < 0.05$) relationships between green leaf N concentration and resorption efficiency in two C4 grasses under warming (Fig. 7a–b). No significant correlations ($P > 0.1$) were found between green leaf N concentration and resorption efficiency in either C4 grasses in the control plots (Fig. 7a–b) or C3 species in both the warmed and control plots (Fig. 7c–e).

Warming significantly increased N use efficiencies of C4 grasses and the whole ecosystem in 2002 and 2003, but had no consistent effect on C3 forbs (Fig. 8). C4 grasses had higher N use efficiency than C3 forbs in both warmed and control plots.

There were no significant effects ($P > 0.05$) of warming on either C concentrations in both green and senescent leaves or C:N ratios in senescent leaves (Fig. 9f–j). However, C:N ratios in green leaves were significantly higher ($P < 0.05$) in the warmed than control plots in the last 2 years of study (2002 and 2003) for almost all species, except for S. asper in 2003 (Fig. 9b) and A. psilostachya (Fig. 9e).

**Discussion**

This study demonstrated a clear pattern that long-term experimental warming significantly decreased green leaf N concentrations in all five dominant species in the tallgrass prairie ecosystem. Even with the decreased leaf N concentrations, whole ecosystem plant N content still increased under warming in comparison with that
under control because of large increases in plant biomasses (Wan et al., 2005). Accordingly, N use efficiency increased under warming at the ecosystem scale and for C4 grasses. In addition, warming-induced decreases in N concentration were much lower for the senescent leaves than the green leaves, leading to decreased N resorption efficiency.

Green leaf N concentration and N use efficiency

This study observed decreases in green leaf N concentrations for all species in the warmed than control plots. Our results are consistent with observations from some of the previous studies (Tjoelker et al., 1999; Weih & Karlsson, 2001; Link et al., 2003). However, other warming studies, mostly in cold regions, showed that elevated temperature increased leaf N concentrations (Nijs et al., 1996; Soussana et al., 1996; Luomala et al., 2003). In the cold regions, elevated temperature substantially enhanced soil N mineralization (Anke & Wright, 1997; Shaw & Harte, 2001) and thus, increased plant N uptake, resulting in higher leaf N concentrations (Tingey et al., 2003). In our study, N mineralization was stimulated in the first year but depressed in the second year of the warming experiment (Wan et al., 2005), presumably resulting in progressively larger decreases in green leaf N concentrations over time (Fig. 2).

Warming effects on green N leaf concentrations also varied with plant functional groups (Fig. 4). At the ambient temperature, C4 grasses have higher N use efficiency (Wedin & Tilman, 1993; Sage & Kubien, 2003), higher water use efficiency (Sage & Kubien, 2003), and more tolerance to heat stress (White et al., 2000) than C3 species. Under warming, C4 grasses showed less decrease in N than C3 grass and forbs (Fig. 4), probably because of less flexibility in leaf N relationships (Fig. 5). C3 grass was the most responsive to warming among the three plant functional groups in term of adjusting leaf N concentration. Nevertheless, the lower N requirement of C4 grasses combined with other heat-tolerant traits enhanced the competitive edge of C4 grasses over C3 species under warming as reflected by enhanced biomass growth (Wan et al., 2005).

Our results showed that warming significantly increased N use efficiency (NUE) of C4 grasses, but had no significant effects on NUE of C3 forbs (Fig. 8a–b). Maranville & Madhavan (2002) summarized the results of NUE in the literature into three cases wherein improved NUE will occur: (1) maintaining constant biomass yield while reducing plant or leaf N; (2) increasing biomass yield at a constant level of plant or leaf N; and (3) reducing levels of plant or leaf N per unit of increase in biomass yield. In our study, increased NUE of C4 grasses resulted from both an increase in biomass production and a decrease in leaf N concentration. Although their green leaf N concentrations significantly decreased (Fig. 2d–e), neither stem N concentrations (Fig. 3) nor biomass growth of C3 forbs (Wan et al., 2005) significantly changed under warming, leading to no change in NUE of C3 forbs (Fig. 8b). Because C4 plants accounted for the majority of ecosystem plant biomass (Wan et al., 2005), the significant increase in NUE in C4 grasses contributed to the significant increases of NUE at the ecosystem level.

Senescent leaf N concentration and N resorption efficiency

We observed consistently lower N concentrations in senescent leaves under warming than control for all species, although most of the changes were statistically not significant (Fig. 2f–j). Other studies observed lower senescent leaf N concentrations in coldest summers.

Fig. 5 Plant N contents in green (a) and senescent tissues (b). The data are shown as means and standard errors, with n = 12. * and ** represent statistical significance at P < 0.05 and P < 0.01, respectively.
than other summers for mountain birth trees [Betula Pubescens ssp tortuosa (Ledeb.) Nyman] (Nordell & Karlsson, 1995) or in the control than warmed plots for Acer rubrum trees (Norby et al., 2000). Warming-induced decrease in N concentration was much less in senescent leaves than green leaves. As a consequence, N resorption efficiencies generally decreased under warming in comparison with those in control, consistent with observations of other studies (Nordell & Karlsson, 1995; Norby et al., 2000). The ratio of leaf soluble to structural N is an important determinant of resorption efficiency (Pugnarie & Chapin, 1993; Rien, 1996). In our study, a higher percent of leaf N may be converted to structural N to meet a large increase in biomass growth in warmed plots (Wan et al., 2005), resulting in decreased N resorption efficiency. The decreased N resorption means that less N was transported from senescent to alive leaves before leaves died in the warmed than control plots. In addition, lower soil moisture in the warmed plots may also contribute to a decrease of N resorption efficiency (Del et al., 1991; Escudero et al., 1992).

Although warming decreased N concentration in senescent leaves, N contents in senescent plant increased significantly (Fig. 5b) under warming in comparison with that in the control, largely because

Fig. 6  N resorption efficiency of (a) Schizachyrium scoparium; (b) Sporobolus asper; (c) Dichanthelium oligosnathes; (d) Aster ericoides; and (e) Ambrosia psilostachya. The data are means and standard errors, with n = 6. * represents statistical significance at P < 0.05.
of warming-induced increase in aboveground biomass (Wan et al., 2005). Increased senescent plant N content suggests that N accumulation in litter likely increased in the warmed in comparison with control plots.

Among the three plant functional groups, warming did not change the relationships between leaf N concentration and resorption efficiency in C3 species (Fig. 7c–e), which supports a view that resorption efficiency is not related to plant N status (Rien, 1996; Norby et al., 2000). However, the relationships were statistically significant (P < 0.05) for C4 grasses under warming, suggesting that changes in leaf N concentrations of C4 grasses under warming altered N resorption efficiency.

**Plant N content and ecosystem implications**

At this experimental site, we observed that the percent increases in aboveground biomass (Wan et al., 2005) were higher than the percent decreases in leaf N concentrations under warming. As a consequence, plant N contents were 4.55%, 13.77%, 19.58%, and 16.24% greater under warming than control in 2000–2003, respectively (Fig. 5a). Warming-induced increases in biomass in the cold climate region partly resulted from enhanced N uptake from soil (Ineson et al., 1998a, b; Rustad et al., 2001). Although warming consistently stimulated N uptake across the 4 years of the experiment in the tallgrass prairie ecosystem, the increases in plant N content were not statistically significant (P > 0.05). Our results suggest that increased biomass growth in our experimental site for the prairie ecosystems (Wan et al., 2005) primarily resulted from direct, stimulatory effects of temperature on plant growth of C4 species rather than from indirect effects through N uptake as reflected by significant increases in NUE of C4 grasses.

The warming-induced changes in plant N contents and other relationships potentially alter ecosystem N cycling. The increased plant N contents in this grassland ecosystem with seasonal growth and death of aboveground tissues must be accompanied by increases
in plant N uptake from soil available N pools. On the other hand, increased senescent plant N contents (Fig. 5b) transfer more N back to soil-N pools through litterfall in the warmed than control plots. Thus, warming increased annual N flux rates through soil N uptake and litterfall N back to soil.

N release from litter pools to soil-available N pools is regulated by litter decomposition rates. At the ecosystem scale, we observed that C₄ litter significantly increased whereas C₃ plant litter showed no change under warming in comparison with control plots (Wan et al., 2005), resulting in decreased quality of bulk litter because of a higher C: N ratio in C₄ grasses than in C₃ forbs (Fig. 9). Thus, an increased litter amount and decreased litter quality presumably resulted in N accumulation and/or immobilization in litter pools, and slowed N releases from litter pools to soil available N pools in the warmed compared with control plots. As a consequence, an imbalance likely occurred between the demand for more plant N uptake and less available N supply because of slowed litter decomposition in the warmed than control plots. Indeed, studies on soil N dynamics at the same site support the imbalance notion. Wan et al. (2005) showed that soil N mineralization rates substantially decreased from years 1 to 2 of the experiment. The total soil N content decreased by 13.7% in the warmed plots compared with that in the control plots without clipping in May 2003 (A. Subedar & Y. Luo, in manuscript). The 13.7% decrease in soil N content may result partly from the redistribution of N between plant and soil pools and partly from N losses under warming. Moreover, N isotope (¹⁵N) data suggest that the experimental warming accelerated N cycling in the ecosystem (A. Subedar & Y. Luo, in manuscript). The imbalance possibly leads to progressive nitrogen limitation (Luo et al., 2004), as reflected by warming-induced decreases in leaf N concentrations that were becoming more substantial over time (Figs 2 and 4).

The growing imbalance between N demand and supply in our warming experiment had not yet significantly limited biomass production in the tallgrass ecosystem by 2003, after 4 years of warming as warming induced significant increases in N use efficiency for both C₄ grasses and whole ecosystem. As of 2003, the warming-induced increases in N use efficiency appeared to have helped sustain higher aboveground biomass production (Wan et al., 2005) under warming than control. However, Knops et al. (2002) argued that the increased N use efficiency could not support long-term increases in productivity at ecosystem scales. Therefore, it is important to observe whether or not the imbalance will continue and would eventually limit aboveground biomass production in the warming experiment in the future.

**Conclusions**

Nitrogen is one of the most important nutrients that determines plant productivity and rates of carbon cycling through the ecosystem, thus regulating their responses to global warming. Therefore, it is important to understand plant N relationships in warmed environments. Our observations indicate that long-term experimental warming significantly decreased N concentrations of both green and senescent leaves of all five species that we studied in the tallgrass prairie ecosystem. Warming also considerably stimulated growth of C₄ grasses and significantly enhanced biomass production in the
ecosystem. Increased biomass production in this ecosystem (Wan et al., 2005) under warming was associated with increased N use efficiency in C₄ grasses. Increases in growth and death of aboveground biomass over seasons are likely accompanied by increases in N uptake from and N return to soil. The long-term implications of the altered plant N uptake and return in ecosystem N and C cycles are yet to be evaluated in the future.

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