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Impacts of climate change on root demography and soil respiration of a perennial grassland

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ABSTRACT

Direct and indirect effects of temperature, drought and elevated CO₂ on grassland ecosystems have been well established when considering one or two abiotic factors, but rarely when considering the interactions of the three factors. For example, the positive effects of elevated CO₂ and temperature on growth and plant C balance may be counterbalanced by drought effects, depending on the thresholds. For the below-ground compartment, experiments on grassland ecosystems have shown that elevated atmospheric CO₂ can affect root dynamics in terms of production, life span, and mortality and decomposition rates. Then it is expected that C cycling is fast and C accumulation is small in soil of grassland subjected to elevated CO₂. Here, we report results of dynamics and demography of roots and soil respiration of perennial grassland monoliths exposed to four different treatments: Control (C), Temperature (T, +3°C in comparison with control), Temperature x Drought (TD, +3°C and 20% lower summer precipitations than in control) and Temperature x Drought x CO₂, according to A2 scenario (IPCC, 2001) (TDCO₂, +3°C, -20% summer precipitations and CO₂ 200ppm above control). Root dynamics was measured by minirhizotron method and soil respiration was measured by a closed chamber technique. Results obtained for the three first years showed a significant increase of root growth (+33%) and new roots mean diameter (+6%) in the TDCO₂ compared to control. Under TD and TDCO₂ soil respiration was 35% higher than in control. These first results confirm higher root activity under A2 scenario (TDCO₂).

Key words: Root dynamic, Climate change, Respiration, Minirhizotron

1. INTRODUCTION

According to A2 scenario (IPCC, 2001), European grassland ecosystems will be subjected, to an increase of 200ppm of atmospheric CO₂ and of 3°C air temperature and a 20% decrease of soil water in summer at the end of the century. In this context, we expect that grasslands response highly depends on root dynamics (Norby & Jackson, 2000), as carbon allocation to belowground compartment and precisely to root system (biomass, exudation, decomposition...) is often greater than aboveground (Coleman, 1976; Sims & Singh, 1978). The belowground compartment (roots, soil, microbes) is still less understood due to difficulties in studying roots processes and biases associated to various methods (Milchunas & Lauenroth, 1992; Arnone et al, 2000; Norby & Jackson, 2000; Milchunas et al, 2005). However, direct and indirect effects of temperature, drought and elevated CO₂ on grassland ecosystems have been well established when considering one or two abiotic factors (Norby, 1994; Rogers et al, 1994; Arnone et al, 2000) but rarely when considering the interactions of the three factors. In this study we test the hypothesis that climate change increases carbon storage in perennial grassland in the short term. For this we report here three years of grassland root dynamics subjected to four different treatments simulating the climate change.

2. MATERIAL AND METHODS

Study site and experimental design

Eighty monoliths (50cm*50cm*40cm) of a temperate grassland (low sheep grazing, 2 cuts a year for 15 years), located in Saint-Genès Champanelle, France (site 1, 45°43'N, 03°03'E, 890m a.s.l., mean annual temperature of 9°C), were extracted and placed in metal boxes in Autumn 2004. In Spring 2005, 60 and 20 monoliths were transferred, to Clermont-Ferrand (site 2, 45°45'N, 03°07'E, 400m a.s.l., mean annual temperature of 12°C) and kept in the site (site 1, control), respectively. Monoliths were grouped by four in 20 mini-FACE systems (ring of 1.4m diameter). Five and 10 rings of sites 1 and 2 were supplied by atmospheric ambient air, respectively, while five rings at site 2 received atmospheric elevated CO₂ concentration. In each ring, one monolith was kept as bare soil by removing all the above ground phytomass and three monoliths were left intact with vegetation. Four treatments were applied: Control (C, site 1), Temperature (T, site 2), temperature and summer soil drought (TD, site 2), temperature and summer soil drought and elevated atmospheric CO₂ (TDCO₂, site 2). Thus, the experiment was an additional design with five replicates per treatment. Mean annual warming of 3°C was provided by the altitudinal gradient between site 1 and 2; summer soil drought (June, July and August) was created by intercepting 20% of rainfall with plastic roof and elevated CO₂ (+200ppm) was provided by mini-FACE method (Miglietta et al, 2001). To obtain the same rain fall as in C treatment, T treatment was watered. Since 2004, all rings were cut in spring and in autumn. Monoliths were dominated by three perennial grasses (*Agrostis capillaris*, *Elytrigia repens* and *Festuca arundinacea*, two forbs (*Taraxacum officinale*, *Veronica* ssp) and three legumes (*Vicia craca*, *V.sativa* and *Trifolium repens*).

Measurements

Climatic data (air temperature (°C), rain fall (mm), wind speed (m s⁻¹) and relative humidity (%)) were recorded and collected using two automatic data logger located in sites 1 and 2. Soil volumic water content was measured with 20cm length probes connected to data logger (Ech₂o-dielectric aquameter, Decagon Devices, Inc. Pullman WA USA). Degree-days were calculated by cumulating mean daily air temperature data above 0°C in each year between 2006 and 2008. In spring 2005, 40 tubes of 50cm length were inserted in the soil with an angle of 45° from soil surface to host minirhizotron system (BTC-2, Bartztechnology, CA, USA). Roots were monitored from March 2006 to January 2009, during 40 dates on 4800 frames. Only three succeeding frames (1.35cm*2cm) comprised in the 5-10cm soil layer were analysed. Length and diameter of root segments were recorded with WinRHIZOTronMF software (V2005a, Regent Instrument, Ca). For each date, length was modified according to growth event while diameter of all roots was not modified after the first drawing. Length was determined per tube surface (cm cm⁻²) and growth rate was the difference in length between two successive dates (cm cm⁻² day⁻¹). Root survival time was the proportion of roots surviving as a function of their age (Kaplan-Meier survival function) (Allison, 1995). Soil respiration was measured by closed system chamber technique (Li6400-09, Licor, USA) on PVC collar (8cm diameter) after removing aerial parts of plants (Bahn et al, 2006). Measurements were done between June 2008 until May 2009 on vegetation and on bare soil monoliths. Data were analysed by repeated measures ANOVA using general linear model procedures and Duncan post hoc test to examine statistical difference between means of main effects and interactions (SAS statistical software, version 6.1, SAS Institute Inc., Cary, NC, USA). Statgraphics Plus for Windows 4.1 was used for the Kaplan-Meier survival model.

3. RESULTS AND DISCUSSION

Table 1. Mean values of root growth rate and mortality rate ($\text{mm cm}^{-2} \text{day}^{-1}$) for the four experimental treatments and statistical results of repeated measure of ANOVA for main effect of treatment, date and treatment x date interaction. n.s.: $P>0.05$; *: $P<0.05$; ***: $P<0.0001$.

Measures	Treatments				MANOVA		
	C	T	TD	TDCO ₂	Treatment	Date	Treatment x date
Root growth rate ($\text{mm cm}^{-2} \text{day}^{-1}$)	0.228	0.295	0.285	0.318	*	***	ns
Root mortality rate ($\text{mm cm}^{-2} \text{day}^{-1}$)	0.165	0.180	0.184	0.199	ns	***	ns

We observed a pronounced effect of date (season) on root growth and mortality, while effects of treatment were marginal (Table 1). T, TD, TDCO₂ only affected growth rate with an increase of 30% compared to control. In spring and autumn, TDCO₂ treatment increased significantly growth rate with two times higher values.

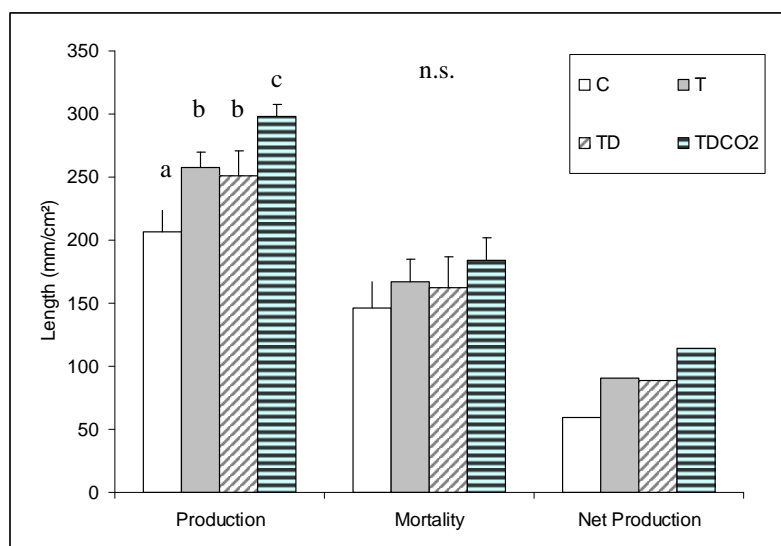


Figure 1. Cumulated root length (mm cm^{-2}) production, mortality and root balance (production minus mortality) during 40 dates of minirhizotron for the four treatments (C, T, TD, TDCO₂). Vertical bars correspond to one standard error; n.s.: $P>0.05$, for production, different letters correspond to statistical differences: $P<0.05$).

During three years of observation, cumulated root production and mortality only differed for high temperature treatments showing higher values of 25% (T and TD), and 33% (TDCO₂) than in control. For root mortality, no statistical difference was observed between treatments. Net production, which is the difference between production and mortality, showed the same pattern than production. The median root lifespan calculated by Kaplan-Meier simulations, resulted higher values for C and TDCO₂ (400 days) than for T and TD (360 days), indicating that CO₂ addition compensated the negative effect of temperature on root survival time. Interestingly, only finest root diameter ($<0.1\text{mm}$) of C and TDCO₂ treatments had higher median root lifespan than T and TD, 340 and 280 days, respectively, while there is no significant effect of treatments on

other diameter classes. Additionally diameter of new roots was significantly higher in TDCO₂ (+6%) compared to control.

Soil respiration of temperature treatments (T, TD, TDCO₂) was higher than C and was positively correlated with mortality and root growth of ($R^2 = 0.35, 0.31, P < 0.01$).

From these results, we may draw first conclusion. Increasing atmospheric CO₂ concentration seems to compensate the negative effects of temperature on soil C loss by increasing root activity (growth, mortality, soil respiration) and median root lifespan. Moreover, below-ground processes seem to be driven by the finest roots which could allow a better acclimation of grassland to climate change.

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