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Increased rainfall variability reduces biomass and forage quality of temperate grassland largely independent of mowing frequency

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ABSTRACT

Climate models indicate that global warming will stimulate atmospheric exchange processes and increase rainfall variability, leading to longer dry periods and more intense rainfall events. Recent studies suggest that both the magnitude of the rainfall events and their frequency may be as important for temperate grassland productivity as the annual sum. However, until now interactive effects between land management practice, such as mowing frequency, and rainfall variability on productivity and forage quality have not been studied in detail. Here, we present the data from a field experiment (EVENT II) in which a Central-European grassland was subjected to increased spring rainfall variability (low, intermediate and extreme rainfall variability without any change to the rainfall amount) and increased mowing frequency (four times compared to twice a year). We assessed biomass production, forage quality parameters, root-length and shoot–root ratio. Enhanced spring rainfall variability reduced midsummer productivity and the leaf N and protein concentrations of a target species, but did not exert any long-term effects on biomass production and forage quality in late summer. However, the increased spring rainfall variability reduced aboveground net primary productivity by 15%. More frequent mowing increased productivity in the first year of the study, but decreased productivity at the end of the second year, showing a decline in the potential for overcompensation after a history of more intense mowing. Generally, more frequent mowing decreased the shoot–root ratio and increased the concentration of leaf N. Increased mowing frequency neither buffered, nor amplified the adverse effects of rainfall variability on productivity, but made leaf N concentrations in early summer more responsive to altered rainfall patterns. These results highlight the fact that even relatively small and short-term alterations to rainfall distribution can reduce production and forage quality, with little buffering capacity of altered mowing frequency. Comparisons with productivity data from the first year of the study, in which both, rainfall distribution and rainfall amount were modified, demonstrate the crucial role of sufficient moisture (annual rainfall amount) for grassland resilience: in this first year, negative effects of extreme rainfall variability lasted until the end of the year. To conclude, increased rainfall variability under climate change will likely affect agricultural yield in temperate meadows. Management strategies to buffer these effects have yet to be developed.

1. Introduction

Climate change is projected to modify not only annual precipitation sum, but also to result in more extreme rainfall regimes in many parts of the world (IPCC, 2007; Jentsch and Beierkuhnlein, 2008). This will cause more severe drought periods as well as an increase in the frequency and magnitude of extreme precipitation events (Trenberth et al., 2003; Min et al., 2011). Evidence is mounting that the frequency and severity of droughts and extreme precipitation events has already increased over recent decades in many regions (Blenkinsop and Fowler, 2007; Haylock and Goodess, 2004; IPCC, 2007).

Primary productivity and ecosystem functioning in terrestrial ecosystems are strongly influenced by the annual amount of precipitation (Sala et al., 1988). However, recent research suggests that rainfall variability may exert an even stronger influence on ecosystem functioning, where especially temperate grassland systems seem to be responsive to changes in rainfall variability. In grassland, more extreme rainfall regimes (less, but more intense rainfall events) affect ANPP (aboveground net primary productivity) (Barrett et al., 2002; Fay, 2009; Heisler-White et al., 2009;

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Knapp et al., 2002), carbon cycling (Chou et al., 2008; Fay, 2009; Harper et al., 2005) and N mineralization (Barrett et al., 2002; Heisler-White et al., 2009). The latter may in turn affect leaf quality in terms of N or protein content. Large reductions in ANPP have been shown in mesic grassland in response to more extreme rainfall patterns (Fay et al., 2003; Heisler-White et al., 2009; Knapp et al., 2008).

In addition to the rainfall amount and variability, land management strategies, such as mowing frequency, can affect productivity and leaf litter quality in managed grassland. More frequent cutting is known to increase leaf N content. However, whether or not mowing increases or decreases the productivity of grassland depends on the mowing intensity, e.g. mowing history, mowing frequency and cutting height (Green and Detling, 2000; McNaughton, 1979; Turner et al., 1993; Weigelt et al., 2009). Mowing or defoliation is likely to alter the response to rainfall variability by altering plant community composition (Swemmer and Knapp, 2008). Furthermore, a reduction of transpirative tissue alters water uptake and consumption and therefore reaction toward rainfall (Heitschmidt et al., 1999; McNaughton, 1979; Yang and Midmore, 2004). Currently, a knowledge gap exists on how land management practices, such as mowing frequency, are interacting with more extreme rainfall regimes: increased mowing frequency might buffer the effects of rainfall variability on grassland, diminishing the amplitude of the response toward rainfall extremes (Swemmer and Knapp, 2008). A study by Bernhardt-Römermann et al. (2011) indicates that climate parameters get less important for biomass production under intermediate mowing frequencies. However, land management strategies might also amplify the effects of rainfall variability. To our knowledge, this is the first study to experimentally manipulate mowing and rainfall patterns in European managed grassland (meadows) in order to identify any potential interactions between rainfall variability and mowing frequency.

The primary objectives of our study were (1) to investigate the factorially combined effects of increased spring rainfall variability and increased mowing frequency on the productivity and the forage quality of semi-natural, Central-European temperate grassland and (2) to determine, whether mowing frequency amplifies or buffers the effects of rainfall variability on biomass production and leaf quality of a target species. We conducted a field experiment in which we altered the temporal distribution and the magnitude of the rainfall events, but not the overall rainfall sum. To assess potential interactions between rainfall variability and mowing frequency, we crossed the factor rainfall variability with the factor mowing frequency (two or four times per year). In the previous year, we altered the total rainfall amounts along with the alterations in rainfall variability. This enables a comparison between the effects of the altered total rainfall amounts and distribution and the effects of altered rainfall variability under constant total rainfall amounts.

We hypothesized that

(i) increased rainfall variability negatively affects productivity and leaf quality, as has been shown for other mesic grasslands,
(ii) increased rainfall variability alone can cause changes in productivity that are comparable to changes caused by alterations in both, variability and the annual sum of rainfall together,
(iii) more frequent mowing increases productivity and forage quality, as has been shown for more frequent, but still moderate mowing frequencies,
(iv) more frequent mowing buffers adverse effects of increased rainfall variability on productivity and leaf quality, as growth responses might be synchronized and less responsive to rainfall changes after mowing.

2. Materials and methods

2.1. Study site

The study was conducted within the EVENT II experiment in a semi-natural grassland in the Ecological Botanical Garden of the University of Bayreuth, Germany, Central Europe (49°55′19″N, 11°34′55″E, 365 m asl) (Jentsch and Beierkuhnlein, 2010). Communities are dominated by tall grasses, especially *Alopecurus pratensis* L. (meadow foxtail). The regional climate is temperate and moderately continental, with a mean annual temperature of 8.2 °C (1971–2000), and daily means ranging between −19.6 and 27.6. The mean annual precipitation of 724 mm (1971–2000) has a bimodal distribution with a major peak in June/July and a second peak in December/January (data: GermanWeather Service). The experiment was installed on a semi-natural, established meadow. For more than 20 years prior to the experiment, the meadow was mown twice per year and not fertilized. The rectangularly shaped experimental area has a total height difference of 95 cm within the diagonal from southwest to north east, and about 7 cm from southeast to north west.

The soil of the experiment is classified as Stagnosol with a sandy-loamy Ap-horizon of about 30 cm depth, a strongly loamy Sw-horizon (20 cm) and a sandy-clayey Sd-horizon (>40 cm). Plant roots mainly occur in the upper 15 cm, with almost no roots penetrating below the A-horizon, mean pH-value is 5.9.

2.2. Experimental design

The EVENT II experiment was established in 2008. The experimental design consists of two factorially crossed factors: (1) manipulation of the temporal distribution and magnitude of rainfall events in the growing season and (2) manipulation of mowing frequency. We implemented three scenarios of rainfall variability treatments in 2008 and 2009, assigned to the same plots: (1) low rainfall variability with weekly irrigation, ensuring a continuous water supply, (2) intermediate rainfall variability, with natural ambient rainfall variability and (3) extreme rainfall variability, including an extreme spring drought.

In 2008, the first year of the study, total growing season amount of rainfall and variability of rainfall were altered. This made it possible to assess direct drought effects, as the extreme rainfall variability treatment also received least total rainfall (see Table 1 for an overview over soil moisture and rainfall parameters in both years).

In 2009, the main year of the study, we controlled the amount of rainfall over the growing season for all treatments and manipulated only the distribution of rainfall, in order to isolate the effect of rainfall variability. All rainfall variability treatments were adjusted to the total 597 mm of rainfall of the low variability treatment in four compensation irrigations (Table 2). Thus, not only the length of the dry intervals, but also the magnitude of rainfall per event was changed.

The low rainfall variability treatment received at least the 30-year weekly average rainfall each week. The vegetation periods from 1971 to 2000 served as a reference (data: German Weather Service). Missing amounts on natural rainfall were added if the weekly rainfall was less than the long-term average for the same week. This treatment ensured continuous water availability. If weekly rainfall exceeded the long-term sum, it was not subtracted for the next irrigation. For 2008, the overall rainfall amount of 553 mm on the low rainfall variability treatment (natural plus irrigated rainfall) within the vegetation period (April 1st–October 30th) exceeded the 30-year-average by 94 mm. In 2009, the total