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Drought-induced shifts in plants traits, yields and nutritive value under realistic grazing and mowing managements in a mountain grassland

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ABSTRACT

Extreme drought events can dramatically impact grassland ecosystems, causing potential loss of forage production for livestock in temperate grasslands. However, knowledge of drought effects on forage production, nutritive value and plant community stability in the real context of farming management is scarce. For this purpose, the effect of a simulated summer drought was studied under two realistic management types on a semi-natural grassland in the Swiss Jura mountains. The first management ("grazing") consisted in six consecutive utilizations by animals over the growing season, representing a rotational grazing system as regionally conducted. The second management ("mowing") consisted of three harvests, corresponding to the usual mowing frequency of hay meadows. In both managements, drought caused minor short-term modifications of species composition and almost no persistent effects were observed. Besides, important short-term changes were observed in community weighted mean of several key functional traits, reflecting a strong decline in community growth during the drought followed by a partial recovery two months later. Forage yields, and to a lesser extent its nutritive value, thus declined during the drought period. Both were still affected in the following months, but had recovered in spring of the following year. Forage loss was twofold higher in the grazing management, but recovery as well as nutritive value was slightly improved in this management. The results suggest that rotational grazing can amplify negative drought impacts, compared to traditional mowing, and highlight the need to adapt such management in dry years. They also demonstrate that, even under a fairly intensive management, resilience of such mountain grasslands after one extreme drought event can be expected to be high, with no persistent changes in species and trait compositions.

1. Introduction

In temperate regions, mountain grasslands are at the core of livestock farming and bear important economic, social and ecological values. In Switzerland, agricultural policy supports forage self-sufficiency and promotes grassland-based livestock farming (Barth et al., 2011). However, with climate change, grasslands will be challenged to meet a growing demand for providing forage as well as other services (Easterling et al., 2000; EEA, 2012). Climate change is very likely to cause a rise in temperatures, to change rainfall patterns and to increase the magnitude and frequency of extreme climatic events such as droughts (IPCC, 2007). For Central Europe, summer droughts are expected to be among the main consequences of climate change (Calanca, 2007; Fischer et al., 2012; Frei et al., 2006) and may cause short-term as well as persistent consequences on grasslands (Jentsch and Beierkuhnlein, 2008).

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Grasslands of the Swiss Jura mountains have a long history of livestock grazing. They have proven to be sustainable over past decades but little is known about their agronomical response under extreme weather events such as severe drought (Gavazov et al., 2013). In particular, the extent to which the production and the nutritive value of the forage will be affected is difficult to predict. Indeed, if yield losses due to droughts have been reported in many studies, their magnitude can be very variable, due to multiple biotic and abiotic factors (i.e. plant diversity, productivity, altitude, management) that may interact (Gilgen and Buchmann, 2009; Grant et al., 2014; Kahmen et al., 2005; Vogel et al., 2012; Wang et al., 2007; Zwicke et al., 2013). In addition, existing information concerning drought effects on the nutritive value of forage are contradictory. For temperate regions, most of available information concerns cultivated grass and legume forages and reports that water scarcity can improve their nutritive value, e.g. with increased crude protein content and decreased fiber concentration, presumably due to delayed maturity of plants (Bittman et al., 1988; Buxton, 1996; Halim et al., 1989; Jensen et al., 2010; Küchenmeister et al., 2013). On the other hand, it can also be expected that a severe water stress, by causing leaf senescence, will lead to an increased stem to leaf ratio as well as to nutrient translocation from leaves to roots, both of which contributing to low forage quality (Bruinenberg et al., 2002; Buxton, 1996).

Nevertheless, predicting how forage production and quality will be affected by droughts requires to account for real management practices undertaken in grassland-based livestock farming. In particular, grazing experiments in real context with animals are rare, despite grazing being the main grassland management worldwide (van Wieren and Bakker, 2008). In drought studies conducted on permanent pastures, grazing is often simulated through cuttings, which are, for reasons of feasibility, generally uniformly applied to the grassland plots (e.g. Gilgen and Buchmann, 2009; Mariotte et al., 2013). However, grazing is likely to impact the spatial structure of the vegetation due to feeding preferences (Adler et al., 2001), and, through defoliation, dejections, and trampling, to have positive or negative interactions with above and below-ground components of grassland ecosystems (Frank, 2007; Kohler et al., 2005). In addition, in many regions, grasslands are usually grazed in a rotational system, as illustrated for the Jura mountains (Mosimann et al., 2012). This implies frequent utilizations, unlike what happens in drought experiments where cuttings are only applied before and after the drought treatment, allowing sometimes a long vegetation regrowth period between utilizations (e.g. Mariotte et al., 2013). While frequent utilizations generally reduces the annual dry matter production, it maintains plants into an active growing and tillering phase instead of maturing naturally, which then provides a forage with improved nutritive value (Bruinenberg et al., 2002). Therefore, it is likely that grassland management through realistic grazing utilization influences the response of the vegetation to drought in a different manner to the more commonly studied mowing utilization.

The plant functional approach, in which both species composition and plant traits are monitored, is well suited for studying grassland responses to environmental changes (e.g. Garnier et al., 2004; Quétier et al., 2007; Suding et al., 2008). Plant functional traits can be simple measurements that depict the stature, the leaf economics spectrum or the root properties of plants (Violle et al., 2007), directly linked to the functions of plant growth, development and resource acquisition (Weiher et al., 1999; Wright et al., 2004). Variations in key plant traits such as specific leaf area (SLA) and leaf nitrogen concentration (LNC), linked to water conservation functions during photosynthesis (Wright and Westoby 2002), have been documented in response to water stress (Jung et al., 2014). At the community scale, trait values are averaged across all species and weighted by species abundance (e.g. Garnier et al., 2004). Variations in community plant traits in response to drought can therefore be due to both modification of species composition and intraspecific variability in traits, i.e. plasticity in plant morphology and physiology (Jung et al., 2014; Lepš et al., 2011). Drought-induced shifts in species composition are however likely to occur on a long-time scale, with potential lasting effect on the community properties, whereas intraspecific trait variations can occur rapidly but with potential effects of short (e.g. seasonal) duration (Jung et al., 2014; Lloret et al., 2012; Suding et al., 2008). Such changes in community plant traits can ultimately influence agronomic services such as forage yields and its nutritive value (Gardarin et al., 2014; Quétier et al., 2007).

In the present study, we experimentally studied the effect of a severe single summer drought on the forage yields and its nutritive value in a mountain grassland in the Swiss Jura. The grassland was managed according to the two main farming systems practiced in the study region: rotational grazing (6 utilizations by sheep per year; each consisting of 2 days grazing followed by 4–6 weeks resting) and mowing (3 forage harvests at 8–10 weeks interval). Shifts in plant species composition and trait values were monitored to study mechanisms of community response to drought and management. In this context, we hypothesized that: (i) the dry matter production and the nutritive value of the forage are negatively affected in the short-term by a severe summer drought, (ii) grazing management further increases the negative effect of drought due to frequent utilizations, (iii) these short-term responses are accompanied by shifts in community plant trait values, while species composition remains stable, (iv) in the absence of persistent changes in species composition and trait values, the recovery in forage production and nutritive value after a single drought event is high.

2. Materials and methods

2.1. Study site

The experiment was conducted from spring 2012 to spring 2013 on a permanent grassland located in the Jura Mountains (Agroscope research station, La Frêtaz, Western Switzerland, 6°33′56.5″E, 46°50′15.5″N, 1200 m a.s.l.). Climate at the site is suboceanic with annual precipitations of 1333 mm (1981–2010 30-year mean, MeteoSwiss). The snow cover usually lasts from mid-November to mid-April. During the summer months (June–August), precipitation reaches 347 mm and temperature 13.5 °C (30-year mean, MeteoSwiss). In 2012, the annual rainfall reached 1490 mm, with relatively frequent precipitation during summer months (June–August: 405 mm). The grassland covers a flat area on a relatively deep soil (50 cm in average), classified as Cambisol eutric (IUSS Working Group WRB, 2006). The topsoil horizon (0–20 cm) contains 24% sand, 44% silt and 32% clay with a mean pH of 6.6. Based on soil texture, the water holding capacity (WHC) of the soil, the soil water content at field capacity (SWC_{fc}) and at wilting point (SWC_{wp}), were estimated, respectively, around 100 mm, 0.35 and 0.15 cm^3 water/cm^3 soil, over the 50 cm depth (Saxton et al., 1986). For validation, we used these estimated parameters to compute the soil water balance, and thus the soil water content (SWC) over the experiment period, following the FAO methodology (Allen et al., 1998) and ensured that the adequacy between computed and observed data of SWC was good. The plant community of the grassland is dominated by grasses (60–80%) with rather nutrient-rich species such as *Poa trivialis*,*Agrostis capillaris*, *Festuca pratensis*, *Dactylis glomerata* and *Lolium perenne*. Both legumes (mainly *Trifolium repens*) and forbs (mainly *Ranunculus acris* and *Taraxacum officinale*), account for about 10–20%. Biomass production (5–7 t ha^{-1}) is high relative to the site