Drought effects on plant water uptake and water use as well as soil carbon dynamics in Swiss grassland systems under changing climate

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1. Three research questions of the project

- Do re-occurring water shortages over mid- to long-term influence the susceptibility of grasslands to drought?
- Do plants in grassland systems shift to different water sources and use water more efficiently under prolonged drought conditions?
- How does drought affect soil CO_2 losses, organic matter decomposition as well as soil organic matter formation?

2. Research Summary

During phase 2, PLANT/SOIL provided first information how extreme drought periods, by prohibiting natural rainfall for 10 to 12 weeks in spring/early summer with rainout shelters and thus strongly reducing soil moisture during these weeks, affected community composition and competition, net primary above- and below-ground productivity, gas exchange as well as soil CO_2 losses after doubling litter inputs. However, it remained unclear if grassland systems also show time-lagged responses to drought periods over the short-term (within a season) as well as over mid- (3 yrs) and long-term (6 yrs). Such time-lags or memory effects might increase the susceptibility of grasslands to drought in the future (IPCC 2007). Therefore, we plan to built on our 3 yrs experiment and extend the drought treatment into the long-term (6 yrs) (Task 1). This will allow us to assess potential time-lagged responses and increased susceptibility to drought at various time scales and provide important long-term input data of three Swiss grasslands along an elevational gradient for the models used in project WP3.2.

Furthermore, plant resource use, in particular water use, will become more relevant when grasslands are to provide forage productivity of high quality despite varying climate (e.g., Nippert and Knapp 2007). If and which grassland plants shift water sources under drought stress is not known. To better understand grassland vulnerability, plant traits related to water use, plant water dynamics as well as water sourcing, water uptake and water use will be studied and most sensitive plants identified (Hector and Bagchi 2007; Suttle et al. 2007) (Task 2). Such process-based information will help to better understand system-scale responses and sensitivity to extreme events.

Soil carbon dynamics under drought conditions are often modelled driving relationships from ambient climate conditions to their very extreme. However, if these relationships really hold true under such extreme conditions is hardly known (e.g., Davidson and Janssens 2006, de Boeck et al. 2007). If soil carbon dynamics are slowed down by low soil moisture, thus increasing soil carbon sequestration, or if lower biomass production will decrease soil carbon sequestration, is not clear yet. We will thus investigate the impacts of drought on soil CO_2 losses, soil organic matter (SOM) decomposition as well as SOM formation under the typical management regimes of three grasslands (Task 3). This information will help us (and WP3.2) to better understand and model soil carbon sequestration potentials in grasslands under drought conditions.

3. Data and methods

The three tasks proposed will be investigated at the three grassland sites Chamau (intensively managed grassland at 400 m), Früebüel (medium-intensively managed grassland at 1000 m) and Alp Weissenstein (expensively managed grassland at about 2000 m) already used during phase 2, thus creating a unique, long-term dataset from a traditional three-stage grassland farming system. Two of these three sites (Chamau and Früebüel) are also part of the EU project Carbo-Extreme. This EU project will provide detailed information about community CO_2 exchange and high-temporal resolution data on carbon isotope fluxes and the fate of recently fixed photosynthates after a ^{13}C-tracing experiment. Here, we will focus on long-term, potentially time-lagged responses to drought (task 1), on water dynamics at the plant species scale (task 2), and on drought impacts on soil carbon dynamics (task 3). Two Ph.D. students will carry out the proposed work, supervised jointly by the PIs.

1. To assess potential time-lagged responses of grasslands to drought and memory effects after the drought period at various time scales. Phase 2 results indicated time-lags of plant responses and longer-lasting memory effects (over winter) after summer droughts. Thus, key parameters representative for various time scales (seasonal, annual, mid-term, long-term) will be measured to assess if re-occurring droughts also increase the susceptibility to drought. Therefore also the recovery phase after an extended drought period will be considered as equally important as the drought period itself for the overall performance of grasslands. The competition among plant species and as a consequence species composition and total biomass production are relevant already in the short- to mid-term, while effects on soil properties will become more important in the long-term after several extended drought periods.

Leaf water potential, stomatal conductance and photosynthetic capacity decline during the day and partially recover during the night throughout the drought period (results from phase 2). Diurnal courses must be analyzed to properly compare the performance of species during the drought period as well as during the subsequent recovery phase. Leaf water potential and gas exchange analyses in abundant species are suitable to detect vegetation acclimation and serve as a basis for model validation. The intrinsic water use efficiency is a key aspect in this context. Reduced transpiration as a consequence of reduced stomatal opening affects cooling in illuminated leaves and higher leaf temperatures may negatively influence CO_2 assimilation. Besides these physiological parameters, the species composition as well as the above- and belowground biomass production are parameters to be addressed. These results together with measured soil characteristics (volumetric soil water content, soil water potential) will provide short- and long-term data for community responses of typical Swiss grasslands and will allow addressing the susceptibility question.

2. To investigate plant traits related to water use, plant water dynamics as well as plant water sourcing and to identify most sensitive plants to drought. Plant traits are known to be good indicators of plant functioning (Diaz and Cabido 2001, Cornelissen et al. 2003) although traits related to water use, such as leaf water content, specific leaf area and specific leaf weight, but also the temporal course of leaf senescence, have not been fully explored yet in concert with physiological responses to pronounced drought. Measurements of leaf water potentials, net CO_2 assimilation rate, transpiration and leaf conductance will be carried out as core parameters at all sites over three years at selected times (before, during, after drought manipulations), but also at higher temporal resolution (diurnals as well as during the transition times before and after drought manipulations; see task 1) at one site per year. This will provide detailed information about competition among plants as well as on sensitivity of plants to drought. Analyses of stable isotopic signatures (carbon, nitrogen) will provide further information about underlying mechanisms such as changed resource use.

In addition, a strong focus will be on plant water sourcing, uptake and use. The origin of plant water uptake and potential shifts during the drought manipulations will be assessed using oxygen and hydrogen isotope ratios in xylem water of dominant plant species (collected according to Barnard et al. 2006). Potential water sources will be collected either event-driven (i.e., precipitation) or on a regular basis (i.e., soil water from different depths, groundwater). In phase 2, some preliminary data have already been collected (e.g., local meteoric water lines), testing the method by Barnard et al. (2006) successfully under field conditions (Gilgen 2009). In combination with root biomass and productivity (see task 1) as well as leaf water potentials and transpiration rates (see above), we will be able to address competition for water among species in the grasslands independently and be able to identify shifts in water sources as a consequence of drought.

3. To quantify the impacts of drought on soil CO_2 losses, SOM decomposition as well as SOM formation in Swiss grasslands. Soil CO_2 fluxes, SOM decomposition and formation *in situ* are important processes driving carbon sequestration potentials in grasslands. Although soil respiration after doubling litter input has been already measured in phase 2, no information is available about soil CO_2 fluxes under ambient litter regime or about their response to drought.

We will measure soil respiration (on a regular basis for one site per year) and soil climate (as in phase 2) to determine its dependency on soil temperature and soil moisture, the two most important drivers (Davidson and Janssens 2006). To assess the long-term carbon turnover, we will use C4 soil cores (originating from a 17-yr-old *Miscanthus* field). Four cores (5 cm in diameter) will be buried per plot: two cores (in 2 mm mesh bags) will allow root growth, soil fauna exchange and thus SOM formation as well as decomposition, two cores (in 1 μm mesh bags, with some drainage holes) will be used only to assess microbial SOM decomposition. One of each type will be harvested after one year (mid of year 2) and after two years (mid of year 3). Based on carbon isotope analysis and root input, SOM turnover rates can be calculated since the C3 roots have very different isotopic signatures than the C4 soil. Although the C4-soil is not the native soil from the individual sites, such a controlled approach will still provide valuable insights into the impacts of drought on soil carbon dynamics.

4. Milestones and deliverables

After 18 months:

- analyses of species competition, aboveground and belowground productivity, root traits and soil properties at Chamau, Früebüel and Alp Weissenstein,
- short-term in-depth physiological responses of grassland plants to drought (one field season at each site), identification of plant water sourcing, uptake depths and water use
- assessment of soil carbon dynamics at short- and mid-term time scales

After 36 months:

- long-term datasets on grassland vegetation (species composition, plant physiology, functional traits, water uptake/use) and soil responses to drought for Swiss grasslands,
- identification of delayed vegetation and soil carbon responses to drought (i.e. recovery, memory effects) and potential of increased susceptibility,
- quantification of soil carbon dynamics at mid- to long-term time scales

5. Contribution to the WP3 and collaboration with other NCCR projects and 3rd parties

Artificial drought periods will be based on climate scenarios of P2.3 PreClim. Model validation and improvement with P3.2 AGRISK (PaSim) will be possible based on 6 yrs of data on responses to drought of typical Swiss grassland types. Soil responses to drought will be carried out jointly with P3.2, task 1. Data will be shared with Swiss Fluxnet and Swiss-wide project Maiolica (PI Buchmann) leading to a comprehensive analysis. Basic infrastructure will be used for this project as well as for the EU project Carbo-Extreme (Co-PI Buchmann). The collaboration of the Institute of Plant Physiology with the Bulgarian Academy of Sciences (project referring to drought responses of Bulgarian wheat varieties) is focused on physiological responses of whole plants to an extended drought period and the subsequent recovery phase. More recently, the response of red and white clover (important grassland species) to soil water status became a crucial issue for the Bulgarian colleagues allowing an even more intense collaboration.

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