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Valorization of grassland management for the water supply in context with climate change

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Zusammenfassung

Die Zunahme von Trockenperioden in ihrer Frequenz aber auch Intensität stellt für die landwirtschaftliche Nutzung von Grasland zur Futterproduktion eine große Herausforderung dar. In einem „Common Garden Experiment“ werden im Stubaital, Österreich, die Auswirkungen von Trockenheit auf verschiedene Graslandökosysteme (hinsichtlich klimatischer Grundvoraussetzungen und Produktivität) mittels Kleinlysimeter (Smart-Field-Lysimeter) untersucht. Dabei zeigte sich, dass die an feuchtere Bedingungen angepasste Vegetation mit +11.4% höhere Verdunstungsraten aufwies. Die dabei gewählte Strategie höheren Wasserverbrauches könnte aber bei zunehmender Trockenheit nachteilig sein und die Frage, ob es zu einer Veränderung der Vegetationsgesellschaft kommt, oder anfänglich physiologische und/oder morphologische Anpassungen erfolgen, bleibt fraglich. Dies kann nur durch eine genaue Betrachtung des Gesamtsystems Vegetation-Boden schlüssig beantwortet werden.

Schlagwörter: Graslandwirtschaft, Klimawandel, Wassernutzungsstrategie, Lysimeter

Summary

Increasing frequencies of droughts in the vegetation period are challenging for the agricultural management of mountain grassland. To analyse the impact of drought on different gradients of agricultural intensity and environmental characteristics, three different grassland ecosystems (in terms of underlying climate and productivity) are investigated using small high precision lysimeters (Smart-Field-Lysimeter) in a common garden experiment at the LTER-site ‘Stubai Valley’, Austria. The simulated sequence of two drought periods intermitted by a recovery (rewetting) period after cutting showed with +11.4% (± 2.7) higher evapotranspiration for the vegetation type S (Stubai Valley, humid climate) than for the vegetation type M from the drier area ‘Matscher Valley’, Italy. However, the selected water spending strategy of the type S might be more vulnerable to drought events and the question, whether such types of plant communities will adapt to drought or to which extent physiological and morphological changes could play a role initially needs detailed analyses of plant soil interactions.

Keywords: grassland management, climate change, lysimeter, plant water-use strategy

Introduction

Increasing frequencies of droughts in the vegetation period are a challenge for the agricultural management of mountain grassland in terms of forage production and other ecosystem services provision (Leitinger et al. 2015) and references therein). Although the concept of ecosystem services (ES) – ES are ‘the benefits people obtain from ecosystems’ - is promising to communicate global change impacts, quantification of ES provision is crucial to develop adequate management strategies in a future environment (Kohler et al. 2017) and references therein). Quantification of ES should focus on the most decisive ecosystem processes (i.e. indicators) to properly assess the *‘indicandum’* (the subject to be indicated), more precisely the target ES. In terms of ‘forage production’ and ‘water provision’, detailed knowledge about the water balance, plant composition and plant functional traits, soil physical- and soil hydrological properties, as well as water sources is needed to accurately quantify the impact of droughts.

In a research cooperation of the Institute for Alpine Environment at the European Academy Bolzano/Bozen (eurac research), the Institute of Ecology with the *Research group* ‘Ecosystem and Landscape Ecology’ at the University of Innsbruck, and the Free University of Bolzano, the research project ‘ClimAgro - Valorization of grassland management for the water supply in context with climate change’ quantifies the impact of precipitation- and temperature change on the ESs water provision and grassland productivity / forage production. The project ‘ClimAgro’ - sponsored by the Province of South Tyrol (Autonome Provinz Bozen – Südtirol, Abteilung Bildungsförderung, Universität und Forschung) - addresses gradients of agricultural intensity and environmental characteristics by investigating three different types of grassland ecosystems in a common garden experiment

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at the long-term socio-ecological research (LTSER) site 'Stubai Valley', Tyrol, Austria (Tappeiner et al. 2013).

The spectrum of research encompasses (among others) the assessment of (1) the water use efficiency (WUE) by analysing the ratio of the stable carbon isotopes ^{12}C and ^{13}C (δ^{13}C) and by ecosystem chamber measurements (CO_2 and H_2O fluxes); (2) the crop evapotranspiration of grassland ecosystems with varying prevailing climatic conditions or strategies (water saving vs. water spending strategy); and (3) water sources used by different grassland ecosystems under drought conditions and reoccurring drought events. This manuscript presents the details of the international research project 'ClimAgro' with respect to the experimental design, sampling strategy and research infrastructure. Results of the second research topic in the project - the crop evapotranspiration of grassland ecosystems with varying prevailing climatic conditions or strategies (water saving vs. water spending strategy) – are shown and discussed.

Materials and Methods

To address gradients of agricultural intensity and environmental characteristics, three different types of grassland ecosystems (in terms of underlying climate and productivity) are investigated in a common garden experiment at the LTER-site 'Stubai Valley', Tyrol, Austria. In addition to local grassland types from the Stubai Valley, soil-vegetation monoliths were taken from an inner-alpine dry valley, the LTER-site 'Matscher Valley', South Tyrol, Italy. The Stubai Valley is characterized by a northern central European climate with MAP and MAN of 1097mm and 6.3°C, respectively, at 972 m a.s.l. The vegetation type (**S**) was excavated close to the area with the common garden experiment (GPS-coordinates see description below). The Matscher Valley is characterized by a dry inner alpine climate with MAP and MAN of 527mm and 6.6°C, respectively, at 1500m a.s.l. Here, irrigation systems are needed to maintain satisfying productivity of the grassland ecosystems. The vegetation type (**M**) was excavated from a grassland area at 1500m a.s.l. close to the village *Mals* (WGS84: N 46°41'9.99", E 10°34'48.65").

To complete for species and management gradients, the third grassland vegetation type (**I**) was a 6 species seed mixture of fast-growing fodder meadows. Analyses of water-balance and measurement of evapotranspiration (ET) was performed using 24 high precision lysimeters, so called Smart Field Lysimeters® (SFL, Company UMS AG, Munich, Germany) with 0.3m in diameter and depth. Please refer to the company website (http://www.ums-muc.de/en/lysimeter/smart-field-lysimeter/) of UMS AG (METER GROUP with METER Environment since 1. January 2017) for further details on installation, measurement principles, and technical details of sensors used. Please note, here and in the following, trade names and companies are mentioned for the benefit of the reader and do not imply any commercial benefit or preferential treatment of listed products.

The common garden experiment (*Figure 1*) was located in an agriculturally used grassland (hay production) in the Stubai Valley near the city of *Neustift im Stubaital*, Tyrol, Austria, at 972 m a.s.l. (WGS84: N 47° 7'4.84", E 11°19'16.97"). Different treatments with three replicates of each grassland type were applied: *control* (long-term precipitation amount and frequency), *drought* (no precipitation), *drought and heat* (no precipitation, increase of surface temperatures by +2K). The heating was performed

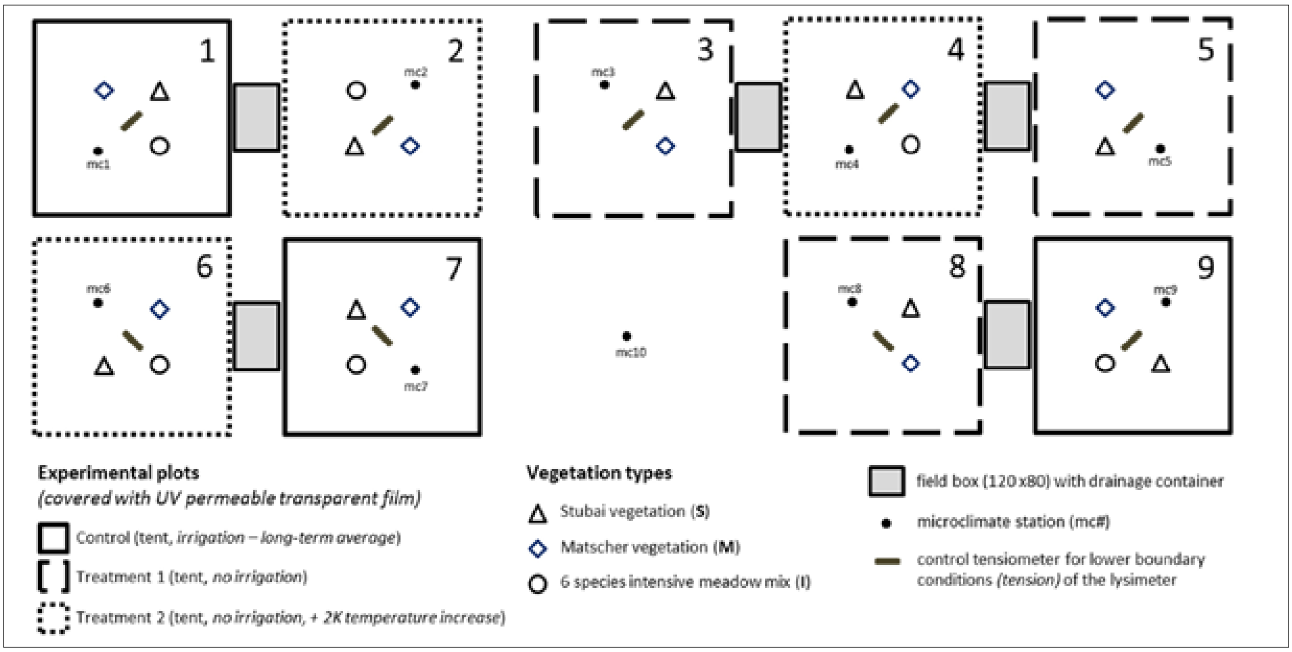

Figure 1: **Experimental design of the common garden experiment using fully equipped 24 high precision lysimeters, also referred to as Smart-Field-Lysimeters (SFL): 3 different grassland types with 6 to 9 replicates each. The lysimeters are organized in 9 plots, each of them covered with a UV permeable transparent film (*Lumisol Clear AF®*, 88% - 92% light transmittance). Microclimate stations recorded wind speed (m s^{-1}), air temperature (°C), relative humidity (RH%), soil moisture (vol%) in 0.1m and 0.05m soil depth, and solar radiation (W m^{-2}). Please note: the intensive seed mixture (vegetation type I) was not part of *Treatment 1 (drought – no irrigation)*.**

using ceramic heaters, and surface temperatures of the lysimeters were measured using an infrared radiometer (SI-111; Apogee Instruments; Logan, UT, USA). This sensor is sensitive in the electromagnetic spectrum from 8 to 14µm and was mounted above the lysimeters in a way that avoids shading, but close enough to limit heating to the lysimeter surface (considering the half-angle field of view of 22° of the infrared radiometer). The reference infrared radiometer was placed in plot 8 (treatment 1, drought, no irrigation) and the measured surface temperature +2K was the 'target-temperature' for plots 2, 4, and 6 (treatment 2, drought, no irrigation, heated to reach +2K of the surface temperature in treatment 1). If the surface temperature of a treatment 2 lysimeters was below plot 8 surface reference temperature + 2K, the ceramic heaters were turned on until the target temperatures were reached. For the irrigation of the plots, a modified version of a small scale rainfall simulator (Newesely et al. 2015, Leitinger et al. 2010) was installed in each of the nine experimental plots. Each plot was covered with a UV permeable transparent film during the (*Lumisol Clear AF*®, 88% - 92% light transmittance) during the experiment. In other words, all treatment types were fully controlled and not exposed to the natural precipitation scheme. Average rainfall between 1970 through 2000 (amounts and intensities) was simulated in the control treatment and regular watering occurred at 01:00 a.m. to reduce transpiration from surface and to allow infiltration of the applied water into the soil. Necessary inspection of the rain simulator and manual refilling took place during daytime. The shelters were left open on those sides facing the main wind direction and not fully closed at the sides but down to just 0.5m above the ground to avoid wind shielding and to obtain natural boundary conditions as far as possible. The quality of the drought could be triggered by the length of the drought period, thereby reducing the available (soil) water for transpiration.

Results and Discussion

First, the influence of sheltering on climate forcings is shown by comparing the data from microclimate station 10 (mc10) to mean values of the other stations in the experimental plots covered with a UV permeable transparent film. Solar radiation decreased by -8% which is in line with the specifications of the type *Lumisol Clear AF*. Mean air temperature increased by +0.36K showing distinct characteristics between day and night with a decrease nocturnal (-0.54K) and a mean increase of +1.22K at daytime – compared to conditions outside the shelters. Relative humidity showed no statistical significant difference at both daytime and nighttime. Given the fact that maximum air temperatures in the sheltered plots were between +3.2K and +10.2K higher than outside the shelters, sheltering of our experimental plots already increased air temperatures, affecting the vapour pressure deficit (VPD) in a complex way: while the increase of surface temperatures by +2K using ceramic heaters was found to be successfully accurate, another important aspect is that absolute humidity of the air might increase in the future by overall increasing evaporation – hardly affecting relative humidity of the air as a consequence. But this only holds true for conditions with adequate water supply. Hence, an experimental setup for temperature increase should on the one hand not heat the air but the leaves to ensure that vapour pressure gradients (VPG) from the leaves to the air represent those predicted in a future climate (Kimball 2005). Results from our treatment 2 corroborate no significant change of the relative humidity of the air measured by our microclimate stations. Additionally, by using ceramic heaters we have the same effect as indicated for infrared heating by simultaneously not affecting the light spectrum. On the other hand, combined with drought, VPG from the leaves to the air might indeed change and has to be taken adequately into account.

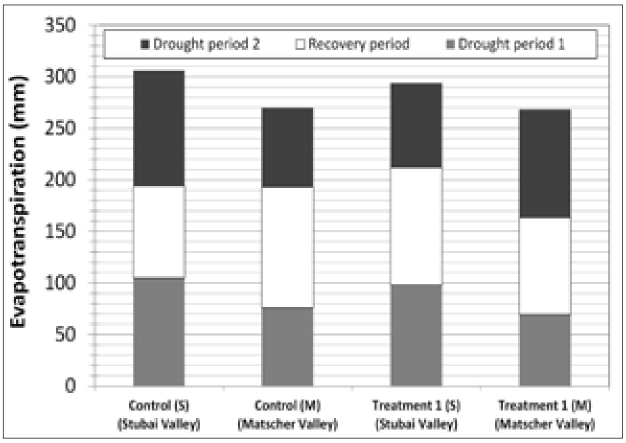

Figure 2: **Total evapotranspiration for the simulated scenario Treatment 1 with *drought period 1* (43 days, June/July), followed by a cut and the *recovery period* (32 days, July/August), and another *drought period 2* (59 days, August/September/ October). Results are compared to the control plots for both vegetation types S and M.**

For treatment 1 and the two managed grassland vegetation types from the climatically different areas Stubai Valley and Matscher Valley, a scenario with *drought period 1* (43 days, June/July), a *recovery period* with long-term average precipitation for all plots (32 days, July/August), and finally *drought period 2* (59 days, August/September/ October) was simulated. Results showed a slight reduction of ET in treatment 1 compared to the control plots for the first drought period with -7mm (-7.1%) and -6.5mm (9.4%) for vegetation S and vegetation M, respectively (*Figure 2*).

Vegetation M from the Matscher Valley revealed generally lower ET (for control and treatment 1 plots) than the vegetation S from the Stubai Valley (29mm) in drought period 1. However, this was not the case in drought period 2: while the control plots followed the pattern found in drought period 1 with ET of -35mm for vegetation M, ET in treatment 1 (drought plots) was higher for vegetation M than for vegetation S (+24mm). Decisive in this context might be the recovery period showing higher ET for vegetation M than for vegetation S at least for the control plots, but vice versa in the treatment 1 plots. More precisely, structure and senescence of the regrowth (vegetation was cut after drought period 1 following the management scheme of the farmer) strongly influence ET in this period. It is well known that plant functional composition (proportion of plant functional groups: grasses, forbs, legumes) changes in the regrowth after every cut (Grant et al. 2014). In general, less grass and more forbs are expected if precipitation variability changes. Moreover, these changes might vary for the vegetation types but also for the different treatments (control *versus* treatment

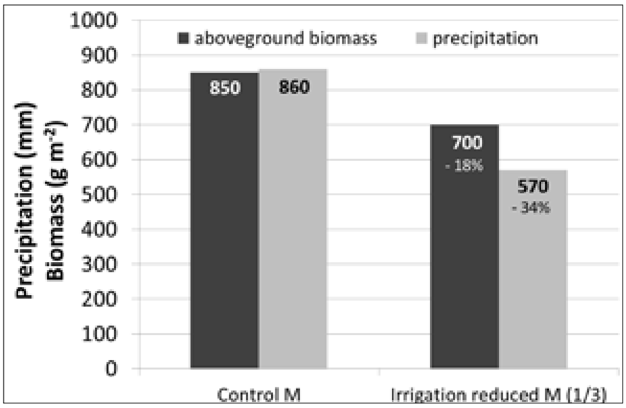

Figure 3: **Special treatment for vegetation type M to test for irrigation efficiency in terms of forage production. When reducing irrigation by 34% compared to the control plots, the amount of aboveground biomass was solely reduced by -18%.**

1). To get a full picture of the impact of different stressors (i.e. cutting, drought) and/or multiple simultaneous stressors (i.e. cutting and drought for treatment 1) for ET and forage production, responses to stressors at canopy and plant level have to be addressed. Additionally, not only aboveground processes but also belowground processes (i.e. plant-soil interactions) have to be taken into account. For details on strategies and grassland community responses to environmental drivers/stressors please refer to Pontes et al. (2015).

In general, the vegetation S showed with +11.4% (± 2.7) higher ET for the overall simulated vegetation period than vegetation M. The amount of ET of vegetation type M revealed that this irrigated vegetation type from the Matscher Valley might not be characteristic for the prevailing climate. In this context it seems to be insignificant if the additional water is provided by natural precipitation or artificial irrigation as long as the needed water is supplied. Nevertheless, our results show that a reduction of irrigation by -34% for the vegetation type M reduces forage production by solely -18% (*Figure 3*). Hence, forage production from grassland ecosystems shows potential for efficiency increase and presents an opportunity to save water under probably drier future conditions.

As mentioned for the comparison of the vegetation types S and M before, a proper distinction between water saving and water spending strategy requires a strong gradient of underlying climatic conditions for the investigated vegetation types (and perfect adaptation of vegetation types to these conditions). In other words, due to the irrigation of the vegetation type M in its origin, a drier vegetation unit from the Matscher Valley might provide a more valuable insight about the selected water use strategy and subsequently vulnerability to climate change. Although a higher vulnerability for vegetation types with a water spending strategy was already strongly suggested by a hydrological modelling study in two grassland sites in the Austrian and French Alps (Leitinger et al. 2015), preliminary results of our experimental studies in 'ClimAgro' in 2016 reveal a much more complex behavior of the plant-soil system especially when adding temperature increase (by heating) as another stressor. In this context, compared to the intensive seed mixture (vegetation type I), the quality of the Stubai Valley vegetation type S in terms of forage production seems to be very close to very intensive grassland management, but simultaneously reflecting available water and water sources (i.e. adapted vegetation type).

Conclusion

The Stubai Valley grassland vegetation S is characterized by a water spending strategy with higher evapotranspiration (ET) whereas the Matscher Valley grassland vegetation (M) is characterized by lower ET and thus a water saving strategy. Nevertheless, we have found distinct responses for different drought periods and the recovery (rewetting) period. To get a full picture, further progress in disentangling the impact of multiple and/or simultaneous stressors is needed. Although forage production and ET are higher for the vegetation type S (Stubai Valley), the selected water spending strategy seems to be more vulnerable to drought events (although quality and frequency of droughts might have varyingly strong impacts). Finally, at what rate plant communities will adapt to drought and to what extent physiological and morphological changes play a role at least initially ist still not fully explored. Within the international research project 'ClimAgro' we will address various research questions in the presented scientific field. Please refer to published and forthcoming journal papers of the authors involved.

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