Ref: bg-2017-253

Title: Community specific hydraulic conductance potential of soil water decomposed for two Alpine grasslands by small-scale lysimetry

Dear Editor Natascha Töpfer!

Dear Reviewer!

Please find enclosed the revised version of 'Community specific hydraulic conductance potential of soil water decomposed for two Alpine grasslands by small-scale lysimetry' (bg-2017-253). We appreciate the time and efforts that you and the reviewers have invested in this manuscript. They have helped us to significantly improve the manuscript. Please find below our specific replies to the reviewers' comments.

Reviewer 1:

R: It would be definitely worth to explain more clearly what the results really mean for Alpine grassland ecosystems.

A: We explain more clearly the impacts of climatic changes on agriculturally used Alpine grassland ecosystems in the introduction and specify management implications in the conclusion section.

R: The manuscript is mostly well-written, however, at the moment there are no distinct sections (introduction, material and methods, results, discussion and conclusion)

A: The section headings got lost during the submission process and were inserted again in the revised manuscript.

R: It might be a matter of taste, but some of the sentences are very long (e.g. lines 44- 47, lines 170-173, lines 352-354)}

A: done

R: My main criticism is about the relationship presented in Figure 5. I think this apparently strong correlation is mainly related to the fact the two variables are not completely independent from each other (ET and ET/DW). Please check this paper by Kenney (1982). Figure 5 and its explanation should probably be removed from the manuscript. Moreover, the methodology provided by Renton and Poorter (2011), for the log-logscaling method, appears to be different than that presented by the authors in lines 222-225.

A: this is not a regression type of way to establish a statistical relationship among the different factors defining total ET. Using the log-log scaling we seek to visualize that both parameters do not

equally contribute to the variability in ET. Biomass Variation has almost no effect, while the abundance of ET variation measured in the experiment is caused by differing rates of ET per unit biomass (water vapour release activity). We added additional description for the procedure to the corresponding section in the Methods chapter.

R: Line 43: which structural changes at the soil-plant-atmosphere interface?

A: changed to functional

R: Line 89: The hypothesis is well formulated, but the two types of vegetation should be addressed earlier in the paragraph. For example mention - also already in the abstract that you studied two different Alpine grassland communities with contrasting strategies of water use and adaptation to drought.

A: We included the a mention on "differently drought-adapted alpine grassland communities" into the abstract

R: While reading the manuscript I had trouble in understanding when the extended periods of drought were manipulated during the experiment. This is important to state in the text and to show in figures 2, 3, and 4. In the same figures I also suggest to use two different colours for the shaded areas. At the moment it is difficult to see which shaded area belongs to each treatment.

A: In Fig. 1 we show the occurrence of water provision to the individual plots and that the application of extended drought periods was not equal among all plots of the D(drought)-treatment. Due to a thunderstorm one of the plots had a water inrush just before 10th of June. However, we later summarize that *" it was argued to define variations in water availability not purely on the basis of contrasting regimes of water input (i.e. irrigated vs. non-irrigated) if these are not causing systematic variations in soil moisture (Kramer, 1983) and that "Therefore, regular irrigation and, respectively, its omission can, counter-intuitively, only be an indicator of contrasting water availability. The establishment of drought conditions in the strict sense of a depleted soil water reservoir is realized by the interaction of pre-treatment SWC, standing biomass and atmospheric effects."*

The assignment of REG and D treatments is a compromise allowing to treat both sets of plots not as the same statistical population, while there were differences within the groups with respect to water provision caused by the accuracy of the irrigation system and in the case of the D-treatment an accidental water influx. However, our main findings are related to differences in water availability based on different SWC% of the soil.
In the case of overlapping standard deviations/ grey shaded areas also different colours would overlap and prevent an assignment to the treatment. Important in these plots are the are the regions when the two treatments are statistically distinct, and standard deviation don't overlap.

R: Please define every acronym the first time it is mentioned.For example in line 16, evapotranspiration (ET).

A: We defined all acronyms as suggested:

A: We have dealt with all following minor comments:

Line 23: the vegetation's reaction to two -**adopted**
Line 34: add space after transpiration -**adopted**
Line 42: change focused to main -**adopted**
Line 45: change composition to abundance -**adopted**
Line 51: can only be predicted inaccurately-**adopted**
Line 79: climate change -**adopted**
Line 119: transplanted from a meadow in Matsch/Mazia -**adopted**
Table 1: Please check that the soil classification is correct. -**adopted**
In Line 171: add a comma before the word addressing and remove the "and"- sentence restructured
Line 174: in the current experiment -**adopted**
Line 219: add space before bracket-**adopted**
 Line 220: please cite the nlme package -**adopted**
Line 227: ET0 should be written as ET0-**?**
Figure 5: The x-axis of the log(DW) is missing –**same as in the main plots**. .. In any case, see my comments above about this figure.
Line 316: change EVT to ET? -**adopted**

Reviewer2

R: Authors find that pasture community coming from a wet site (rainfall ca.1100 mm) exhibits a water-spending strategy while the pasture community coming from a mesic site (rainfall ca. 525 mm) exhibit a water-saving strategy, what is non-surprising.

A: Our manuscript seeks to reveal how these two different strategies are realized in the same environment and along the gradients of combined variation of soil water provision and atmospheric demand. To our knowledge, no comparable dataset was published which contrasts the water spending potential of two vegetation types in this way. Showing that for a given combination of SWC and ET0 values, two vegetation types reveal differences in their eco-hydrological behaviour, which is not primarily product of differences in growth and standing biomass, leads to questions about the underlying mechanisms.

R: However, some possible artefacts and/or strangle results (the surprisingly low biomass production in wet community respect to the mesic community; the 16-fold difference among wet and mesic communities for g DW produced by Kg of water), and some interpretations that are questionable (mesic community use better soil moisture at low range of SWC), besides of many other small details (see annotated pdf) need a revision.

A: Potential artefacts of the experimental setting on the productivity of our experimental populations are discussed in a revised version of the manuscript and will be addressed in detail in the answers to the specific comments. However, in some cases we can only provide hypotheses as explanation for specific results. The reviewer is arguing that potential artefacts might be the cause for particular results. Artefacts within the experimental proceedings, however, would not have affected particular vegetation x treatment combinations exclusively like reviewer2 argues, but all experimental entities evenly, since they were all treated the same way.

R: English languages is also sometimes awkward.

A: We improved language and clarity according to the specific suggestions by the reviewers.

A: Answers to specific comments in the pdf RC2-supplements (typos and spelling mistakes found by the editors were corrected and are not listed in the following)

R: I miss a heading for this section (L25)

A: The section headings got lost during the submission process and were inserted again in the revised manuscript.

R: in the temporal occurrence of what (L30)

A: changed to "temporal occurance of rainfall events"

R: Which is the fomer?

A: changed to: "as it is"

R: separation of evaporation from the transpiration seems also fundamental. Frequent rainfall event of low volume increase loss of water by rainfall interception that is directly evaporated from the plant camopy before reaching soil-root system. Rainfall concentrated in less events, if soil can accumulate the water, could be in some way more efficient for the ecosystem (L70-72)

A: Information regarding the separation of interception from ET was added in the manuscript

R: I assume you checked common atmospheric parameters inside the sheltered areas (L87-88)

A: Yes, we did check the atmospheric parameters in the shelters, differences to the outside conditions are mentioned in the M&M section. However, here we intend to say that temperature, air humidity, radiation, and wind speed in the shelters were driven by natural fluctuation (in contrast to precipitation/soil humidity which were controlled). We rephrased the sentence to make this clearer.

R: A brief description of the soil description, with common soil depth and rooting profile would help. And and brief expalnation why you select 30 cm depth. (L110)

A: Soil parameters were added in table 1, information on rooting distribution which led to the lysimeter depth chosen were added in the text (former studies showed that 90% of the root biomass is located above 20 cm in both vegetation types.

R: This experimental set up is a peculiar common garden experiment. It is in between a proper common garden (i.e. both vegetation types are planted in similar environmental conditions outside

from their origin) and a transplanting experiment (i.e. each vegetation type is planted in each site). The authors only modified the availability of water, but following this experimental design is is difficult to unravel the effect of water from other confounding factors. For instance, even if the availability of water is optimal for the mesic vegetation type, other factors may not (e.g. temperature, soil properties or biota that are modified by a higher availability of water). In my opinion, this set up could bias the results in favor of the vegetation type that has not been out-transplanted. (L117-119)

A: A potential bias was avoided by an extensive recovery and acclimatization period, see information added at the end of the paragraph.

R: enough? Did you do any check to ensure the full restoration of plan community/density? (L131)

A: More than 8 month of recovery time after installation including the winter season and the first growth in spring should be sufficient, the development of the vegetation during the recovery time was visually checked. This information was added in the manuscript

R: please, rewrite easing the reading (L170-172)

A: The sentence was simplified in the manuscript.

R: please, clarify.Do you intend to separate the water directly evaporated from the plant surface (ranfal interception)? (L194-195)

A: We specified in the introduction that evaporation of intercepted water was not separated from ET as it plays **a minor role in the investigated ecosystems.**

R: It is apparent in the figures that biomass followed a non-linear pattern and that was the main reason of using a gamm. I would include this information here to clarify why the author chose this technic and not the linear mixed model used to assess other variables. (L214)

A: The information requested was added in the manuscript.

R: a more conservative patter than...what? If you use a higher number of knots then the non-linear patter of the model could be overemphasized. However, chosing 5 knots rather than 4 or 6 seems quite arbitrary decisions. Why not use Generalized cross validation and allow the model to chose the optimal number of knots given the data? (L216)

A: The information requested was added in the manuscript.

R: Better placed at the end of the section (L219-L220)

A: The sentence was moved to the end of the section as suggested.

R: be specific, which covariates? (L222)

A: This sentence says that vegetation type was a factor in all models we applied --- additional covariates are described below

R: This looks like a quite complex model for this type of data. How did the authors validate the model to assess if there are signs of overfitting? (L227-228)

A: This question is addressed in the revised manuscript.

R: which covariates? (L231)

A: The covariates are now described better in the revised version of the manuscript.

R: whatabout the comparison among underneath and outside conditions?(L236)

A: Information on the differences of microclimatic conditions inside and outside the shelters were added in the M&M section.

R: I think that mm would clearer ad easier to interpret for most readers (L237)

A: SI unit for ET is defined as kgH2Om-1d-1, we could still change to mm if this is preferred.

R: How much of this variation is due to differences in soil structure between M and S sites? Or is this effect eliminated because in both cases soil water conditions are dictated by surrounding unaltared soil-plant system? (L250-253)

A: Information on soil parameters was added to table1. We also discuss possible reasons for the different behavior of SWC in the discussion section.

R: much higher than ETo (average daily ET0 was 3.26). Any comment? (L257)

A: As the biomass and canopy height of both our vegetation types is much higher than it is assumed for ET0, it is not surprising that actual ET is also higher. This information was also added to the manuscript

R. I would say that ET is higher in S at least during the first half of the experiment (L259)

A: The manuscript was adapted accordingly.

R: Although differences among watering regimes are strong only for a short periods, values seem lower for D most of the time (L261)

A: The manuscript was adapted accordingly.

R: differential among what? please, check the phrase. (L276-277)

A: "differential" was changed to "increment"

R: I would have expected the contrary. The drought-prone community be less sensitive to water shortage, and the local community to be more productive than the drought-prone community. This deserves an explanation.(L285)

A: Initial deficient automatic irrigation in the REG-treatment was too low for the local vegetation causing an early peak and early senescence for the S-type, while it was sufficient for the M-type to enable continuous growth. Manual corrections of irrigation were too late for the S-type. This explanation was included in the manuscript.

R: Where/How can we see this difference in the figure 5? (L302-304)

A: This sentence was a relict from an older version of the MS, when the log-log-scaling was done with x&y switched and not to the rational in Poorter and Renton. Sentence was removed and the message adopted

R: in figure 5 you show a range from -0.86 to 7.2. Why? (L311)

A: field site averages vs average values of individual plots --- the matter was clarified in the MS

R: Where is this table? (L314)

A: The table was included in the new version of the manuscript.

R: differences in figure 4 for S are slight but seem stronger than differences showed here (L330)

A: Fig 4 also shows that for the REG and the D treatment of the S vegetation the biomass values at the beginning of the experiment were also slightly different - therefore the total biomass gain (end value - start value) in both treatments was about the same for this vegetation type

R: consequence of any experimental artefact???? (L336-337)

A: A consequence of insufficient initial irrigation as described before.

R: 0.16 compared to 2.6. This difference seems abnormally high. (l341-343)

A: This was influenced by early senescence of the S-vegetation type and is now discussed in the manuscript in more detail.

R: lower for M mesocosm? Maybe I am lossing something, ... (L343-344)

A: This phrase was deleted in the revised manuscript.

R. however, one could say that for M mesocosm ET/DW never reach the values of S mesocosm. that is, S mesocosm seems to be able to transpire more water per DW unit at low SWC. (L360-361)

A: This part was rephrased accordingly in the revised manuscript.

R: efficient probably is not the best term, as Figure 6B show that at high ETo, S mesocosm consume more water per DW unit that the M mesocosm. That is, M mesocosm exhibits a higher water use efficiency. (L366)

A: We agree with the reviewer and rephrased the sentence

R: The slope is higher for M mesocosm. However at low SWC, ET/DW is always lower for M mesocosm than for S mesocosms. indeed, as you say, for most of the SWC and ETo combinations, M mesocosm showed lower ET/DW values than S mesocosm. From these data, i would not say that M mesocosm has a higher potential to use even scarce water resources ((L368-369)

A: The manuscript was adapted accordingly stressing the water-saving strategy of the M-type vegetation.

R: however, soil texture seem finer for M mesocosm (Table 1). Once would expect a higher water holding capacity for M than for S. Of course, other factors matter (SOC, structure ...) (l379-380)

A: More soil properties were integrated in table 1 and the possible influence of soil parameters discussed in more detail.

R: This information would have been a nice addition to the study (L388)

A: At least the abundance of functional groups was included in table1

R: see comments above that question if really M mesocosm work better than S at low SWC (L393)

A: These comments were answered above.

We sincerely hope that the revised version of this manuscript now fulfils all necessary criteria to be published in *Biogeosciences*.

We thank you very much for your time spent on our manuscript.

Sincerely yours,

Erich Tasser, on behalf of all Authors

Community specific hydraulic conductance potential of soil water decomposed for two Alpine grasslands by small-scale lysimetry

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ABSTRACT

For Central Europe in addition to rising temperatures an increasing variability of precipitation is predicted. This will increase the probability of drought periods in the Alps, where water supply has been sufficient in most areas so far. For Alpine grasslands, community specific imprints on drought responses are merely understood. In a replicated mesocosm experiment we compared evapotranspiration (ET) and biomass productivity of two differently drought-adapted alpine grassland communities during two artificial drought periods divided by extreme precipitation events using high precision small lysimeters. The drought adapted vegetation type showed a high potential to utilize even scarce water resources combined with a low potential to translate atmospheric deficits into higher water conductance with biomass production staying below those measured for the non-drought-adapted type. The non-drought-adapted type, in contrast, showed high water conductance potential with strongly increasing ET rates when environmental conditions became less constraining. With high rates even at dry conditions, this community appears not to be optimized to save water and might experience drought effects earlier and probably stronger. In summary, the vegetation's reaction to two co-varying gradients of potential evapotranspiration and soil water content revealed a clear difference of vegetation development and between water-saving and water-spending strategies regarding evapotranspiration.

INTRODUCTION

Comprehensive alterations in the climate system of the earth are projected for the future decades. Due to increased greenhouse gas concentrations in the atmosphere, the global average temperature is predicted to rise. These changes in the energy budget of the atmosphere are suggested to propagate alterations in atmospheric circulation and modify precipitation patterns worldwide (IPCC, 2013; Knapp et al., 2008; Solomon et al., 2009). Such variations can result in changes of the spatial distribution of precipitation and thereby affect average values of rainfall locally. However, concurrent changes in the temporal occurrence of rainfall events are predicted to increase the variability of rainfall with longer intervals in between and more extreme events. This will lead to stronger variability in soil water availability and longer droughts (IPCC, 2013, 2012).

The water balance in terrestrial ecosystems is dominantly controlled by plant processes. It is suggested that up to 80% of the terrestrial water loss to the atmosphere is mediated through plant transpiration (Jasechko et al., 2013). Consequently, it is assumed that plants will experience drought stress more frequently, which may constrain primary productivity as ~~the latter~~it is substantially controlled by the supply of water (Knapp et al., 2008). These direct effects of limited water provision to the system will be accompanied by increased water demand in a warmer world, leading to more negative water balances, which will accentuate drought effects on vegetation processes (Heimann and Reichstein, 2008). However, structure and functionality of the ecosystems - defining rates of evapotranspiration - are also subject to local climatic conditions. Hence, a direct feedback mechanism is established, which might amplify or dampen the global and local consequences of climatic change on ecosystems (Heimann and Reichstein, 2008).

Defining productivity-precipitation relationships of ecosystems is of ~~focused~~main interest, because ~~structural~~functional changes in soil-plant-atmosphere interface, which control water fluxes into the atmosphere, will inherently be affected by the manifestation of that relationship. However, beyond the direct implications of limited water availability on biomass production and growth, ~~the composition~~indirect mechanisms define this relationship. The abundance of individual plant species in the community and resulting functional structure of that community will adjust, optimising water use according to different life-history strategies by competitive

84   interactions (Peñuelas et al., 2004). In turn, immediate vegetation responses to

85   fluctuations in precipitation patterns and the strength of interaction with productivity

86   functions will strongly depend on the functional composition of the community and

87   ecosystem considered. Therefore, intrinsic characteristics of vegetation will impose

88   another layer of complexity for defining the interactive feedbacks in the relationship

89   between water budget and productivity.

90   The impact of shifting precipitation regimes can only be predicted ~~only~~

91   inaccurately if the crucial components of the ecosystem water budget - soils, plants

92   and the atmosphere - are evaluated separately and isolated. Due to the complex

93   interactions and processes at different spatio-temporal scales the response of

94   ecosystems to shifts in the water regime are preferably examined in an integrative

95   manner on the system level (Silva, 2015). Manipulative experiments are a well suited

96   option for investigating the effects imposed by changes in precipitation frequency

97   and intensity below and above the natural range on the ecosystem level (Estiarte et

98   al., 2016). Since we currently lack knowledge needed to validate the projections for

99   consequences of future changes in rainfall regimes, insights from such integrative

100   investigations are highly valuable for providing important benchmarks of model

101   based assessments (Estiarte et al., 2016).

102   Numerous studies were performed to reveal the ~~response~~responses of

103   temperate grasslands to climatic changes and ~~extremes, while only few~~ droughts

104   (Poorter et al. 2012, Reichstein et al. 2013). While investigations on responses of

105   above- and belowground carbon fluxes targeted Alpine systems (Bahn et al.

106   2009, Hasibeder et al. 2015, Ingrisch et al. 2017), only few studies addressed

107   components of the ecosystem water budget (De Boeck et al., 2016). While the Alps

108   did not often experience droughts during the past (van der Schrier et al., 2007), the

109   region has undergone exceptionally fast climatic changes during the late 19th through

110   early 21st century (Auer et al., 2007; Beniston, 2005; Böhm et al., 2001; Ciccarelli et

111   al., 2008; Rebetez and Reinhard, 2008). Water availability, especially in the light of

112   future climatic changes in European Alps in the next 100 years (IPCC, 2007), is

113   already seen as a limited and valuable resource with the potential of socio-

114   economical conflicts. Therefore, the importance of agricultural management with a

115   potentially higher water demand as a consequence of sprinkling becomes evident.

116   Considering the fundamental role Alpine systems have to water accumulation and

117   freshwater supply for large parts of Europe (Messerli et al., 2004; Viviroli et al., 2003)

it seems surprising that the responses of ecosystems in the Alps to changes in precipitation have not drawn more scientific attention. However, while projections suggest only moderate variations of yearly average rainfall in the Alps, significant alterations within the temporal occurrence of rainfall events with a decrease in summer precipitation and increases from winter through spring are implied (Beniston, 2012; Beniston et al., 2007). The decrease of water supply during warmer summer months will potentially increase the frequency and intensity of drought events in the near and longer future in Alpine ecosystems (Gobiet et al., 2014).

For unravelling ecosystem water fluxes at the soil-plant-atmosphere interface, the lysimeter methodology provides the precise and realistic means ~~by allowing~~. They also allow to decompose the driving sub-processes: evapotranspiration (ET), precipitation (P) and drainage below the rooting zone (Peters et al., 2014). Even quantifying interception would be possible by comparing the increase of lysimeter weight and soil water content during precipitation. This was however not a focus of this experiment as interception is estimated to account for less than 10% of rainfall during the growing season based on Wohlfahrt et al. (2006). By avoiding systematic errors prone to traditional measurement systems, the determination of the net water balance is highly accurate and robust (Schrader et al., 2013). If embedded into a surrounding ecosystem, automated lysimeter units, which do not need access to perform manual weighing, measure water fluxes with a minimum of disturbance to the natural boundary layer and microclimatic conditions. Such implementations of autonomous weighable high precision lysimeters provide unprecedented realism to the description of ecosystem water balances, especially when filling of the lysimeters was performed to maintain natural soil layering and the connectivity of pores, while keeping potential impacts on the vegetation community low. Over the recent years, several of these units have been established over Europe, e.g. a network of 126 lysimeters at 12 sites has been established to monitor climate ~~chance~~change induced alterations in hydrological cycling within the TERENO project in Germany (Bogena et al., 2006; Zacharias et al., 2011). However, the large dimensions (1m diameter/ volume) and the corresponding economic efforts for their establishment did mostly eliminate the possibility for replicated manipulative experiments employing fully integrated lysimeters.

In a common garden experiment we used a network of automated small scale lysimeters to emerge community specific differences in the temporal dynamics of soil

water depletion and evapotranspiration. Two different Alpine grassland communities were subjected to contrasting levels of water availability. Sheltered from natural precipitation, soil water content was manipulated by applying two distinct irrigation regimes: one providing water in regular intervals and another exposing the corresponding experimental units to extended periods of drought. ~~The natural variability in the~~ Changing atmospheric demand of water vapour driven by the natural variability of air temperature and humidity coupled to the manipulated water availability in the soil allowed to investigate and reveal vegetation specific conductance properties and water utilisation patterns. For this study we hypothesize that the vegetation adapted to local, humid conditions and characterized by high biomass and a water spending strategy will keep transpiration rates high while soil water availability is decreasing until a sudden decline near wilting point. As a consequence it will also continue to produce biomass until the break point. In contrary, the water saving strategy of the drought-adapted vegetation will lead to a continuous decrease of transpiration and biomass production with decreasing soil water availability.

 MATERIAL & METHODS

168 *Characteristics of the experimental field site and lysimeter installation*

169 The study site of the experiment was established during early summer 2014 in
170 the LTER-Austria site 'Stubai' (valley bottom meadow) Neustift im Stubaital (A). The
171 site for the garden-experiment was located on the valley floor at 972 m a.s.l.
172 (WGS84: N47.115833, E11.320556) in a meadow used for hay production.

173 Table 1 Summary of site conditions and vegetation properties

site	Stubai (S) – study site location			Matsch/Mazia (M) – transplant origin		
municipality	Neustift im Stubaital, Wipptal/Austria			Mals/Malles, Vinschgau/Italy		
elevation/ altitude (m a.s.l.)	970			1570		
longitude/ latitude	47°07'05"N 11°19'17"E			46°41'19"N 10°34'42"E		
average temperature (°C)	6.5			6.6		
average precipitation (mm)	1097.0			526.7		
growing season length (no of days with average temperature of at least 5 °C)	224			190		
land-use	hay meadow/ 3cuts per yr/ fertilized with cow dung			hay meadow/ 2cuts per yr/ fertilized with cow dung		
soil type	gleyed ~~Camisol~~Cambisol (A-Bv-Go)			~~Camisol~~Cambisol (Ah-Bv-C)		
soil classification	loamy sand to sandy silt			loam to sandy loam		
soil physical parameters in different soil depth						
	0.05 m	0.15 m	0.25 m	0.05 m	0.15 m	0.25 m
soil texture (%)						
sand	31	31	34	25	34	40
silt	58	63	61	43	45	43
clay	11	6	6	32	21	17
soil organic matter content (%)	3.6	1.3	0.7	7.4	3.9	2.3
plant available water (vol%)	32	39	39	34	33	27
phytosociological classification	Poo trivialis - Alopecuretum pratensis (Regel 1925)			Ranunculo bulbosi-Arrhenatherum (Ellmauer)		
species inventory	*Achillea millefolium, Carum carvi,*			*Achillea millefolium, Anthoxanthum*		

(responsible for 90% of total plant cover in the lysimeter)	*Pimpinella major, Poa trivialis, Ranunculus acris, Rumex acetosa, Taraxacum officinale, Trifolium pratense*			*odoratum, Anthriscus sylvestris, Carum carvi, Festuca rubra, Leontodon hispidus, Lotus corniculatus, Poa trivialis, Primula veris, Taraxacum officinale, Trifolium montanum, Trifolium pratense, Veronica officinalis*		
abundance of functional groups (%, mean ± s.d.)	graminoids	forbs	legumes	graminoids	forbs	legumes
	14.2 ± 5.5	67.8 ± 10.2	14.1 ± 9.0	49.2 ± 25.1	28.3 ± 20.1	18.8 ± 17.9

174

175   For this experiment six plots of 3.5 × 3.5 m were established. Traversing the
176 corresponding area, each plot was defined by installing half-cylindrical metal frames.
177 In the centre of each plot these frames providing the base for the rain sheltering
178 reached a height of approx. 2.5 m. In each corner at the outer plot margin four
179 irrigation sprinklers pointing towards the centre of the plot were set up. The irrigation
180 system described in detail by (Newesely et al., 2015) was used to simulate
181 precipitation during periods of experimental manipulation of water provision to the
182 system.

183   In the centre of each plot two small-scale lysimeters with 0.3 m diameter and
184 0.3 m depth were installed in collaboration with, and supervised by the employees of
185 the manufacturer (Smart-Field-Lysimeter, UMS/Meter Group Munich, Germany).
186 Every lysimeter was filled with a soil-vegetation monolith by cutting the hollow
187 cylindrical lysimeter blank into an undisturbed patch of the corresponding ecosystem.
188 This compression free procedure allowed to remain the original and unaffected
189 stratification of the soil and to conserve the natural composition of pore spaces within
190 the monolith. The filled lysimeter blanks were subsequently excavated and cut
191 horizontally at a depth of 0.3m. With 90 % of root biomass distributed above 0.2 m in
192 both investigated vegetation types, a lysimeter depth of 0.3 m was assumed to be
193 sufficient. The bottom of the lysimeter was closed with a tension controlled hydraulic
194 boundary connected to a bi-directional pumping system to regulate water flow into
195 and out of the lysimeter. After inserting soil moisture, temperature (EC-5 Small Soil
196 Moisture Sensor, Decagon Devices, USA) and matrix potential probes (MPS-2,
197 Decagon Devices, USA) at 0.05, 0.15 and 0.25m depth into the lysimeter monolith,
198 each system was placed on a weighing platform (accuracy of 0.005 kg, PL-50,
199 UMS/Meter Group Munich, Germany). Two of these lysimeter units were installed in

the centre of every experimental plot within a two by two ~~quadratic~~squared grid of 1.2m edge length with their relative position to each other assigned randomly.

The two monoliths in every plot were excavated from different types of vegetation, one containing a mesocosm of the meadow surrounding the experimental field site (S, Table 1), and another one which was excavated and transplanted from a meadow in Matsch/Mazia with contrasting environmental and biotic properties to those of the study site (M, Table 1). The Stubai grassland is classified as Poo trivialis - Alopecuretum pratensis with a community of low complexity: abundant Poaceae accompanied by some herb species (Wohlfahrt et al., 2008). The meadow is actively managed, cut two to three times each year and fertilized with cow manure in spring and autumn (approximately 0.35 kg dry matter per m², Table 1). The local climate is dominated by high total precipitation values, especially in the summer. The vegetation of second origin (Matsch/Mazia) is characterised by the traditional, more extensive use of the corresponding system. The Matsch Valley has a dry inneralpine climate with a mean precipitation of 527 mm per year and a mean temperature of 6.6 °C (Hydrographical Department of the Autonomous Province of Bozen-South Tyrol). The vegetation is a dry hay meadow (Ranunculo bulbosi - Arrhenatherum, Ellmauer) on loam to sandy loam. The site is fertilized with cow dung and cut two times each year. The excavation location of the replicate lysimeters was optimized according to the presence of representative and joint species in the respective vegetation patches. After installing the local and transplanted lysimeter mesocosms during early summer 2014 into the experimental plots, the vegetation surrounding the lysimeters ~~could~~was allowed to recover from disturbances of necessary soil works required to wire the fully automated measuring system until spring 2015.This extensive recovery period of more than 8 months including the winter season and the initial growth phase until the first harvest in the actual measuring year should provide a sufficient acclimatisation and regeneration of both vegetation and soil in the lysimeters and prevent a bias between vegetation types.

At the field site, all experimental plots and the vegetation in the lysimeters was managed (cut, fertilized) concurrently to land-use scheme of the surrounding meadow. The experimental period started in the last third of June 2015 during the re-growth interval after the first cut at the beginning of June. With beginning of the

experiment on June 10th 2015 rain shelters were closed using a UV permeable transparent polythene film (Lumisol Clear AF, 88% - 92% light transmittance). In order to avoid shielding of the wind and to allow the establishment of natural boundary conditions, Air temperature (on average 0.26 K higher in the shelter) and humidity (+0.11 %) were hardly affected by the shelters while radiation was reduced by 25% and wind speed by 50% even though shelters were left open on the sides facing the main wind direction and closed down to just 0.5 m above the soil level on the lateral sides. Over a period to minimize shielding of 52 days the plots of the experiment were subjected to control watering within the two different irrigation schemes (Fig. 1). wind. Concurrently with closing of the rain shelters (10/06) precipitation was provided from the irrigation sprinklers mimicking average rain fall amounts and intensities for the 30 year period between 1970 through 2000 in the treatment with regular watering. However, due to a mistake by the technician responsible for setting up the automated irrigation protocol. Over a period of 52 days (20/06-10/08) the plots of the experiment were subjected to control watering within the two different irrigation schemes (Fig. 1), one providing water on a regular basis (REG) and one with extended drought periods (D). However, due to technical problems the watering scheme stayed below the intended amounts for approximately the first half of the experimental period making manual compensation occasionally necessary. (starting on 15/07). Automated irrigation was programed to occur around mid-night in order to avoid immediate transpiration from the surface and allow the provided water to penetrate into the soil compartment. Manual adjustments and checks on the precipitation simulator were usually performed during day-time. The lysimeter mesocosms in the treatments with regular watering (REG) received approx. 117 kg_{H2O} per m², those in the treatments with extended drought periods an average of 65 kg_{H2O} per m² throughout the duration of the experiment and according to the scheme presented in Fig. 1.

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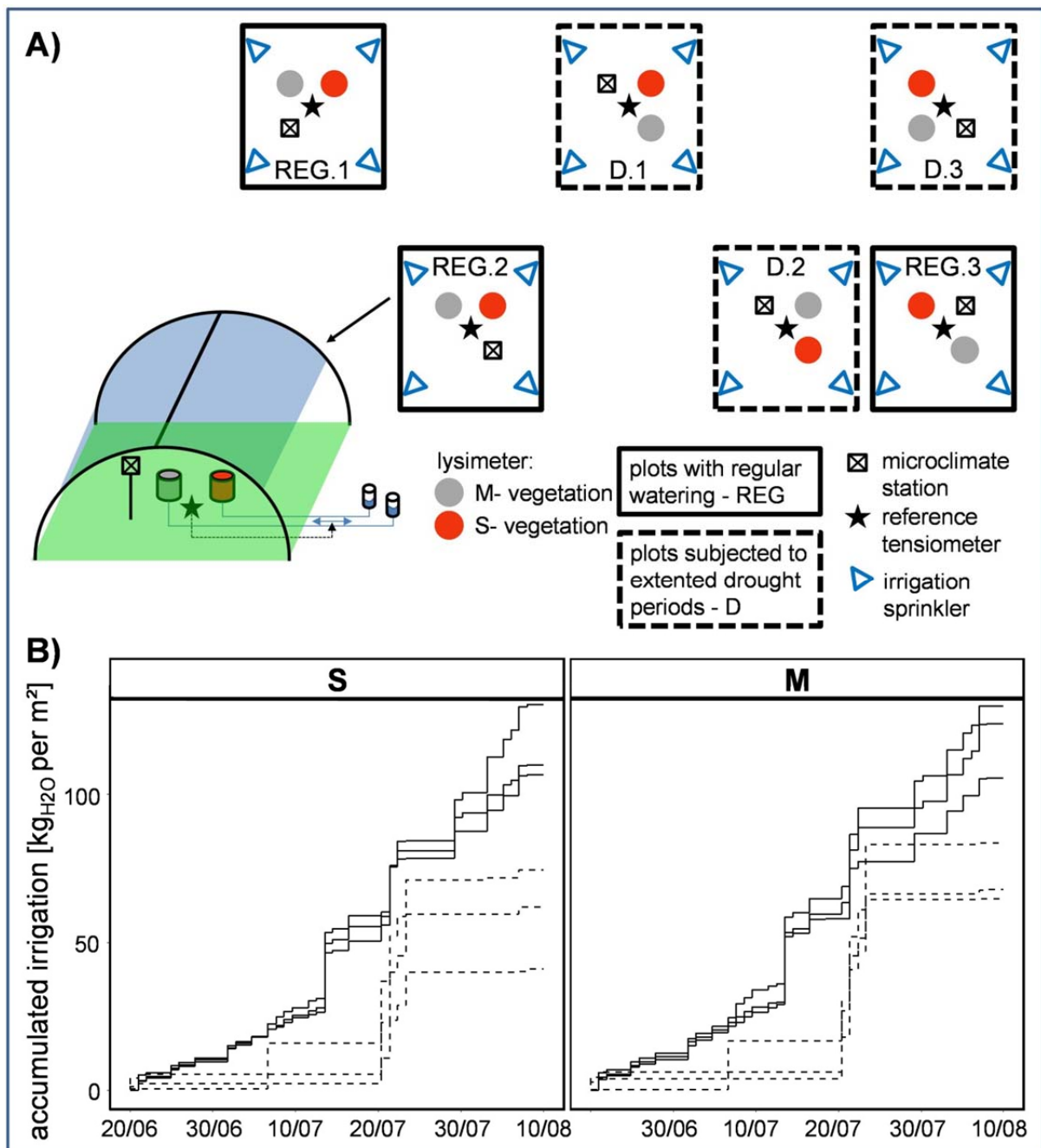


Fig 1: A) Schematic overview of the experimental design and plot setup; B) Manipulation of water availability for individual lysimeters of the two vegetation types (Stubai (S) & Matsch/Mazia (M)) by contrasting irrigation schemes - one providing water on a regular basis (REG, solid lines), one with extended drought periods (D, dashed lines)

Automated measurements

In the centre of each of the six plots a microclimate station measuring air temperature and relative humidity (height: 1m; U23-002 HOBO® External Temperature/Relative Humidity Data Logger, Onset Computer Corporation, USA), solar radiation (height: 1m; S-LIB-M003, Solar Radiation Sensor, Onset Computer Corporation, USA), wind speed (height: 1 m; DAVIS® Standard Anemometer 7911, Davis Instruments, USA) and soil water content 0.05 and 0.2m below the ground (S-SMA-M005, Soil Moisture Smart Sensor – 0.2 m ECH2O® probes, Decagon, USA) was installed. The corresponding measurements were logged for every ten minutes interval (HOBO Microstation® Data Logger; Onset Computer Corporation, USA).

For each of the lysimeter, weight data were recorded every minute, data received from matric potential, soil temperature and water content sensors (each in 0.05, 0.15 and 0.25 m depth) in ten minutes intervals. The hydraulic boundary at the bottom of each lysimeter was connected to a reservoir of drainage water with the corresponding container also being placed on a balance. A bi-directional pumping system allowed the adjustment of the water content at the lower boundary of the lysimeter by transferring water either from the drainage container into the lysimeter or the contrary direction. This implementation allowed to adjust the water levels at bottom of the lysimeter according to a reference matric potential measured at the same depth in the natural unaffected soil column of the respective experimental plots.

Manual measurements of biomass development

~~Since variation in total~~Variability of water flux from vegetation canopies to the atmosphere ~~is~~has two components: a~~ product of~~) the variation in standing biomass and b) the water vapour release activity per unit biomass. Therefore, decomposing and addressing these two factors independently is advisable, especially ~~in replicated experiments or~~ when functionally different communities with ~~different biomass progression rates~~differing biomasses are being compared~~ over longer periods~~. However, non-destructive biomass estimation of complex stands in the field can be challenging with respect to desired accuracy. In order to generate robust estimates different methodologies were combined in the current experiment. Measurements of maximum and average canopy height (Machado et al., 2002) were supplemented with a pin point procedure (Jonasson, 1988) and measurements of projected area (Lati et al., 2013) for ~~the~~biomass estimation ~~of biomass present~~ in the lysimeters. For

301 measuring pin contacts a thin metal rod was lowered through a plate placed above
302 down to the lysimeter. Pin measurements were replicated in seven (out of 21)
303 randomly assigned positions for each lysimeter and point in time. Pin contacts were
304 referenced within three height classes (0-20, 20-40, 40+ cm above the ground) and
305 by functional group identity of the plants. For the determination of projected area of
306 the lysimeter canopies the methodology proposed by Tackenberg (2007) was
307 adapted. Digital images of the lysimeter stands in front of a white half-cylindrical
308 background were scaled according to a size standard in each picture, converted to a
309 black-white colour scheme, before black pixels were enumerated. On average,
310 biomass of the lysimeters was estimated for every third day through the period of the
311 experiment. The different methods for non-destructive biomass estimation were
312 calibrated against weighted biomass at the harvests prior and subsequent to the
313 experiment. (10/06 and 10/08). Based on these calibrations the biomass
314 development in the lysimeters was predicted throughout the experimental period.

315

316 *Data processing and statistics*

317 To calculate the water mass fluxes at the soil-vegetation-atmosphere interface
318 of the upper lysimeter boundary, weight differentials of the drainage reservoir and
319 the lysimeters were summarized and subsequently cleared for spikes and signals of
320 implausible strength (Schrader et al., 2013). The latter was necessary because the
321 sensitive weighing elements are susceptible to environmental noise or accidental
322 interference by other experimental proceedings (e.g. biomass estimation), while
323 providing a high accuracy and temporal resolution. The combined weight signal was
324 separated into irrigation induced weight gain of the lysimeter units and weight loss
325 caused by evapotranspiration from the upper lysimeter boundary based on the recorded
326 activity times of the precipitation simulator.. Subsequently, daily totals were calculated for
327 both mass differentials.
328 A soil-specific calibration of the soil moisture and the MPS-2 sensors sensor is a
329 necessary prerequisite for a sensor to achieve its highest degree of absolute accuracy
330 in soil water content (SWC) measurements. A substrate moisture retention curve (pF
331 vs. volumetric water content) and the hydraulic conductivity as a function of pF
332 (log10 of the matric potential) were determined for both types of soil-vegetation

monoliths (M, S). The soil hydraulic parameters were determined in the laboratory, using the method of (Schindler, 1980) with the HYPROP system (UMS/Meter Group Munich, Germany). Using the soil specific moisture retention curve, absolute SWC was corrected based on soil matrix potential data. To summarize the time course of water availability in the soil of each lysimeter unit, the average values of SWC of both layers between 0.05 - 0.15m and 0.15 – 0.25m were integrated and summarized on a daily basis.

The evaporative demand of the atmosphere is expressed by the reference crop evapotranspiration (ET_0). It represents the evapotranspiration from a standardized vegetated surface and was calculated in this study after the FAO Penman-Monteith standard method (Allen et al., 1998). ET_0 integrates the most important atmospheric components (solar radiation, temperature, VPD and wind velocity) defining the atmospheric water demand. Daily averages were used as a summed up explanatory parameter to capture the atmospheric draw of water vapour from the lysimeter vegetation for further analysis.

Non-destructive estimates for the standing biomass in the lysimeters were calibrated at the harvests before and after the experimental period. Nine different regression models were generated for the different estimation techniques individually and in combinations ~~(appendix 1).~~. Based on the prediction of these models biomass was estimated for every measurement (total of 16) during the experiment. ~~Generating~~The biomass development in the different lysimeters followed a non-linear trajectory. To generate a consensus time-course ~~for~~describing the ~~biomass development~~growth progression in every lysimeter, a general additive mixed model smoother was fitted for each unit (gamm-function in the mgcv-package, R Development Core Team, 2015) with the different prediction methodologies defining random (observer) - effects. ~~In order to generate a more conservative pattern, the~~The flexibility of the time course defined with these smoothers was constrained by allowing a maximum of five knots for these smoothers. Granting an approximate average of three measurement points per knot (16 to 5) successive sampling points were capable to change the trend of biomass progression while implausible fluctuation were prevented. Based on these models, standing biomass was predicted on a dry weight basis for every lysimeter entity and each day of the experiment.

~~All statistical analysis presented here were performed using the R statistical programming language~~(R Development Core Team, 2015). For the evaluation of evapotranspiration

responses mixed effects models were fitted using the *nlme*-package. ~~These~~ (Pinheiro et al., 2017). All these models included the identity of the different vegetation types (categorical) in full factorial combination with additional covariates defining the fixed part of the model~~.~~ as detailed below. To reveal the drivers of variation in daily ET rates and separate the effects of ~~variability~~variation in biomass (DW –dry weight) and evapotranspiration rates per unit biomass (ET/DW) among the different monoliths, a log-log-scaling method was applied on the formula ET = ET/DW $\times$ DW based on the methodology provided by (Renton and Poorter, 2011). This procedure allows decomposing the importance of different factors of sources in the variation of a synergistically (multiplicative) defined trait and is not meant to establish a statistical relationship between independent parameters. For summarizing the time courses of SWC and ET_0 the day of the experiment and the two irrigation schemes were considered as additional categorical variates. For modelling the response surface of ET along the two dimensions of ET_0 and SWC, the latter two and all possible interactions with vegetation type were defined as continuous covariates for the fixed part of the model. However, all models included a random intercept for the experimental plot in which the data were collected. Nested within the random effect for the plot, the lysimeter identity was included as another random effect to fully represent the dependence structure in the hierarchical design of the experiment. ~~Were~~Where they were found to significantly improve the model fit, lysimeter specific response to continuous covariates in the fixed part were included as random slopes~~.~~ (see Table 2). Further, to account for autocorrelative errors according to the time-series origin of the data, a continuous autocorrelation structure (corCAR1 in *nlme*-package) was defined by the day of the experiment. All statistical analysis presented here were performed using the R statistical programming language (R Development Core Team, 2015).

RESULTS

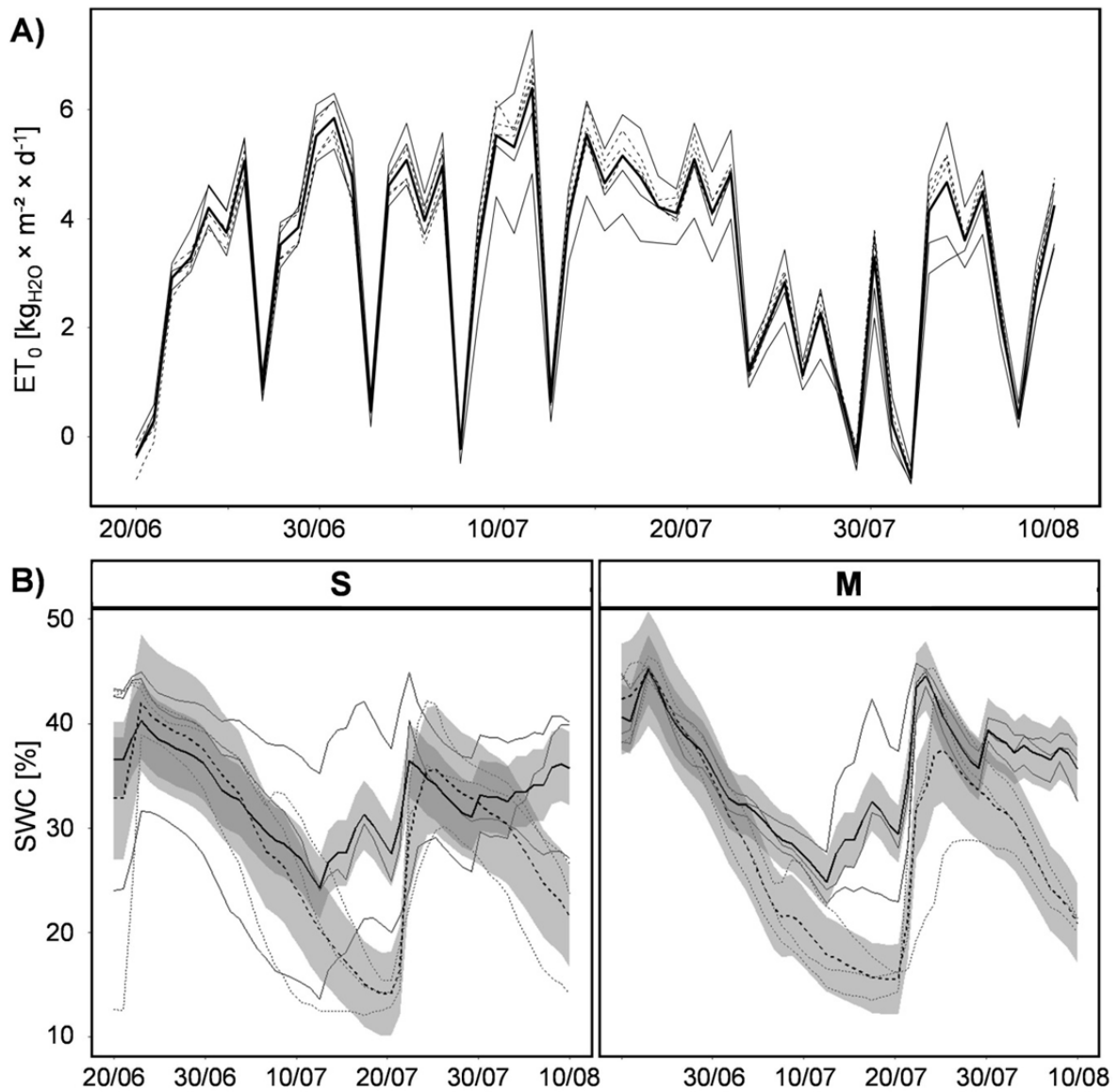
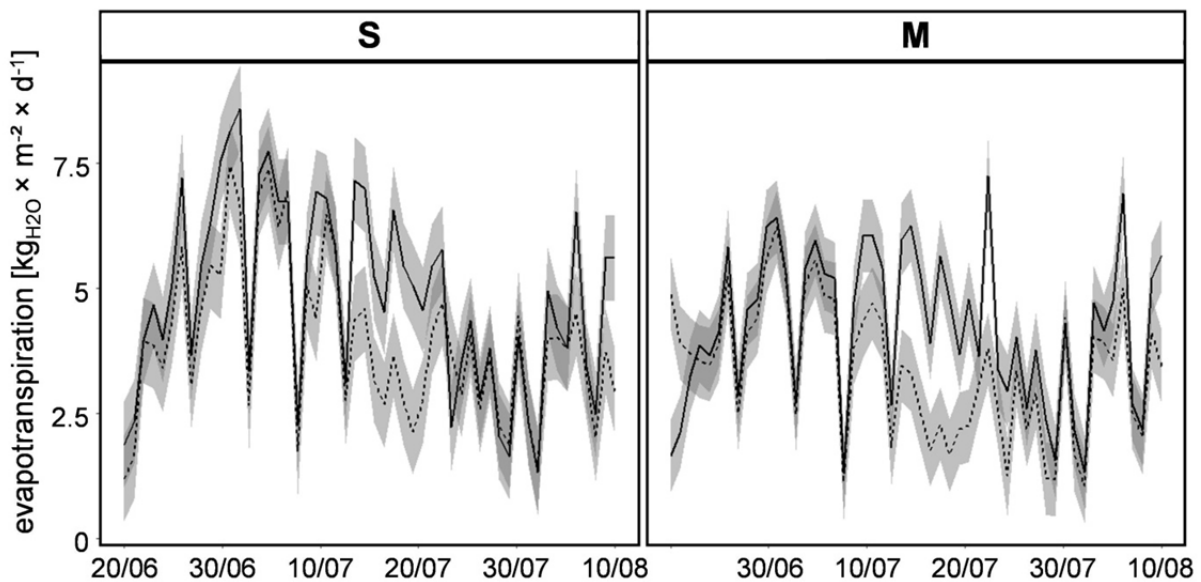



Fig 2: Atmospheric demand (ET_0) and soil water content (SWC) as drivers of ET, A) dynamics of daily average ET_0 over the course of the experiment (bold line: all plot average, thin lines: individual plots); B) dynamics of daily average SWC for two vegetation types (S & M, see Table 1) in contrasting irrigation schemes (REG - solid lines, D - dashed lines; bold lines: treatment average; shaded area: standard deviation, thin lines: individual plots); S: Stubai, M: Matsch/Mazia.

402 *The drivers of ET:* The average air temperature during the course of the experiment was
403 17.5 °C (± 3.1°C – standard deviation). Among the different plots no systematic
404 variation of temperature, relative humidity and solar radiation was measured by the
405 microclimate stations underneath the shelters. Summarizing the different
406 atmospheric components defining rates of ET, ET_0 was calculated. During the
407 duration of experiment the average daily ET_0 was 3.26 kg_{H2O} m^{-2} d^{-1} (± 1.95 SD) with
408 a minimum at 0.75 and a maximum of 6.4 kg_{H2O} m^{-2} d^{-1}. However, since ET_0 is
409 subject to short-term natural variation of the underlying environmental parameters,
410 fluctuations between consecutive days were found to be very pronounced and no
411 temporal trend was revealed over the period of the experiment (Fig. 2).

412
413 Fig 3: Dynamics of daily average ET over the course of the experiment for two
414 different vegetation types (S & M, Table 1) subjected to contrasting irrigation regimes
415 (REG - solid lines, D - dashed lines; shaded area – standard deviation); S: Stubai, M:
416 Matsch/Mazia.

417

418   During the time of the experiment the two contrasting irrigation schemes led to
419 distinct SWC dynamics within the respective mesocosms (Fig. 2). Since SWC in all
420 lysimeters was high at the beginning of the experiment the value initially decreased
421 in all plots irrespective of treatment indicating that the water irrigated on plots with
422 regular irrigation did not fully compensate the loss of water by ET of the
423 corresponding communities. The first clear effects of ~~differential~~different irrigation

became ~~only~~ apparent in the lysimeters with the M-type of vegetation only after applying approximately two weeks of drought. ~~Variation in SWC of~~ In the lysimeters ~~belonging to~~with the S-type of vegetation the variability of SWC was ~~rather strong and it took those units longer to manifest~~far stronger, a distinct ~~effects of the different~~ difference between watering schemes could be observed there only after the start of additional manual watering. After approximately one month, SWC in both vegetation types revealed clear effects of the contrasting irrigation strategies. At that time, SWC of both treatments was restored to similar values observed during the initial stages of the experimental period in order to avoid distress in the drier mesocosms. Rates of daily ET from the lysimeters were varying very strongly through the period of the experiment and did not reveal a general temporal trend (Fig. 3). ~~The~~As the canopy height and biomass of both vegetation types was clearly higher than the reference vegetation assumed for ET_0, the average evapotranspirative water loss for the lysimeter unit during the duration of the experiment ~~was~~also surpassed ET_0 with 4.9 kg_{H20} m^{-2} d^{-1}. Subject to the atmospheric water vapour pressure deficit the recorded fluxes were characterised by a similar unsteadiness as the variability of the underlying environmental parameters would suggest. ~~No consistent differences in daily water flux from~~During the ~~lysimeter mesocosms to the atmosphere could be detected according to the identity~~first third of the ~~community. Also the~~experiment ET of the S-type lysimeters was on average higher than the M-type, afterwards no clear difference between vegetation types could be detected.. A clear difference of ET between contrasting irrigation regimes ~~did not impose a overall difference in the rates of ET within the experimental period. However,~~was only found during periods of strong divergence of SWC among the two ~~irrigation~~ treatments~~, daily ET was lower for entities subjected~~ (approx. 15/07 to 25/07) during the rest of the experimental period ET on the drought regime was only slightly lower than in the regular one.

450

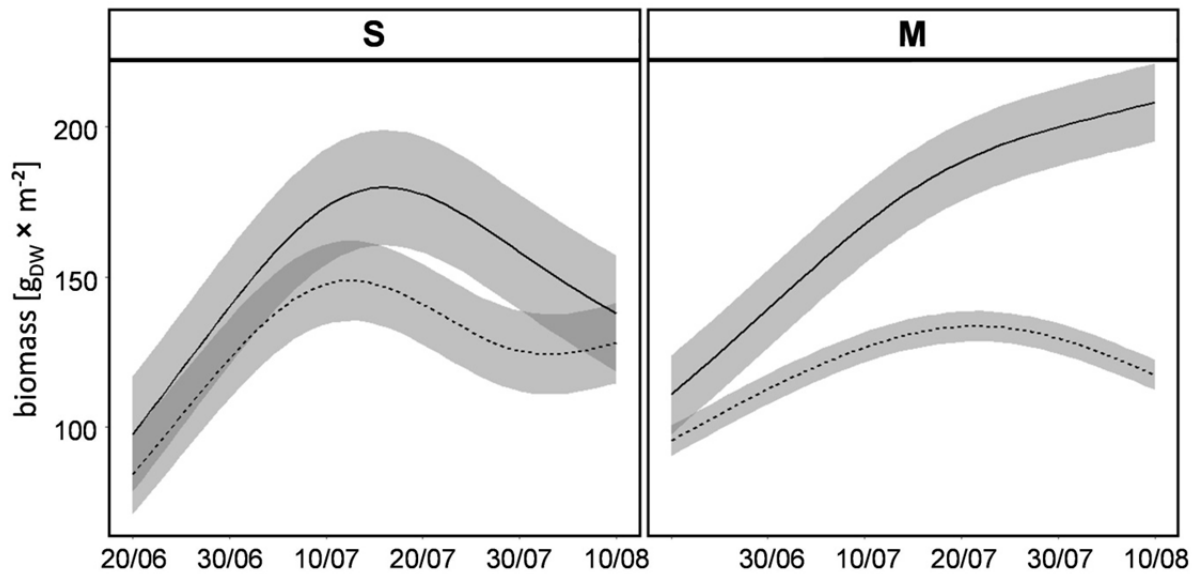



Fig 4: ~~Trajectories~~Predictions of biomass development for the two vegetation types (S: Stubai, M: Matsch/Mazia, Table 1) subjected to contrasting irrigation regimes (REG - solid lines, D - dashed lines; shaded area – standard deviation) throughout the duration of the experiment based on non-destructive measurements

The prediction of biomass development combined from the different non-invasive estimation methods suggested distinct growth trajectories for the two vegetation types in interaction with the two irrigation regimes. The mesocosms with communities belonging to the local S-type revealed larger biomass ~~differentials~~increment during early stages of the experiment irrespective of the applied irrigation regime. However, with increasing duration of the experiment, growth dynamics started diverging in treatments with contrasting water provision, with biomass differences peaking at the mid-time of the experimental period. After that peak, the prediction of dry weight suggested a decline in standing biomass for both water regimes in the S-communities. Towards the end of the experiment, biomasses of communities in the different water treatments converged to similar values. This pattern of vegetation development indicates that the early irrigation rates of the REG treatment were indeed too low and the manual compensation came too late for a regular development of the vegetation. Thus, also the S-type lysimeters subjected to the REG-treatment suffered a drought related early peak of biomass and subsequent senescence with just a short delay to the D-treatment. A different pattern of biomass

472 development was detected for the transplanted mesocosms (M). From the beginning

473 of the experiment growth processes of the different irrigation treatments yielded

474 distinct trajectories. In the treatment experiencing regular water provision the

475 biomass gain per unit time was stronger than in the mesocosms being subjected to

476 irregular watering. That pattern was consistent throughout the experiment, with a

477 strictly monotonic increase of standing biomass in the M communities of well-

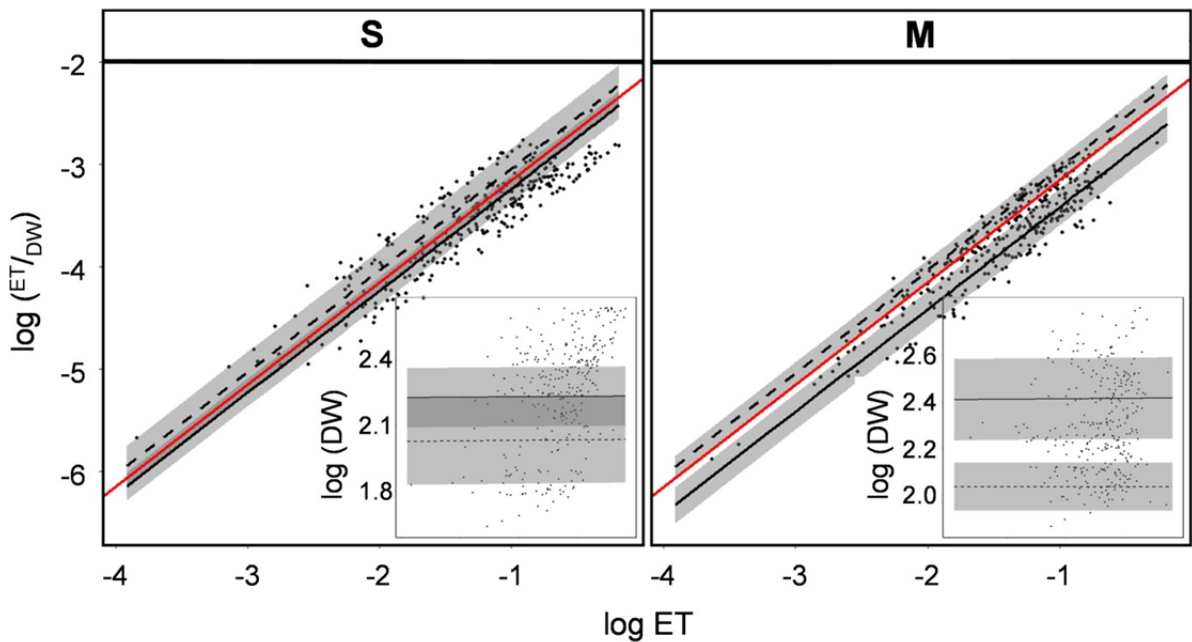
478 watered plots. In contrast, the vegetation of the M-type in the plots with restricted

479 watering growth started stagnating during the second half of the experimental period.

480 Unlike the S-type, at the end of the investigation period, biomasses in the M-type

481 communities were clearly distinct according to the different watering regimes, with

482 the standing mass in the regularly watered plots approximating double the amount

483 compared to the treatment with restricted water provision.

484

485 Fig 5: Log-log scaling for the two factors defining variability of ET: ET rates per unit

486 dry weight (ET/DW) and standing biomass (=dry weight, DW) for the two different

487 vegetation types (S & M, Table 1) subjected to contrasting irrigation regimes (REG -

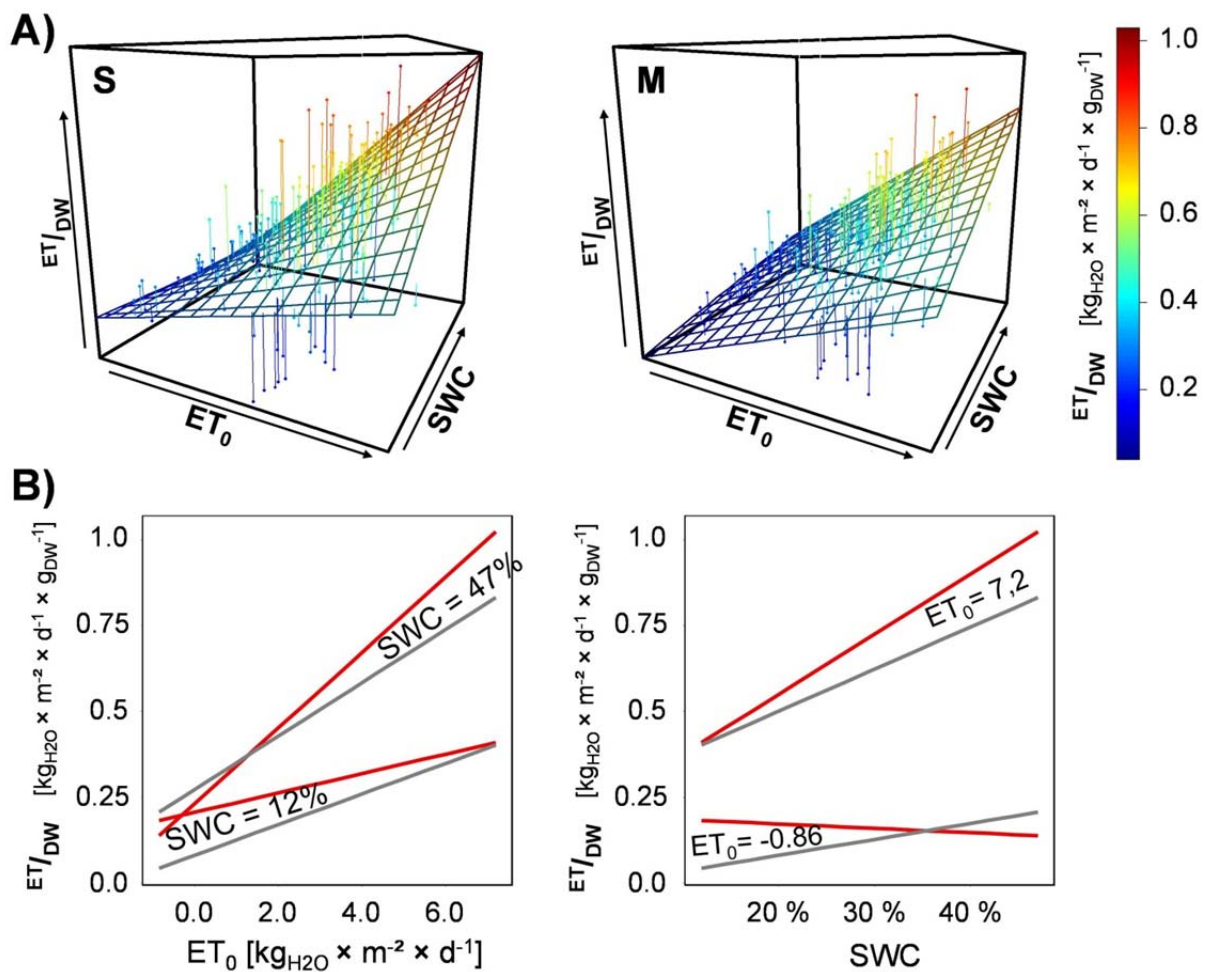
488 solid lines, D - dashed lines; shaded area – standard deviation), red line indicates a

489 reference function with the slope of 1. X-axes of the sub-plots have the same limits

490 and units as the corresponding main plots.

491

492   Variability of ET is subject to variation in evapotranspiration rates per unit
493   biomass (ET/DW) and the variation in the standing biomass. Hence, when
494   comparing rates of ET differentiating both underlying components will provide deeper
495   insights on how the vegetation interface of different communities mediates the water
496   flux from the soil. A strong positive correlation of total daily ET and ET/DW was
497   found (Fig 5). The log-log-scaling of ET/DW with ET revealed a slope of 0.998
498   arguing that variation in ET rates measured during the course of this experiment is
499   almost exclusively defined by the variation in ET rates per unit biomass (100% = 1).
500   This relationship was independent of vegetation type and irrigation scheme. ~~The effect~~
501   ~~of biomass variation on the variance of total rates of ET however did have a very small and~~
502   ~~insignificant effect. For the local communities (S) the more biomass to be found in the lysimeter~~
503   ~~mesocosms the bigger was the total daily water flux to the atmosphere, while the transplanted~~
504   ~~communities revealed a different pattern. For M-type communities the amount of biomass in the~~
505   ~~lysimeters had no strong effect on the rates of total ET.~~However, variations of biomass did not
506   have an effect on the variability of total ET rates (Fig. 5).

507

508   Fig 6 A) 3D plots: response surface of ET per unit DW (ET/DW) along the two-
509   dimensional variation of ET_0 and SWC for the two different vegetation types (S:
510   Stubai, M: Matsch/Mazia, Table 1); B) projections of ET/DW response along ET_0 and
511   SWC at maximum/minimum value of the particular other (red: S-communities, grey:
512   M-communities)

513   After revealing ET/DW as the most important driver in defining variation in the
514   rates of total ET from the lysimeter mesocosms, the effect of combined variation in
515   ET_0 and SWC on rates of ET per unit biomass was modelled in dependence of the
516   vegetation type (ET/DW = f(ET_0×SWC×vegetation type)). ~~The~~On the entire field site,
517   on average ~~the~~ daily sums of ET_0 ranged from -0.75 to a maximum of 6.4 kg_{H2O} m^{-2}
518   d^{-1}, while ~~the~~within the individual plots daily average values ranged from -0,86 to 7,2
519   of 6.4 kg_{H2O} m^{-2}. The averaged SWC realized during the duration of the experiment
520   covered a range from approximately 12-47% (Fig. 5). Both, ET_0 and SWC had a
521   highly significant and positive effect on achieved rates of ET/DW (Fig. 6, Table 2).
522   However, as implied by a significant synergistic interaction of ET_0 and SWC, rates of
523   ET/DW increased stronger if SWC and ET_0 increased concurrently than the
524   individual gradients of either would imply (Fig 6.). With increasing ET_0 the response
525   of ~~EVT~~ET/DW was stronger the higher SWC was. However, there was a significant
526   difference how both vegetation types responded within the landscape of
527   environmental drivers defining ET/DW (Table 2). The local (S) vegetation had higher
528   rates of ET/DW - when both ET_0 and SWC were low - than the transplanted
529   vegetation type (M), suggesting a higher base rate of ET/DW. On the low end of
530   investigated SWC the M-vegetation had a stronger response to ET_0 than the local S-
531   vegetation. Despite that stronger response of the transplanted vegetation (M) along
532   the ET_0 gradient at low SWC, the maximum rates of ET/DW converted to similar
533   values due to the higher base flux at low ET_0/ low SWC in the S-vegetation. In turn,
534   under conditions of high soil water availability the ET_0-response of the S-type was
535   much more pronounced than in the M-type. A similar pattern was found comparing
536   the SWC-response of both vegetation types for the range of different ET_0 values
537   realized during the experiment. At low ET_0 the M-type vegetation responded stronger
538   to variations in SWC, while there was almost no response in the S-type. However, at
539   high ET_0 the response of the S-type to increasing SWC was again much more
540   pronounced than in lysimeters with the M-type. Because of the higher rates of

541 ET/DW at low ET_0/SWC and the overall increased response potential of the S-type

542 vegetation, the ET/DW values achieved in the M-communities stayed below those

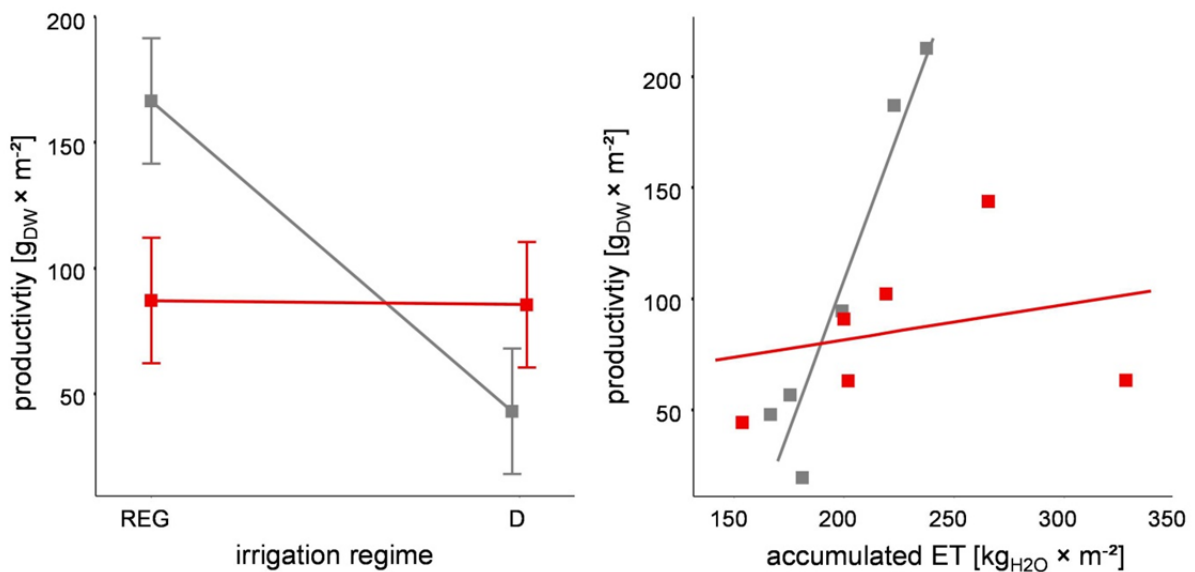
543 found in the local vegetation for almost the entire range of combinations between

544 ET_0 and SWC investigated in this experiment.

545 Table 2 Parameter and parameter interactions affecting the ET_0-SWC landscape of

546 ET

Parameter	F-value	p-value
ET_0	341.31	**<0.001**
SWC	28.09	**<0.001**
vegetation type	2.81	0.154
ET_0 × SWC	37.20	**<0.001**
ET_0 × vegetation type	1.24	0.265
SWC × Vegetation type	2.74	0.098
ET_0 × SWC × Vegetation type	7.08	**0.008**

547

548

549 Fig 7: Productivity of two vegetation types (± standard error, Stubai - red &

550 Matsch/Mazia - grey; Table 1) subjected to contrasting irrigation schemes (Fig 1),

551 right panel: dry matter productivity of two vegetation types (see above) as function of

552 accumulated evapotranspiration over the experimental duration

553   Comparing the productivity of the two vegetation types among the two irrigation

554 treatments revealed a contrasting response for the DW productivity (Fig. 7, left

panel). For the local S-Type the biomass gain over the experimental period did not show a strong dependence on the applied watering regime. ~~The~~Due to the insufficient irrigation mentioned before the productivity of the S-type stayed well below from what would be expected for the vegetation outside the experimental site in both treatments. For the M-communities, however, productivity was on average more than two fold higher in the plots experiencing regular water provision compared to those exposed to extended periods of drought.

Integrated over the entire experimental period, the biomass productivity per unit water usage was significantly higher for the transplanted mesocosms M (Fig 7, right panel). The data suggested a productivity increase of 2.6g_{DW} per kg of water for the M vegetation. In contrast, for the S-type mesocosms the average increase of productivity per 1kg of evapotranspiration was approximately only 0.~~16g.~~16g_{DW} per kg but was strongly influenced by highly variable productivity of the two lysimeters with the highest accumulated ET (Neglecting this one observation, productivity in the S-vegetation was around 0.91g_{DW} per kg of water). This pattern suggests that biomass generation in the M-type vegetation is ~~significantly more~~strongly dependent on ET and therefore water availability~~, while the differences in the slope imply lower~~. For the S-type vegetation the early decrease of biomass in both treatments and the high variability of productivity at high ET made it difficult to assess an integrated trend in water use efficiency ~~of water use with respect to dry weight accumulation in the S mesocosms.~~

575 for the entire experimental period.

576

DISCUSSION

578   It is intuitive to understand, that ET_0 and SWC impose independent and
579 interacting effects on water fluxes from the soil to the atmosphere with one of either
580 constraining the total rates of ecosystem ET (Kim and Verma, 1991; Perez et al.,
581 2006). Beyond the effects of these abiotic drivers, the measurements of the present
582 experiment reveal a community specific signal in the definition of ecosystem water
583 exchange. The community specific configuration of the soil-plant-atmosphere
584 interface is instinctively acknowledged if distinct vegetation types are compared.
585 Water fluxes from the system will to some degree always scale with productivity and
586 total biomass of the vegetation (Zeppel et al., ~~2014and~~2014 and references therein).
587 This ~~context~~relationship will drive variation in ET of contrasting biomes together with
588 environmental parameters affecting the availability ~~of water~~ and the atmospheric
589 ~~deficit~~demand of water.

590   However, results of this experiment reveal that vegetation specific differences
591 have a component, which defines ecosystem water flux beyond the impact of
592 variations in total biomass. Such differences will be important to understand and to
593 consider if communities of the same type need to be evaluated with respect to their
594 particular impact on the hydrological regulation of the ecosystem. The response of
595 water fluxes along co-operating gradients of SWC and ET_0 indicated divergence in
596 the conductance potential of the two alpine grassland communities, which were
597 independent from the biomass present. At low SWC ~~the response~~lower values of
598 ET/DW for the M-type ~~to~~ vegetation indicate a better ability to control water loss in
599 dry conditions event though the difference to the S-type diminishes with increasing
600 ET_0 ~~was much stronger than for the S-type arguing for a higher efficiency to mobilise limited water~~
601 ~~resources from the soil column~~. Conversely, under conditions of high soil water availability
602 water fluxes from the S-type responded much stronger to increases of ET_0
603 suggesting a higher overall conductance potential. Similar implications were
604 revealed along the gradient of soil water availability. SWC variations had almost no
605 effect on the S-type communities when the atmospheric draw was small, while the
606 M-type mesocosm still mediated fluxes to the atmosphere. Under high ET_0 however,

the divergence in the response of ET between S & M-communities to varying SWC suggests that, from starting at similar rates, ET of the S-type ~~became much more efficient to conduct water to the atmosphere~~increased far stronger the less soil water became limiting. These differences between the two vegetation types indicate different strategies in the water utilisation. For the M-type this strategy may be summarized by ~~a high potential to utilize even scarce water resources, a~~overall lower ~~potential to translate atmospheric deficits into higher water conductance with~~ ET rates ~~of ET staying below those measured~~than for the S-type for most environmental scenarios included within the experimental period and a stronger control of transpiration especially at low SWC. ~~.~~ This implies an overall conservative and water saving strategy. For the S-communities, in contrast, which show high water conductance potential with strongly increasing ET rates when environmental conditions become less constraining, an acquisitive strategy is suggested. With high rates even at base level ~~these communities~~this community appear not to be optimized to save water and might experience drought effects earlier and probably stronger, when water availability becomes limiting. There might be some dampening effect ~~as soil hydrological properties indicate a higher amount of plant available water for the S-type. The permanent wilting point (pF 4.2) in the main rooting zone (averaged values for 0.05m, 0.15m, 0.25m soil depth) was at a SWC of 13% (± 8.3 SD) and 17% (± 3.1 SD) for the S-vegetation type and the M-vegetation type, respectively. Whereas field capacity (pF 2.1) was found to be at a SWC of 46% (± 4.4 SD) and 43% (± 6.8%) for the S-vegetation type and the M-vegetation type, respectively. In summary, the plant available water was found to be 33 vol% for the S-type and 26 vol% for the M-type. However, the variation at 0.05m soil depth was very low and even a slightly higher amount of plant available water was found for the M-type (S-type: 28 vol%; M-type: 29 vol%) at this soil depth.~~of soil hydrological properties event though the slightly higher amount of plant available water for the S-type might be offset by a finer texture and higher organic matter content regarding soil water storage capacity. The different pattern of SWC with an earlier distinction between REG- and D-Treatment after the first 2-3 weeks of the experiment are more likely caused by the lower ET of the M-type vegetation during this period. Although soil hydrological properties play a role in the community specific conductance potential of soil water to the atmosphere, differences found for the investigated two different vegetation types turned out to be not decisive in this context.

Sharing a common environment, the differences in biomass-independent conductance potential between the two Alpine grassland communities are likely to have a foundation in a contrasting physiological, functional and structural

organisation of the vegetation. Functional divergence in water utilisation, evapotranspiration and other aspects of hydrological regulation of ecosystems (e.g. infiltration, surface run-off) between communities can be manifested by the frequency distribution in the values of particular traits (Díaz et al., 2013). Canopy complexity - density and size, growth form composition, composition and diversity of vascular structures, stomatal density and conductance mediate community specific differences in the evapotranspiration aboveground (de Bello et al., 2010) Belowground, the structure and depth of the individual rooting systems is an important determinant for the water utilisation potential of communities (Knapp et al., 2008). Along the variation and composition of these traits water usage and consequently also drought resistance of contrasting communities is defined. The differences in the two vegetation types suggest high exploitation potential for scarce soil water, probably facilitated by a higher priority on water exploitation in the soil in the M-mesocosms and, conversely, a stronger importance on aboveground structures mediating light capture and gas-exchange, leading to an increased response potential of ET for atmospheric triggers in the local S-communities.

The clear vegetation response to variable water availability observed in the present experiment is not common in studies targeting Alpine grasslands (de Bello et al., 2010). Based on multi-annual measurements of evapotranspiration at 16 sites in the Austrian Alps, it was suggested, that even during years with low annual precipitation Alpine grasslands do not experience water stress (Wieser et al., 2008). Gilgen and Buchmann (2009) could not conclude on a general drought response of grasslands in Switzerland, while acknowledging a site-specific impact with communities receiving less annual precipitation being more susceptible to drought stress than those at higher rainfall levels. Also arguing for a co-defined and interactive manifestation in the effects of varying water availability, a strong drought response of Alpine grassland functioning was revealed under scenarios of co-occurring heat waves (De Boeck et al., 2016). A modelling study for grassland ecosystems in the Austrian- and French Alps suggested a higher vulnerability to drought for communities with a water spending strategy targeting on water provision of the ecosystems in general (Leitinger et al., 2015). However, it seems inappropriate to synthesize a general summary on the response of Alpine grasslands to variations in water availability given the small body of research performed. Considering the different spatio-temporal scales, the range of parameters measured,

676 and the management and biodiversity spectrum of different grassland types in the
677 Alps, drawing broad and universal generalisation yet becomes unrewarding. For
678 experiments with contrasting treatments the practicalities of manipulating water
679 availability potentially also need to be considered for the interpretation of the results.

680 Drought scenarios are usually generated by rain-out shelters using a UV-
681 permeable, transparent film for roofing. If compared to unroofed controls,
682 temperature differences and attenuation of photosynthetically active radiation
683 reducing total productivity will have to be expected as pure artefacts of the sheltering
684 (Vogel et al., 2013). However, even if both treatments are sheltered, differential
685 irrigation may not immediately lead to the realisation of varying water availabilities.
686 The beginning of the present experiment was marked by the establishment of the
687 rain-out shelters and the omission of irrigation in the treatments with irregular
688 watering (D). From this point, it took approximately two weeks for the SWC of both
689 irrigation schemes to diverge significantly in M-type mesocosms, for the S-type even
690 longer. Therefore, regular irrigation and, respectively, its omission can, counter-
691 intuitively, only be an indicator of contrasting water availability. The establishment of
692 drought conditions in the strict sense of a depleted soil water reservoir is realized by
693 the interaction of pre-treatment SWC, standing biomass and atmospheric effects.
694 Variations in vegetation water status have to be defined in context of water
695 availability (supply) and physiology, phenology and the leaf-to-air evaporative
696 gradient (Gilbert and Medina, 2016). The beginning of the experiment was
697 characterized by combination of days with consistently high averages of ET_0 and
698 high SWC in all mesocosms. This combination led to high ET and a decrease of
699 SWC for all experimental units. Due to the parallel decline of SWC irrespective the
700 watering regime applied, the water availability differentiation among the treatments
701 was delayed. For such reasons, it was argued to define variations in water
702 availability not purely on the basis of contrasting regimes of water input (i.e. irrigated
703 vs. non-irrigated) if these are not causing systematic variations in soil moisture
704 (Kramer, 1983). Defining water supply based on the continuous range of SWC rather
705 than discrete irrigation treatments considers soil type specific characteristics of
706 matric potential and hydraulic conductivity. Also practical problems with realizing
707 discrete treatments of water availability in the field (i.e. precipitation entry to
708 sheltered plots due to heavy winds, spatio-temporal variation in the effectiveness of
709 automated irrigation) will be migrated by referencing ecosystem responses to

710 gradients of water supply. Defining vegetation responses along continuous ranges of
711 environmental factors will further yield stronger information about the response
712 surface of the system and improves model building and testing (Beier et al., 2012).

713

CONCLUSION

715   Irrespective the variability of different water availabilities within the two irrigation
716 regimes, mesocosms subjected to regular watering (REG) had on average a higher
717 productivity than those with irregular and in total less irrigation. However, significant
718 differences between the different communities were found in the response to
719 variations in the water supply (Fig 7). Relating total productivity to the amount of
720 evapotranspirative water release over the experimental period revealed a higher
721 biomass gain per unit water in the M-type communities. The higher water use
722 efficiency in the biomass production of these mesocosms together with their overall
723 stronger water saving strategy reinforces their optimisation to scarce water supply.
724 For the local S-communities, in contrast, the low biomass differential per unit water
725 consumption indicates a high potential to conduct water from the soil to the
726 atmosphere and that productivity of this vegetation is probably not often constrained
727 by water availability in its natural context. (Brilli et al., (2011) expect from a water
728 spending strategy to have a cooling feedback in terms of climate warming. Hence,
729 the optimization of future grassland management could play a crucial role by
730 adapting species composition. Furthermore, understanding the specific hydraulic
731 conductance potential of soil water for varying grassland ecosystems is a
732 prerequisite to achieve maximum agricultural yield in a future environment. However,
733 a negative feedback for water provision services (i.e. down-stream water users) has
734 to be expected. Further decisive changes remain debatable: How will 'water
735 spending' plant communities adapt if droughts occur more frequently and possibly
736 with higher intensities (Bahn et al., 2014; Reichstein et al., 2013). To what extent
737 play – at least initially - physiological and morphological changes a role or is there an
738 immediate shift to a better adapted community?

739

740

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