Water balance and global change: future perspectives for alpine farming

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Abstract

Global change influences landscape composition and ecosystem properties and functions. One affected ecosystem service is the provision of water for agriculture, power supply, and households. In agriculture, land management without irrigation is desired but endangered if air temperature and water demand by plants increases. The current study shows that adapted management in low altitudes and intensification of meadows in higher altitudes could (1) compensate for temperature increase, and (2) reach higher productivity rates due to a more balanced use of water. Hence, the steady loss of alpine meadows and pastures – by socioeconomic reasons – threatens the future capital of alpine farming.

Keywords: alpine grassland, climate change, evapotranspiration, land-use change, water balance.

1 Introduction

Global change (climate and land-use change) affects the water balance of mountain grasslands (Beniston 2006; EEA 2004; IPCC 2007; Metzger et al. 2006; Wieser et al. 2008). Depending on topography, soil type, and land use, changes in productivity take place and could result in further economic pressure for alpine farming (Cernusca et al. 1999; Tappeiner et al. 2003). Sustainable productivity rates depend on a balanced use of water by plants, high water storage capacities of soils, and topographical characteristics of managed areas.

Measuring evapotranspiration (EVT) for different land-use types and plant communities at varying sea levels helps us to understand changes of water availability in a future environment. Linked with transplantation experiments, this method is promising to cover most projected climate- and land-cover scenarios.

Although the mentioned approach is well established, our study is innovative in so far as the field work as well as data analyses was supported by more than 50 pupils from a secondary school for agriculture and food industry (hlfs Kematen). Hence, a huge number of field measurements could be conducted simultaneously, covering a whole alpine valley. Here, we address the following three key questions:

1. How will temperature increase affect water balance of alpine grassland ecosystems?
2. How will different types of grassland ecosystems affect soil water content and water retention?
3. How will management (cutting) affect water balance?

2 Materials and methods

The study was conducted within the project *Top-Klima-Science* (SPA/01/2007/133/A/Klimawandel), funded by the Austrian Ministry for Science and Research (BM.W_F). The main objective of *Top-Klima-Science* was to quantify the basic parameters of ecosystem water balance of agricultural areas managed in an alpine valley using an innovative spatial approach. In an international cooperation, the Institute of Ecology, the Institute of Botany (both University of Innsbruck) and the Institute for Alpine Environment of the European Academy Bolzano/Bozen (EURAC) worked together with the partner school hlfs Kematen. Two classes with about 50 students were involved in every part of the project: starting with developing scientific hypotheses to field work, data analysis and the presentation of results.

In our study site Stubai Valley (300 km², Tyrol, Austria) 24 sites on 8 different altitudinal transects (valley bottom, hillside, and sub-alpine/alpine region) ranging from 900 m a. s. l. up to 2,400 m a. s. l. were equipped with weather stations recording microclimate (Figure 1). Additionally, 24 small lysimeters were installed on each site (Figure 2) and data on EVT, infiltration capacities, leaf conductivity and soil wetness was collected. Moreover, soil and vegetation analyses on all selected plots complete the comprehensive data pool (Figure 2).

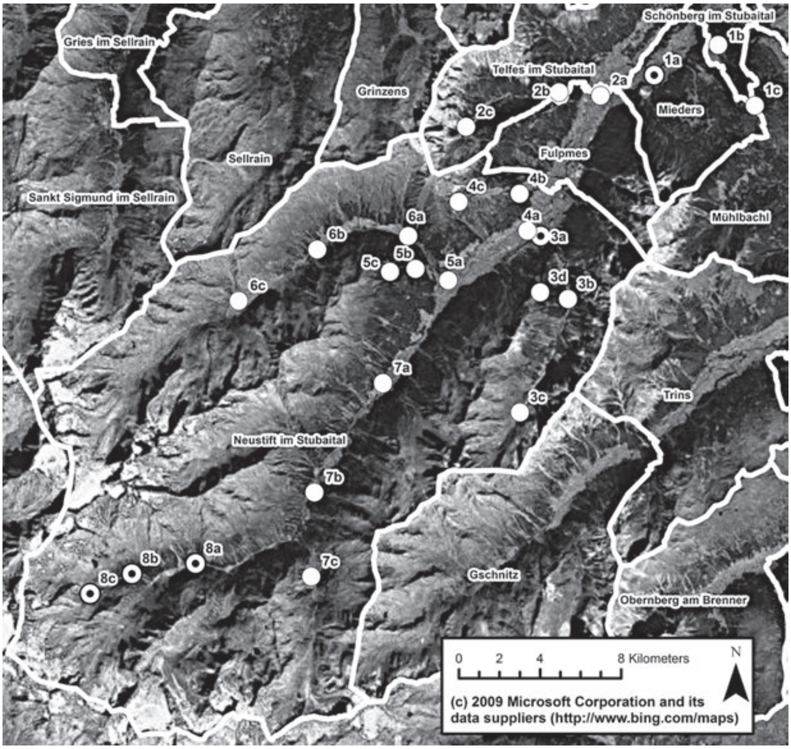

Figure 1: Study area 'Stubai Valley' with all study sites in the Top-Klima-Science project. The analyzed altitudinal transect into the valley is marked (1a, 3a, 8a, 8b, 8c).

The lysimeters on each plot contained samples of high-biomass local vegetation (1 cut/1 uncut), low-biomass local vegetation (1 cut/1 uncut), alpine standard vegetation (1), intensive standard vegetation (1 cut/1 uncut), and water for potential transpiration (1). Each type was replicated three times resulting in a total number of 24 lysimeters per study plot (Figure 2).

The current study uses data from the year 2009 and presents results from an altitudinal transect into the valley (960–2,309 m a. s. l, cf. Figure 1: 1a, 3a, 8a, 8b, 8c). Data from the two standard vegetation types (see descriptions below) on 01.07.2009, a clear sky day were used. Although representative for this kind of weather condition, water balance behaviour might be different for cloudy or rainy days.

1. *Alpine standard vegetation* (Caricetum curvulae, also referred to as **AS**), transplanted from 2,309 m a.s.l. to all sites, dominated by *Carex curvula, Agrostis rupestris, Oreochloa disticha, Pedicularis kerneri* and attended by *Cetraria islandica, Silene acaulis, Loiseleuria procumbens, Salix herbacea*, *Primula glutinosa*;
2. *Intensive standard vegetation* (also referred to as **IS**), seed mixture for intensively used hay meadows in the valley bottom, Typ A 8 SR 036/003, transplanted to all sites with mainly *Poa pratensis, Festuca pratensis, Phleum pratensis, Festuca rubra, Arhenatherum elatius, Dactylis glomerata*, *Lotus corniculatus* and mixed with some *Daucus carota, Plantago lanceolata, Carum carvi, Achillea millefolium, Campanula carpatica, Centaurea jacea*.
   Three replicates of the IS were mown the day before measurement (30.06.2009) to analyse the effect of cutting on evapotranspiration.

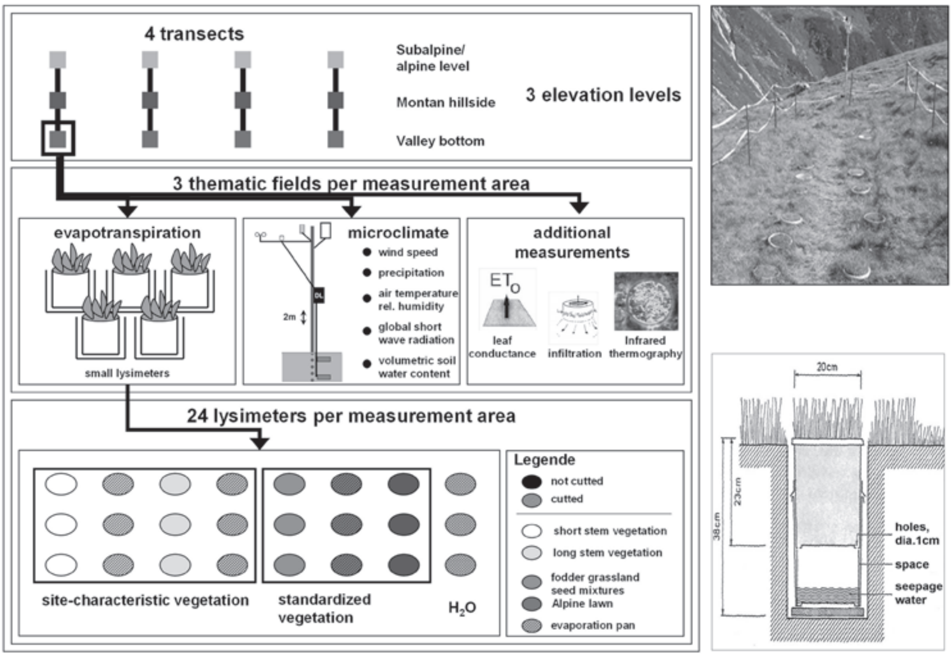

Figure 2: Experimental design, picture of study site, and scheme of the used small lysimeter type.

3 Results and Interpretation

Forced by the vapour pressure deficit, evaporation decreases with increasing altitude due to lower air temperatures. Figure 3 proves for the evaporation over free water surface clearly lower daily sums of evaporation even in alpine areas. In the valley bottom, evaporation reaches 5 mm d^{-1}, whereas around 2,000 m a. s. l. evaporation sharply declines to ca. 1 mm d^{-1}. Mean daily temperature decreases from 17.99 °C on 960 m a. s. l. to 9.85 °C on 2,309 m a. s. l.

In vegetation covered environments, this simply linkage becomes more complex as vegetation type and structure alters evaporation through transpiration. Results revealed increasing evapotranspiration (EVT) rates for the *Alpine Standard Vegetation* transplanted to lower altitudes and decreasing EVT rates for the *Intensive Standard Vegetation* when transplanted to higher altitudes (Figure 4). Regarding management, cutting had a distinct effect on EVT, leading to comparable evapotranspiration between *Alpine Standard Vegetation* and cut *Intensive Standard Vegetation* (Figure 4). Although temporarily, cutting significantly decreases the amount of phytomass – thus transpiring surfaces – and EVT decreases unless enough phytomass is regrown and evapotranspiration as well as productivity increases again. In other words, even if plant communities change, land management could top the influence of vegetation type and structure concerning water balance and finally catchment yield.

In lower altitudes with high air temperatures, water stress might occur and the closure of the stomata is induced. In this case, transpiration stops (Figure 4, site 1a at 960 m a. s. l.) leading to lower EVT sums. Whether vegetation suffers water stress or not must be validated by measurements of leaf conductivity and soil water content, which is part of ongoing data analyses.

Regarding total water balance for July 2009 (Figure 5), the drop of EVT from nearly 50% of precipitation to 33.3% by transplantation from the valley bottom to

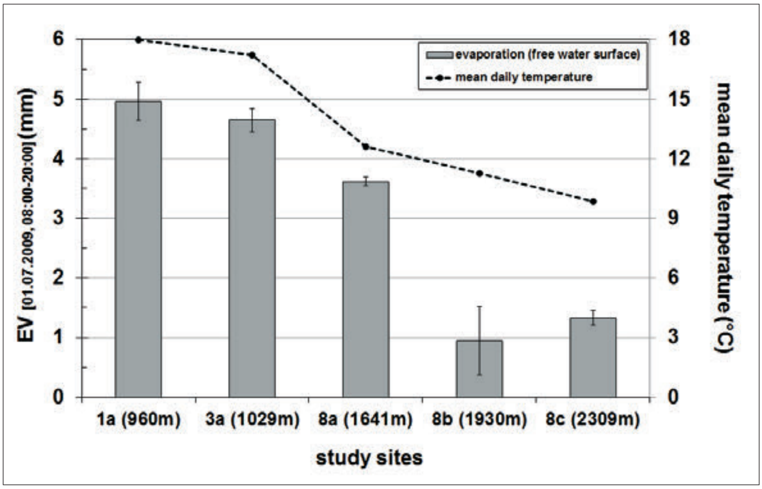

Figure 3: Correlation of altitude and evaporation from a free water surface (daily sum, 01.07.2009, 08:00–20:00 UTC+2).

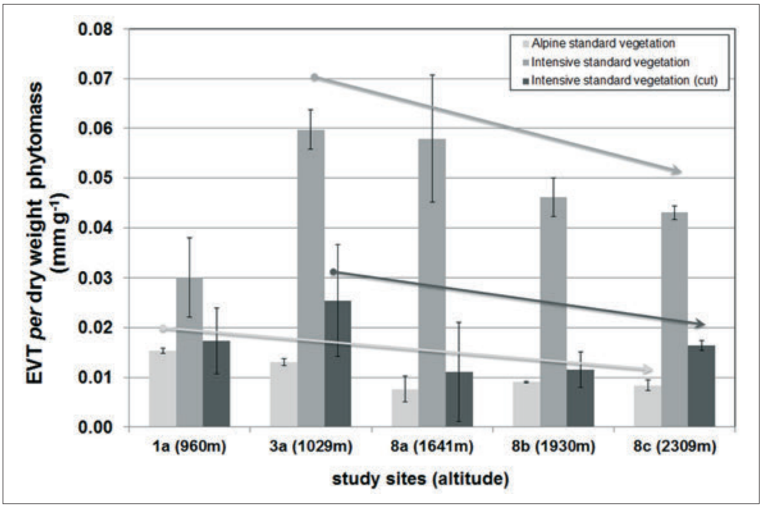

Figure 4: Evapotranspiration (EVT) per dry weight phytomass (daily sum, 01.07.2009, 08:00–20:00 UTC+2) for different standard vegetation types and differently managed intensive standard vegetation.

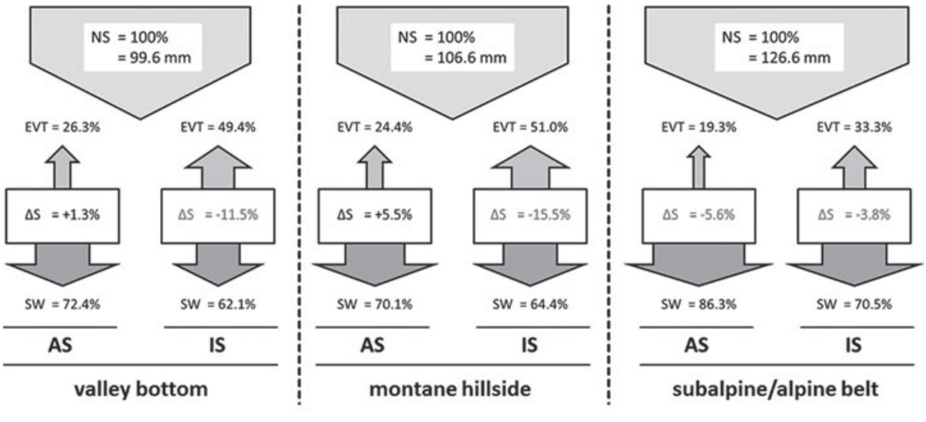

*Figure 5: Water balance for July 2009 (**NS**… precipitation; **EVT**… evapotranspiration; **SW**… deep percolation; **ΔS**… soil water content) for different standard vegetation types: **AS**… Alpine standard vegetation type (transplanted from 2,300 m a. s. l.), **IS**… Valley bottom standard vegetation type (intensively used hay meadow, seed mixture), unmown. Data from 1a (valley bottom), 8a (montane hillside), 8c (subalpine/alpine belt).*

the alpine belt, leads to increasing deep percolation and more balanced soil water content (cf. Figure 5, *IS valley bottom* versus *IS subalpine/alpine belt*). Nevertheless, in humid environments with usually high soil water content, the change in soil water storage is of minor importance. However, the comparison between the transplanted vegetation types reveals a more 'exploiting' strategy from the *Intensive standard vegetation* under favourable environmental conditions. Hence, the changes in EVT are proportionally higher (Figure 5) and the *Alpine standard vegetation* – adapted to higher altitudes – almost reaches transpiration rates of the *Intensive standard vegetation*.

4 Conclusion

To conclude, if air temperature increase and changing precipitation regime lead to longer dry periods, productivity of intensively used meadows will decrease significantly unless irrigation takes place. Alternatively, adapted management in low altitudes and intensification of meadows in higher altitudes could compensate for temperature increase and reach higher productivity rates due to a more balanced use of water. In the light of our results, alpine meadows and pastures could be the future capital of alpine farming and abandonment of currently non-profitable areas should be avoided.

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