^{13}Carbon allocated to the leaf growth zone of *Poa pratensis* reflects soil water and vapour pressure deficit

Auerswald K., Landinger C., Wittmer M. and Schnyder H.
Lehrstuhl für Grünlandlehre, Technische Universität München, D-85350 Freising
Corresponding author: wittmer@wzw.tum.de

Abstract

Leaf expansion is extremely sensitive to water stress caused by a shortage of soil water content or a high vapour pressure deficit. Both parameters also influence stomatal opening, which affects the discrimination of the heavier carbon isotope (^{13}C) during photosynthesis. Thus, photosynthates reflect the water status of the leaf by their ^{13}C content and this signal is incorporated in the leaf growth zone. This mechanism was elaborated by analysing the ^{13}C content of the leaf growth zone of *Poa pratensis* sampled at eleven sites with different soil organic carbon and at three different times (early spring to mid summer) during the growing period to cover wide ranges in soil water content (15-500 mm for 1 m depth) and vapour pressure deficit (0.5-2 kPa). Discrimination varied by about 5‰. This variation and hence stomatal opening of *P. pratensis* was mainly determined by vapour pressure deficit and less by the soil water content. A large vapour pressure deficit, however, only occurred during times of low soil water content. The combined effect of both influences was described best by the ratio of vapour pressure deficit and the logarithm of soil water content. Analysis of ^{13}C in the leaf growth zone offers an elegant way to record stomatal opening as influenced by water stress with high temporal resolution.

Keywords: 13-C, isotope, natural abundance, discrimination, Kentucky bluegrass

Introduction

Water stress is recorded in the isotopic composition of the assimilates as it affects stomatal opening, which in turn modifies discrimination (Δ) of the heavier ^{13}C because of the coupling of water vapour loss and CO_2 assimilation through the stomata. Schnyder *et al.* (2006) have shown that differences in water availability lead to an isotopic signal that is transferred from herbage to grazer tissues. A much finer spatio-temporal resolution, and hence more direct insight into the effects of water stress, should be possible by analysis of the carbon isotope composition (δ^{13}C) of the leaf growth zone (LGZ), which is fed by recent assimilates and hence records water stress within the rooting area of a plant at a daily resolution.

Water stress, in principle, results from two drivers: the soil water content (SWC) and the water vapour deficit (VPD) of the atmosphere. The δ^{13}C of the LGZ could allow quantification of the contribution of each driver to actual water stress in natural conditions. A major constraint in analysing this relation, however, results from the poorly defined root zone, which gradually fades out into the unrooted subsoil and thus only allows quantifying SWC by assuming the construct of an "effective" root depth. This difficulty in the quantification of the SWC is reduced where root depth is defined by a discontinuity between a fine-grained, shallow, well-rooted soil over permeable but unrooted coarse sediment.

Here, we tested the hypothesis that the LGZ is a high-resolution recorder of water stress. We use this to quantify the influence of VPD and SWC within a wide range of water stress in natural conditions. To do this, we took advantage of fully drained peat soils overlaying gravel, which provided a wide range of rooting depths that are well defined due to a sharp discontinuity between peat and gravel. Other soil properties and grazing conditions were similar.

Material and methods

The investigations were carried out on the Grünschwaige Grassland Research Station (48°23'N 11°50'E, 435 m a.s.l.) situated at the north end of the Munich Gravel Plain, Germany. The leaf growth zone (lower half between the last nodium and the ligule) of *Poa pratensis* was sampled three times (early spring to mid summer) at 10-11 sites differing in soil water capacity to cover wide ranges in SWC and VPD. Volumetric SWC was determined by taking soil cores of the peat soil. The soils were well above the groundwater table during sampling. Plant available water was modelled following Allen *et al.* (1998) and yielded r^2 = 0.8 with SWC. Both were largely determined by soil depth, which varied from 5 to 95 cm. VPD was taken from a meteorological station in 3 km distance. The $\delta^{13}C$ of the LGZ was measured and Δ was calculated by taking into account the seasonal variation of $\delta^{13}C$ in air CO_2. The calculations followed Wittmer *et al.* (2008).

Results

The air temperature at the time of sampling varied between 10 and 25 °C, VPD varied between 0.5 and 1.2 kPa. SWC varied between 15 and 500 mm between sites and dates while plant available water differed between 10 and >200 mm. The Δ varied by about 5 ‰.

Δ strongly decreased with increasing VPD (Fig. 1A) and it increased with increasing SWC (Fig. 1B). The influence of SWC was sub-proportional (logarithmic), indicating that an increase in water supply had a stronger effect if the initial SWC was low than on an initially wet soil. Furthermore, the influence of SWC seemed to be smaller (r^2 = 0.18, P<0.05) than that of VPD (r^2 = 0.48, P<0.001) and the regression was shifted between dates. Combining both counteracting influences in a ratio VPD/lg(SWC) then explained 58% of the variation (root mean squared error: 1.25 ‰) between samples (Fig. 1C). More importantly, the regression for the individual dates did not deviate from the overall regression, indicating that VPD/lg(SWC) fully accounted for the spatio-temporal variation of Δ.

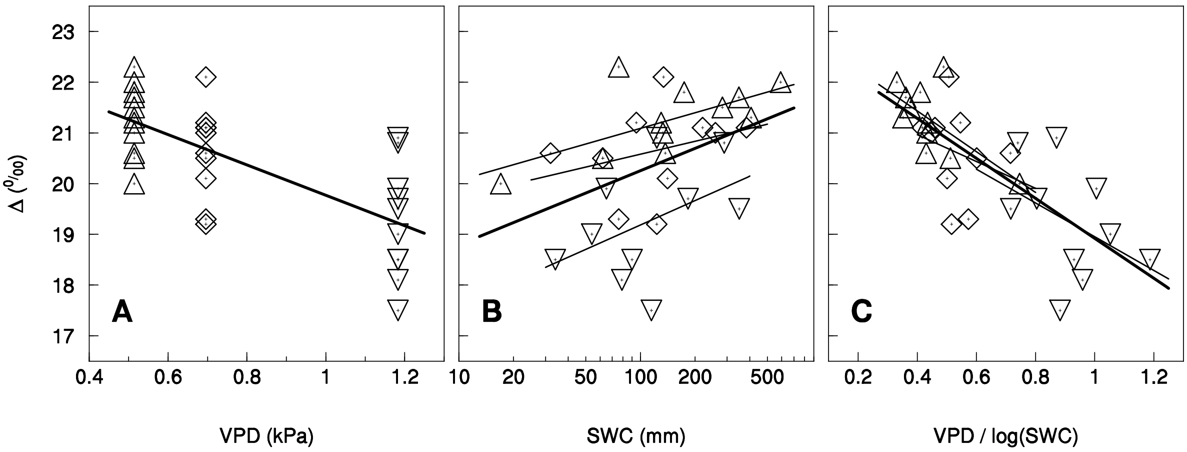

Fig. 1. Influence of vapour pressure deficit (VPD) (A), soil water content (SWC) (B) and the ratio of VPD and the logarithm of SWC (C) on ^{13}C discrimination (Δ) as recorded in the leaf growth zone. (Upright triangles = April, diamonds = May, downward triangles = July; thick line = overall regression; thin lines = monthly regressions)

Discussion

The $\delta^{13}C$ of the LGZ sensitively recorded differences in water availability (SWC) and water demand (VPD), confirming that internal CO_2 concentration was strongly influenced by both parameters. The influence of VPD differences between dates seemed to be more pronounced than that of SWC, although VPD differed only by a factor of three, while SWC differed by two orders of magnitude. However, a high VPD was generally associated with a low SWC. The seasonal trend of VPD hence also included some seasonal variation in SWC. Both influences were thus not fully separated in natural conditions.

This also implied that sites of low water storage capacity profited from nearby soils of high storage capacity, which caused VPD to be lower than would be the case if only soils of low storage capacity were present. The influence of soil water availability on stomatal opening, discrimination and water use efficiency thus not only depended on the soil properties in the rooting zone of a particular plant but also on soil properties on a larger scale, which is large enough to influence VPD substantially.

In consequence, the influence of SWC must become more important on a larger spatial scale, which integrates over the mosaic of soils, and on a larger temporal scale, because daily fluctuations in VPD level out while the effects of the slowly changing SWC accumulate. This agrees with the finding by Schnyder *et al.* (2006) that the variation in discrimination between pastures and between years was closely related to the variation in SWC on the examined scale.

Interestingly, the response of Δ towards SWC (either when tested alone or as ratio VPD/lg(SWC)) did not differ with VPD. This indicates that the influence of SWC is independent from the influence of VPD, although at low VPD usually also the range in SWC is smaller than at high VPD (the standard deviation of SWC was 175 mm at VPD = 0.5 kPa, while it was 105 mm at VPD = 1.2 kPa).

Conclusions

The LGZ records stomatal opening as influenced by water stress with high temporal resolution. In this study, VPD had a stronger effect on this signal than SWC.

References

Allen G.A., Pereira L.S., Raes D. and Smith M. (1998) *Crop Evapotranspiration – Guidelines for Computing Crop Water Requirements*. FAO Irrigation and Drainage Paper 56, 293 pp.

Schnyder H., Schwertl M., Auerswald K. and Schäufele R. (2006) Hair of grazing cattle provides an integrated measure of the effects of site conditions and interannual weather variability on $\delta^{13}C$ of temperate humid grassland. *Global Change Biology* 12, 1315–1329.

Wittmer M.H.O.M., Auerswald K., Tungalag R., Bai Y.F., Schäufele R. and Schnyder H. (2008) Carbon isotope discrimination of C3 vegetation in Central Asian Grassland as related to long-term and short-term precipitation patterns. *Biogeosciences* 5, 913-924.

EGF 2010

Kiel Germany

Grassland in a changing world

Edited by

H. Schnyder
J. Isselstein
F. Taube
K. Auerswald
J. Schellberg
M. Wachendorf
A. Herrmann
M. Gierus
N. Wrage
A. Hopkins

VOLUME 15
GRASSLAND SCIENCE IN EUROPE

Published by

Organising Committee of the 24th General
Meeting of the European Grassland Federation
and
Arbeitsgemeinschaft Grünland und Futterbau der
Gesellschaft für Pflanzenbauwissenschaften

The individual contributions in this publication and any liabilities arising from them remain the responsibility of the authors.

ISBN 978-3-86944-021-7

Printed by

MECKE DRUCK UND VERLAG
Christian-Blank-Straße 3
37115 Duderstadt Germany

Distributed by

European Grassland Federation EGF
W. Kessler · Federation Secretary
c/o Agroscope Reckenholz-Tänikon Research Station ART
Reckenholzstrasse 191
CH-8046 Zürich, Switzerland
E-mail fedsecretary@europeangrassland.org