Höhere Bundeslehr- und Forschungsanstalt
Raumberg-Gumpenstein

16. Gumpensteiner Lysimetertagung 2015, 107 – 112
ISBN 13: 978-3-902849-19-9

Estimation of evapotranspiration and crop coefficient of an intensively managed grassland ecosystem with lysimeter measurements

Jannis Groh[1*], Thomas Pütz[1], Jan Vanderborght[1] and Harry Vereecken[1]

Zusammenfassung

Im Rahmen dieser Studie werden die Wasserbilanzkomponenten eines intensiv genutzten Graslandstandortes (Wirtschaftsgrünland) in Rollesbroich (Deutschland) vorgestellt. Der Niederschlag, die Evapotranspiration und die Nettosickerwasserbildung wurden mittels eines wägbaren Lysimeters bestimmt. Die Studie befasst sich darüber hinaus mit der Berechnung der täglichen Evapotranspiration und dem Pflanzenkoeffizienten (K_C) während einer Vegetationsperiode mit mehreren Schnittzeitpunkten in 2014. Die täglichen K_C-Werte zwischen den einzelnen Grasschnitten wiesen am Anfang geringere und in der mittleren sowie zum Ende der Pflanzenentwicklungsphasen höhere Werte im Vergleich zu den Standardwerten nach ALLEN et al. (1998) auf. Während der Vegetationsperiode bestand ein moderater linearer Zusammenhang zwischen den auf täglicher Basis berechneten K_C-Werten und den gemessenen Blattflächenindizes.

Schlagwörter: TERENO SOILCan, wägbare Lysimeter, Evapotranspiration, Wasserhaushalt, Pflanzenkoeffizient, Wirtschaftsgrünland

Summary

This study presents the water balance components of an intensively managed grassland site in Rollesbroich, Germany. The precipitation, evapotranspiration and net seepage water were obtained from a weighable lysimeter system. We will focus on the calculation of daily evapotranspiration and crop coefficient (K_C) during a growing season with four cuts in 2014. Daily crop coefficients (K_C) of each cutting cycle showed in general lower K_C at the initial and higher values at the mid and late crop development stages than standard values in literature (ALLEN et al. 1998). A regression analysis between daily calculated K_C- and measured leaf area index (LAI) values showed a moderate linear relationship during the vegetation period.

Keywords: TERENO SOILCan, weighable lysimeter, evapotranspiration, water balance, crop coefficient, intensive grassland

Introduction

Crop evapotranspiration (ET_C) is an important process which is closely related to crop yield and a main component of ecosystem water budgets. The ET_C combines the process of evaporation from the soil surface and transpiration by plant. The estimation of ET_C and crop water requirement is of great importance for agricultural water management (HASHIM et al. 2012) at regional to national scale.

The standard method to estimate ET_C was recommended by the Food and Agriculture Organizations (FAO) and involves the calculation of a reference potential evapotranspiration (ET_O) and a crop specific K_C value which accounts for differences (agronomical and physical) between ET_O and ET_C. A reliable calculation of ET_C strongly depends on the appropriate estimation of K_C values. K_C values vary not only between different types of ecosystems, but also between regions (KO et al. 2009) as environmental factors (LOCKWOOD 1999, YANG and ZHOU 2011, YANG et al. 2014) and conditions allow a variation in variety and in crop growth stage development (ALLEN et al. 1998). The appropriate estimation of ET_C with the standard FAO-Method strongly depends on the assumption of the K_C value during the growing season. Ignoring daily fluctuations or K_C development during individual cutting periods can affect the amount and the dynamic of the ET_C estimation from the crop coefficient approach. An appropriate estimation of ET_C is important in assessing the crop water requirement and crop yield. Our study will present daily dynamics of water fluxes derived by lysimeter measurements and K_C values for an intensive managed grassland ecosystem in Rollesbroich. Crop evapotranspiration from lysimeter measurements (ET_C-LY) will be compared by a standard method of crop ET (ET_C-FAO). A further objective of this study will be the relation between K_C and measureable plant parameter (e.g. LAI).

Materials and Methods

Within the framework of SOILCan, a set of six weighable lysimeters (UMS GmbH, Munich) were installed at the test site Rollesbroich (50°37’17”N, 6°’18´15”E, 515 m a.s.l.) which is located in the TERENO Eifel/Lower Rhine Valley observatory in Germany (PÜTZ et al. 2011). The set of lysimeters have a depth of 1.5 m, a surface of 1 m², a 50 l leachate tank, a tension controlled bottom boundary and are arranged in a hexagonal design around a central placed service unit,

[1] Institute of Bio- and Geosciences: Agrosphere (IBG-3), Forschungszentrum Jülich GmbH, D-52425 JÜLICH
[*] Ansprechpartner: Jannis Groh, j.groh@fz-juelich.de

which provides the measurement equipment and data recording devices (ZACHARIAS et al. 2011, PÜTZ et al. 2013). The lysimeter station is part of the SOILCan-lysimeter network which comprises in total 132 lysimeter at 13 different test sites in Germany and has the focus on long term effects of climate change on the terrestrial systems (ZACHARIAS et al. 2011). The grassland vegetation around the lysimeter is intensively managed with four cuts in the observation period (2014-05-19, 2014-07-18, 2014-08-25, 2014-11-12). The plant community was classified as ryegrass "Lolio perennis-Cynosuretum cristati" (SCHUBERT et al. 2001). The average temperature (T) of 8.7°C and annual precipitation (P) 1067 mm are slightly higher in comparison to the long term annual average values (T = 7.7°C, P = 1033, period 1981 - 2001) from a nearby meteorological station Simmerath (GEBLER et al. 2014). The weighing system allows a resolution of 0.1 kg for the lysimeter and 0.01 kg for the leachate tank and measurements were logged with a frequency of 1 min^{-1}. The lysimeter data of one lysimeter (Ro3) were processed in three steps, in order to convert noise prone high frequency measured weight data's into daily precipitation and evapotranspiration:

- Elimination of outliers by an manual filter
- Smoothing filter, AWAT (PETERS et al. 2014) on a minutely basis with an average time of 1 – 61 min, a minimum and maximum threshold of 0.009 kg respectively 0.24 kg
- Calculation of daily fluxes

Under the assumption that no evapotranspiration occurs during precipitation events, in- and decreasing mass changes (ΔW) can be related to precipitation respectively ET_C. The separation of precipitation (P) and ET_C can be derived from the lysimeter mass balance equation:

$$\Delta W = \Delta W_{LY} - \Delta W_{Drain} \quad \text{(Eq.1)}$$

$$\Delta P = \begin{cases} \Delta W & , if\ \Delta W > 0 \\ 0 & , if\ \Delta W < 0 \end{cases} \quad \text{(Eq.2)}$$

$$\Delta ET_C = \begin{cases} 0 & , if\ \Delta W > 0 \\ -\Delta W & , if\ \Delta W < 0 \end{cases} \quad \text{(Eq.3)}$$

where ΔW_{LY} and ΔW_{Drain} is the mass change of lysimeter and leachate tank weight between two consecutive time steps. The daily estimation of K_C can be calculated from the ratio of the measured ET_C and ET_O (ALLEN et al. 1998):

$$K_C = \frac{ET_C}{ET_O} \quad \text{(Eq.4)}$$

Here, ET_C represents the measured flux by the lysimeter system and ET_O the daily grass reference evapotranspiration. The ET_O was calculated by the Penman-Monteith equation (ALLEN et al. 1998):

$$ET_O = \frac{0.408\,\Delta\,(R_n - G) + \gamma \frac{900}{T+273} u_2\,(e_s - e_a)}{\Delta + \gamma\ (1 + 0.34\,u_2)} \quad \text{(Eq.5)}$$

where ET_O is the daily grass reference evapotranspiration (mm d^{-1}), R_n is the net radiation at the grass surface (MJ m^{-2} d^{-1}), G the soil heat flux density (MJ m^{-2} day^{-1}), ϒ the psychrometric constant (kPa $°C^{-1}$), T is the air temperature at 2 m height (°C), u_2 is the wind speed at 2 m height (m s^{-1}), e_s is the saturation vapour pressure (kPa), e_a is the actual vapour pressure (kPa) and Δ is the slope of the vapour pressure curve (kPa $°C^{-1}$). The required meteorological input parameter solar radiation (Pyranometer CMP3, ecoTech), T (MeteoMS, EcoTech), relative humidity (rH, MeteoMS, EcoTech), u_2 (MeteoMS, EcoTech), air pressure (MeteoMS, EcoTech) for calculating the ET_O was taken from the lysimeter climate station in Rollesbroich. According to the crop coefficient approach, a reference crop ET (ET_C-FAO) is calculated through multiplying ET_O with a crop specific coefficient under the assumption of standard conditions (no water stress). Different constant K_C-FAO values were taken from ALLEN et al. (1998) for the initial stage ($K_{C\ ini}$), mid-season stage ($K_{C\ mid}$) and at the end of the late season stage ($K_{C\ end}$) for the forage crop rye grass hay. The beginning and length of the development stages for rye grass hay were estimated by leaf area index (LAI, lysimeter) and grass length measurements (surrounding field) with: 0.95 for $K_{C\ ini}$ (2014-01-01 – 2014-03-31), 1.05 for $K_{C\ mid}$ (2014-04-01 – 2014-10-31) and 1 for $K_{C\ end}$ (2014-11-01 – 2014-12-31).

Additionally measurements of precipitation were taken from the nearby rain gauge (Pluvio, OTT Hydromet GmbH), leaf area index (LAI-2200 Plant Canopy Analyzer, LI-COR) above the grassland lysimeter and soil moisture content (TDR-Probes CS610, Campbell Scientific) in 10 cm depth of the lysimeter. The regression analysis between daily K_C values and the plant parameter LAI were conducted with the stats package of the software R (R-CORE-TEAM 2014).

Table 1: **Monthly sums of precipitation (P-LY = lysimeter, P-RG = rain gauge), crop evapotranspiration (ET_C-LY = lysimeter, ET_C-FAO = FAO-method), net seepage water (SW = lysimeter) and the change in soil water storage (ΔS) of an intensive managed grassland lysimeter in Rollesbroich (2014). Monthly ET_C-LY sums were corrected by monthly sums of extracted water with suction cups (∑ 16.2 mm) and values for P-LY as well as ET_C-LY during 11 days, with a layer of snow on the lysimeter, were corrected by values from P-RG respectively ET_O.**

Month	P-LY (mm)	P-RG (mm)	ET_C-LY (mm)	ET_C-FAO (mm)	SW (mm)	ΔS (mm)
Jan	74.1#	63.5	21.2*	18.9	60.8	-7.9
Feb	59.5	46.8	24.2	26.1	33.7	1.6
Mrz	32.0	23.1	53.3	51.9	7.3	-28.6
Apr	52.2	45.4	81.0	74.5	0.1	-28.9
Mai	72.6	61.8	88.3	92.0	-0.2	-15.5
Jun	89.7	80.6	99.5	107.5	-3.5	-6.3
Jul	198.5	176.9	89.5	108.6	41.4	67.5
Aug	160.5	150.0	92.7	85.6	53.8	11.4
Sep	54.4	49.4	54.3	56.5	20.1	-20.0
Okt	81.3	71.7	39.3	40.3	33.2	8.9
Nov	70.1	48.6	32.9	20.6	36.3	0.9
Dez	122#	103.7	17.5*	15.8	92.1	12.4
∑	1067.0	921.5	696.3	698.4	375.0	-4.3

#Corrected with P-RG values due to a layer of snow on the lysimeter: Jan (3 days), Dec. (9 days); *Corrected with ET_C-FAO values due to a layer of snow on the lysimeter: Jan (3days), Dec. (9 days)

Results and discussion

In this section we present first preliminary results that were obtained from our weighable lysimeter systems. *Table 1* shows the monthly sums of the water balance components calculated from lysimeter data, the precipitation measured from the rain gauge (P-RG) and reference ET_C-FAO for the year 2014. The monthly water balance components from the lysimeter measurements showed for the study site large precipitation sums for the summer (July, August) and winter month (December). In comparison with the rain gauge, the monthly precipitation amount measured by the lysimeter were for all months higher and the annual value was for the observation period 14 % larger than for P-RG. This observation was in a good agreement with studies by GEBLER et al. (2014). The large difference and underestimation of precipitation by P-RG might be related to aerodynamic effects (FU et al. 2011).

The crop evapotranspiration was low during winter months (Dec. – Feb.), increased with the initial growing season in March and showed in the summer months from Mai until August the highest monthly ET_C sums. The yearly sum of the ET_C-LY was slightly lower than calculated ET_C-FAO, but the monthly dynamic during the year was different. The difference between both ET_C estimation methods was very low in winter time (Dec. – Feb.). For months in the initial stage and the end stages of the late growing season (Apr., Nov.) the monthly ET_C from lysimeter measuremnts were higher and in the mid stage of the growing season (Jun. – Jul.) the ET_C-FAO estimations were generally larger. However the monthly value for August showed larger values from lysimeter measurements. A closer examination on hourly basis for the month August, showed that runoff, which may take place between the inner and the outer lysimeter cylinder, occurred after a heavy rainfall event (40 mm, 2014-08-26).

The yearly net seepage water (SW) was 375 mm, monthly values indicates, that especial winter months and high precipitation events in summer (Jul., and Aug.) coincide with high SW rates. In the time from March to April SW is very low and a small upward directed water flow occures during Mai until the beginning of July. The highly variable response of seepage water rates after a heavy rainfall event (2014-08-26; P = 40 mm) between all six lysimeter indicates the occurrence of preferential flow. The observation of high variable flow could be related beside the existence of biotic macropores especially to the pedological situation at the test site which show a high spatial variable stone content in the subsoil (QU et al. 2014).

The change on soil water storage (ΔS) for 2014 was very low, but the monthly sums indicate that high precipitation events during the summer led to a refill of soil water reservoir.

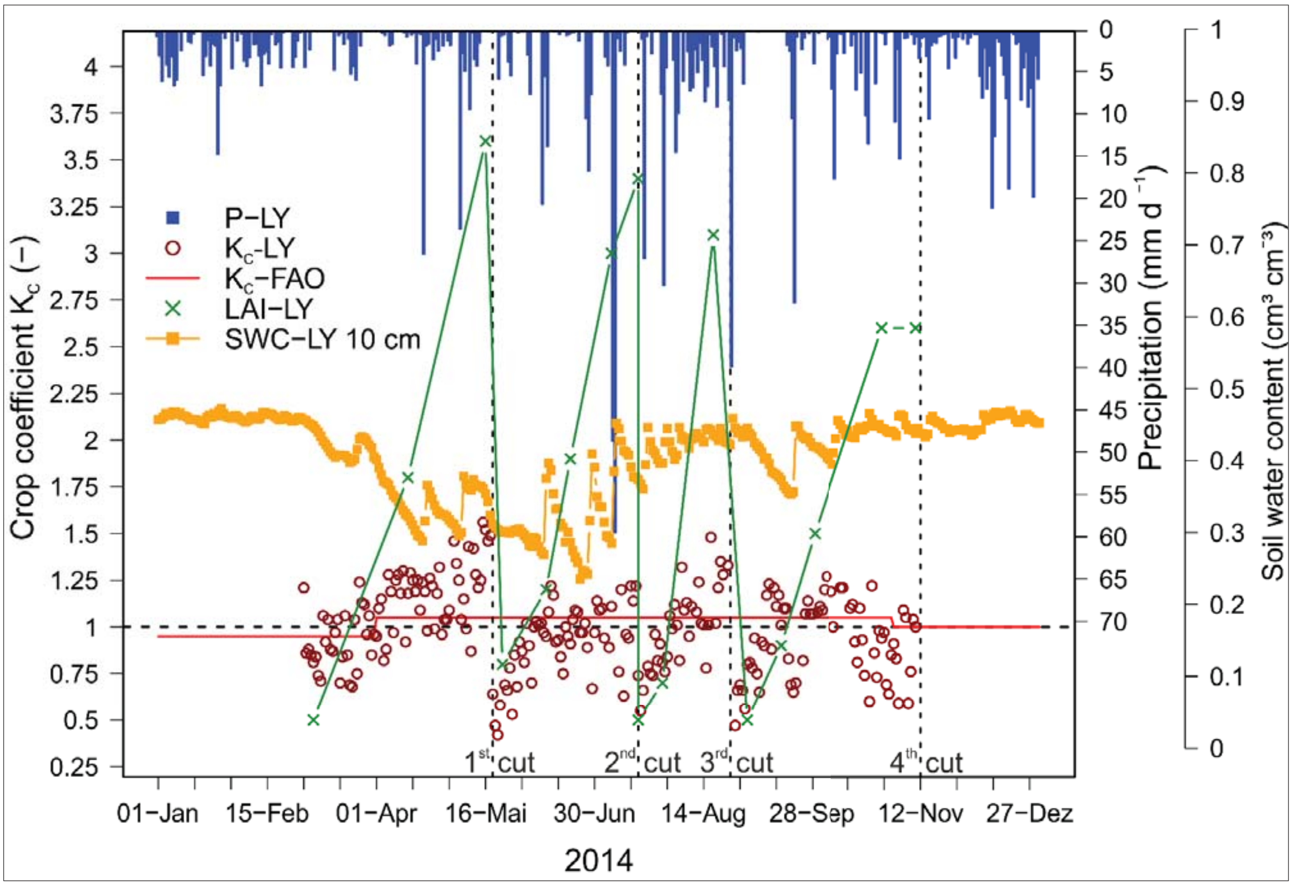

Figure 1: **Daily values for precipitation (P-LY = lysimeter), leaf area index (LAI = lysimeter), soil water content (SWC-LY = lysimeter) in 10 cm depth and crop coefficients from the ratio of ET_C-LY and ET_C-FAO and a standard method with constant values during the growing season of an intensive managed grassland site at Rollesbroich.**

Figure 1 illustrates the temporal development of the daily K_C-values derived by the ratio ET_C-LY and ET_O, a growth stage constant K_C factor (K_C-FAO), precipitation and leaf area index measurements for the growing season in 2014. On days with long lasting precipitation events during daytime the crop coefficient approach estimated very small K_C values (< 0.4) which not corresponded well with the K_C development during the specific time windows (outlier). ET_C-LY are for this specific days very low in comparison to the ET_C-FAO, as the method itself, to calculate fluxes from lysimeter measurements, assume that no ET occure during precipitation events or that at least ET is negligible in that time (HANNES et al. 2014).

The K_C-LY values in *Figure 1* follow the temporal development of the LAI measurements for each cutting cycle during the growing season. At the beginning of the growing season or after the cut, K_C-LY values (K_{Cmin} = 0.42) are much lower as recommended literatur values (K_C-FAO) for rye grass hay. While at the mid and the late end of each cycle K_C-LY values (K_{Cmax} = 1.56) are larger than recommended K_C-FAO values. The different dynamics during the cutting cycles of the K_C value from both methods explain well, why the sum of ET by ET_C-LY and ET_C-FAO are in total similar, but not in their temporal dynamic.

Figure 2 shows the relationship of calculated K_C and measured LAI values for the grassland lysimeter in Rollesbroich. It was found that LAI measurements correlate moderately (r^2 = 0.56) with the K_C values obtained from lysimeter measurements.

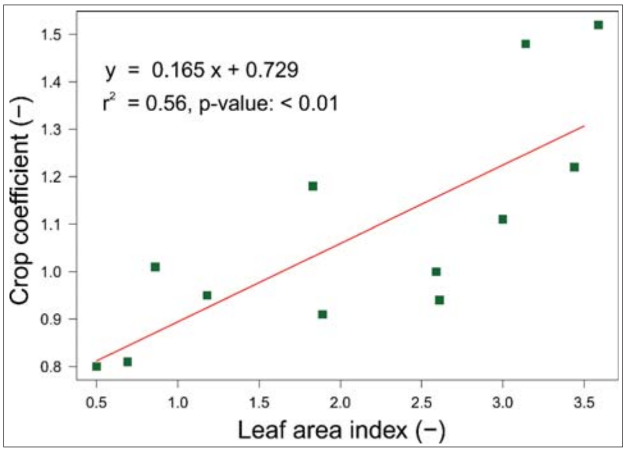

Figure 2: **Scatterplot of crop coefficient and leaf area measurements of a grassland lysimeter at Rollesbroich and regression line of a simple linear model for the growing season in 2014.**

Conclusion and Outlook

Overall, this study presents the first results of the water balance components of an intensive managed grassland site in Rollesbroich, Germany. A comparison of annual precipitation amounts obtained by a lysimeter and a rain gauge, showed that lysimeter derived total precipitation was with 14 % significant larger. Monthly values of seepage water indicate, that high rates of seepage water were observed during the winter months and especially during extreme precipitation events. It was found that preferential flow plays a major role for seepage water rates during heavy rainfall. Yearly sums of crop evapotranspiration derived by lysimeter measurements and the FAO-method showed a good agreement. However, the monthly dynamic observed during the growing season was found to be different. Larger ET_C-FAO sums during the summer months indicated that ET_C from the lysimeter was rather water than energy limited. Furthermore it was found, that daily crop coefficient was dependent on the crop development stages with values deviating from standard literature values. Further measurements are being performed to corroborate these first findings. Moderate results were obtained for the relationship between K_C values and LAI measurements.

Acknowledgment

The TERENO infrastructure is funded by the Helmholtz Association and the Federal Ministry of Education and Research. We thank Ferdinand Engels, Leander Fürst, Rainer Harms and Werner Küpper for supporting the weekly sampling and ongoing maintenance of the experimental setup in Rollesbroich.

References

ALLEN, R.G., L.S. PEREIRA, D. RAES and M. SMITH, 1998: Crop evapotranspiration – Guidelines for computing crop water requirements FAO, Rome.

FU, S., T.O. SONNENBORG, K.H. JENSEN and X. HE, 2011: Impact of Precipitation Spatial Resolution on the Hydrological Response of an Integrated Distributed Water Resources Model, gsvadzone 10(1), 25-36.

GEBLER, S., H.-J. HENDRICKS FRANSSEN, T. PÜTZ, H. POST, M. SCHMIDT and H. VEREECKEN, 2014: Actual evapotranspiration and precipitation measured by lysimeters: a comparison with eddy covariance and tipping bucket. Hydrol. Earth Syst. Sci. Discuss. 11(12), 13797 - 13841.

HANNES, M., U. WOLLSCHLÄGER, F. SCHRADER, W. DURNER, S. GEBLER, T. PÜTZ, J. FANK, G. von UNOLD and H.J. VOGEL, 2015: High-resolution estimation of the water balance components from high-precision lysimeters, Hydrol. Earth Syst. Sci. Discuss. 12(1), 569-608.

HASHIM, M.A.A., S. SIAM, A. AL-DOSARI, K.A. ASL-GAADI, V.C. PATIL, E.H.M. TOLA, M. RANGASWAMY and M.S. SAMDANI, 2012: Determination of Water Requirement and Crop water productivity of Crops Grown in the Makkah Region of Saudi Arabia Australian Journal of Basic and Applied Sciences 6(9), 196-206.

KO, J., G. PICCINNI, T. MAREK and T. HOWELL, 2009: Determination of growth-stage-specific crop coefficients (Kc) of cotton and wheat. Agricultural Water Management 96(12), 1691-1697.

LOCKWOOD, J.G., 1999: Is Potential Evapotranspiration and its Relationship with Actual Evapotranspiration Sensitive to Elevated Atmospheric CO2 Levels? Climatic Change 41(2), 193-212.

PETERS, A., T. NEHLS, H. SCHONSKY and G. WESSOLEK, 2014: Separating precipitation and evapotranspiration from noise - a new filter routine for high resolution lysimeter data. Hydrol. Earth Syst. Sci. Discuss. 18(3), 1189 - 1198.

PÜTZ, T., R. KIESE, S. ZACHARIAS, B. BOGENA, E. PRIESACK, U. WOLLSCHLÄGER, M. SCHWANK, H. PAPEN, G. von UNOLD and H. VEREECKEN, 2011: TERENO-SOILCan - Ein Lysimeter Netzwerk in Deutschland. Gumpensteiner Lysimetertagung 14, 5-10.

PÜTZ, T., K. KIESE, U. WOLLSCHLÄGER, E. PRIESACK, E. BORG, H. GERKE, H., PAPEN and H. VEREECKEN, 2013: TERENO-

SOILCan - Ein Lysimeternetzwerk zur Untersuchung des Klimawandels, Gumpensteiner Lysimetertagung 15, 57-62.

QU, W., H.R. BOGENA, J.A. HUISMAN, G. MARTINEZ, Y.A. PACHEPSKY and H. VEREECKEN, 2014: Effects of Soil Hydraulic Properties on the Spatial Variability of Soil Water Content: Evidence from Sensor Network Data and Inverse Modeling. gsvadzone 13(12).

R-CORE-TEAM, 2014: R: A language and environment for statistical computing, R Foundation for Statistical Computing, Vienna, Austria.

SCHUBERT, R., W. HILBIG and S. KLOTZ, 2001: Bestimmungsbuch der Pflanzengesellschaften Deutschlands, Spektrum Akademischer Verlag Heidelberg.

YANG, F. and G. ZHOU, 2011: Characteristics and modeling of evapotranspiration over a temperate desert steppe in Inner Mongolia, China. Journal of Hydrology 396(1–2), 139-147.

YANG F., Q. ZHANG, R. WANG and J. ZHOU, 2014: Evapotranspiration Measurement and Crop Coefficient Estimation over a Spring Wheat Farmland Ecosystem in the Loess Plateau. PLoS ONE 9(6), 1-7.

ZACHARIAS, S., H. BOGENA, L. SAMANIEGO, M. MAUDER, R. FUSS, T. PÜTZ, M. FRENZEL, M. SCHWANK, C. BAESSLER, K. BUTTERBACH-BAHL, O. BENS, E. BORG, A. BRAUER, P. DIETRICH, I. HAJNSEK, G. HELLE, R. KIESE, H. KUNSTMANN, S. KLOTZ, J.C. MUNCH, H. PAPEN, E. PRIESACK, H.P. SCHMID, R. STEINBRECHER, U. ROSENBAUM, G. TEUTSCH and H. VEREECKEN, 2011: A Network of Terrestrial Environmental Observatories in Germany All rights reserved. gsvadzone 10(3), 955-973.