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Quantification of dewfall based on lysimeter studies

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Zusammenfassung

Lysimeter sind wichtige Messgeräte zur Erstellung von Wasserbilanzen und finden Anwendung in der Landwirtschaft, der Forstwirtschaft und anderen Umweltdisziplinen. Dabei stellt bei wägbaren Lysimetern die Wägegenauigkeit einen Schlüsselparameter dar. Neuere Lysimeter mit hoher Genauigkeit ermöglichen eine detaillierte Messung des Taus. Es werden aktuelle Ergebnisse zur Quantifizierung der Taumenge für kurz- und längerfristige Zeitperioden sowie für unterschiedliche Pflanzenbestände (Gras und Ackerfrüchte) vorgestellt und diskutiert. Die Untersuchungen werden ergänzt durch Modellrechnungen zur Taubildung mit der Penman-Monteith-Gleichung. Dabei zeigten sich qualitativ gute Übereinstimmungen. Die Gleichung unterscheidet jedoch nicht, ob das Tauwasser aus der Atmosphäre oder dem Boden bzw. dem Pflanzenbestand kommt. Nur das Erstere wird von einem Lysimeter erfasst, so dass weitere Forschungsarbeiten zur Aufteilung der Tauberechungen nach Quellen des Tauwassers notwendig sind.

Schlagwörter: Taubildung, Lysimeter, Penman-Monteith-Gleichung

Summary

Lysimeters are an important tool for water balance studies in agriculture, forestry and other environmental settings. A key parameter of a lysimeter is its weighing precision: the higher it is, the better the resolution of the weight measurements. Nowadays some advanced weighable lysimeters are available, which make it possible to measure dewfall accurately.

With the help of high precision weighing lysimeters some studies on dewfall were carried out at the Falkenberg lysimeter station of the Department of Soil Physics of the Helmholtz Centre for Environmental Research - UFZ. They demonstrated that such lysimeters can be used successfully to quantify the amount of dew precipitated during a night or longer periods (e.g. a year). The results of the studies further showed that the type of vegetation and its growth stage have an influence on dewfall. More dew was deposited in spring and autumn, since in April, September and October the typical weather conditions favored dew formation. On crops the rate of dewfall increased with their growth. In the maturation period dew occurred more frequently and the amount of dew reached a peak.

In addition, the Penman-Monteith (PM) equation was used in our studies to calculate dew formation on grass, using lysimeter data on dewfall as reference. Most of the meteorological data required in the PM-equation were obtained at the UFZ lysimeter station. The time course of the calculated dew amounts agreed well with measured values, but deviations in the daily amounts were sometimes fairly large. This is because the equation does not differentiate whether the dew originates from the atmosphere, the soil, or the plant canopy. Only the former is registered by a lysimeter. Hence, further studies are required to separate the sources of dew in the calculations.

Keywords: dew formation, lysimeter, Penman-Monteith equation

Introduction

Lysimeters are often used for the hydrological studies. They can quantify actual evaporation from a bare soil or actual evapotranspiration from a soil covered by vegetation. Moreover, seepage from lysimeters can be collected, which allows an assessment of the water loss from a soil profile and, thus, groundwater recharge. The seepage water can be analyzed in the laboratory for its various constituents. Hence, lysimeters can be employed to monitor the fate of solutes in a soil, too.

In our studies high precision weighing lysimeters were used to measure dewfall. They monitor mass changes continuously and with high resolution so that the course of dewfall during a day (or more to the point a night) can be followed. Lysimeters have several advantages over dew gauges. First, they measure only dewfall, while dew gauges often record dewrise and dewfall. However, only the latter represents a real gain of water to a plant, because the former originates in the soil it grows in (MONTEITH 1957). Second, the influence of the type of vegetation on dewfall can be investigated accurately, because the vegetation of interest can be planted on the lysimeter.

Studying dewfall is of importance, since dew is part of the precipitation at a site. In humid regions it normally contributes only a small percentage to the total precipitation over a longer term (week or month). However, in semi-arid and arid regions dew plays an important role in the water balance. Also, dew can significantly lower the evaporative loss of soil water during some periods of the day (MONTEITH 1957). Dew formation releases heat, which can be

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an important component in the night-time heat budget of the local atmosphere (WHITEMAN et al. 2007). On the other hand, dew plays a significant part in the development of plant foliar diseases (e.g. PEDRO and GILLESPIE 1982a, b, JACOBS et al. 1990, WILSON et al. 1999).

Lysimeters are a very promising tool for measuring dewfall (MEISSNER et al. 2007). However, they are not readily available at every study site because of their high cost. Hence, there is a large body of literature on ways to compute dew formation from meteorological factors. They range from simple correlations of dew formation with weather data, to neural network models and complex numerical simulations of atmosphere - canopy systems in which the amount of dew is an output parameter (RICHARDS 2004).

Some of the better models to estimate dew formation, i.e. water vapor condensation (and evaporation), were developed on the basis of the surface energy balance, e.g. the Penman-Monteith (PM) equation or the vegetation models SiB (SELLERS et al. 1986, 1989) and Cupid (NORMAN 1979, NORMAN and CAMPBELL 1982, WILSON et al. 1999). The latter two consider the soil and different layers in a crop and are thus rather complex. We therefore chose the PM-equation (MONTEITH 1973), to calculate dew formation in our studies and compared the results with dewfall measured by weighing lysimeters.

In summary, the objectives of this article are 1) to examine the ability of high precision weighing lysimeters to quantify the amount of dew precipitated during a night and during the course of a year, and 2) to assess how well dew formation calculated with the PM-equation compares with dewfall measured by weighing lysimeters.

Material and methods

The studies were carried out at the Falkenberg lysimeter station of the Department of Soil Physics of the Helmholtz Centre for Environmental Research - UFZ, which is located in northern Germany, some 120 km northwest of Berlin.

The site is 21 m above sea level, its mean annual precipitation is 588 mm with a maximum in July (69 mm) and a minimum in February (29 mm; RUPP et al. 2007). Its potential annual evapotranspiration is 565 mm, also with a maximum in July (106 mm) and a minimum in February (8 mm). The surrounding area is plain and mainly under grass.

Four identical weighable lysimeters were employed in these studies. Each has a surface area of 1 m², a depth of 2 m, and is filled with a sandy soil. A detailed description of the lysimeters is given by MEISSNER et al. (2007). They can discern mass changes as small as 30 g, which for their 1 m² surface area corresponds to a depth of 0.03 mm of water. Their mass is recorded every 10 minutes.

To compare dewfall on different vegetation two lysimeters were planted with maize from April through September 2004 (they were bare prior to that), and with barley thereafter until July 2005. For the remainder of the year they were kept fallow. The other two were under continuous grass in both years.

Dewfall results in a mass increase of a lysimeter. Hence, to identify dewfall the lysimeter records were surveyed for periods with mass increases. Since a mass increase may also result from rain or snow, the periods with a mass increase were compared to the precipitation data collected at the site by a continuously recording tipping-bucket rain gauge. Mass increases not concurrent with rain or snow were finally classified as dew.

The variant of the PM-equation used here to calculate dew formation has the form

$$E = \frac{\Delta(R_n - G) + \rho c_p \delta_e / r_a}{\lambda(\Delta + \gamma)}$$

where E = dew formation (if E < 0) or evaporation (if E > 0) (g/m²/s), Δ = rate of increase of the saturation vapor pressure with temperature (mb/K), R_n = net radiation (W/m²), G = soil heat flux (W/m²), ρ = density of air (1.204 kg/m³), c_p = specific heat of air (1003.5 J/kg), δ_e = vapor pressure deficit of the air (mb), r_a = aerodynamic resistance to vapor transport (s/m), λ = latent heat of vaporization of water (2442 kJ/kg), and γ = psychrometer constant (0.66 mb/K). (All values are for 293 K and 101.3 kPa atmospheric pressure.)

There is a weather station at the lysimeter station, which records rainfall, solar radiation, soil and air temperature (at various depths and heights, respectively), relative humidity, and wind velocity. Some other meteorological variables needed in the equation, in particular incoming and outgoing long wave radiation, can be derived with empirical equations.

Results

Amount of dew measured with lysimeters

Figure 1 illustrates the amount of dewfall per dew-night in 2004 and 2005. In each month of the two years dewfall per dew-night on grass didn't vary as much as on crops. From July to September and in December 2004 as well as in April and May 2005 it was higher on crops than on grass. At all other times it was higher on grass.

Figure 2 shows the amount of dewfall in each month in 2004 and 2005. For the grass lysimeters there was a peak in spring and autumn in both years, when the weather conditions at the site favor dew deposition. For the cropped lysimeters this was only the case in 2005; the peaks in September and December 2004 were a result of crop development (see below).

For the crop lysimeters dewfall rose steeply from a minimum in May until September 2004, concurrent with the growth of the maize crop, and then fell sharply after its harvest. After a second rise from November to December it dropped again to an annual minimum in February 2005 from where it increased once more until May, concurrent with barley growth, followed by another decline after harvest.

In 2004 the total amount of dewfall was notably higher on the grass lysimeters than on the cropped ones (31.8 mm compared to 27.2 mm), while in 2005 the figures

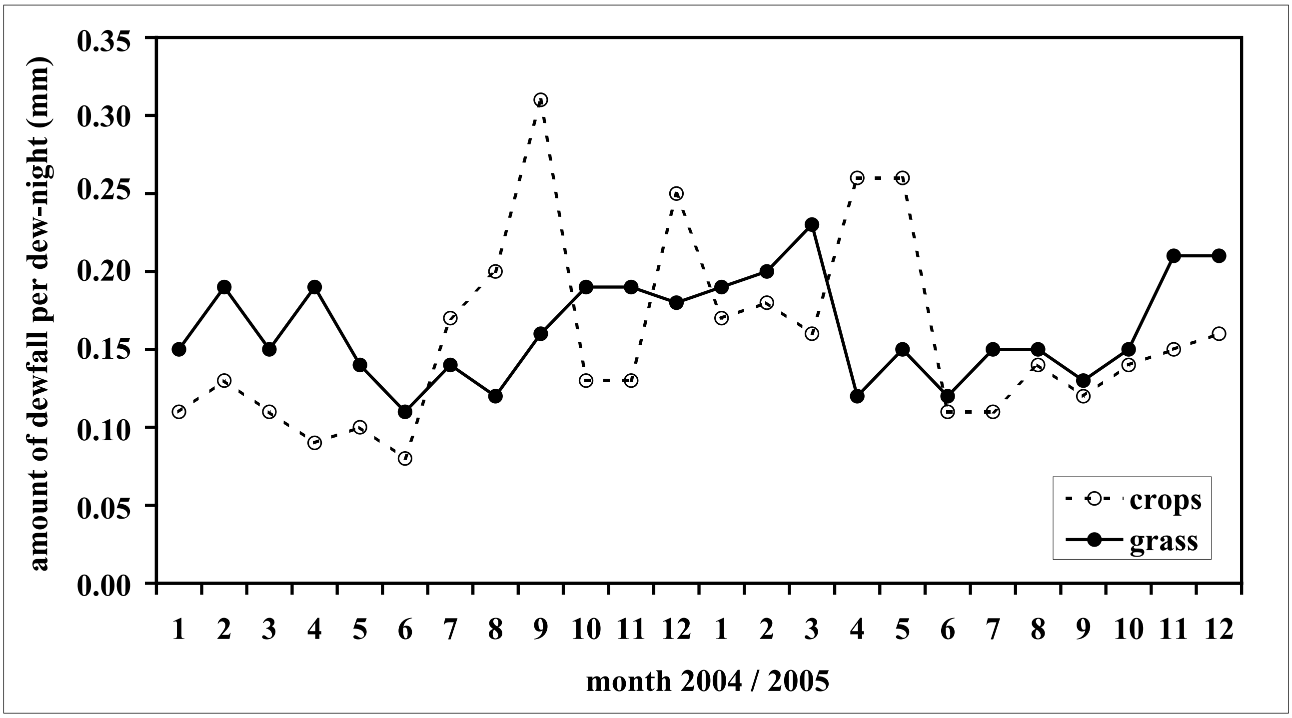

Figure 1: **Amount of dewfall per dew-night on the lysimeters with grass and with crops in 2004 and 2005.**

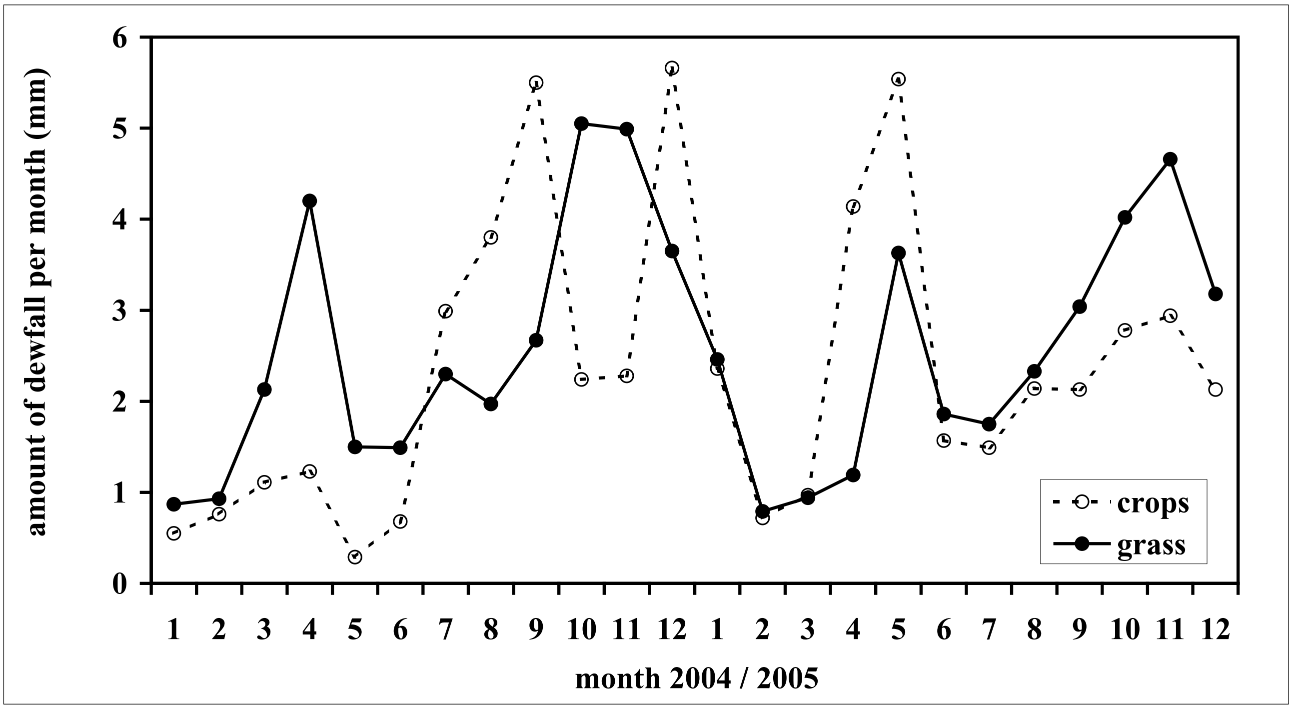

Figure 2: **Amount of dewfall per month on the lysimeters with grass and with crops in 2004 and 2005.**

were similar (29.9 and 28.8 mm, respectively). However, in the period when the maize was growing (May through September 2004) there was more dewfall on the cropped (13.26 mm) than on the grass lysimeters (9.93 mm). In the period when the cropped lysimeters were under winter barley (October 2004 to mid-July 2005) the amount of dewfall was similar, namely 26.22 mm on barley and 25.43 mm on grass.

Comparison of calculated and measured dew amounts

For this comparison only the grass lysimeters were looked at, to avoid the intricacies of having to account for a rapidly and markedly changing vegetation cover. The period form April 1st to October 31st, 2004 was chosen, which coincides with the growing period of grass at the site.

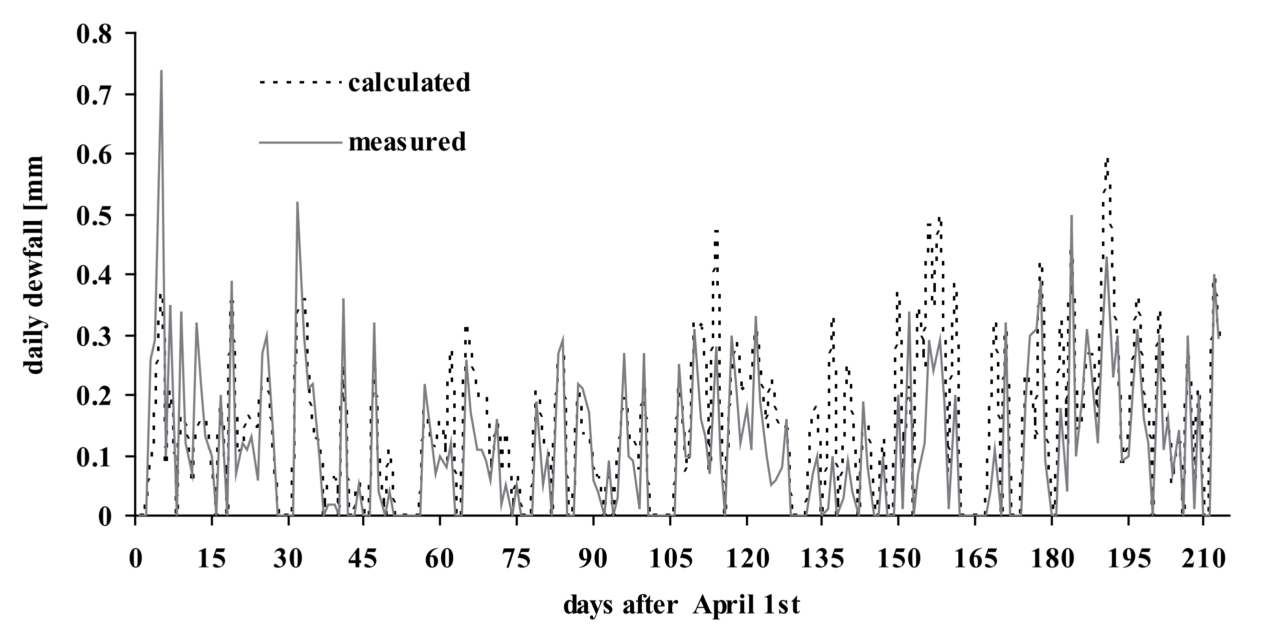

Figure 3: **Dewfall on grass measured by lysimeters and calculated with the Penman-Monteith equation from April 1st to October 31st, 2004.**

The dewfall over the whole period is plotted in *Figure 3*. The values calculated with the PM-equation are generally in good qualitative agreement with the lysimeter measurements. Earlier in the growing season calculated and measured data agree better than in the later period. Especially from about 100 to 160 days after April 1st (i.e. mid-July to mid-September) the PM-equation yields much higher values than measured with the lysimeters. The deviations are most likely due to the fact that the PM-equation does not differentiate whether the dew originates from the atmosphere, the soil, or the plant canopy. Only the former is registered by a lysimeter (and of use to a plant, see above). The computational separation of the dew sources will be looked at in further studies.

Conclusions

The amount of dew measured in our investigation equals 5.2 to 6.9% of the annual and up to 47% of the monthly precipitation during the study period. This indicates that dew can play a notable role in the water balance of grass and crops in northern Germany.

The studies also illustrate the effect of vegetation on dewfall, which increased with the growth of the crops. In the maturation period the dewfall per month was greater on crops than on grass.

The PM-equation can be used to estimate daily dew formation. This method just needs standard meteorological data, which can be obtained at typical meteorological stations. Hence, it is more widely useable than lysimeters. However, at times there were large deviations between lysimeter measurements and computations, because in the way used here the PM-equation does not differentiate between atmosphere, soil, or plant canopy as the source of dew, while lysimeters only register dew originating from the atmosphere (dewfall). The separation of the dew sources in the calculations will be the subject of further work.

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