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Effect of exposure on the water balance of two identical lysimeters

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SUMMARY

This study looks at the water balance of two identical weighable lysimeters located right next to each other. They contain the same soil and are managed in the same way. Both were planted with maize. The area around them was planted with maize, too, to ensure that the lysimeters were located inside a crop. The only difference between them was that one side of lysimeter 2 was exposed due to a footpath.

At first both yielded similar results. However, as the maize became taller lysimeter 2 began to show consistently more precipitation and drainage. After harvest the differences disappeared again.

Since precipitation often falls at an angle, a crop with an exposed side receives more than a crop without one, if the precipitation falls towards the exposed side. The additional precipitation a crop with an exposed side may capture increases with the height of the crop. After harvest this exposure effect therefore disappears completely. Compared to lysimeter 1, lysimeter 2 accumulated >100 mm of additional precipitation during the growth of the maize. After the maize was removed, both crops recorded the same amount of precipitation again.

Lysimeter 2 showed more drainage, too, because the additional precipitation led to higher water contents, which in turn caused the water holding capacity of the soil to be exceeded on more days than in the case of lysimeter 1. The difference in actual evapotranspiration was small, because lysimeter 2 was exposed towards west-northwest and therefore received only little more radiation, and because the distribution of the rainfall pattern was such that the additional precipitation led to a similar amount of additional drainage rather than to an increase in the volume of stored water, which could have been consumed by evapotranspiration later.

The data clearly illustrate that exposure can significantly alter the water balance of a lysimeter, which makes it inadvisable to extrapolate data obtained under such circumstances to the field. This should be well known to people working with lysimeters. However, apparently it is not, because there are many lysimeters in operation which have one or more exposed sides. The objective of this paper is to bring this problem back to mind.

1. Introduction

Lysimeters are an important tool for hydrologic studies. Modern day lysimeters are placed on a weighing mechanism and hooked up to a data logger, which allows the recording of their mass at regular intervals. Furthermore, they are equipped to measure drainage out of the bottom of the lysimeter vessel and, quite frequently, to record runoff from the surface. From changes in the mass of the lysimeter vessel rainfall and evapotranspiration can be determined, after accounting for drainage and runoff.

In most cases a lysimeter is intended to be a small representative sample of a larger area, equipped to measure various parameters of the water balance equation. The results of these measurements are then extrapolated to the larger area. To be fully representative of field conditions a lysimeter must fulfil certain requirements (Allen et al., 1991, 2011): It must contain undisturbed soil. It must be deep enough not to hinder root growth. It must have a large surface area to encompass at least some of the small scale natural variability in soil and crop characteristics. It must be placed several metres inside a stand of the same vegetation as on the lysimeter to avoid edge effects. It must be placed even deeper inside a stand, typically several tens to several hundreds of metres (Monteith and Unsworth, 1990; Campbell and Norman, 1998; Allen et al., 2011), to provide enough fetch. Drainage through the bottom of the soil in the lysimeter vessel must be unimpeded, i.e. it must proceed as in the natural soil outside the vessel. There are other conditions a lysimeter must fulfil, too, which are outlined in Schiff (1971), Allen et al. (1991) and Allen et al. (2011).

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The cost of a lysimeter increases with its size. Furthermore, the bigger it is, the more difficult it becomes to cut an undisturbed soil monolith for the lysimeter. Hence, many lysimeters have a surface area of just 1 m^2 and are <2 m deep. Also, the sites where lysimeters are located are often too small to provide the required fetch, and sometimes even too small to prevent edge effects. Finally, unimpeded drainage is difficult to achieve due to the artificial boundary at the bottom of the lysimeter vessel.

It has long been known that any one or a combination of these problems may cause the water balance of a lysimeter to deviate from the field situation it is supposed to represent (Schiff, 1971; Allen et al., 1991). Nevertheless, there are many lysimeters in operation which suffer from one or more of these problems, but data are collected with them and extrapolated to larger areas. There is little quantitative information in the literature on how erroneous data from such lysimeters may be.

We were asked to assist in the analysis of data from two identical weighable lysimeters located right next to each other. They contain the same soil and are managed in the same way. Both were planted with maize. The area around them was planted with maize, too, to ensure that the lysimeters were located inside a crop. Under these conditions one would expect more or less identical results from both lysimeters. However, they were rather different.

It is not unusual that supposedly identical lysimeters show different results (e.g. Meissner et al., 2010). This is typically due to the natural variation of soil properties, which in turn may lead to differences in the development of the crop grown on the lysimeters, specifically in rooting depth, leaf area and plant biomass. However, here the differences arose, because the crop on lysimeter 2 was exposed on one side, which resulted from a footpath leading towards the lysimeters. It has been altered in the meantime to avoid the exposure.

The lysimeters were not set up to study the exposure problem, it occurred coincidentally during the first years of their operation. Nevertheless, this produced valuable data to provide a quantitative example of the effect of exposure on the water balance.

The exposure problem should be well known to people working with lysimeters. However, this is apparently not the case, because there are many lysimeters in operation which have one or more exposed sides. The objective of this paper is to bring back to mind that exposure can alter the water balance of a lysimeter, which makes it inadvisable to extrapolate data obtained under such circumstances to the field.

2. Materials and methods

2.1. Site description

The location of the lysimeters looked at here is immaterial for the purpose of this paper. Furthermore, we do not want to point to a lysimeter site with room for improvement which is not our own. Its location is therefore not specified.

The climate in the region around the lysimeter site is moderately continental with dry, cold winters and wet, hot summers with a distinct rainy season from June to September when some 80% of the annual precipitation takes place. Rainfalls >40 mm/d typically occur several times a year. In summer, evapotranspiration can occasionally reach 8–10 mm/d. Annual precipitation usually varies between 600 and 800 mm, while the annual potential evapotranspiration is typically around 1000 mm.

2.2. Installation, management and technical data of the lysimeters

The lysimeters (Table 1) were installed in summer 2010 and the weighing mechanisms for the lysimeter vessels, the tipping bucket arrangements for measuring drainage and all other devices were calibrated. After that, some trial runs were carried out to discover and fix any problems. Routine operation therefore only started in spring 2011. The lysimeters are completely identical in design, equipment and operation and are located <1 m apart. They have a circular cross-sectional area of 1 m^2 and are 2 m deep. The soil depth is 1.8 m, the lowest 0.2 m are a sandy-gravelly drainage layer. A more detailed description of the type of lysimeter looked at here can be found in Meissner et al. (2008).

The lysimeter vessels are weighed every minute, the individual values are then averaged to get a mean value for the hour. The mass is recorded to the nearest 100 g, even though the actual weighing precision of this type of lysimeter is 10–20 g (Xiao et al., 2009). For the aforementioned cross-sectional area of 1 m^2 a mass change of 100 g translates into a change in the volume of water in the lysimeter vessel of 0.1 l, which is equivalent to a depth of 0.1 mm of water on the surface. The amount of drainage water leaving the bottom of the vessel is measured with a tipping bucket arrangement. It has a precision of 10 g, which is equivalent to 0.01 l $\triangleq$ 0.01 mm of water with respect to the dimensions of the lysimeter vessel.

The soil cores in the lysimeters were taken from land used for agriculture about 20 km south of the lysimeter station. They were cut directly next to each other to ensure that they are as similar as the natural variation of soils allows. The extraction method employed is described in Meissner et al. (2008).

The silty-clayey material in the top 45 cm of the profile (Table 1) has a very stable structure, which remains so even upon wetting. This structure gives it a saturated hydraulic conductivity of $2.3 \cdot 10^{-5}$ m/s, which is similar to that of the much coarser underlying loamy sand. The high conductivity paired with the stable structure enables the soil to absorb without runoff the high-intensity rainfalls which frequently occur during the rainy season.

The lysimeters are located in the northwestern quadrant of a 15 m × 15 m fenced enclosure (Fig. 1) which is surrounded by lawn. In May 2011 and 2012 maize, the main crop in the area, was planted on both lysimeters and inside the entire enclosure (row spacing 40 cm, plant spacing 25 cm) to ensure that the lysimeters were located inside a crop. The maize was harvested in October (Table 1).

Fig. 1 shows a footpath which leads from the entrance of the enclosure almost directly towards lysimeter 2. It is about 1 m wide and kept free of vegetation to ensure good access to the lysimeters. The layout and maintenance of the path have the effect that the side of lysimeter 2 facing west–northwest is exposed. This has been corrected by now to avoid the exposure.

A critical examination of the site and the lysimeters shows that there is room for improvement with respect to at least two other factors as well: First, the lysimeter enclosure is surrounded by lawn, which is a smoother surface for approaching air than the

Table 1
Some information about the lysimeters.

Lysimeter type	Two weighable lysimeters in a container station with a common access shaft (manhole) and gravity drainage at the bottom of the vessels
Weighing procedure	Weighing every minute, subsequent averaging of the data to obtain a mean value for every hour, recording of the mass to the nearest 100 g
	Drainage determined with a tipping bucket arrangement
Soil texture	0–30 cm: 1% sand, 60% silt, 39% clay
	30–45 cm: 16% sand, 64% silt, 20% clay
	>45 cm: 91% sand, 4% silt, 5% clay
Crop	Maize, planted May 5th, row spacing 40 cm, plant spacing 25 cm (i.e. 8 plants per lysimeter), harvested October 25th, grain yield ~1.4 kg (dry mass) on each lysimeter