Journal of Hydrology 548 (2017) 382–390

Contents lists available at ScienceDirect

Journal of Hydrology

journal homepage: www.elsevier.com/locate/jhydrol

Research papers

Assessing the effect of micro-lysimeters on NRWI: Do micro-lysimeters adequately represent the water input of natural soil?

Giora J. Kidron [a,*], Rafael Kronenfeld [b]

[a] Institute of Earth Sciences, The Hebrew University, Givat Ram Campus, Jerusalem 91904, Israel
[b] Meteorological Unit, Israel Meteorological Service, Kibbutz Sede Boqer 84993, Israel

ARTICLE INFO

Article history:
Received 17 July 2016
Received in revised form 17 January 2017
Accepted 4 March 2017
Available online 6 March 2017
This manuscript was handled by K. Georgakakos, Editor-in-Chief, with the assistance of Xin Li, Associate Editor

Keywords:
Dew
Fog
Negev Desert
Non-rainfall water input
Water vapor

ABSTRACT

The use of micro-lysimeters (MLs) by the scientific community for the measurement of non-rainfall water input, NRWI (dew, fog, water vapor) has become more widespread. With MLs being isolated bodies, we hypothesized that changes in heat flux may affect the surface temperatures and subsequently NRWI. Measurements were conducted with MLs of various lengths (3.5, 12, 20, 30, 40, 50 cm for 2014 and 3.5, 12, 50 cm for 2015), and on the adjacent soil that served as a control (COT) using cloths attached to glass plates in Sede Boqer (Negev Desert, Israel) during the late summer and fall of 2014 and 2015. In addition, periodical temperature and moisture measurements were also conducted on additional lysimeters. Non-significant differences in NRWI characterized MLs 12–50 cm-long, which could have been therefore grouped (termed ML12/50). However, these lysimeters and especially the 3.5 cm-long ML (ML3.5) yielded substantially higher values than that of COT, with the ratio of ML12/50 to COT and the ratio of ML3.5 to COT being up to 2.4 and 5.8, respectively, implying, as was indeed found during periodic measurements, lower nocturnal temperatures and subsequently higher moisture content at 0–0.2 cm at the MLs in comparison to COT. This was also reflected in the amount of recorded mornings with effective (>0.03 mm) NRWI: 34 mornings based on the ML12/50 in comparison to only 4 when based on COT. The findings raise serious concerns regarding published data on NRWI and call for proper calibration between the amounts obtained by the MLs and the natural intact soil.

1. Introduction

The use of lysimeters by the scientific community has widely increased since the middle of the 20th century (Harrold et al., 1959; Peters and Russel, 1959; England, 1963; Ritchie and Adams, 1974; Kowal and Kasam, 1973; Dunin et al., 1988; Ding et al., 2010; Evett et al., 2012). With technical improvements and lower costs, the use of small-size lysimeters, termed micro-lysimeters (MLs) has become more widespread. High resolution load cells connected to data loggers facilitate accurate long-term measurements of the ML mass. As a result, data regarding the evaporation rate as well as water input (especially non-rainfall water input, NRWI, such as dew, fog and water vapor) is increasingly available.

Measuring several centimeters and up to tens of centimeters in diameter and depth, MLs were extensively used for studying evaporation rates (Dugas and Bland, 1989; Allen, 1990; Wallace et al., 1993). However, due to differences in heat flux between the MLs and the soil, greater attention was paid in the selection of an adequate construction material (van Bavel, 1961; Evett et al., 1995; Todd et al., 2000), and proper dimensions such as diameter and length (Ritchie and Burnett, 1971; Boast and Robertson, 1982; Schawcroft and Gardner, 1983; Dugas and Bland, 1989; Klocke et al., 1990; Daamen et al., 1993; Evett et al., 1995; Todd et al., 2000). Thus, following the high thermal conductance of the ML walls, caution was called for in the use of metal MLs (Todd et al., 2000) with polyvinylchloride (PVC) being regarded as a preferential construction material (Daamen et al., 1993; Evett et al., 1995). As for the lysimeter dimension, while Daamen et al. (1993) did not find a significant effect of the lysimeter's diameter (6, 15 or 21 cm), or length (10 or 20 cm), Evett et al. (1995) maintain that out of the lengths examined (10, 20, 30 cm), the longer lysimeters yielded more reliable results (in agreement with Boast and Robertson, 1982), concluding that >10 cm-long lysimeters are required. In contrast, Todd et al. (2000) and Jacobs et al. (2000) maintained that the minimal lysimeter lengths should be 7 and 3.5 cm, respectively.

MLs are also commonly used to study NRWI, which require precise measurement due to the minute quantities involved. Micro

---

* Corresponding author.
E-mail address: kidron@mail.huji.ac.il (G.J. Kidron).

http://dx.doi.org/10.1016/j.jhydrol.2017.03.005
0022-1694/

lysimeters were used for studying NRWI in the Negev Desert, Israel (Jacobs et al., 1999, 2000; Ninari and Berliner, 2002; Agam and Berniler, 2004), Tabernas Desert, Spain (Uclés et al., 2013, 2014), Tengger Desert, China (Wang et al., 2014) and the Namib Desert, South Africa (Maphangwa et al., 2012; Matimati et al., 2013). In all the above studies, the values obtained were assumed to reflect the intact bulk soil. Yet, with fog interception, water vapor adsorption, and dew condensation being temperature-dependent, even minute differences in temperatures between the intact bulk soil and the ML may significantly alter NRWI and may provide unreliable data.

We hypothesized that due to the ML design (usually two pipes, one inserted into the other to allow free movement necessary to facilitate the weighing of the inner soil-filled pipe), differences in heat flux may characterize the lysimeter in comparison to the intact soil. Resulting from the fact that the inner tube is disconnected from the bulk soil, we hypothesized that a more efficient longwave radiational cooling at the lysimeter will be reflected in lower nocturnal temperatures and higher NRWI at the lysimeter in comparison to the bulk soil. It is further hypothesized that the rate of nocturnal cooling will be faster and subsequently the NRWI will be higher at small-volume (short) lysimeters. The current research examines these hypotheses.

2. Methodology

2.1. The research site

The research was conducted in Sede Zin, a flat loessial valley (7 × 3 km) at Sede Boqer, Negev Desert Israel, approximately 100 m west of the meteorological station of Kibbutz Sede Boker (34°23′E, 30°56′N). Long-term rain precipitation at the site is ~95 mm, falling during November and April. Afternoon sea-breeze winds that carry water vapor from the Mediterranean Sea facilitate vertical near-ground temperature inversion which results in dew condensation (Beysens, 1995; Zangvil, 1996). Average annual dew and fog precipitation is ~33 mm, with ~200 dewy and foggy days (Evenari, 1981). Average annual temperature is 17.9 °C; it is 24.7 °C during the hottest month of July and 9.3 °C during the coldest month of January (Bitan and Rubin, 1991). Annual potential evaporation is ~2600 mm (Evenari, 1981).

2.2. Microlysimeter construction

During 2014 (August 10th and December 20th) 6 pairs of MLs with variable lengths of 3.5, 12, 20, 30, 40 and 50 cm (termed ML3.5, ML12, ML20, ML30, ML40 and ML50, respectively) were established (with data for ML3.5 only available since September 20th, 2014). During 2015 (August 20th and October 12th) four MLs for each of the following lengths were operative: ML3.5, ML12 and ML50. Each ML was constructed of two 0.5 cm-thick PVC pipes, 15.8 cm-diameter and 18.8 cm-diameter for the inner and outer pipe, respectively, inserted into one another, creating a space (termed herein air gap) of 1.5 cm in between the pipes. The inner pipe had a 0.2 cm-thick plastic bottom that was placed on a 2.0 cm-thick polyurethane base. While the thin bottom assured a good thermal conductance (Evett et al., 1995), the polyurethane base disconnected the lysimeter from the underlying bulk soil, thus mimicking a typical lysimeter, which is disconnected from the underlying soil by a load cell.

The inner pipe was filled with adjacent soil that was thoroughly mixed, and then packed into the lysimeter. Packing was time consuming to allow for a similar bulk density (1.39–1.43 g cm^{-3}) and moisture content (2.9–3.1% v/v) of all lysimeters. A similar procedure were employed for the control plots (by filling a 50 cm-depth pit with the same soil) to assure similar conditions at all plots.

All MLs were inserted into the ground and leveled in accordance with the natural (flat) surface. To facilitate smooth wind flow, and given the fact that the amount of NRWI was not determined by direct weighing (and therefore the soil-filled pipe was not removed or allowed to move freely), a 2 cm-thick polyurethane ring was inserted at the top, in between both pipes, thus creating a smooth leveled surface with the adjacent soil, which also served to reduce the heat loss through the air gap (Fig. 1).

2.3. Measurements of NRWI, temperatures and soil moisture content

Velvet-like 6 × 6 × 0.15 cm cloths (Universal Company, Germany) were attached to 10 × 10 × 0.2 glass plates, which were put at the center of each ML during each afternoon. During the following morning the cloths (along with the glass plates) were collected. The cloths were placed in separated flasks that were immediately sealed and brought to a nearby lab in order to measure the amount of NRWI condensed onto them. A new set of cloths attached to glass plates was re-placed on the MLs during the late afternoon for the next measurements.

Our assumption that the NRWI condensed onto the glass plates may adequately represent the amount of NRWI at the lysimeter was based on previous findings, which indicated that the temperature of the glass plate will proportionally change in accordance with the substrate temperature on which it is placed (Kidron et al., 2000; Kidron, 2010). Therefore, due to the fact that the amount of NRWI is temperature-dependent (Monteith, 1957; Beysens, 1995), we assumed that differences in temperatures of the soil surface will be reflected in the amount of NRWI condensed onto cloths attached to the glass plates. The method, known as the Cloth-Plate Method (CPM) was found to be very sensitive to minute temperature differences, capable of monitoring small differences of <0.01 mm of NRWI, as also verified during various measurements (Rao et al., 2009; Zhuang and Zhao, 2014). Yet, in order to increase the sensitivity of the glass plates to reflect the temperature of the underlying surface, the glass plates (except for one pair in 2014 and two pairs in 2015 that were placed on plywood on the adjacent soil and served as reference, termed CPM) did not overlie a 0.5 cm-thick plywood (as originally designed; see Kidron, 1998) but were placed directly on the soil surface of

Fig. 1. Micro-lysimeters (bottom) and glass plates serving as control (top) in the field. Arrow points at the 1.5 cm-wide and 2.0 cm-thick polyurethane ring inserted in between the inner and the outer pipe aiming to reduce heat loss through the air gap.