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Microlysimeter station for long term non-rainfall water input and evaporation studies

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ABSTRACT

Non-rainfall atmospheric water input (NRWI), which is comprised of fog, dew and soil water vapour adsorption (WVA), has been proven to be an important water source in arid and semiarid environments. Its minor contribution to the water balance and the difficulty in measuring it have resulted in a wide variety of measurement methods (duration and quantification), especially for dew. Microlysimeters seem to be the most realistic method for dew measurement on natural surfaces and they can also detect WVA. This paper presents an automated microlysimeter that enables accurate studies of NRWI and evaporation on soil and small plants. Furthermore, we have developed a field strategy for their long term placement and installation which prevents damage from rainfall, soil movement or other field conditions, keeping the microlysimeters balanced and dry. This design allows the measurement of evaporation and NRWI on different cover types, including small plants. By monitoring the surface temperatures, dewfall and water vapour adsorption can be distinguished and the relative contribution of dew and WVA on the NRWI can also be found. Our automated microlysimeter design, construction and field installation have proven to be an useful and effective tool in an NRWI study.

1. Introduction

Non-rainfall atmospheric water input into an ecosystem can originate from fog, dew or water vapour adsorption (WVA). Fog occurs when the atmospheric water vapour concentration reaches saturation, a mass of condensed water droplets remains suspended in the air and is deposited on the surface by interception. Dew forms when the temperature of the surface where water will condense equals or falls below the dew point temperature of the surrounding air. WVA takes place when the relative humidity of the air is higher than the relative humidity in the pore space in the soil while the surface temperature is higher than the dew point temperature of the surrounding air (Agam and Berliner, 2006).

Non-rainfall atmospheric water has been proven to be an important water source in arid and semiarid environments (Jacobs et al., 1999; Kalthoff et al., 2006; Uclés et al., 2013; Veste et al., 2008). Some studies have confirmed that summer soil WVA plays an important role in the stomatal conductance and vital transpiration in *Stipa tenacissima* in SE Spain (Ramirez et al., 2007), dew plays an important role in biomass production of plants at low water cost (Ben-Asher et al., 2010) and dew evaporation in the morning alleviates moisture stress in plants by cooling the leaves and reducing transpiration losses (Sudmeyer et al., 1994). Furthermore, several studies have stated that dewfall can play an important role in the development of biological soil crusts (del Prado and Sancho, 2007; Kidron et al., 2002; Pintado et al., 2005) and microorganisms (Lange et al., 1970). Dew and fog may also have a negative effect on plants promoting bacterial and fungal infections (Duvdevani, 1964), which may have an important impact on agriculture (Kidron, 1999). Some attempts have been made to study the duration and quantification of non-rainfall water input (NRWI), but there is no international agreement on how this should be done. Its minor contribution to the water balance and the difficulty in measuring it, have resulted in a wide variety of measurement methods, especially for dew.

Dew duration has been long studied, mainly because of its importance in plant diseases, as leaf wetness duration can determine pathogen and fungus development. But leaf wetness duration is a difficult variable to measure or estimate, since wetness varies considerably with weather conditions, surface cover type or crop, as well as position, angle, geometry and location of the leaves (Hughes and Brimblecombe, 1994; Madeira et al., 2002; Magarey et al., 2006). Some micrometeorological data and mathematical models have been used to predict leaf surface wetness duration

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(Madeira et al., 2002; Magarey et al., 2006; Monteith and Butler, 1979; Pedro Jr and Gillespie, 1981a,b; Weiss et al., 1989). However, the use of leaf wetness sensors is necessary when estimations by empirical or physical models are too complex. For this purpose, Gillespie and Kidd (1978) developed an electrical impedance grid that has evolved on actual commercial leaf wetness sensors. These sensors consist of a wire grid that a current can flow through when free water bridges the gap between two trace wires. The wires are energized by a potential difference from a datalogger's excitation circuitry. When dew or rain is deposited on the sensor surface, the datalogger senses the current due to the presence of water on the grid.

As dew may have an important role in the water budget in arid and semiarid ecosystems (Jacobs et al., 1999; Kalthoff et al., 2006; Uclés et al., 2013; Veste et al., 2008), its quantification becomes an important issue. Some theoretical and modelling methods, such as the Bowen ratio technique (Kalthoff et al., 2006; Malek et al., 1999), the Penman Monteith equation (Jacobs et al., 2002; Moro et al., 2007) and, more recently, the Combined Dewfall Estimation Method (CDEM) (Uclés et al., 2013) may be found in the literature. These techniques can quantify the amount and duration of dew, but require an enormous amount of atmospheric variable data. Furthermore, they can be difficult to implement and do not measure fog or WVA, or do not differentiate between these two phenomena and dew.

Other efforts at estimating dew have resulted in the development of direct measurement methods using artificial surfaces, such as the Duvdevani dew gauge (Duvdevani, 1947; Evenari et al., 1971; Subramaniam and Kesava Rao, 1983), the cloth plate method (Kidron, 2000; Kidron et al., 2000) and the Hiltner dew balance (Zangvil, 1996). The Duvdevani dew gauge consists of a rectangular wooden block (32 cm × 5 cm × 2.5 cm) coated with a special paint where dew condenses. Using reference dew photographs, the dew amount can be stated visually in the early morning. The cloth plate method consists of an absorbent cloth (6 cm × 6 cm) attached to a glass plate (10 cm × 10 cm × 0.2 cm) and placed on a wooden plate (10 cm × 10 cm × 0.5 cm). The cloth is collected in the early morning and it is weighed and dried to calculate its water content. Beysens et al. (2005) used plexiglas surfaces as dew collectors and some attempts have also been made to measure dew on plants using artificial collecting surfaces such as poplar wood stick, sunflower stick and filter paper (Yan and Xu, 2010). These methods are unable to record the dew duration but the Hiltner dew balance does. This method consists of a continuous registration of the weight of an artificial condensation plate hanging 2 cm above the ground. All these direct measurement methods are easy to implement but under or overestimate dew, since their surface properties are different from natural surfaces. Hence, these dew measurement methods are useful for intersite comparisons but do not provide real values and are unable to measure WVA.

Microlysimeters are an effective method for measuring NRWI on natural surfaces, as they can detect dew and WVA with accuracy (Uclés et al., 2013). Several NRWI studies have been done with manual microlysimeters (Jacobs et al., 2000, 2002; Ninari and Berliner, 2002; Rosenberg, 1969; Sudmeyer et al., 1994; Waggoner et al., 1969). However, manual methods usually underestimate NRWI, because the beginning and end of the measurement period are predetermined by the researcher and the entire water input period may be reduced. Recently, automated weighing microlysimeters are being more used (Graf et al., 2004; Heusinkveld et al., 2006; Kaseke et al., 2012; Uclés et al., 2013), because this method avoids daily manipulation of the sample and records continuously anywhere. Sample dimensions in automated microlysimeters are determined by the load cell characteristics, since the larger the sample or the load cell are, the lower the resolution. Heusinkveld et al. (2006) and Kaseke et al. (2012) used a 1.5 kg rated capacity single-point aluminium load cell for measuring dewfall on bare soil and on biological soil crusts (BSCs). Indeed, microlysimeter studies have focused on bare soil and BSCs monitoring, as sampling cup dimensions are insufficient for plants. However, Uclés et al. (2013) successfully used a larger load cell (3 kg rated capacity) to measure NRWI on small plants.

The accuracy of the automated microlysimeter measurements depends on their field installation as they must be buried with the surface of the soil samples flush with the surrounding soil. Furthermore, they have to be mounted with the balance of the load cells perpendicular to avoid eccentricity. After burial, the soil tends to move and the microlysimeter may tip, twist, be thrown out of the balance and break. Another common problem is damage from soil movements caused by rain and water entering the load cell case. Therefore, only short automated microlysimeter studies have been done with a small number of replicates. The study of Kaseke et al. (2012), for example, had to be stopped because of an imminent rainstorm storm which could have flooded and damaged the load cell. Microlysimeters must be improved and a suitable field installation method must be developed to be able to deal with all these drawbacks and carry out long-term studies with all the replicates needed.

This paper presents an automated microlysimeter (MLs) which may be used for the accurate study of NRWI and evaporation on soils and small plants. We have also developed a long-term MLs field installation and placement strategy which avoids damage from rain, soil movement or other field conditions, keeping the MLs balanced and dry. In this study, 12 MLs were installed in a Mediterranean semiarid steppe ecosystem (Balsa Blanca, Almería, SE Spain) with different cover types in the sampling cups (plants, BSCs, stones and bare soil). The MLs and the field installation were tested for: (1) input signal; (2) sample dimensions with two different soil types; (3) load cell temperature dependence; and (4) effectiveness of the field installation strategy. MLs data for 49 days (May–June 2012) were analyzed and their daily signal and the possibility of differentiating between WVA and dew were verified. Furthermore, the sensitivity of the MLs in differentiating NRWI and evaporation on different cover types was also studied.

2. Materials and methods

2.1. Study site

Most of the measurements were conducted at Balsa Blanca, but El Cautivo field site was also used for Test_2.

Balsa Blanca is a Mediterranean coastal steppe ecosystem in Almería, SE Spain (36°56′30″ N, 2°1′58″ W, 208 m a.s.l.). This site, which is one of the driest ecosystems in Europe, is located in the Cabo de Gata-Níjar Natural Park. Balsa Blanca is in the Níjar Valley catchment, 6.3 km away from the Mediterranean Sea. Vegetation is sparse and dominated by *S. tenacissima*. The mean annual air temperature is 18 °C and the long-term average rainfall is 220 mm (historical data recorded by the Spanish Meteorological Agency (1971–2000); www.aemet.es). The predominant soils are thin, with varying depths (about 30 cm at most, average 10 cm), alkaline, saturated in carbonates, with moderate stone content, frequent rock outcrops (Rey et al., 2011) and with a sandy loam texture. For further information of the study site, see Uclés et al. (2013).

The study site at El Cautivo was used for testing our second hypothesis (Test_2). El Cautivo field site is a badlands ecosystem located in the Sorbas-Tabernas basin in Almería, SE Spain (N 37°00′37″, W 2°26′30″). Soils are silty loam, affected by surface crusting processes (Cantón et al., 2003), and in general soil is less developed and organic matter content is lower than in Balsa Blanca soils.