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Partitioning of non rainfall water input regulated by soil cover type

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ABSTRACT

In arid and semiarid environments, where precipitation is scarce and mainly limited to the wet season of the year, the water contribution by non-rainfall water inputs (NRWI) may play a significant role in the water balance. Natural ecosystems are heterogeneous with a great variety of surface covers, such as stones, biological soil crusts (BSC), bare soil, trees, shrubs and other plants. To be able to understand the role that NRWI may have in a system, all the surface types involved and all the NRWI sources (fog, dew and water vapour adsorption) should be differentiated, analyzed and studied separately. This manuscript study NRWI on different cover surfaces of the soil in a natural coastal-steppe ecosystem. Automated microlysimeters were located in the field containing small *Macrochloa tenacissima* plants, bare soil, stones and biological soil crusts. Daily changes in the water content of the samples were registered. The different sources of NRWI were differentiated and their partial contributions to the total NRWI and to the daily evaporation were analyzed.

Each cover type showed a different response in the presence of NRWI and these responses were also dependent on the NRWI source. In turn, the surface cover influenced the subsequent evaporation the day after. The number of dew events varied with the surface cover type and water vapour adsorption occurred all days in all the covers, alone or preceding a fog or a dew event. Dew represented the main NRWI source in plants and stones, while water vapour adsorption was the main input in bare soil and BSC. Fog was a minor component of the NRWI during the study period and its partial contribution to the total input was similar for all the cover types. NRWI satisfied a great part of the evaporation in the sample, especially in plants and stones.

1. Introduction

Free liquid water on the Earth's surface can come from the soil (dew rise), the plants (guttation) and the air (fog, dew, and soil water vapour adsorption) (Garratt and Segal, 1988). This last source has been called non-rainfall atmospheric water input (NRWI) and has been studied because of its role in the water budget of arid and semiarid ecosystems. Fog occurs when the atmospheric water vapour concentration reaches saturation and a mass of condensed water droplets remains suspended in the air. These droplets can be later intercepted by a surface. Dew forms when the temperature of a surface is lower or equal to the dew point temperature and water directly condenses on it. When this temperature condition is not satisfied and the relative humidity of the air is higher than the relative humidity of the pores in the soil, a water vapour gradient from the atmosphere to the soil is created and water is added to the soil by water vapour adsorption (WVA).

Dew can play a significant role in arid and semiarid regions because of its influence in the water balance (Hao et al., 2012; Jacobs et al., 1999; Moro et al., 2007; Uclés et al., 2013b; Veste et al., 2008). Dew may alleviate water stress on plant leaves in the early morning (Sudmeyer et al., 1994) and some desert plants can use dew as a water source (Ben-Asher et al., 2010; Evenari et al., 1971). It has been reported the influence that dew has on some desert animal communities (Broza, 1979; Moffett, 1985; Steinberger et al., 1989), and in the development of biological soil crusts (del Prado and Sancho, 2007; Kidron et al., 2002; Lange et al., 1992; Pintado et al., 2005; Rao et al., 2009). WVA contributes a significant amount of water to the soil, affecting its properties and hence the radiation and energy balance (Verhoef et al., 2006) and it can supply plants with water vital to its survival in seasons with a severe water deficit (Ramirez et al., 2007). Fog may play an important role in the hydrological cycle of some ecosystems (del-Val et al., 2006; Hamilton and Seely, 1976) and can be considered a vital water source for endemic flora and fauna (Seely, 1979).

Natural ecosystems are heterogeneous with a great variety of surface covers, such as stones, biological soil crusts (BSC), bare soil, trees, shrubs and other plants. Some studies can be found in the bibliography about NRWI deposition in different surfaces using microlysimeters but they do not differentiate between dew, fog and WVA. Furthermore, because of the difficulty on measuring NRWI on plants, they mainly focus on BSC and bare soil (Liu et al., 2006; Maphangwa et al., 2012; Pan et al.,

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2010) or in bare soil and mulching (Graf et al., 2004; Li, 2002). Only a few studies can be found regarding the vegetation contribution to the NRWI of a system (Uclés et al., 2013a, 2013b) and they stated that plants and shrubs can play a significant role in the NRWI. Indeed, Uclés et al. (2013b) found that plants contributed with a 64% of the dew deposition in a semiarid ecosystem, pointing out the significant role that vegetation may have in NRWI. Different scenarios occur in bare soils, since several studies found that dew is a rare occurrence on them, and that WVA is the main NRWI in this surface cover (Agam et al., 2004; Kaseke et al., 2012; Pan et al., 2010; Uclés et al., 2013a). On the contrary, dew deposition can be a significant water source in BSC compared with bare soils (Maphangwa et al., 2012; Zhang et al., 2009) and some lichen species have proven to intercept sufficient water from fog and dew to sustain positive net photosynthesis for a considerable portion of the day (Lange et al., 2006). Hence, each cover type shows a different response in the presence of NRWI and these responses are also dependent on the NRWI source; dew, fog or WVA. Therefore, to be able to really understand the role that NRWI may have in an ecosystem, all the surface types involved and all the NRWI sources should be differentiated, analyzed and studied separately. But no bibliography can be found about these responses in the different cover types and over dew, fog and WVA conditions.

This study aims to evaluate the differences in NRWI on different cover surfaces of the soil (plants, stones, BSC and bare soil) in a natural ecosystem using automated microlysimeters. We hypothesize that the different sources of NRWI (fog, dew and WVA) contribute differently to the total NRWI and to the daily evaporation of the surface cover. In turn, the surface cover may also influence the NRWI at night and the subsequent evaporation the day after. Hence, the different sources of NRWI (fog, dew and WVA) are differentiated and their partial contributions to the total NRWI and to the daily evaporation of the sample are analyzed.

2. Material and methods

2.1. Study site

The Balsa Blanca experimental field site is a coastal-steppe ecosystems and it is one of the driest areas in Europe. It is located only 6.3 km away from the Mediterranean Sea, in the Cabo de Gata-Níjar Natural Park in Almería, Spain (36°56′30″N, 2°1′58″W, 208 m a.s.l.). Vegetation is sparse and dominated by *Macrochloa tenacissima* (=*Stipa tenacissima*, alpha grass) combined with bare soil, stones and biological soil crusts in the open areas. Its mean annual air temperature is of 18 °C and its long-term average rainfall is 220 mm, mainly in winter (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).

For further information about the site, see Uclés et al. (2013b) and Rey et al. (2011).

2.2. NRWI measurement method and data analysis

There is not a standard method or instrument internationally accepted for measuring NRWI, but there has been an increased use of microlysimeters in the last years since they are able to register the different NRWI sources (fog, dew and WVA) in an undisturbed natural surface. In this study, the NRWI amounts were measured by automated microlysimeters (MLs) and their construction, field installation and sample dimensions were done following Uclés et al. (2013a). The MLs were constructed using a single-point aluminum load cell (model 1022, 0.013 × 0.0026 × 0.0022 m, Vishay Tedea-Huntleigh, Switzerland), and the PVC sampling cups were 0.15 m diameter and 0.09 m deep. Field calibrations were successfully made twice a month using standard loads and they had a satisfactory resolution of 0.1 g (0.0055 mm).

Nine automated microlysimeters (MLs) were located in the field. Three microlysimeters contained small *M. tenacissima* plants, and the other six microlysimeters contained undisturbed soil samples with different surface covers: 2 MLs with bare soil, 2 MLs with stones and other 2 MLs with biological soil crusts (BSC). Plants had a Leaf Area Index (LAI) of around 0.4 $m^2 m^{-2}$, and were 0.2 m wide and 0.3 m high. Stones were embedded in the soil and covered the 40% of the sample surface. BSCs consisted of cyanobacteria and lichens (mainly *Diploschistes diacapsis* and *Squamarina lentigera*) and covered the 100% of the sample.

Daily changes in the water content of the samples were analyzed. Negative changes in mass in the MLs corresponded to ET and positive changes to NRWI, which was calculated as the difference in weight between the night-time maximum and the minimum of the day before. Since the plant and stone samples did not cover the 100% of the surface, some bare soil was directly exposed to the atmosphere and the MLs registered also its NRWI. Hence, in the NRWI calculations of the plant and stone samples, the water amount from bare soil was removed proportionally to its surface cover in the sample using the information provided by the bare soil samples. Hence, the NRWI was referred by the real surface cover of each cover type. It is worthy to mention that the *M. tenacissima* plants in the area were bigger than the plants used in these samples. No bigger plants could be selected because of the limitation in the capacity rate of the load cell. Nevertheless, this study raises interesting results in the comparison of NRWI between plant and no plant surfaces.

The different NRWI sources for each cover type were also differentiated (dew, fog and WVA). The surface temperature of each of the cover types was compared with the dew point temperature of the air to differentiate between dew and WVA. The surface temperatures were monitored with thermocouples. They were buried 2–3 mm in the soil for the monitoring of the BSC and bare soil temperatures (0.2 mm wire core diameter; Thermocouples Type TT-TI-24-SLE, Omega Engineering, Broughton Astley, UK). In the case of stones, thermocouples were inserted into thin fissures of the rock and covered with isolated adhesive tape to avoid the direct insolation from the sun. In the plants, a thinner thermocouple was used (0.13 mm wire core diameter; Thermocouples Type TT-T-36-SLE, Omega Engineering, Broughton Astley, UK) and it was located inside the fold of the *M. tenacissima* leaf to avoid the direct insolation from the sun and to minimize the air temperature influence. Finally, a fog event was determined when the relative humidity of the air (*RH*) was over 99% and the beginning of a fog event was also corroborated by wetness sensors (model 237, Campbell Scientific, Logan, UT, USA).

Air temperature and *RH* were monitored at a height of 0.5 m by a thermo-hygrometer (HMP45C, Campbell Scientific, Logan, UT, USA) with an accuracy of ±3% *RH* (90 to 100% RH) and rainfall was measured by a tipping bucket rain gauge (ARG 100, Campbell Scientific, Logan, UT, USA). MLs and meteorological data were recorded at 15-second intervals and averaged every 15 min by dataloggers (CR1000, Campbell Scientific, Logan, UT, USA). The study was developed during 74 days (Doy 121–195, year 2012) and only one small rainfall event occurred during this period (Doy 170, 1.2 mm).

An estimation of the contribution of each cover type to the total NRWI in the ecosystem was done as follows. The specific amounts calculated with the MLs' samples for each cover type were extrapolated to the total ecosystem using their ecosystem coverage in the case of bare soil (2.3%), BSCs (20.8%) and stones (12.2%). As referred before, the plants used in this study were smaller than the plants presented in the area. For this reason, the NRWI in these plants was calculated in terms of liters of water in m^2 of leaves using the LAI of each plant. After that, the contribution of plants to the entire ecosystem was estimated using the ecosystem LAI (0.46, 0.32, 0.19 and 0.14 in April, May, June and July, respectively) which was calculated from the extrapolation of the canopy LAI to the vegetation cover using the linear relation