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Non-rainfall water inputs are controlled by aspect in a semiarid ecosystem

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ABSTRACT

Differences in vegetation pattern between slope aspects in semiarid environments are well known, with shaded aspects presenting a higher biomass. The micrometeorological and soil conditions involved in non-rainfall water inputs (NRWI), comprising dew and water vapour adsorption (WVA) were compared between two contrasted slopes and different environmental conditions (wet and dry periods). Changes in natural soil surfaces were measured using automated microlysimeters, and the partial contributions of dew and WVA to the total NRWI were clarified. Dew amounts were higher on the northeast facing slope and were directly related to dew durations. Differences in dew deposition between slopes were mainly driven by insolation patterns, which controlled the surface temperatures, the soil water content and, in turn, dew duration. Apart from spatial variation in microclimate, WVA deposition was higher in the southwest facing slope due to its higher clay content and electric conductivity and because of its lower soil water content. Water vapour adsorption was directly governed by the relative humidity amplitude in summer (with dry soil) but not in winter. A significant amount of water evaporation was satisfied by NRWI, reaching 100% in dry periods and being WVA the main input.

1. Introduction

The non-rainfall water input (NRWI) composed of fog, dew and water vapour adsorption (WVA) may play a significant role in the water balance of arid and semiarid environments, where water availability is an important limiting factor. Fog consists of the condensation of water droplets in the air because of saturation of the water vapour concentration. Dew forms when vapour water is directly condensed on a surface because of its lower surface temperature compared with the dew point temperature of the air. Finally, WVA occurs when this temperature condition is not achieved and the water uptake by the soil is governed by a gradient in the water vapour pressure between the soil and the free atmosphere.

Dew has been studied in arid and semiarid environments because of its significant role in the water budget (Jacobs et al., 1999; Uclés et al., 2013b). It is also an important water source for animals (Steinberger et al., 1989), plants (Ben-Asher et al., 2010) and biological soil crusts (del Prado and Sancho, 2007; Lange et al., 1997; Pintado et al., 2005). Consequently, many attempts have been made to quantify dew in arid and semiarid environments. Its low amount and the difficulty in measuring it have resulted in the use of a great variety of methods, not always comparable, such as theoretical models (Kalthoff et al., 2006; Uclés et al., 2013b) or artificial condensing surfaces (Duvdevani, 1947; Kidron, 2000; Zangvil, 1996). Theoretical methods are often difficult to implement and require a great amount of data input, while artificial surfaces are easier to implement but under- or over-estimate dew, because their surface properties are different from natural ones. In the past few years, manual (Jacobs et al., 2000; Ninari and Berliner, 2002) and automated microlysimeters (Heusinkveld et al., 2006; Kaseke et al., 2012; Uclés et al., 2013a, 2013b) have been used more frequently in dew studies, which is advantageous, because measurements are made over natural surfaces. In addition, microlysimeters not only register dew but also WVA, which contributes a significant amount of water to the soil (Kosmas et al., 1998), affecting its surface properties and hence the radiation and energy balance (Verhoef et al., 2006). Water vapour adsorption may also supply water to vegetation that can be vital to its survival in seasons with a severe water deficit, giving rise to a close relationship between soil water

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dynamics and plant water response, and playing a significant role in the stomata conductance and transpiration of vegetation (Ramirez et al., 2007). Its theoretical quantification, e.g. by use of the aerodynamic diffusion equation (Milly, 1984), requires a great amount of meteorological and soil data, which can be difficult to obtain. Some attempts have also been made using empirical equations based on meteorological factors, such as the daily relative humidity amplitude (Kosmas et al., 1998) or the soil evaporation of the day before (Agam and Berliner, 2004), but these equations may lead to inaccurate estimates of WVA when used for a site or season different from the one for which the equation parameters were derived (Verhoef et al., 2006). Microlysimeters have become the most used WVA quantification method and some studies have reported WVA as the predominant input vector in bare soils in arid and semiarid environments (Agam and Berliner, 2004; Kaseke et al., 2012; Pan et al., 2010).

NRWI (mainly dew) have been measured in several arid and semiarid environments, but few efforts have already been made to study its variability among habitats, such as different slope aspects. There are differences in the vegetation pattern between sun-facing and shaded slopes in semiarid environments because they are exposed to different micrometeorological conditions. Normally, the shaded slopes present a higher biomass (Jacobs et al., 2000; Kappen et al., 1980; Kidron, 2005; Lázaro et al., 2008) as a result of the differences in solar radiation, which affects soil properties and, in turn, vegetation and fauna (Kutiel and Lavee, 1999). A few authors have examined differences in the deposition of dew between aspects, but unfortunately, none of them has studied WVA, and in many cases their results were contradictory. Studies using the cloth plate method (CPM) have reported that aspect controls dew precipitation in the Negev with higher dew depositions in the shaded (northwest) than in the sun-facing (southeast) aspects (Kidron, 2005; Kidron et al., 2000) and with the lowest dew amounts in the wadi bed (Kidron et al., 2000). Other studies in the Negev, however, using microlysimeters have shown a different pattern, with higher dew depositions in the sunny slopes (Jacobs et al., 2000) and with the highest dew amounts in the wadi bed (Heusinkveld et al., 2006). Furthermore, these studies were developed during or after the dry season (summer or autumn) but no data in the wet season or with wet soil are available in the literature. Dew and WVA are different processes to study, and their relationship with the micrometeorological variables and soil properties should be examined separately and in different seasons.

We hypothesized that WVA would play an important role in the NRWI and could account for the observations of differences in NRWI amounts between different aspects. We present a study of the water uptake by soil using natural surfaces in a badland ecosystem (El Cautivo, Southeast Spain) characterized by contrasting vegetated (dwarf shrubs, biocrusts, annual plants and grasses) north-to east-facing slopes and bare and eroded south-to west-facing slopes. Non-rainfall water input sources (dew and WVA) and their partial contributions to the total NRWI are differentiated and compared between these two contrasted aspects using automated microlysimeters in a wet and a dry periods.

2. Material and methods

2.1. Study site

The El Cautivo field site is a badland ecosystem located in the Neogene–Quaternary Sorbas-Tabernas basin in Almería, Southeast Spain (N37°00′37″, W2°26′30″). The site is surrounded by several ranges that are around 2000 m a.s.l.: Sierra de Gádor, Sierra Nevada, Sierra de Filabres and Sierra Alhamilla. Altitude in the study site varies from 247.5 to 382.5 m a.s.l. Several studies related to its geomorphological, hydrological and erosion properties have been carried out at the site (Cantón et al., 2004; Lázaro et al., 2008). The climate is semiarid thermo-Mediterranean, with a mean annual temperature of 17.8 °C and a mean annual rainfall of 235 mm, mostly in winter, as recorded over a 30 years period (1967–1997) in Tabernas (5 km from the site) (Lázaro et al., 2001). The predominant wind directions in the site are northwest in winter and southeast in summer (Lázaro et al., 2004). The most obvious features of these badlands are their vegetation pattern: northeast-facing slopes (*NEF*) are covered by vegetation: grasses, dwarf shrubs, annuals and an important cover of biological soil crusts (BSC) including many species of terricolous lichens (*Diploschistes diacapsis*, *Squamarina lentigera*, *Lepraria isidiata*) and often patches dominated by cyanobacteria, while southwest facing slopes (*SWF*) have a less developed soil, a minor vegetation and BSC cover (*D. diacapsis*, *Fulgensia desertorum*, *Endocarpon pusillum*) and were formerly bare and eroded (Lázaro et al., 2008). The average cover is 38% plants and 55% BSC in the *NEF slopes* and 2% plants and 18% BSC in the *SWF* slopes. Soils on both slopes have a silty loam texture but their composition and electric conductivity vary: 20.9% clay, 60.8% silt, 15.9% fine sand, 2.4% coarse sand and 0.029 dS m^{-1} in the *NEF* slopes; and 24.0% clay, 63.8% silt, 12.0% fine sand, 0.2% coarse sand and 0.061 dS m^{-1} in the *SWF* slopes (Cantón et al., 2003).

2.2. Meteorological measurements

The micrometeorological and soil conditions involved in dew and WVA depositions are studied and compared between the two contrasted slopes. The mean micrometeorological variables that were monitored were: insolation, relative humidity, wind velocity, soil water content, dew point temperature and air and soil surface temperatures. Both slopes in the experimental area were equipped with two micrometeorological stations. Each of them was composed by:

Soil thermocouples (TCAV, Campbell Scientific, Logan, UT, USA) which averaged temperature was used to correct the soil water content (CS616, Campbell Campbell Scientific, Logan, UT, USA). Air temperature and relative humidity (*RH*) were monitored at a height of 0.5 m by a thermo-hygrometer (HMP45C, Campbell Scientific, Logan, UT, USA). Rainfall was measured by a tipping bucket rain gauge (ARG 100, Campbell Scientific, Logan, UT, USA) and wind speed was measured at a height of 0.5 m (A100L2, Campbell Scientific, Logan, UT, USA). Soil surface temperature (T_s) in both slopes was monitored by thermocouples buried 0.002–0.003 m deep (Type T, Thermocouples, Omega Engineering, Broughton Astley, UK). Total monthly potential insolation as well as the monthly duration of direct incoming solar radiation were calculated for each slope under clear sky conditions using the Solar Radiation tool in ESRI® ArcMap 10.1 and based on a 1 m resolution Digital Elevation Model obtained from an airborne light detection and ranging (LiDAR) survey with a resolution of 4 height points per square metre.

2.3. Microlysimeters measurements

Two automated microlysimeters (ML) were located at each aspect to register the water changes in the uppermost soil layer. The undisturbed soil samples were taken from the respective slopes. The samples surfaces were largely covered by biocrusts (mainly lichens) and by some cyanobacteria and bare soil. The selected soil samples had a similar biocrust cover to minimise the influence of the variability of their cover or composition in the study. It was assumed that differences in the crust cover or composition were negligible and that differences in NRWI in the ML between slopes