Atmospheric Research 151 (2015) 101–109

Contents lists available at ScienceDirect

Atmospheric Research

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

The role of dew in the monsoon season assessed via stable isotopes in an alpine meadow in Northern Tibet

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A R T I C L E   I N F O

Article history:
Received 12 September 2013
Received in revised form 22 January 2014
Accepted 18 February 2014
Available online 28 February 2014

Keywords:
Kobresia pygmaea
Dew
Meadow degradation
Water cycle
Ecosystem
Stable isotope

A B S T R A C T

Rain in the summer monsoon season is the main water input for the water cycle in the alpine meadow ecosystem of Northern Tibet, however, dew has been observed frequently in Nagqu, especially during consecutive dry days. Under climate change and human disturbance, degradation of the meadow leads to surface property changes and these may affect dew formation. The amount of dew formed on top of the vegetation surface was therefore measured on normal *Kobresia pygmaea* meadow and partly-degraded crusted meadow soil for 12 dew days in the 40 observation days from early-July to mid-August in 2011. The converted average daily dew depth was significantly higher on the normal meadow and the average of 0.15 mm/night was three times that on the degraded surface between 20:00 and 7:00. To qualitatively identify the role of dew in the local water cycle, water samples from atmospheric water vapour, rain, creek water and groundwater were collected in July and August of 2011 for the analysis of stable water isotopes using the isotope ratio infrared spectroscopy method (IRIS); the vapour samples were collected by cryogenic trapping. It is shown in a δD–$\delta^{18}O$ space that the dew contains water that has been terrestrially recycled by evapotranspiration. This research takes an initial step to see the impact of meadow degradation on dew formation, with regard to its formative conditions and moisture source, suggesting that dew may be an active water source for meadow growth and hydrological processes during summer dry spells on the high plateau.

1. Introduction

Dew is usually considered a minor component of the water balance; however, much research has identified its significance in the local water balance in arid and semiarid environments during certain periods of the year (Sun et al., 2008; Moro et al., 2007; Jacobs et al., 1999). In the natural ecosystem, dew is supposed to be a major or even the only water source for plant growth in semi-arid and arid areas, where the amount of rainfall is minor and evaporation is high (Jacobs et al., 1999). As an important water input, dew plays a role in physiological activities in the plant such as facilitating seed germination (Gutterman and Shem-Tov, 1997), improving photosynthesis (Rao et al., 2009), mediating water status in plant under water stress (Munné-Bosch and Alegre, 1999), and providing moisture directly to leaves and to biological soil crusts (Stone, 1957; Sun et al., 2008).

Usually, direct condensation of atmospheric water vapour is considered to be true dew (dew or condensation as will be the focus of this study), because it brings a net gain of water to the soil–plant–water system, compared to guttation from leaves and distillation of soil water (Monteith, 1957). As a physical phenomenon, it is a process of phase transformation resulting from nocturnal radiative loss of heat from the soil–vegetation surface when temperature drops below the dew point of the

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http://dx.doi.org/10.1016/j.atmosres.2014.02.014
0169-8095/

ambient air, accompanied by latent heat (LE) release. Thus, dew is favoured when radiative cooling is the dominant mechanism of surficial heat loss (Richards, 2004). In the following morning, evaporation of dew directly from the canopy or the bare soil surface after prior dew infiltration involves exchange of latent-heat flux between the land surface and the atmosphere (Pitacco et al., 1992; Agam and Berliner, 2006; Zhang et al., 2009), which is the other part of the diurnal cycle of water and energy flux opposite to dew formation.

In arid and semi-arid regions the amount of dew can reach and even exceed other forms of precipitation for an extended period, or even the whole year (Kalthoff et al., 2006); research in humid areas also finds that dew may be the biggest component over periods from a few days to a month (Tuller and Chilton, 1973), although it only contributes a small percentage to the annual precipitation. However, there has not been much attention paid to dew in the cold alpine area of the Qinghai-Tibetan Plateau.

The Qinghai-Tibetan Plateau has a major impact on the large-scale circulation and its hydrological impact goes far beyond its boundary (Park et al., 2011). In Northern Tibet, *Kobresia* meadow, dominated by species from this genus of sedge family (sometimes called bog sedge), is widely distributed as an important alpine ecosystem that both maintains the environment and provides pasture resource for local Tibetans (Miehe et al., 2008). This area has a characteristic geomorphology consisting of mountain-ringed basins with lakes and rivers. The hydrological process in these mountain–basin units is partially closed, with a daily exchange of moisture between the mountain and the basin (Kurita and Yamada, 2008). In the plant growth season, the Indian Monsoon brings in moisture to provide ample precipitation; however, there are frequent dry days and dry spells even during the monsoon season, causing a temporary lack of water provision for the vegetation. Dew usually occurs from May to September during dry spells, especially under a strong cooling condition when the atmospheric moisture is high but no rainfall forms. Therefore, it acts as an alternative water source for the alpine meadow when rainfall ceases, and has its own advantages in this ecosystem (Zhang et al., 2011): the direct absorption of dew formed on the surface of leaves can decrease the internal water loss; it helps to reduce the surface tension between soil and water to allow water to penetrate easily to reach the plant roots; and it is more evenly distributed both spatially and temporally during the dewfall period, than rainfall, and does not cause oversaturation and soil erosion, which is critical for *Kobresia* meadow where degradation is serious. Degradation can be manifested as changes of plant community structure and function, as well as reduction in soil water and nutrients (Li et al., 2011). It is possible that the formation of dew will be reduced on degraded meadow surface, so that the following evaporation of dew to form rain, and the subsequent recharge of soil moisture, may be affected. Therefore, this study takes an initial step to quantify the amount of dew in the *Kobresia* meadow to assess the role of dew during the monsoon season; to analyse moisture recycling through dew formation with respect to local water components; and to assess the potential impact from meadow degradation on the hydrological cycle of this *Kobresia* meadow landscape.

2. Experimental methods

2.1. Study area

The studied *Kobresia* meadow is located in Kema Village in Nagqu County in Northern Tibet (32°16′N, 92°06′E), where the average altitude is 4470 m. Kema is in the Nagqu River Basin, which lies between the Tanggula Mountains in the north and the Nyainqêntanglha Mountains in the south, forming a mountain–basin unit (Fig. 1). It is in a sub-frigid semi-humid monsoon climate zone (Fig. 2). The temperatures are low and the diurnal variation in daily temperature is significant. According to the records from Nagqu Meteorological Station (31°19′ N, 92°04′ E), the mean annual temperature is −1 °C, the mean annual precipitation is 432 mm and the mean annual humidity is 52%. The rainy season from May to September brings warm and humid climatic conditions and provides about 89% of the annual precipitation in this region.

The dominant plant species at the study site is *Kobresia pygmaea*, which is a typical Chinese-Himalaya plant and the smallest of the High Asian Cyperaceae (Zhou, 1982), mostly growing no taller than 2 to 3 cm but dominating vegetation mats with 90% cover or more. This meadow provides the best summer and autumn grazing for sheep and yaks in Nagqu due to its high foraging value and easy access. Overgrazing, droughts and rodents are all thought to be implicated in the severe degradation.

Two plots, one of normal *Kobresia* meadow and one of degraded compact crust surface are chosen to represent two contrasting situations for observation of the soil–vegetation–hydrology combination (Fig. 1). The plots are unbounded sampling sites each of ca. 25 m^2 in area and are located to the south of the Nagqu River on a gentle hill slope facing NNW. The normal meadow plot is within an area of 3.2 ha in the middle part of a gentle slope which is preserved behind a fence, and the degraded crust plot is outside the fence only about 10 m from the first plot, down the slope on a slightly steeper gradient.

Normal *Kobresia* meadow has a dense plant cover that can reach 90%, dominated by *K. pygmaea*. It has a height of about 1–3 cm and has a litter layer on the soil surface. A typical turf layer (Afe) forms to a thickness of around 18 cm, with roots concentrated mostly in the upper 10 cm. Root density decreases down the profile to about 20 cm. There is coarse gravel beneath the surface from a depth as shallow as 20 cm. In addition to *K. pygmaea*, other monocotyledons include Carex spec., Festuca spec., Poa spec., *Stipa purpurea*, Trisetum spec., and *Kobresia humilis*. Other perennial herbs include *Aster flaccidus*, Iris spec., *Lancea tibetica*, *Potentilla saundersiana*, *Potentilla bifurca*, *Potentilla fruticosa* v. *pumila*, Ranunculus spec., *Thalictrum alpinum*, *Oreosolen wattii*, *Saussurea graminea*, *Lamiophlomis rotata*, *Lagotis brachystachya* and *Oxytropis glacialis*.

The crusted meadow has a polygonal crack-like pattern. On some moist parts of the surface there are mosses growing. Clusters of *K. pygmaea* look distinct on the black background, and there is no litter layer. The height of *K. pygmaea* is usually 1–2 cm, and the coverage is diverse depending on the different degrees of degradation, although in most cases it does not exceed 40%. Other species include *P. saundersiana*, *P.*