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Relationship between dew presence and *Bassia dasyphylla* plant growth

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Abstract: Dew has been recognized for its ecological significance and has also been identified as an additional source of water in arid zones. We used factorial control experiment, under dew presence in the field, to explore photosynthetic performance, water status and growth response of desert annual herbage. *Bassia dasyphylla* seedlings were grown in contrasting dew treatments (dew-absent and dew-present) and different watering regimes (normal and deficient). The effects of dew on the water status and photosynthetic performance of *Bassia dasyphylla*, grown in a desert area of the Hexi Corridor in Northwestern China, were evaluated. The results indicated the presence of dew significantly increased relative water content (RWC) of shoots and total biomass of plants in both water regimes, and enhanced the diurnal shoot water potential and stomatal conductance in the early morning, as well as photosynthetic rate, which reached its maximum only in the water-stressed regime. The presence of dew increased aboveground growth of plants and photosynthate accumulation in leaves, but decreased the root-to-shoot ratio in both water regimes. Dew may have an important role in improving plant water status and ameliorating the adverse effects of plants exposed to prolonged drought.

Keywords: dew; *Bassia dasyphylla*; water status; photosynthesis performance; biomass allocation pattern

In dryland environments, precipitation usually occurs in short events (Loik *et al*., 2004), and large precipitation events are fewer during drier periods. The presence of dew provides an additional moisture source for animals, plants and human beings, especially in extreme drought environments (Shachak and Steinberger, 1980; Munné-Bosch *et al*., 2010), and may be critical for drought avoidance of plants under drought conditions when the amount of moisture in the soil declines. The ecological significance of dew for plants in arid regions has long been recognized (Stone, 1957 a, b; Li, 2002; Zhang *et al*., 2009), and its ecological effects on plants have been the focus of research during the past 250 years. Researchers have focused on the distribution of dew (Duvdevani, 1947; Kidron, 1998, 1999; Kidron *et al*., 2000), physiological response of plants to dew as well as growth and survival response of the plants to presence or absence of dew (Stone, 1957a, b; Grammatikopoulos and Manetas, 1994; Boucher *et al*., 1995; Barradas and Glez-Medellin, 1999; Breshears *et al*., 2008; Munné-Bosch, 2010).

The ecological significance of dew for the survival of plants, especially water-stressed plants, has been studied by a number of researchers (Stone 1957a, b; Grammatikopoulos and Manetas, 1994; Boucher *et al*., 1995; Munné-Bosch *et al*., 1999). Plants benefiting from dewfall include coniferous species, rainforest trees, presaharian plants and Mediterranean plants. Dew has been shown to improve the survival of tree species (Stone, 1957a, b; Barradas and Glez-Medellin,

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1999) and reduce plant transpiration rate (Stewart, 1977). Dew also helps many trees (such as *Citrus*, tropical deciduous trees and *Pinus strobus*) and food plants (such as watermelon, cucumber and beans) recover from water stress (Stone, 1957b; Duvdevani, 1964; Boucher *et al*., 1995; Clus *et al*., 2008). Dew events in arid regions have also been shown to improve water relations of two evergreen shrubs (Munné-Bosch *et al*., 1999).

Plants' response to natural environments can be evaluated by the daily patterns of CO_2 assimilation rates, stomatal conductance, and other water-related parameters (Schulze and Hall, 1982; Quick *et al*., 1992; Chaumont *et al*., 1997). Several studies, taking these parameters into account, have found evidence that dew uptake of leaf improves the water status of plants (Katz *et al*., 1989; Yates and Hutley, 1995). The application of simulated dew events demonstrated directly absorbed dew by hairy leaves and this phenomenon prevented the depression of photosynthetic capacity associated with drought, and led to the recovery of normal water content of plants in drought situations (Grammatikopoulos and Manetas, 1994). Although leaf uptake of dew has been demonstrated in many plant species (Stone and Fowells, 1955; Waisel, 1958; Stark and Love, 1969; Grammatikopoulos and Manetas, 1994; Boucher *et al*., 1995), the ecological significance of this natural phenomenon still remains controversial (Stone, 1963). Monteith (1963) hypothesized that the dew on leaf's surface would evaporate too rapidly to significantly affect internal water content of plants. In principle, if ample water is supplied through roots, the small amount absorbed by leaves would not make a significant contribution to plant fitness. In arid environments with frequent dewfall, however, water obtained from leaf uptake, even though it is not transported to the root zone, has been shown to dramatically benefit plants (Grammatikopoulos and Manetas, 1994). Several experiments on the effects of dew on plant growth have also been performed. Duvdevani (1964) reported that stem length, number of living leaves, total number of leaves per fruit, and total number of mature fruits increased for cucumbers exposed to dew. Breazeale *et al*. (1953) showed that leaf uptake of dew by tomato plants stimulated root growth. Stone *et al*. (1956) demonstrated that water stress imposed on the roots of *Pinus ponderosa* was diminished by the dew uptake of leaves. Boucher *et al*. (1995) reported that artificial dew significantly increased seedling root growth.

In spite of the special ecological role of dew in plants, little research has been conducted to explore the dew uptake by leaves of annual desert plants and dew effects on the plant photosynthesis and water status in the arid regions of China. Additionally, previous studies were carried out in greenhouses or applied the method to simulate dew events, but few studies have used natural dew events to investigate the ecological role of dew for annual desert plants and the response of plants to dewfall in the field. The study explored the photosynthetic, water status and growth response of desert annual herbage to dewfall in the field. Much emphasis is given to the ecological importance of dew for plant survival in drought environments and how this phenomenon modifies diurnal plant water status and photosynthetic capacity. We tested the hypotheses that the presence of dew is able to relieve drought through improving the plant water status and photosynthetic performance by a control experiment.

1 Materials and methods

1.1 Study area

The experiment was carried out in Linze Inland River Basin Research Station (100°07′E, 39°21′N) on the edge of the Linze Oasis which lies at the middle reaches of the Hexi Corridor in Northwest China. This region has a temperate continental climate, characterized mainly by drought, high temperature and frequent strong winds (Fig. 1). The mean annual temperature is 7.6°C, the maximum 39.1°C occurs in July and the minimum –27°C appears in January. The average annual precipitation is 117 mm, with 65% concentrating between July and September. The mean annual potential evaporation and total number of sunlight hours are 2,390 mm and 3,045 h, respectively. The soils are characterized by sandy soil, sandy loam and grayish brown desert soil. Generally, dew occurs most frequently at the end of summer or in the beginning of autumn (Zhao *et al*., 2010).

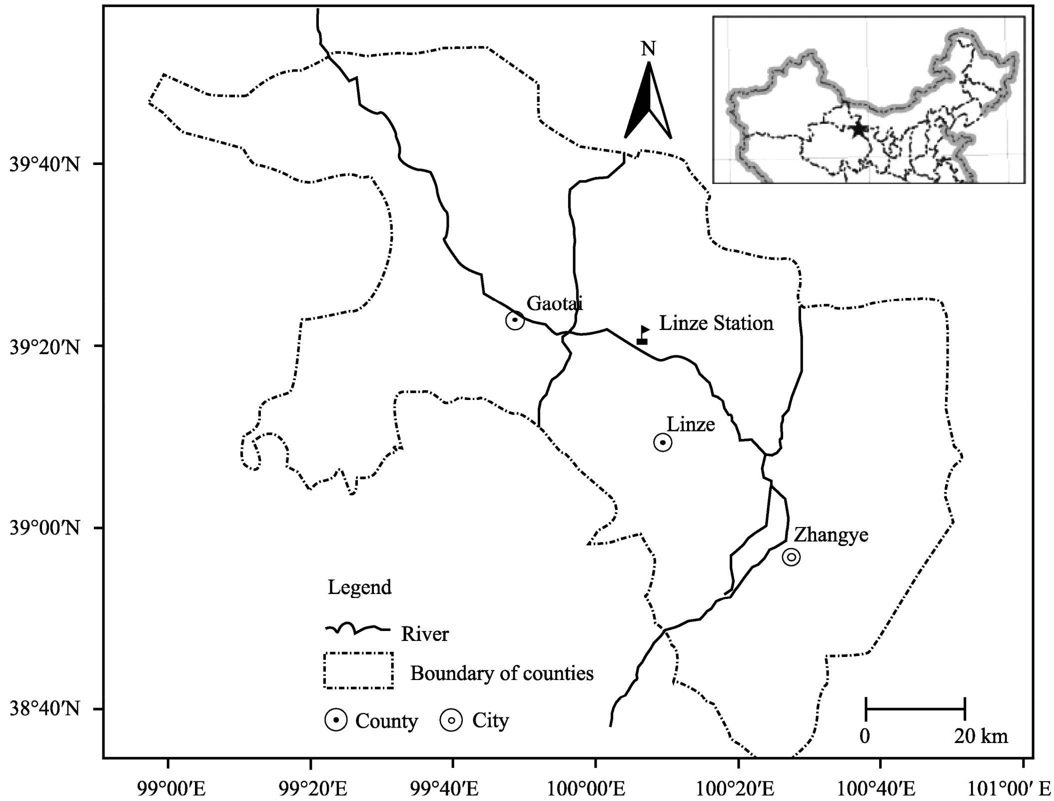

Fig. 1 Schematic map of the study area

1.2 Plant species

Bassia dasyphylla (Fisch. et Mey.) O. Kuntze is the dominant annual plant growing on fixed and semi-fixed dunes and is well adapted to local climate. Seedlings and adult plants of the species are adapted to sand burial. The presence of hairs on the adaxial surface of leaves is a typical morphological characteristic of this plant. Generally, *Bassia dasyphylla* relies on precipitation for its water need. However, the majority of precipitation in arid and semiarid regions occurs as small events, especially in drier periods. In our study region, over half of the precipitation events are less than 5 mm (Zhao *et al*., 2010). Therefore, additional moisture source can be significant for *Bassia dasyphylla* during dry periods, when water stress is stronger. The importance of dew on the survivability of *Bassia dasyphylla* needs to be taken into consideration.

1.3 Experimental design

In the beginning of May, *Bassia dasyphylla* seedlings were transplanted and grown individually in plastic pots (15 cm in diameter) filled with sandy soil (sand: 75.9%, silt: 20.5%, clay: 3.6%). The pots were watered twice a week regularly. After two months, when all the seedlings had finished apical growth, we selected 20 pots to be used for the experiment. The experiment was set up as a 2×2×5 factorial design, with two watering regimes (normal, well–watered group and deficient, water–stressed group) and two dew treatments (dew–absent and dew–present), and with 5 replicates per treatment. The two contrasting watering regimes were: (1) plants irrigated twice a week, keeping the average gravimetric soil water content of surface layer (0–5 cm) at about 6%; and (2) plants not watered at all, keeping the average gravimetric soil water content of surface layer (0–5 cm) at about 2%–3%. During the period when rainfall was expected, a clear PVC sheet was used to cover all plants. Two dew treatments were imposed: (1) plants deprived of dew by hanging a cover over them from sunset until a short before sunrise, and (2) plants not treated in any way. The cover was at least 0.5 m above the plants to allow full air exchange under the high cover at night. The presence of the cover increased air turbulent movement, which reduced surface layer air cooling. Therefore, lower cooling rate is of no advantage for dew formation. Additionally, frequent temperature measurements, repeated on many occasions, close to the bare ground and under such high cover, indicated that the night minima were less than one degree higher han the minima taken close to ground not covered. Therefore, the cover did not have a significant impact on increasing the leaf temperature.

Measurements were taken after the occurrence of dew overnight followed by a clear day when we could see dewfall on the pot surface, so we initially defined the days as measurement days. In a 4-week study period, there were 3 dew events observed by naked eye. Diurnal shoot water potential was estimated with a pressure chamber. Three measurements were taken for relative water content (RWC, %) at early morning, and calculated by equation:

$$RWC=(FW-DW)/(TW-DW)\times100.$$

Where FW is leaf fresh weight, TW turgid weight 24 h after putting leaf into water, and DW means dry weight after drying at 85°C until it reaches a constant weight.

Diurnal stomatal conductance (gs), CO_2 assimilation rate (A), vapor pressure deficit (VPD), air temperature (Ta) and photon flux density (PFD) from 8:00 to 18:00 were measured with a Li-6400 Portable Photosynthetic System (Li-COR, USA). The climatological monitoring of 3 days is shown on Fig. 2. Three assimilating shoots were measured on each plant. At the end of the experiment, the plants were dug out to collect roots as much as possible and separated into two parts: aboveground and belowground. The morphological variables measured were root dry mass, stem biomass and total leaf biomass.

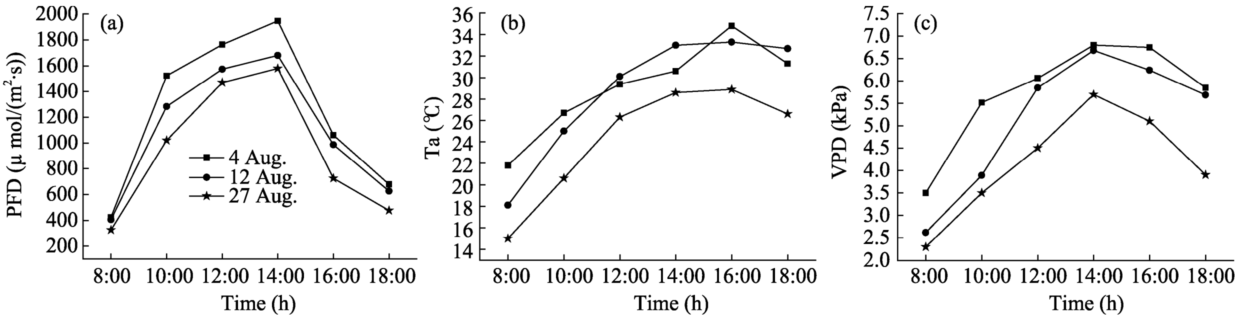

Fig. 2 The diurnal variations of photo flux density (PFD), air temperature (Ta) and vapor pressure deficit (VPD) of measurement days

1.4 Statistical analysis

Differences in diurnal shoot water potential, relative water content in the early morning, diurnal CO_2 assimilation rate, stomatal conductance rate and morphological variables under the different treatments of the same water regime were analyzed by independent sample T test at 0.05 level using SPSS.

2 Results

2.1 Water content variables

Both water potential and RWC in water-stressed *Bassia dasyphylla* were significantly decreased. The RWC increased with the presence of dew in both the well-watered group (P=0.000) and the water-stressed group (P=0.000), with an 89% increase in the plants exposed to dew compared with those of no dew in the water-stressed group (Table 1). The presence of dew significantly increased the diurnal average water potential of the water-stressed plants (P=0.000) (Fig. 3a), whereas it did not cause a significant difference in the well-watered group (P=0.141) (Fig. 3b). Especially notable was the effect on the midday water potential in the water-stressed seedlings. There was a 16% increase in the water potential of the dew-present treatment compared with the dew-absent treatment, whereas there was only a 3% increase in the water potential of the well-watered seedlings in the dew-present treatment compared with the dew-absent treatment.

Table 1 Relative water contents of *Bassia dasyphylla* leaves in the early morning

Treatments	Relative water content (%)	
	well watered group	water-stressed group
Dew-absent	49.32 ± 5.93^a	32.82 ± 6.03^a
Dew-present	65.24 ± 3.34^b	62.03 ± 3.54^b

Note: These data represent the mean±SE of three sampling dates. Different letters indicate significant differences between dew-absent and dew-present plants under the same group at $P<0.05$ level.

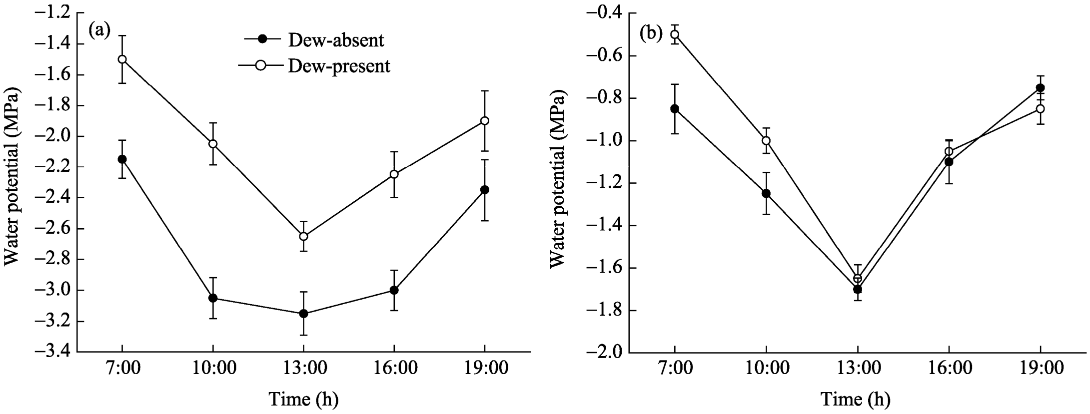

Fig. 3 The diurnal variation of leaf water potential of *Bassia dasyphylla*. (a) water-stressed group, (b) well-watered group. Each value is a mean±SE.

2.2 Diurnal variations of photosynthesis

A one-peaked daily pattern of net CO_2 assimilation rate (A) was observed in the well-watered group throughout the study period, achieving a maximum daily peak rate at 10:00 in the morning (Fig. 4b), whereas a two-peaked diurnal pattern of net CO_2 assimilation rate was observed in the water-stressed group, with a maximum peak rate at 10:00 and second peak rate at 16:00 (Fig. 4a). The occurrence of dew significantly increased the diurnal average CO_2 assimilation rate and the maximum peak rate of the water-stressed group (P=0.004; P=0.000); there was no significant difference in the well-watered group (P=0.821; P=0.853). The stomatal conductance followed a one-peaked daily pattern in both watering regimes, with a maximum peak in early morning. In the water-stressed group, stomatal conductance decreased by 52% and 46% throughout the day in the dew-absent and dew-present treatments, respectively (Fig. 4c). A stomatal conductance increased by 31% before 10:00 was observed in plants exposed to dew, compared with those dew-absent in the water-stressed group. The occurrence of dew significantly increased the stomatal conductance rate of the water-stressed group (P=0.000) from 8:00 to 10:00; there was no significant difference in the well-watered group (P=0.305) (Fig. 4d).

2.3 Seedling growth variables

All growth variables were significantly reduced in the water-stressed group. Across all measurements, growth was always markedly greater for plants of dew-present treatment than for plants of dew-absent treatment in both groups. The total dry mass of plants exposed to dew was significantly greater in both the well-watered group (P=0.028) and the water-stressed group (P=0.041) than those not exposed to dew. The occurrence of dew significantly increased the aboveground dry biomass (P=0.015) and the total leaf dry biomass (P=0.005) in the water-stressed group. Stem dry mass and root dry mass of plants exposed to dew were significantly greater in the water-stressed group than in other 3 treatments (Fig. 5).

2.4 Biomass allocation

The root-to-shoot ratio of plants not receiving dew increased by 15% and 19% in the well-watered and water-stressed group, respectively, compared with plants exposed to dew. The stem-aboveground ratio in plants not receiving dew was greater than that in plants exposed to dew, in both watering regimes, whilst the leaf-aboveground ratio was lower (Fig. 6).

3 Discussion

The presence of dew significantly increased the diurnal water potential and RWC in the early morning, however, the impact was greater in plants of the water-stressed group, suggesting that dew directly influences plant water status. When water potential is lower, in extremely drought environments, the effect of dew on plant water status is greater. The obvious response of RWC and water potential of water-stressed plants to dew might be due to dew absorption by leaf. Leaf hairs can absorb water directly from atmospheric hu-

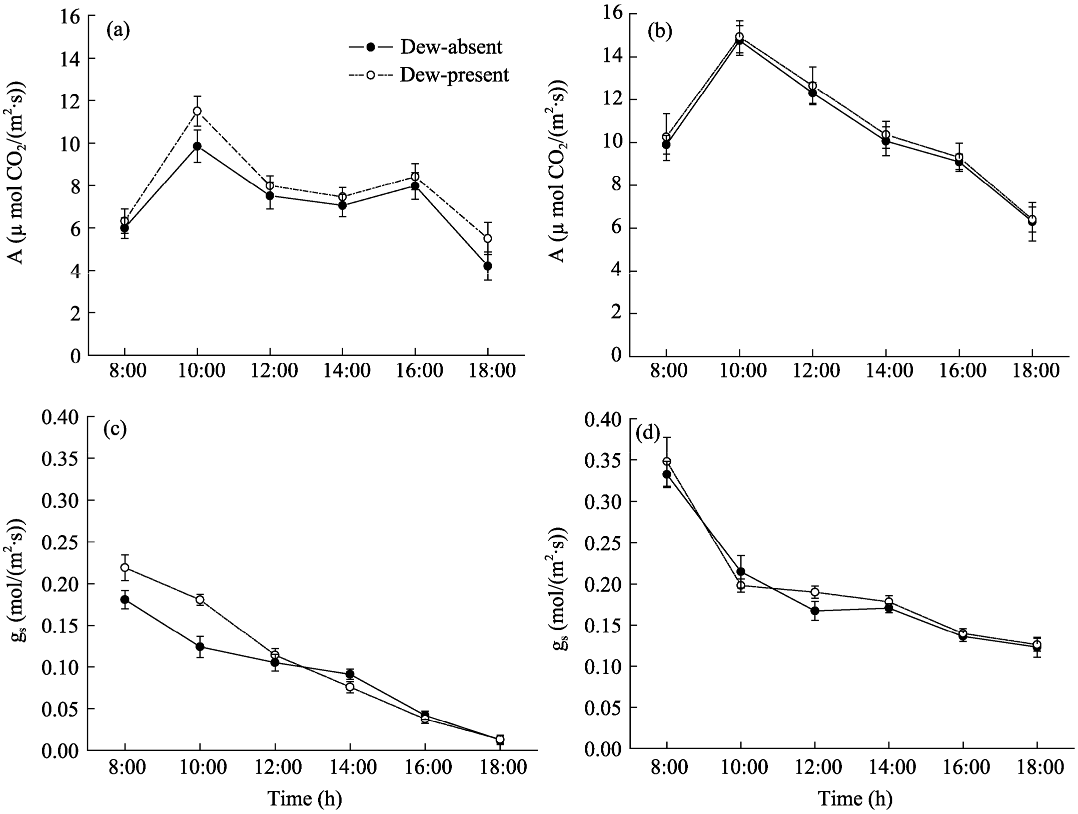

Fig. 4 The diurnal variation of net photosynthetic rate (A) and stomatal conductance (g_s) of *Bassia dasyphylla*. (a) and (c): water-stressed group, (b) and (d) well-watered group. Each value is a mean±SE.

midity, precipitation (Rundel, 1982) and dew (Stone, 1963; Gram matikopoulos and Manetas, 1994; Yates and Hutley, 1995). The hairs on the adaxial surface of *Bassia dasyphylla* leaves can afford a much larger

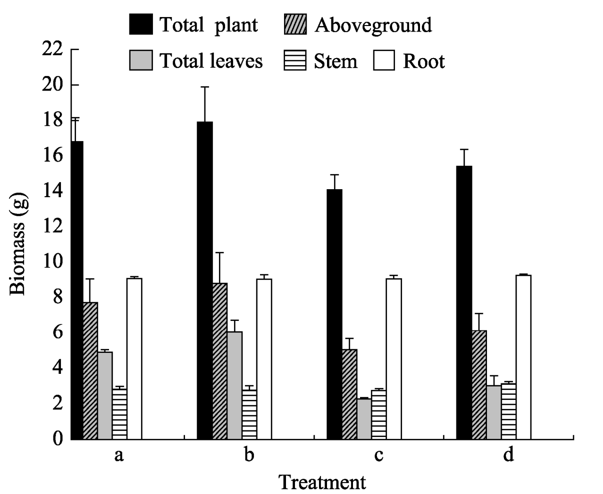

Fig. 5 Biomass variation of *Bassia dasyphylla*. a, well-watered+dew absent; b, well watered+dew-present; c, water stressed+dew-absent; d, water-stressed+dew-present. Each value is a mean±SE.

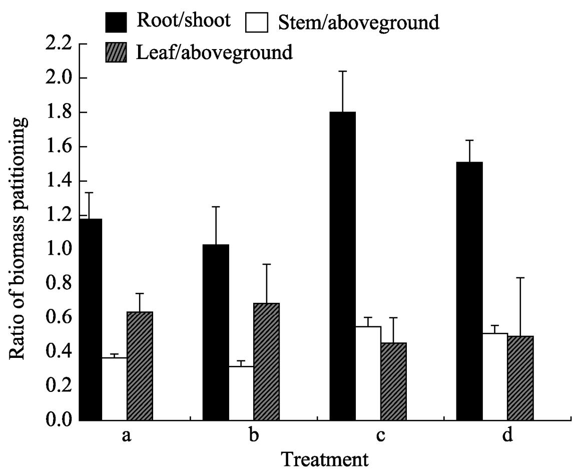

Fig. 6 Ratio of biomass partitioning of *Bassia dasyphylla*. a, well watered+dew–absent; b, well watered+dew–present; c, water-stressed+dew–absent; d, water-stressed+dew–present. Each value is a mean±SE.

surface area for water condensation, potentially ensuring a longer duration of surface water. It is likely that the effects of dew uptake by leaf may be substantial, resulting in a considerable increase in plant water status. Our results on *Bassia dasyphylla* indicated that the mechanism of dew uptake by leaf is likely to be central in maintaining the water status of dryland plants. Arid land ecosystems are characterized by long periods of water deficit with few precipitation events (Loik *et al*., 2004). Although the presence of dew may not be adequate to substantially enhance soil moisture, it may be sufficient to wet leaves and to ameliorate the plant water status of *Bassia dasyphylla* in drought environments.

The occurrence of dew caused an increase in photosynthetic rate and stomatal conductance of the treatment plants, which demonstrated another mechanism that might be critically associated with physiology and water available. Indirect effects of dew on photosynthetic rate and stomatal conductance were also shown in water-stressed plants, indicating that dew is likely to play a key role in controlling stomatal behavior. Although the presence of dew contributed significantly to stomatal conductance in water-stressed plants, increased stomatal conductance did not result in increased transpiration losses and reduced RWC or water potential in the early morning. As suggested by Meinzer (1993), transpirational losses are controlled by both stomatal- and canopy-level resistances to vapor transfer, hence increased stomatal conductance does not necessarily translate into increased water loss by plants. These results also indicated that the presence of dew may play an important role in avoiding irreversible damage that the photosynthetic apparatus may suffer when RWC falls below 30% (Kaiser, 1987). The occurrence of dew to aid photosynthetic performance recovery is notable, suggesting once the plants in drought habitat underwent a short-period exposure to dew, the photosynthetic capacity of plants could be improved by increased plant water status. Therefore, dew may be more important in ameliorating plant water relations and photosynthetic capacity, both of which are critical to plant survival, in prolonged drought than in well watered environments.

Additionally, at the end of the experiment, we observed that water-stressed plants of dew-present grew better than those of dew-absent which visibly wilted and the lower leaves had abscised. The increased total leaf dry biomass of plants with dew in drought conditions observed here again confirmed the presence of dew did improve the water status of plants. In addition, we found that, although the occurrence of dew also stimulated root and stem growth in water-stressed plants, probably dew has a more positive role to shoot growth than to root growth. Therefore, in both water regimes, the root-to-shoot ratio of plants with no dew was greater than that of those with dew. Clearly, these results indicate that dew has a definitely beneficial effect on the aboveground growth of plants.

4 Conclusion

In conclusion, our experiment highlights that dew has a short-term effect on plant survival in drought circumstances. The present results do demonstrate that dew gives a remarkable contribution in RWC, water potential and photosynthetic performance to *Bassia dasyphylla* plants grown in extreme drought environments. These improvements, in turn, lead to an increase in total dry biomass of plants, and notably aboveground biomass. These findings not only emphasize an indirect role of hairs in leaf water status to dew maintenance and retention, but also support the hypothesis that the contribution of dew to *Bassia dasyphylla* plants exposed to prolonged drought may be critical. In future studies, we are planning to explore whether there is a long-term ecological effect of dewfall on the plants in drought environments.

Acknowledgements

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