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Short communication

Unusual canopy architecture in the umbrella thorn acacia, *Vachellia tortilis* (= *Acacia tortilis*), in the United Arab Emirates

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ABSTRACT

Populations of the umbrella thorn acacia, *Vechellia tortilis* (formerly *Acacia tortilis*), in the United Arab Emirates (UAE) have an unusual tilted canopy architecture compared with the flat or dome-shaped morphology typical throughout its pan-tropical range. UAE populations were shown to have a distinctive tilt as a result of consistent height and canopy angle differences between opposing sides of canopies. These tilted canopies were found to be highly directional in their orientation, facing almost due south. The wind environment and latitude were excluded as potential causes for this morphology. Canopies of *V. tortilis* were shown to have a mean compass orientation and slope which maximized canopy exposure to the midday sun, specifically during peak summer when climactic conditions are extreme relative to populations elsewhere in the pan-tropical range of this species. It is suggested that the unique canopy architecture characteristic of the UAE population is a plastic response which maximizes soil shading and reduces soil temperature around the base of the tree. Such shading would reduce evaporative loss of soil moisture that had been deposited in the surface layers by hydraulic lift from the taproots, enhancing total water availability and water transport efficiency in this hot, hyper-arid climate.

1. Introduction

Plants living in hot arid environments are subjected to a number of abiotic stressors, including water stress, extreme temperatures, and high irradiance levels (Lambers et al., 2008; Pallardy, 2010). One of the primary adaptations used by xeric plants to minimize stress from these conditions is through variation in canopy structure. Because the canopy intercepts photosynthetically active solar radiation, variation in canopy architecture can strongly influence leaf temperature, photosynthetic processes, water conductance, and gas exchange characteristics in desert plants (Cruiziat et al., 2002; Lines et al., 2012; Pockman and Sperry, 2000; Smith and Hughes, 2009; Valiente-Banuet et al., 2010).

The umbrella thorn acacia, *Vechellia tortilis* (Forssk.), formerly *Acacia tortilis* (Forssk.) (Kyalangalilwa et al., 2013), is a woody tree that is widely distributed across eastern Africa, northern Africa, and the Middle East where it occurs in semi-arid deserts and savannahs (Doran et al., 1983). The prominence of *V. tortilis* on the African savannah has made it a subject of intense study, particularly concerning herbivory (Birkett and Stevens-Wood, 2005; Fornara and Du Toit, 2008; Ludwig et al., 2008) and facilitation of understory plant communities (Ludwig et al., 2003; Moustakas et al., 2013). However, to date no research has examined the canopy architecture of the umbrella thorn acacia in relation to its environment.

Variation in canopy architecture is likely to be particularly important for *V. tortilis* populations in Arabia, where environmental conditions are among the most extreme in its geographic range. *V. tortilis* is generally the dominant tree in wadi beds and alluvial plains that line the foothills of the arid mountains in the region (Hall et al., 2011; Llewellyn et al., 2010; Wardman and Warrington, 1997), and Arabian populations experience low rainfall (annual mean $\leq$ 150 mm) and temperatures considerably higher and lower than in most of its range (summer maxima: $\geq$50 °C and winter minima: $\leq$10 °C) (Almazroui et al., 2012; Boer, 1997). Unlike the flat, inverted-cone shape that is common to this species throughout its wide pan-tropical range, populations in northeastern Arabia appear to be characterized by a tilted morphology with a strongly angled canopy. The purpose of this study was to quantify the canopy architecture of a *V. tortilis* population in the United Arab Emirates and to relate canopy characteristics to aspects of the physical environment.

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2. Materials and methods

This study was conducted on *V. tortilis* trees located within 10 km of the town of Madam, United Arab Emirates (UAE), in the alluvial gravel plains that form the western foothills of the Hajjar mountains that border the eastern UAE and northern Oman in Arabia (N 24.913, W 55.776). The environment of this location is classified as hyper-arid (annual precipitation: 82 mm; mean monthly precipitation: 6.8 ± 0.6 mm), with air temperatures ranging from a winter minimum of 8.0 °C to a summer maximum of 48.9 °C (annual mean: 28.4 °C); it is located at 310 m altitude (Boer, 1997; NCMS, 2011).

The canopy architecture of 70 adult *V. tortilis* (>1 m height) were characterized by measuring aspects of crown height, canopy angles, and canopy directionality. The height of the highest and lowest points on the perimeter of each canopy crown was measured to the ground, and the angle of the canopy was measured for both the high and the low points. These points were also used to estimate canopy directionality, where a compass heading (azimuth) was measured for the plane formed between the high and low sides of the canopy for each tree. The linear width of the canopy between the highest and lowest points was used in conjunction with the height measurements to estimate the overall canopy slope. Angles were measured with a Bosch DAF220 Miterfinder and canopy directionality with a Garmin GPSmap 76CSx.

Various environmental and solar data parameters were collated for this area to explore their potential influence on canopy morphology. Environmental data included temperature and precipitation averaged from 2003 to 2011 (NCMS, 2011) and wind strength and direction for 2013 from Al-Ain International Airport (N 24.2617, E 55.6092) (ASOS, 2013). In terms of solar parameters, the compass direction and elevation of the sun for the summer and winter solstice and during peak summer temperatures (mid-August) for 2013 were calculated, and the compass direction (azimuth) data corrected to magnetic north for comparison with the canopy directionality (Michalsky, 1988; Seidelmann, 2006).

A *t*-test for dependent samples was used to assess difference in height between the low and high side of trees; data were distributed normally (Chi square test for continuous data; high side: $X^2 = 4.66$, p = 0.58; low side: $X^2 = 3.74$, p = 0.59). Because directionality and angle represent circular data (0 – 360°), circular statistics were used to calculate means, confidence intervals, and to perform statistical tests for these data (Zar, 1999). A Hotelling's paired test for non-independent data was used to assess whether the canopy angle on the high and low side of the crown were significantly different from one another, and a Rayleigh's uniformity test was used to assess whether there was significant directionality on the canopy orientation (Zar, 1999). Circular statistics as well as compass rose and angular diagrams were generated in Oriana 4.01 (Kovach Computing). The effect of canopy shading on soil surface temperature was assessed with an infrared thermal imaging camera (FLIR T640bx) at noon (12:30–13:30) on 19 October 2014, with image analyses used to calculate the average soil temperature within tree canopy shade and an equivalent area of non-shaded, exposed soil.

3. Results and discussion

The results of this study indicate that *V. tortilis* populations in the UAE have unique canopy architecture, and that this is likely due to the relatively extreme environmental conditions of this location. Trees here were shown to have a distinctive tilt to the canopy crown, with high sides that were significantly taller than the low sides of the canopy perimeter (Fig. 1a; mean difference: 90.9 ± 4.5 cm, *t*-test for dependent samples: $p < 0.001$). The apparent tilt of the overall canopy crown was accentuated by divergent canopy angles on the high and low sides of these trees (Fig. 1b), where there was a near horizontal canopy angle on the high side of the canopy (−0.5° ± 1.5°) compared to the steep downward slope on the low side (−24.8° ± 1.5°), and these differed significantly (Hotelling's $F = 102.5$, $p < 0.001$). This tilted morphology is distinct from that possessed by populations in east Africa and other parts of the Middle-East (Israel), where the canopies are dome shaped or flat and typically grow out parallel to the ground (Kotzen, 2003; Mwalyosi, 1990; Pellew, 1983). The tilted canopies of *V. tortilis* showed highly consistent, non-random directionality in their compass orientation (Fig. 1c; Rayleigh test $p < 0.001$). On average, the canopies were oriented near due south (187°), and all canopies sampled were oriented between 126° (ESE) and 240° (WSW); no trees were oriented toward the north.

This unusual tilted morphology, coupled with the strong directionality of the trees, is likely due to environmental factors unique to this area. Canopy directionality in other tree species has been associated with the wind climate in locations where winds consistently come from one direction, with denser, slower growing branches often observed on the windward face, resulting in a wind-facing canopy orientation (Brüchert and Gardiner, 2006; Coutand, 2010; García-Verdugo et al., 2009; Telewski, 1995, 2012).

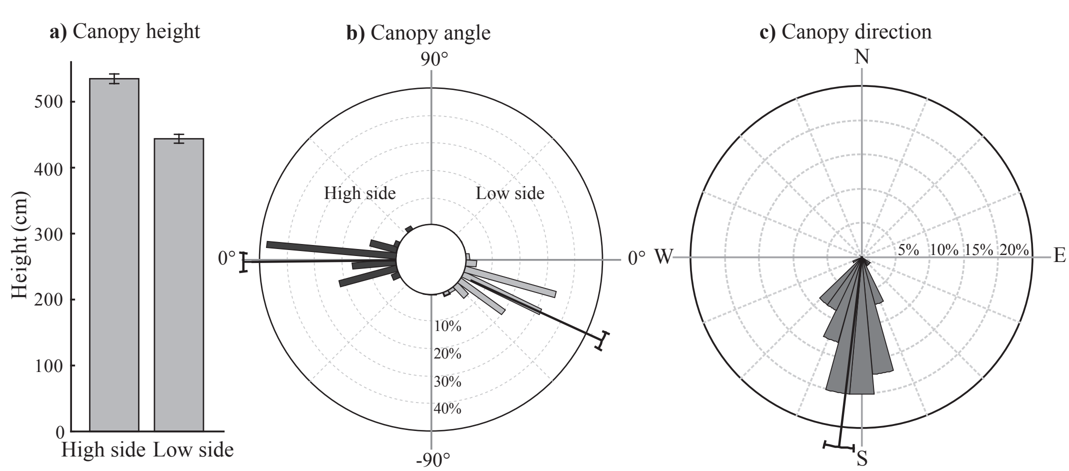

Fig. 1. Characteristics of *V. tortilis* canopies in the UAE, including (a) mean height and (b) angle on the high and low sides of the canopy, as well as the (c) direction of orientation of the canopy face. Bars in (b) and (c) represent the percent of samples in 10° intervals, with the line and whiskers indicating the mean and 95% confidence intervals.