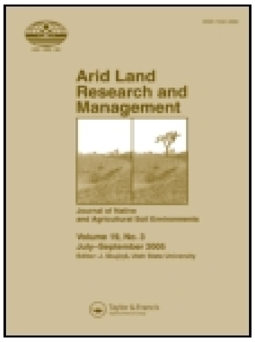

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Effects of variability in landscape types on the microclimate across a desert–oasis region on the southern margins of the Tarim Basin, China

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ABSTRACT

Microclimates play important roles in controlling water budgets and water vapor transportation, as well as vegetation growth characteristics. In order to understand the differences in meteorological parameters under different vegetation cover (VC) and terrain conditions, wind velocity, air temperature, relative humidity (RH), photosynthetically active radiation (PAR), and solar radiation were simultaneously monitored on shifting, semi-fixed and fixed sandy lands, and an oasis. The air temperature and RH differences among the four landscape types were obvious in the period from May to October. It was found that the higher elevations of semi-fixed sandy land can influence PAR and solar radiation during sand-blowing weather. The differences of air temperature and RH among the four sites during the dust-storm and rainy days were not obvious, but their differences during sand-blowing weather were greater than during rainy weather and less than during floating-dust and sunny weather. The differences of PAR and solar radiation among the four landscape types were most obvious during the dust-storm event. During most of the weather types studied, significant positive correlations were found between wind velocity and temperature, PAR, and solar radiation, as well as between temperature and PAR, and solar radiation. Meanwhile, significant negative correlations were found between RH and wind velocity, temperature, PAR, and solar radiation. VC and topography were found to be the main factors influencing the changes in meteorological parameters between desert–oasis ecotone and oasis.

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KEYWORDS
Cele; desert–oasis ecotone; microclimate; oasis; spatial variation

Introduction

The microclimate, which is the climate near and above the ground layer—distinct from the macroclimate due to being influenced by the local landscape type and conditions (Weng, Chen, and Shen 1981)—is the most important environmental factor influencing

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the growth and development of vegetation. Results have shown that the sum of daily average sensible and latent heat flux densities decreases as the surface resistance and albedo increases, and the surface roughness decreases with vegetation removal (Novak 1990). Varying vegetation cover and the presence of slopes in all directions have been shown to induce a strongly varying microclimate in a coastal dunes area (Wartena, Van Boxel, and Veenhuysen 1991). Natural vegetation and artificial shelterbelts are an important function of decreasing wind velocity and air temperature and increasing relative humidity (RH). Taha, Akbari, and Rosenfeld (1991) reported correlations between air temperature and wind speed within the canopy and their corresponding ambient open-field values in Davis, CA, USA.

The microclimates of oasis, forest, farmland, and desert environments have all been investigated (Sinclair and Knoerr 1982; Bryant et al. 1990; Liu and Xin 1994; Zuo and Hu 1994; Spittlehouse et al. 2004; Lin 2007; Rambo and North 2009; Rao 2009). However, most studies have stressed the differences between the microclimate of vegetated areas and those of bare surroundings, particularly in terms of air temperature. For example, Mueller and Day (2005) examined the microclimate differences of urban ground cover in Phoenix, Arizona, USA. In an arid coastal ecosystem, EI-Bana, Nijs, and Kockelbergh (2002) found that the average soil temperature and PAR were highest in the internebkha space and lowest at the nebkha crest. Feng et al. (2006) researched the microclimate characteristics of the Hexi oasis in the hyperarid zone of China, pointing out that, during dust storm events, the PAR was significantly lower than on cloudy days. Wang et al. (2008) also analyzed air temperature in an arid ecosystem, as well as RH, but along the shelterbelt of the Tarim desert highway. In quantifying the microclimatic differences between young longleaf-pine silvopasture and open-pasture, Karki and Goodman (2013) found that silvopasture demonstrated higher average air temperature values.

However, only a limited number of studies have investigated the microclimate differences between desert and oasis zones. The desert–oasis ecotone plays a very important role in ensuring the ecological security and internal stability of oasis. Furthermore, a large area of desert–oasis land has been reclaimed in recent years, resulting in a continuously decreasing underground water table. In the Hotan area of the Tarim Basin, China, such excessive reclamation of desert–oasis land has led to much of the natural vegetation having been removed, and the microclimatic environment has become increasingly unstable and fragile. In this study, we aimed to analyze the microclimatic differences between the desert–oasis ecotone and oasis zones, and discuss the reasons for the differences. In addition to helping understand the ecological function of the desert–oasis ecotone, this work also provides a theoretical basis for aboveground heat and vapor transportation between desert and oasis land. It is supposed that VC and topographical characteristics would affect the changes of meteorological parameters under different weather conditions. The air temperature would be decreased and RH would be increased with increasing VC from shifting sandy land to oasis, and the PAR and solar radiation would be higher on higher topography in oasis-desert ecotone because the higher topography can intercept more sand and dust particles in the air and it can be absorbed more solar radiation (Figure 1). The outcomes in this research are in line with our preliminary expectations. The effects of variability in different landscape types on the microclimate would be mainly affected by VC (including plant types and plant height) and topography between desert and oasis.

Materials and methods

Study area

Cele County lies between the southern margin of Taklimakan Desert and the northern Kunlun Mountains, situated over the area (35°l7′55″–39°30′00″N, 80°03′24″–82°10′34″E) (Figure 1). It belongs to a typical continental warm temperate climate zone, and is a region that is seriously affected by the hazards of wind-blown sand. The weather that causes the blown sand occurs continually with 20–30 days of gales and dust storms annually. Sand-blowing and floating-dust weather amount to more than 90 and 150 days on an annual basis, respectively (Zhang 1995). The average precipitation is 35.1 mm, and the potential evaporation capacity is 2600 mm annually. There is frequently a large difference between daytime and nighttime air temperature, with the annual extreme highest and lowest air temperatures being 41.9°C and −23.9°C, respectively. The annual prevailing wind direction is westerly and northwesterly (Yang 1990), and the annual average wind velocity at a height of 2 m is 2.36, 1.75, 1.60, and 0.96 m/s at the shifting sandy land, semi-fixed sandy land, fixed sandy land, and oasis sites, respectively (Mao et al. 2014). The sand grains at the surface of the desert–oasis ecotone are very fine aeolian sands, and the average grain size range is 70–165 μm (2.6–4 ϕ). The soil moisture content in the surface layer (0–20 cm) is between 0.15 and 0.35%. It is influenced by irrigated water in the oasis, where the soil moisture content is much greater than 5%.

Materials and methodology

In July 2010, four weather stations were set up at different sites in the desert–oasis ecotone and oasis of Cele County. Observed parameters included wind velocity, wind direction, air temperature, RH, PAR, and solar radiation. Wind cups were installed at heights of 0.5, 1, 2,

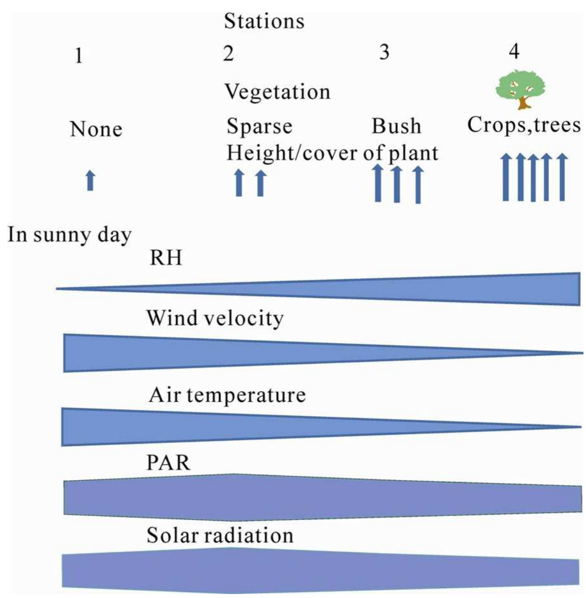

Figure 1. The scheme on the microclimate effect in different landscape types in sunny day.

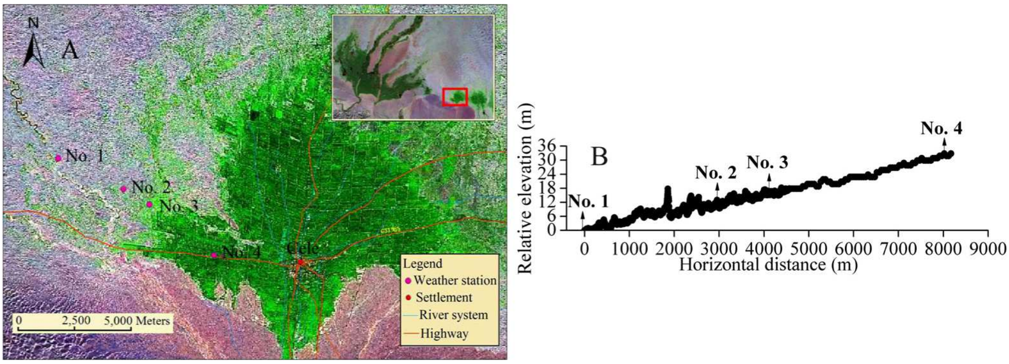

Figure 2. Positions of the four weather monitoring stations.

4, 8, and 10 m (including wind vanes) (Figure 2A). The air temperature and RH probes were installed at heights of 0.5 and 2 m respectively, and the PAR and solar radiation probes were installed at heights of 1.5 m. The weather stations comprised HOBO U30 meteorological surveying instruments, which log data every second. The logging interval time was 10 min, continuously. The observation period was from early July 2010 to December 2011. The sites of weather station No. 1, No. 2, and No. 3 were representative of shifting sandy land, semi-fixed sandy land and fixed sandy land, respectively. The site of weather station No. 4 was representative of the oasis, where cotton and pomegranate are planted with a vegetation coverage (VC) of more than 80%. The total VC was 3, 27, and 67% at the shifting sandy land, semi-fixed sandy land, and fixed sandy land sites, respectively.

The surface of the shifting sandy land vegetation (site No. 1) mainly comprised sparse *Tamarix* spp. shrubs, *Hexinia polydichotoma*, and *Halogeton glomeratus* grasses. At the site of weather station No. 2, the surface vegetation mainly comprised tall *Tamarix* spp. shrubs, *Alhagi sparsifolia*, and *Karelinia caspia*. Around weather station No. 3, the composition was comparatively flourishing with *A. sparsifolia* and abundant *H. glomeratus* grasses (Table 1).

The topography becomes generally higher from the shifting sandy land of site No. 1 to the oasis of site No. 4. The largest elevation difference on the section line was approximately 33 m (Figure 2B). The highest point was a tall *Tamarix* spp. Nebkha (nebkha is a mound which is deposited by shrubs or grasses on the land of arid or semi-arid regions where the wind power is usually stronger and vegetation is sparse). During the observation time, six typical weather types were chose, including a sunny day in summer on 6 July 2011, a dust storm event on 12 March 2011, a sand-blowing event on 26–27 June 2011, a dust-floating day on 29 June 2011, a rainy day on 10 July 2011, and a sunny day in winter

Table 1. General conditions at four landscape types.

Site	Latitude	Longitude	Elevation	Vegetation type (m)	VC (%)	Landscape type
No.1	37°02′37″	80°40′53″	1349	*Tamarix spp., Halogeton glomeratus, Hexinia polydichotoma*	3	Shifting sandy land
No.2	37°01′47″	80°42′32″	1359	*Tamarix spp., Karelinia caspia, Alhagi sparsifolia*	27	Semi-fixed sandy land
No.3	37°01′21.0″	80°43′25.7″	1355	*Alhagi sparsifolia, Halogeton glomeratus*	67	Fixed sandy land
No.4	37°00′11.7″	80°45′23.4″	1367	Cotton, Pomegranate	>80	Farmland

on 25 December 2010, and the changes and differences among the different meteorological parameters at the four distinct landscape sites were analyzed. Xinjiang time is used in the local area, so all observation times in the experiments adopted local time. There is a difference of about 2 h between the local time and Beijing time.

Results

Changes in monthly averages of meteorological parameters in the four landscape types

Wind velocity

In the period April to September especially, the average monthly wind velocity decreased significantly at the same height from the shifting sandy land to the oasis site (Figure 3). The average monthly velocity at the semi-fixed sandy land and fixed sandy land sites at 0.5 m height was 47.46 and 64.75% less than at the shifting sandy land site, respectively; while in June – again compared to that at the shifting sandy land site – the average wind velocity at the semi-fixed sandy land, fixed sandy land, and inner oasis sites was 25.22, 27.93, and 65.27% less. The average wind velocity at the height of 2m and 10 m on semi-fixed sandy, fixed sandy ground, and oasis were reduced by 26.83, 31.67, and 59.76% (at 2m); and 8.65, 14.53, and 45.27% (at 10m), respectively, compared with that on shifting sandy land. The average monthly velocity in January at the semi-fixed sandy land, fixed sandy land, and

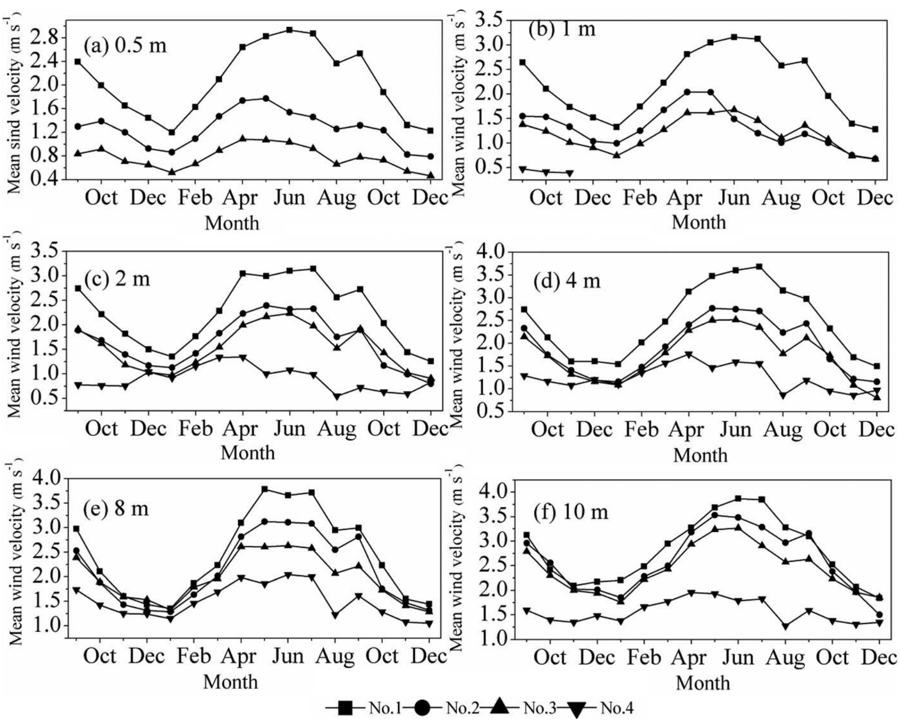

Figure 3. Average monthly wind velocity on the four landscape types at different heights from September 2010 to December 2011 in the study region in Cele County, China.

inner oasis sites at 2 m height was 16.3, 27.93, and 32.07% less than at the shifting sandy land site, respectively.

Air temperature and RH

From May to October, the trends of change of average monthly air temperature and RH at the heights of 0.5 and 2 m were primarily the same; however, average monthly air temperature at the height of 2 m was comparatively higher than that of 0.5 m (Figure 4a and b). On the contrary, average monthly RH at the height of 0.5 m was comparatively higher than that of 2 m (Figure 4c and d). From May to October in particular, when the desert vegetation and crops are in their growing season, the differences in air temperature among the four landscape types are larger than at other times of the year, and the average monthly air temperature was found to decrease gradually from the shifting sandy land to the oasis site.

The RH at the oasis site was higher, especially in summer, than at the other sites in the desert–oasis ecotone because of the effect of irrigation on the farmland. Obvious differences in RH across the different sites of the desert–oasis ecotone were only apparent in the growing season. Greater abundance of the natural (xeric) vegetation, which relies on deep underground water for survival, can lead to greater levels of leaf transpiration. The surface soil, with its low soil moisture, provides minimal water vapor to the air near the ground, meaning there is greater evaporation of the water transpired from the branches and leaves of the natural vegetation, which lowers the air temperature and increases the RH during the growing season. There is a lower boundary layer in the oasis compared

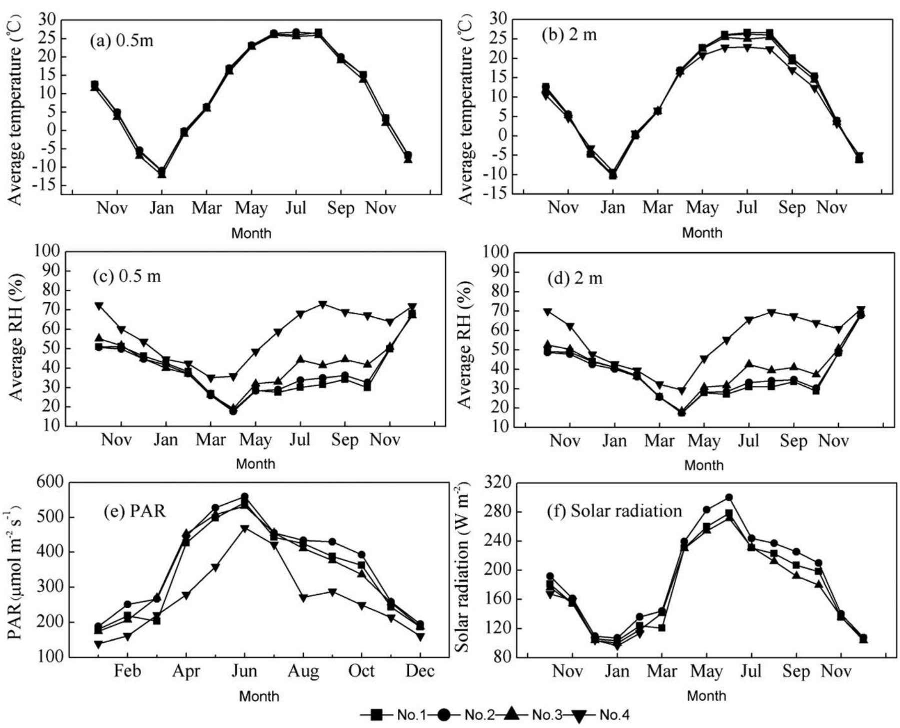

Figure 4. Average monthly meteorological parameter changes on the four landscape types from October 2010 to December 2011: (a) air temperature at 0.5 m; (b) air temperature at 2 m; (c) RH at 0.5 m; (d) RH at 2 m; (e) PAR; (f) solar radiation.

to the desert environment, which, by storing moisture acts as a protective layer for the development of the oasis ecosystem. The closer to the oasis from the shifting sandy land site, the higher the RH became. For example, in August, the increases in average monthly RH from the shifting sandy land site to sites 2, 3, and 4 were 10.45, 30.88, and 131.13% greater, respectively. From May to October in 2011, these values were 6.89, 30.09, and 111.12% greater (at 0.5 m) and 5.2, 24.21, and 104.74% greater compared with that at the shifting sandy land site (at 2 m). The differences along the transect of monthly air temperature between the heights of 0.5 and 2 m reached a maximum in July when air temperature was at its highest because vertical convection currents are more powerful on shifting sandy land than on semi-fixed or fixed sandy land.

PAR and solar radiation

The trends of change for PAR and solar radiation were coherent with one another; the maximum PAR and solar radiation occurred in June and the minimum occurred in January (Figure 4e and f). The differences of PAR and solar radiation among the four landscape types in the period from March to October were greater than at other times of the year, and the PAR and solar radiation at the semi-fixed sandy land site was greater than that at the shifting sandy land and fixed sandy land sites because the former was situated at comparatively higher elevation along the prevailing wind direction.

Relationship between average monthly wind velocity and average monthly air temperature

The data of the 33 months between August 2010 and August 2013 were chosen, and the correlation between average monthly wind velocity and average monthly air temperature was established. The determination coefficient between average monthly wind velocity and average monthly air temperature was 0.83, which revealed that air temperature change could cause wind velocity change, thus inducing dust storms, sand-blowing and dust-floating events to frequently occur in spring and summer (Figure 5). On the contrary, less sand-blowing events occurred in winter when the air temperature was comparatively lower. This accounted for the fact that air temperature change was basically accordant with wind velocity change in this arid area on the southern margins of the Taklimakan Desert.

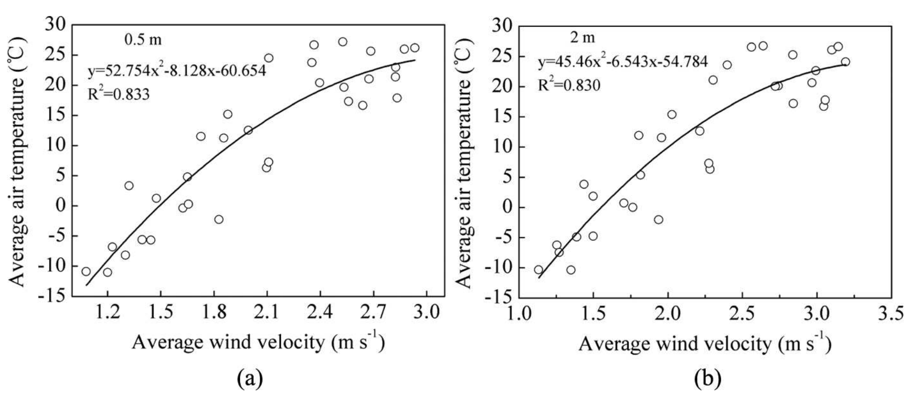

Figure 5. Correlation between average monthly wind velocity and average monthly air temperature on shifting sandy land at (a) 0.5 m and (b) 2 m height.

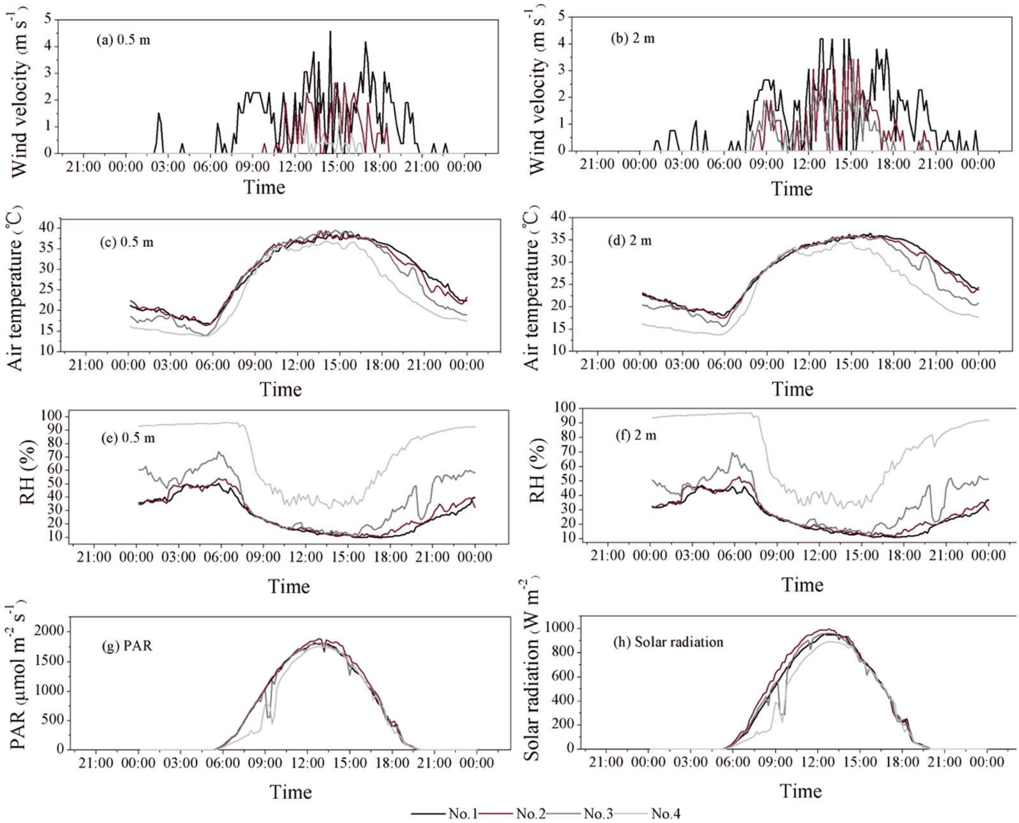

Figure 6. Daily changes in meteorological parameters on the four landscape types during a sunny weather day in summer: (a) wind velocity at 0.5 m; (b) wind velocity at 2 m; (c) air temperature at 0.5 m; (d) air temperature at 2 m; (e) RH at 0.5 m; (f) RH at 2 m; (g) PAR; (h) solar radiation.

Changes of meteorological parameters in the different landscape types or conditions

Sunny weather on 6 July 2011

At night, the wind velocity was mostly 0 m/s (Figure 6a and b). Compared to over the shifting sandy land, the average wind velocity at the height of 2 m over semi-fixed sandy land, fixed sandy land, and the oasis were 54.05, 60.74, and 100% less, respectively. However, wind velocity increased with increasing air temperature and reached its maximum at 15:00, lagging the highest air temperature (at noon) by 2 h. There was almost no sand-blowing wind after noon at all sites apart from the shifting sandy land site, and there was almost no wind in the oasis during the whole of the day.

The air temperature at the shifting sandy land site was higher than that at the semi-fixed sandy land, fixed sandy land, and oasis sites, in that order, at the heights of 0.5 and 2 m (Figures 1 and 6c and d). Air temperatures at the height of 2 m at the semi-fixed sandy land, fixed sandy land, and oasis sites were 0.78, 5.16, and 15.99% less, respectively, compared with that at the shifting sandy land site. The RH differences showed an opposite trend, with that at the semi-fixed sandy land, fixed sandy land, and oasis sites at the heights of (0.5 m, 2 m) being (7.69%, 7.83%), (46.12%, 39.4%), and (174.62%, 180%) greater, respectively, compared with that at the shifting sandy land (Figure 1). The air temperature and RH differences among the four landscape types at night were higher than during daytime (Figure 6e and f).

From 10:00 to 17:00, PAR at the semi-fixed sandy land site was higher than that at the shifting sandy land, fixed sandy land, and oasis sites, in that order (Figure 6g and h). The PAR differences among them were very small at other times of the day, and PAR in the oasis was always smallest, being influenced by shelterbelts and crops. Total daily amount of PAR (DΣPAR) at the shifting sandy land, fixed sandy land, and oasis sites was 3.4, 4.66, and 14.93% less, respectively, compared with the semi-fixed sandy land site. The total daily amount of solar radiation (DΣSOL) at the surface in the shifting sandy land, fixed sandy land, and oasis sites was 4.21, 5.5, and 17.89% less, respectively, compared with that at the semi-fixed sandy land site (Figure 7g and h). According to Yuan, Tang, and Yan (2009), the highest PAR value occurred at 12:00 in Gurbantunggut Desert in spring, but there was a 2 h lag between the highest air temperature and the highest PAR value. This conclusion is close to the times of 12:30 and 15:00 when PAR and air temperature respectively reached their highest points in summer on the southern margins of the Taklimakan Desert. The microclimate differences of the other five weather situations are discussed compared to that shown in Figure 1.

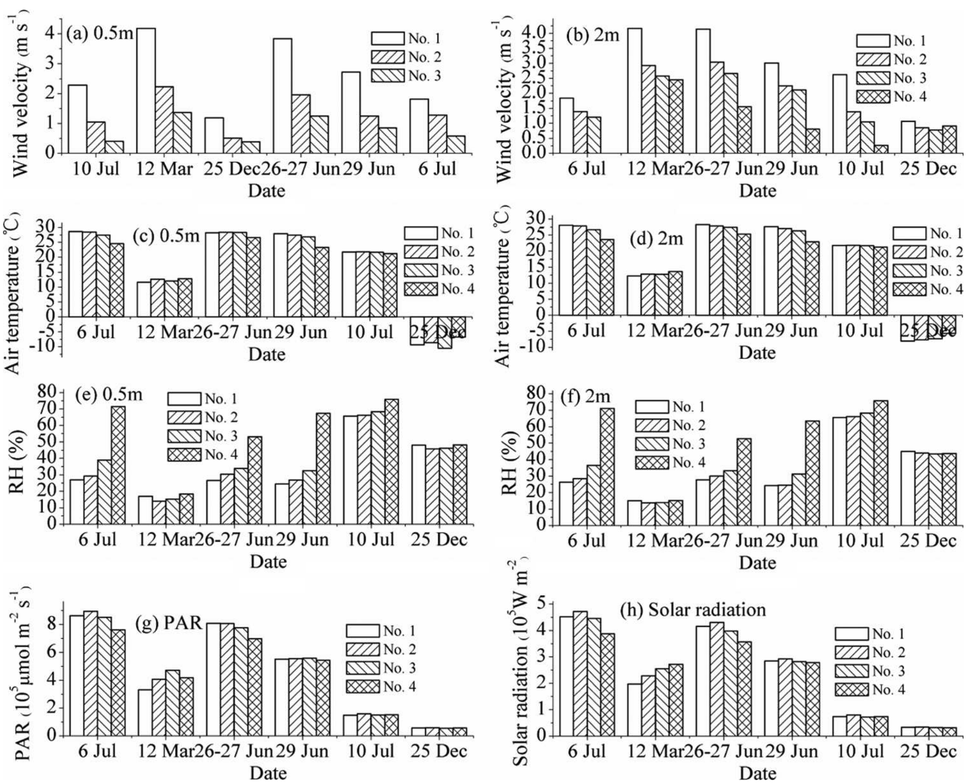

Figure 7. Average daily changes in meteorological parameters in the four landscape types during six weather conditions: (a) average daily wind velocity at 0.5 m; (b) average daily wind velocity at 2 m; (c) average daily air temperature at 0.5 m; (d) average daily air temperature at 2 m; (e) average daily RH at 0.5 m; (f) average daily RH at 2 m; (g) total daily amount of PAR (DΣPAR); (h) total daily amount of solar radiation (DΣSR).

Dust storm event on 12 March 2011

Average wind velocity decreased gradually at the height of 2 m from the shifting sandy land to the oasis site during this dust storm event in spring (Figure 7b). Compared with at the shifting sandy land site, the average diurnal wind velocity at the semi-fixed sandy land, fixed sandy land, and oasis sites were 26.35, 27.85 and 45.62% less, respectively. Daily average air temperature and RH at the shifting sandy land, semi-fixed sandy land, fixed sandy land, and oasis sites were 13.1°C, 13.57°C, 13.69°C, and 14.13°C; and 13.77, 12.97, 12.73, and 14.53%, respectively (Figure 7c–f). In total, PAR on this day at the fixed sandy land site was greater than that in the oasis, semi-fixed sandy land, and shifting sandy land sites, in that order (Figure 7g). DΣSOL during the dust storm increased from the shifting sandy land to the oasis site. DΣSOL at the semi-fixed sandy land, fixed sandy land, and oasis sites were 15.75, 29.78, and 38.34% higher (Figure 7h), respectively, compared with the shifting sandy land site. The withered grasses of the higher VC at the fixed sandy land can intercept and absorb finer floating dust particles, which can greatly influence the absorption, diffusion and dispersion of PAR and solar radiation.

Sand-blowing weather on 26–27 June 2011

During the sand-blowing day in summer, the average diurnal wind velocity at the height of 2 m on the semi-fixed sandy land, fixed sandy land, and oasis were 38.68, 45.11, 87.54% less, respectively, compared with that on the shifting sandy land (Figure 7b). Compared with the average daily temperature of 28.17°C at the height of 2 m at the semi-fixed sandy land site, values at the shifting sandy land, fixed sandy land, and oasis were 1.44, 2.99, and 10.42% less, respectively (Figure 7d). Meanwhile, compared with the daily RH of 27.99% at the height of 2 m at the shifting sandy land site (Figure 7f), values at the semi-fixed sandy land, fixed sandy land, and oasis sites were 7.99, 20.23, and 90.38% higher, respectively.

The daily average PAR value were 560.47, 564.44, 537.20, and 482.94 μmol m^{-2} s^{-1} from the shifting sandy land to the oasis, respectively. The PAR value in the semi-fixed sandy land site was the highest among the sites, and PAR and solar radiation at the other two sites on desert-oasis ecotone were very close. Compared with the semi-fixed sandy land site, DΣSOL at the shifting sandy land, fixed sandy land, and oasis sites was 3.34, 7.62, and 17.16% less, respectively. Meanwhile, PAR and solar radiation were at their maximum (among all sites) at the semi-fixed sandy land site (Figure 7g and h), where the undulating topography strengthens the ability to resist blown sand, verifying the notion that taller plants and topography can influence PAR and solar radiation.

Floating-dust weather on 29 June 2011

Floating-dust weather usually occurs after sand-blowing weather, or is accompanied by strong sand-blowing conditions. Compared with the daily average air temperature and RH values of 27.22°C and 25.35% at the height of 2 m in the shifting sandy land site (Figure 7b and d), the diurnal average air temperature and RH at the semi-fixed sandy land, fixed sandy land, and oasis sites were 2.14, 4.54, and 16.67% less, and 9.42, 28.01, and 153.47% more, respectively. Temperature and RH differences among the four landscape types during the floating-dust weather were greater than during the sand-blowing weather. Compared with DΣPAR of 551963 μmol m^{-2} s^{-1} at the shifting sandy land site, values at the semi-fixed sandy land and fixed sandy land sites were 0.59 and 1.4%

higher, respectively, while it was 14.52% lower in the oasis. DΣSOL at the semi-fixed sandy land site was highest among the four landscape types, followed by the shifting sandy land, fixed sandy land, and oasis sites, in that order. The diurnal average wind velocity at the four sites during the floating-dust weather was obviously greater than that on the sunny days during summer. Differences of daily air temperature and RH among the four landscape types on the floating-dust day were very close (but slightly larger) to those on the sunny day, but were obvious for PAR values compared with the sunny day.

Rainy weather on 10 July 2011

Compared with the average wind velocity of 2.51 m/s at the height of 2 m in the shifting sandy land site (Figure 7b), the diurnal average wind velocity at the semi-fixed sandy land, fixed sandy land, and inner oasis sites were 56.06%, 65.45%, and 97.68% lower, respectively. Daily average air temperatures at (0.5, 2 m) were [(21.98°C, 22.1°C, 21.95°C, 21.51°C), (21.66°C, 21.53°C, 21.37°C, 20.84°C)] and RH was [(63.94%, 64.56%, 66.46%, 74.36%), (61.92%, 63.93%, 65%, 73.68%)] from the shifting sandy land to the oasis, respectively (Figure 6c–f), which were very close to each other. DΣPAR from the shifting sandy land to the oasis site were 149695.6, 159003.1, 149950.6, and 151836.6 μmol m^{-2} s^{-1}, respectively (Figure 6g). In addition, the differences for PAR and solar radiation among the four landscape types were less than on sunny days.

Sunny weather on 25 December 2010

During the sunny day in winter, the wind velocities at the heights of 0.5 and 2 m were lower than those in the other seasons. The wind velocities at the height of 2 m along the transect line from the shifting sandy land to the oasis site were 1.06, 0.86, 0.78, and 0.91 m/s, respectively (Figure 7a and b). The air temperature in the oasis was highest, which was higher than at the semi-fixed sandy land, fixed sandy land, and shifting sandy land sites, in that order (Figure 7c and d). Air temperature at the height of 2 m in the oasis was higher than that in the shifting sandy land, semi-fixed sandy land, and fixed sandy land sites by 2.49°C, 2.16°C, and 1.66°C, respectively. This accounted for the fact that it is cooler in summer and warmer in winter in the oasis. Because of solid precipitation in winter, the RH values among the four landscape types were very close, albeit the RH in the shifting sandy land site was slightly higher than elsewhere, because lower air temperatures can retain more vapors in the air. DΣPAR and DΣSOL at the semi-fixed sandy land site were greatest among the four landscape types. Meanwhile, at the shifting sandy land, fixed sandy land, and oasis sites, DΣSOL was 2.92, 5.15, and 6.29% lower, respectively, compared with the semi-fixed sandy land site. However, DΣPAR at the oasis site was larger than that at the shifting sandy land site, but solar radiation was smaller.

Correlations between metrological parameters in the different landscape types or conditions

On sunny days in summer or winter during the dust storm event, during sand blowing days and floating dust days, significant positive correlations were found between wind velocity and air temperature, PAR, and solar radiation; and between air temperature and PAR, and solar radiation ($p < 0.01$). Meanwhile, significant negative correlations were found between RH and wind velocity, air temperature, PAR, and solar radiation (Table 2), which accounted for the fact that wind velocity, air temperature, and heat are synchronously

Table 2. Correlations between wind velocity, air temperature, RH, PAR, and solar radiation on shifting sandy land.

Weather type	Parameters	$V_{0.5m}$	V_{2m}	$T_{0.5m}$	T_{2m}	$RH_{0.5m}$	RH_{2m}	PAR	SR
Sunny day in summer	$V_{0.5m}$	1							
	V_{2m}	0.900**	1						
	$T_{0.5m}$	0.185**	0.191**	1					
	T_{2m}	0.659**	0.664**	0.307**	1				
	$RH_{0.5m}$	−0.187**	−0.189**	0.384**	−0.241**	1			
	RH_{2m}	−0.651**	−0.653**	−0.296**	−0.987**	0.247**	1		
	PAR	0.569**	0.557**	0.221**	0.659**	−0.187**	−0.628**	1	
	SR	0.575**	0.561**	0.224**	0.667**	−0.188**	−0.636**	0.999**	1
Dust-storm day	$V_{0.5m}$	1							
	V_{2m}	0.982**	1						
	$T_{0.5m}$	0.846**	0.819**	1					
	T_{2m}	0.871**	0.846**	0.995**	1				
	$RH_{0.5m}$	−0.781**	−0.755**	−0.967**	−0.960**	1			
	RH_{2m}	−0.759**	−0.735**	−0.937**	−0.940**	0.988**	1		
	PAR	0.309**	0.273**	0.602**	0.553**	−0.597**	−0.591**	1	
	SR	0.334**	0.299**	0.608**	0.561**	−0.599**	−0.592**	0.990**	1
Sand-blowing day	$V_{0.5m}$	1							
	V_{2m}	0.973**	1						
	$T_{0.5m}$	0.372**	0.336**	1					
	T_{2m}	0.408**	0.372**	0.988**	1				
	$RH_{0.5m}$	−0.329**	−0.292**	−0.936**	−0.941**	1			
	RH_{2m}	−0.308**	−0.274**	−0.888**	−0.912**	0.988**	1		
	PAR	−0.026	−0.064**	0.752**	0.670**	−0.722**	−0.656**	1	
	SR	−0.026	−0.064**	0.758**	0.678**	−0.727**	−0.661**	0.998**	1
Floating-dust day	$V_{0.5m}$	1							
	V_{2m}	0.959**	1						
	$T_{0.5m}$	0.261**	0.232**	1					
	T_{2m}	0.128**	0.097**	0.980**	1				
	$RH_{0.5m}$	−0.025	−0.004	−0.919**	−0.956**	1			
	RH_{2m}	0.109**	0.128**	−0.847**	−0.913**	0.985**	1		
	PAR	0.410**	0.390**	0.772**	0.661**	−0.603**	−0.492**	1	
	SR	0.408**	0.388**	0.770**	0.660**	−0.601**	−0.491**	0.997**	1
Rainy day	$V_{0.5m}$	1							
	V_{2m}	0.967**	1						
	$T_{0.5m}$	−0.565**	−0.566**	1					
	T_{2m}	−0.538**	−0.542**	0.992**	1				
	$RH_{0.5m}$	0.542**	0.552**	−0.983**	−0.987**	1			
	RH_{2m}	0.540**	0.550**	−0.983**	−0.988**	0.999**	1		
	PAR	−0.498**	−0.490**	0.725**	0.642**	−0.638**	−0.638**	1	
	SR	−0.482**	−0.472**	0.714**	0.634**	−0.629**	−0.629**	0.983**	1
Sunny day in winter	$V_{0.5m}$	1							
	V_{2m}	0.939**	1						
	$T_{0.5m}$	0.626**	0.605**	1					
	T_{2m}	0.561**	0.545**	0.987**	1				
	$RH_{0.5m}$	−0.352**	−0.339**	−0.807**	−0.852**	1			
	RH_{2m}	−0.263**	−0.260**	−0.734**	−0.794**	0.990**	1		
	PAR	0.872**	0.796**	0.785**	0.705**	−0.429**	−0.319**	1	
	SR	0.858**	0.783**	0.795**	0.715**	−0.436**	−0.326**	0.999**	1

Note: #x0002A; **correlation is significant at the 0.01 level (two tailed); $V_{0.5}$ and V_{2m}: wind velocity at the height of 0.5 and 2 m; $T_{0.5m}$ and T_{2m}: air temperature at the height of 0.5 and 2 m; $RH_{0.5m}$ and RH_{2m}: relative humidity at the height of 0.5 and 2 m; SR: solar radiation.

changing in the desert area, with higher temperatures above the ground surface after noon over shifting sandy land easily exciting the occurrence of sand-blowing events in sunny weather during summer.

During the rainy weather, significant negative correlation was found between wind velocity and PAR and solar radiation, and positive correlation between wind velocity and RH (Table 2), which was different from other conditions. This was because, before the rain event, strong sand-blown wind occurred, which contained a lot of water vapor, causing the air temperature, PAR, and solar radiation to fall.

Discussion

During dust-storm days on a desert oasis in China's hyperarid zone, PAR and total radiation were found to be significantly lower than on cloudy or clear days (Feng, Zhou, and Xi 2009), which is consistent with our study. However, the degree of weakening for PAR and solar radiation was different in the desert–oasis land and inner oasis; DΣPAR on one day at the fixed sandy land site was higher than in the oasis, semi-fixed sandy land, and shifting sandy land, in that order; and DΣSOL during the dust storm increased along the transect from the shifting sandy land to the oasis. This was mainly influenced by factors including wind direction, VC (including plant types and plant heights), and higher topography (Figure 8). There is greater evaporation of the water transpired from the branches and leaves of the vegetation, which lowers the air temperature and increases the RH during summer. The sand and dust density distribution in the different landscape types can effectively influence the amount of PAR and solar radiation. Higher topography caused by *Tamarix* spp. nebkhas chain upwind main prevailing direction in semi-fixed sandy land could intercept more fine silt, sand and clay in the upper flow layer of sand-blowing wind, which resulted in a rapid decrease in silt, sand, and clay particles distributed in the air flow, and thus weakened the amount of absorption and diffusion of solar energy and increased the values of solar radiation and PAR.

During the late night, dawn and early morning, all types of vegetation created a cooling effect, including various types of plant covering in the summer (Potchter et al. 2008).

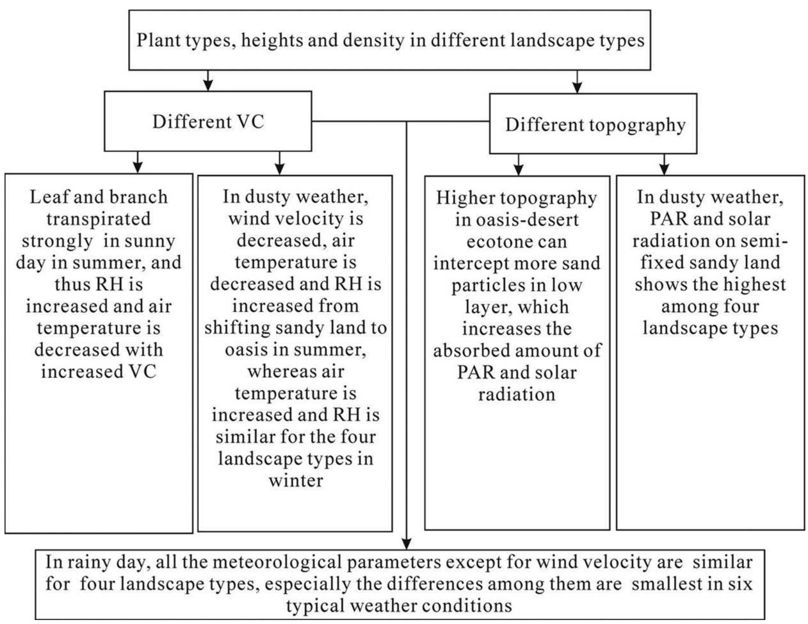

Figure 8. A conceptual model of different landscapes impacts on weather conditions (VC represents vegetation coverage).

However, the differences of air temperature among the four landscape types were largest during the late night and afternoon in the Cele area on the sunny day in summer. From nighttime throughout morning in winter in hyper-dry Arava Valley in Israel, all vegetation types were up to 2°C warmer than the surrounding desert (Potchter et al. 2012). In a sunny day in winter in Cele, daily air temperatures in oasis was increased by up to 2.49°C in comparison to frontier desert, which was a little warmer than Arava Valley area in Israel, and which reflected the fact that oasis have a warming effect compared with the surrounding desert area at that time of the year. The nighttime air temperatures was found to be substantially higher (>2°C) in the shrubland than in the grassland, especially during calm winter night in the northern Chihuahuan desert(He et al. 2010), which suggests that more shrubs should be preserved near Cele oasis to ensure the ecological security of oasis and increase air temperature in winter. In Cele desert-oasis ecotone and oasis, the plant types, plant height, vegetation cover and topography units were different, microclimatic parameters can be influenced by synoptic conditions in different landscape types.

VC, soil moisture, plant types, and topography are the main factors influencing microclimatic differences between the oasis and the desert–oasis ecotone. For example, the existence of strong local circulation and local interaction between the Gobi Desert and an oasis in the Heife area of China has been reported, which is caused by the heterogeneity of different landscape types (Hu, Wang, and Zuo 1993; Zuo and Hu 1994). The heterogeneous distribution of energy and water vapor drives oasis circulation, giving rise to upward flow above the desert area and downward flow in oasis areas (Lü and Shang 2005). This kind of local circulation effect of moisture and heat should exist between the desert and oasis in Cele. However, the main prevailing wind direction is W and WNW, meaning it is very hard for water vapor in the oasis to be transported to the desert in the easterly and northerly direction at the surface, against the dominant wind direction. Further observations and verification should be conducted for soil thermal and latent heat, evaporation and turbulence in the upper layers across a wider range of areas.

Conclusions

Average monthly wind velocity at the semi-fixed sandy land, fixed sandy land, and oasis sites at the height of 2 m were 25.22, 27.93, and 65.27% lower in June, respectively, compared with that at the shifting sandy land site. During the sunny day in winter, air temperature at the height of 2 m in the oasis was higher by 2.34°C, 2.01°C, and 1.6°C than at the shifting sandy land, semi-fixed sandy land, and fixed sandy land sites in order, respectively.

The air temperature and RH differences in the period of May to October among the four landscape types were greater than in other months. Vegetation transpiration and soil moisture content play important roles in changes of air temperature and RH.

During the six weather conditions, the air temperature during the floating-dust day and sunny day decreased gradually along the transect from the shifting sandy land to the oasis. Differences of PAR and solar radiation among the four landscape types were most obvious during the dust-storm event, and there were no obvious differences for PAR and solar radiation during floating-dust weather and rainy weather. Significant positive correlations were found between wind velocity and temperature, PAR and solar radiation, as well as between temperature and PAR, and solar radiation. Meanwhile, significant negative correlations were found between RH and wind velocity, temperature, PAR, and solar radiation, which accounted for the fact that wind velocity, air temperature and heat are synchronously changing in the desert area. Natural vegetation of the oasis–desert ecotone is very important, which is a matter of urgency to protect the ecotone land against excessive reclamation and abusive levels of grazing. VC should be increased using artificial or natural measures to strengthen its ability to resist sand blowing hazards, and ensure that the oasis is preserved.

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